Learnings for European Autonomy to Deliver Europe's Rail in 2030

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(version for Public Consultation Phase)

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Scope of the document and how to participate in the consultation

This document **represents the basis for a Stakeholders' Public Consultation phase to be run** in the framework of the "LEADER 2030 project" **between January 7th and February 28th, 2026**.
The "LEADER 2030-Learnings for European Autonomy to Deliver Europe's Rail in 2030" project has for main objective to conduct research activities aiming at **providing answer to the following key question: "*will there be enough raw materials and components to bring to the market in 2030 all the Railway innovations EU-Rail is delivering?*"**

The following partnership with complementary skills tried to answer this challenging question:

- **ERCI-European Railway Clusters Initiative** (Belgium): Europe's only railway meta-cluster network, uniting 18 rail innovation clusters operating on 17 European countries, to connect SMEs, large companies and research organisations and strengthen the competitiveness of the European rail industry. It acts as a B2B and innovation matchmaking platform, bringing customers and suppliers together, supporting cross-border cooperation
- **Railenium** (France): French government-certified Technological Research Institute (IRT) for rail, bringing together industry and academia to develop, validate and test breakthrough railway technologies and improve the competitiveness of the rail sector. It acts as a "common house" for partners across the rail ecosystem, running R&I projects that address major societal and technological challenges in France and internationally
- **GKZ-Geokompetenzzentrum Freiberg** (Germany): An independent "triple-helix" network (industry–research–public authorities) covering the full value chain of mineral raw materials and geo-energy. It supports projects and coordination at national/international level and is embedded in Saxony's mining and materials hub, spanning from mining and processing to advanced materials and semiconductor-related value chains
- **Teknopark Istanbul** (Türkiye): Türkiye's major technology development zone established by the Presidency of Defence Industries and the Istanbul Chamber of Commerce to boost national technology development and innovation capacity. It hosts and supports R&D companies (notably defence/aerospace and advanced tech), providing an ecosystem for domestic and international entrepreneurs to develop technologies at international standards.

The document condenses and summarises for a public usage **facts, trends and recommendations resulting from more than 800 pages of desk and field analysis and research produced** so far under the "LEADER 2030" project, namely the Deliverables:

- ***D1.1 – Map of disruptions experienced so far by the Rail Supply industry and lessons for the future*** (developed by ERCI-European Railway Clusters Initiative), providing key insights from desk research on disruptions in supplies having impacted Europe in the most recent years, as well as the results of the European survey of the Rail Supply industry on disruptions experienced since 2018, launched by the project

- ***D1.2 – Lessons on disruptions and resilience from other sectors*** (developed by Teknopark Istanbul and ERCI-European Railway Clusters Initiative), providing analysis of the Defence, Aerospace, Clean Energy Infrastructures, Automotive sectors under the point of view of dependencies, disruptions and policy measures adopted to reduce their vulnerabilities; cross-references between these sectors and the railway sector, where relevant; summary of take-aways/inspirations considered more relevant for the prosecution of the project
- ***D1.3 – Supplies alerts for the future*** (developed by ERCI-European Railway Clusters Initiative), detailing about the type of railway supplies affected by disruptions, listing which end products are suffering from different types of supply difficulties
- ***D2.1 – Map of Railway needs in 2030*** (developed by Railenium), comprehensively mapping Europe's Rail innovations expected by 2030, identifying necessary technologies, raw materials, and supply chain requirements across various tiers (OEM, Tier 1, 2, 3), as well as highlighting subsystems and components that will become obsolete or significantly reduced due to technological advancements, signaling key areas of industry transformation
- ***D3.1 – Forecast for autonomy, bottlenecks and gaps for Europe's Rail 2030 raw material supply*** (developed by GKZ-Geokompetenzzentrum Freiberg), analysing past crises causing raw material supply distortions and availability constraints; assessing disruptions linked to energy politics and shortages, including risks from production closures or outsourcing; reviewing sourcing strategies of the most affected EU Member States, with a focus on countries with strong rail economies; mapping the availability, provenance and supply chains of key raw materials, including European and overseas sourcing options; examining EU and global regulatory frameworks affecting access and economically viable domestic sourcing; addressing geopolitical factors and sustainable sourcing schemes to support a resilient rail supply chain up to 2030

plus, **other systematised data gathered on a continuous basis** during the project implementation from multiple sources (**desk analysis, field visits, specialistic workshops and online meetings, participation in conferences**) and used to complement, strengthen and validate the project results.

This visionary project was:

- the reason why its Coordinator was awarded the **"Women in Rail Award 2024 – Research and Innovation" category**, co-organised and assigned during InnoTrans 2024 (Berlin, Germany) by the European Commission-DG MOVE-Women in Transport Platform, the Europe's Rail Joint Undertaking, EURA-European Union Agency for Railways, ALE-Federation of European Train Drivers' Unions, CER-Community of European Railways, EIM-European Rail Infrastructure Managers, UNIFE-The European Rail Industry
- present at the **"WCRR-World Congress on Rail Research 2025"** (Colorado Springs, USA) with the selected and peer-reviewed Scientific Paper **"Forecast of gaps in critical supplies for Rail Innovations. A pan-European approach for resilience"**.

In specific details, this document aims at presenting the following to the target audience:

- PART I: a synthetic but comprehensive **framework analysis** of the state of the art and multiple factors impacting and suitable to further condition the availability of critical supplies required by the rail sector, now and in the future. This section serves as an **'introductory journey' to the following parts** to provide the right framing and understanding of the specific challenges affecting the rail sector and the recommendations proposed.
- PART II: a **snapshot of how the rail value chain** has been **already impacted** by supply disruptions, as well as of how **some key innovations** promoted by the Europe's Rail Programme **risk to be impacted** by the above framework.
- PART III: a **set of recommendations** for both the rail industry and European, National, Regional institutions to increase the availability of critical supplies needed, thus fostering European industrial autonomy and an 'undisrupted' transformation of the European rail sector through the regular introduction of the target innovations.

The document is especially **delivered to the attention of**:

- Europe's Rail JU and all its governing bodies, included the Scientific Steering Group
- The European Commission relevant DGs and services, the European Parliament, the European Social and Economic Committee, the European Committee of the Regions, Member States, European Regions
- The European organisations of the rail sector
- The European organisations of relevant sectors (raw materials, advanced materials, polymeric materials, electronics, etc. but also Automotive, Clean-Tech, Defence, etc. as close sectors affected by similar supply risks)
- The European Railway Clusters and any relevant European Cluster sectors (raw materials, advanced materials, polymeric materials, electronics, etc. but also Automotive, Clean-Tech, Defence, etc. as close sectors affected by similar supply risks)
- The National Rail Associations and any relevant National Association
- Individual enterprises of the rail and other relevant value chains, including start-ups and scale-ups
- Academia, Research organisations and Technology Centres
- Relevant European, National, Regional R&D&I projects
- Any other interested organisation

with the **kind request to contribute to the document by validating and/or integrating and/or confuting the practices and recommendations listed (PART III)**.

Contributions must be delivered via this link: https://ec.europa.eu/eusurvey/runner/LEADER-2030
Contributions are not anonymous, as it is in the scope of the process to know the identity of the contributors. However, *personal names, surnames, roles and contacts* will **not** be published and will be managed and used according to GDPR principles by the project partners exclusively for the

project purposes.

Abbreviations and acronyms

Abbreviation / Acronym	Description
BRI	Belt and Road Initiative
CRM(s)	Critical Raw Material(s)
CRMA	Critical Raw Materials Act
ETP ESR	European Technology Platform on Sustainable Mineral Resources
EU	European Union
EU-Rail / EU-Rail JU	Europe's Rail Joint Undertaking
EU-Rail AWP	Europe's Rail Annual Work Programme
EU-Rail MAWP	Europe's Rail Multi-Annual Work Programme
EU-Rail MP	Europe's Rail Master Plan
GVCs	Global Value Chains
HREE(s)	Heavy Rare Earth Element(s)
JRC	Joint Research Centre of the European Commission
LEADER 2030	"Learnings for European Autonomy to Deliver Europe's Rail in 2030" project
LREE(s)	Light Rare Earth Element(s)
LNG	Liquid Natural Gas
MSP	Minerals Security Partnership
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturers
R&D	Research and Development
REE(s)	Rare Earth Element(s)
R&I	Research and Innovation
RFC(s)	Rail Freight Corridor(s)
SME(s)	Small and Medium-sized Enterprise(s)
SRM(s)	Strategic Raw Material(s)
USD	United States Dollars

Background

The present document is adopted in the framework of the "LEADER 2030-Learnings for European Autonomy to Deliver Europe's Rail in 2030" project, funded by the Europe's Rail programme.

Europe's Rail is the European Union's flagship programme to modernise rail transport across Europe. As Public-Private Partnership under the Horizon Europe programme of the EU, it brings together public authorities, rail companies, industry and researchers to make trains and rail networks more efficient, reliable and attractive.
The programme, based on a high-level Master Plan, a Multi-Annual Work Programme (MAWP) and Annual Work Programmes (AWPs), focuses on digitalisation, automation and new technologies to improve how rail systems are planned, operated and maintained. Its goal is to increase capacity, punctuality and safety, while reducing costs and environmental impact.
Europe's Rail aims to deliver concrete solutions such as smarter traffic management, more interoperable systems across countries, and better passenger and freight services. Overall, it supports the transition to rail as a key pillar of sustainable and climate-friendly mobility in Europe.

Within Europe's Rail, **Flagship Areas** are the main thematic pillars that define where innovation is needed most across the rail system. They cover key domains such as railway operations, traffic management, infrastructure, rolling stock, and customer services. Each Flagship Area sets a long-term vision and clear objectives to address capacity limits, complexity, digital transformation and sustainability. They ensure that research and innovation efforts are aligned and focused on delivering system-wide benefits rather than isolated solutions.

Flagship Projects are the concrete, large-scale collaborative projects developed under these areas. They bring together multiple technologies, organisations and disciplines to design, test and validate new solutions.
These projects aim to deliver mature, deployable innovations rather than purely theoretical research. They often include demonstrations in real or near-real operational environments. Together, Flagship Areas and Projects ensure that Europe's Rail delivers integrated, interoperable and practical solutions for the future European rail system.

This document is issued in the framework of the **Exploratory Research Project "LEADER 2030"** as described in the EU-Rail AWP 2022.
Exploratory Research projects in Europe's Rail focus on early-stage, high-risk and high-potential ideas that could shape the future of rail in the long term. They explore new concepts, technologies and approaches before they are mature enough for large-scale development. These projects help build the scientific and technological foundations for future Flagship innovations.
Therefore, **this document and the overall "LEADER 2030" project ultimately aim to contribute with intelligence information to the execution of all Flagship Projects**.

PART I

FRAMEWORK ANALYSIS: FACTS AND TRENDS

Introductory Note: An unstable world pressing on Value Chains

When the Europe's Rail Call funding this project was launched (September 2022), the European industrial ecosystems had learnt to experience the impact of **supply disruptions** mostly as a result of the COVID-19 crisis and its multiple ways influencing the regular flow of global and continental supplies. The Suez Canal blockage in 2021 had shown how other types of events could have similar impact on Global Value Chains. Russia's aggression to Ukraine in February 2022 had just started to show its impact on the same supply flows.
Since then, the awareness about the existence of supply disruptions and the threat of countries' **supply dependencies** has exponentially grown; nowadays, any day, we can read everywhere news about supply problems and news about actions and strategies aimed at supply resilience and autonomy adopted both at macro level (European Union and individual countries in all continents) and at micro level (multinational companies, mainly, but also smaller companies).

As digitalisation and clean-tech deployment scale up worldwide, **dependencies and potential disruptions risks grow globally** as these transformations drive the sharply rising global demand for critical raw materials for batteries, renewables and electrification, advanced electronics, semiconductors, etc..
The list of EU policy actions aimed at strengthening Europe's autonomy for critical minerals and supplies mostly required for making happen the Green Deal (now re-shaped as "Green Deal Industrial Plan") and the twin Digital and Green Transition has been extending month after month, showing full awareness about supplies' risks and steady attention to **mitigation solutions** – still, new mines can't start exploitation and new value chains (e.g., for Rare Earths (REEs) or semiconductors) don't establish overnight; minerals processing technologies and expertise are almost concentrated in a single country in the world; technology can help reduce the quantities of critical materials and components needed or substitute critical minerals with other materials, but this requires years. And the investment volumes needed and economically sustainable business models often lack.

In a world where **supply chains** can **express a *country's bargaining power*** and **have become a *negotiation tool***, and where **competition between not only countries but also sectors** is expected to intensify for access to scarce materials and advanced components, what can be done **in the meantime** and **what else** can be done to further increase the chance to stay resilient and competitive for the European rail value chain while it's preparing to introduce a great number of coordinated innovations?

1. Supply Disruptions vs Supply Dependencies

Throughout this document, threats to regular, planned supplies for the railway sector (and not only) are posed by the increasing presence of these **risk drivers**:

- **Disruption** *(micro-economic definition)*
  "Incident, whether anticipated or unanticipated, that causes an unplanned, negative deviation from the expected delivery of products and services according to an organization's objectives" (ISO Standard 22301:2019).
- **Disruption** *(macro-economic definition)*
  "Supply chain disruptions are defined as unexpected and unforeseen events or circumstances that disturb the regular flow of goods and materials along the value chain" (Novoszel, Wakolbinger, 2022).
- **Dependency** *(macro-economic definition)*
  "Reliance on a limited number of actors for the supply of goods, services, data, infrastructures, skills and technologies combined with a limited capacity for internal production to substitute imports" (European Commission, 2021).

While supply ***disruptions*** can be **triggered** through a variety of factors, where a **series of unrelated events** disturb the regular flow of goods and materials along the value chain, causing a shortage (e.g., logistic breakdowns, lack of material supplies, energy security, etc.), ***dependencies*** have **a more structural cause** (e.g., geological concentration and limited viable deposits, technological barriers, economic and industrial specialisation, mining market attractiveness and sustainability, geopolitical and strategic factors, supply chain complexity, etc.).
Thus, while disruptions are event-driven and *often temporary*, dependencies are structural and *long-lasting*, shaping the magnitude and persistence of supply constraints when disruptions arise. **Ultimately**, disruptions reveal the *fragility of supply chains*, but dependencies explain why certain materials and sectors remain *persistently vulnerable* to such shocks. Here below **the two great categories**.

Critical Raw Materials

- **Critical Raw Materials** (CRMs) are defined by the European Commission as "a set of non-energy, non-agricultural raw materials that, due to their high economic importance and their exposure to high supply risk, often caused by a high concentration of supply from a few third countries, are considered critical".
- CRMs are coupled with those called **Strategic Raw Materials** (SRMs), that are a subset of CRMs, and that are defined by the European Commission as "the raw materials that score among the highest in terms of strategic importance, forecasted demand growth and difficulty of increasing production".

- The European Commission has been mapping the raw materials *critical to the EU* since 2011, with updates every three years. The list of CRMs passed from 14 in 2011 to 34 in 2023 (i.e. the latest edition).
- The **EU CRMs list** includes: Antimony (Sb), Arsenic (As), Baryte (BaSO4), Bauxite, Beryllium (Be), Bismuth (Bi), Boron/Borate (B), Cobalt (Co), Coking Coal, Copper (Cu), Feldspar, Fluorspar, Gallium (Ga), Germanium (Ge), Hafnium (Hf), 10 Heavy Rare Earth Elements (HREEs), Helium (He), 5 Light Rare Earth Elements (LREEs), Lithium (Li), Magnesium (Mg), Manganese (Mn), Natural Graphite, Nickel (ni), Niobium (Nb), 5 Platinum Group Metals (PGMs), Phosphate Rock, Phosphorus (P), Scandium (Sc), Silicon metal (Si), Strontium (Sr), Tantalum (Ta), Titanium metal (Ti), Tungsten (W), Vanadium (V).
- Behind this list lies a very wide variety of metals and mineral inputs whose supply is complex because many are not mined 'on purpose' but emerge from interconnected value chains where **one main commodity yields several strategic elements** as by-products or impurities (e.g., Bauxite supply Aluminium (Al) but can also yield Gallium (Ga) and Scandium (Sc); Copper (Cu) production can deliver Molybdenum (Mo), Gold (Au), Silver (Ag), Selenium (Se) and Tellurium (Te); Tungsten (W) ores may co-produce Molybdenum (Mo) and Tin (Sn); Antimony (Sb) is often linked to Gold (Au) but can come with difficult impurities such as Arsenic (As); Germanium (Ge) is typically recovered from Zinc (Zn) refining residues; and Hafnium (Hf) is almost entirely obtained as a by-product of producing Zirconium (Zr) from Zircon).
- Hence, the availability of many "critical" inputs **depends not only on mining, but also on processing capacities and their economics** (e.g. Rare Earth Elements (REEs) are called "rare" not because they are scarce in the Earth's crust, but because they are usually dispersed in low concentrations and tightly bound within complex minerals, making them difficult, energy-intensive and costly to extract and separate into usable pure forms).
- CRMs are the **foundation of Europe's** twin Digital and Green Transition **ambitions**. However, the EU's access to these materials is anything but secure. CRMs are in fact at the basis of *global* digital and clean transformations, making the **demand for CRMs continue to rise** across all scenarios (e.g., EU's only demand for rare earth metals (REEs) is expected to increase six-fold by 2030 and seven-fold by 2050 and for Lithium (Li) twelve-fold by 2030 and twenty-one-fold by 2050).
- Not only: key drivers of CRMs consumption are manyfold, but all have in common a raising demand, albeit some CRMs are replaced by others. There will therefore always be critical raw materials, and critical issues.
- The EU consumes about 25% of the world's CRM supply but produces only about 3%. Recent investments and exploration have revealed new potential—especially for materials like Lithium (Li), Rare Earths (REEs), Tungsten (W), Graphite—and efforts exist to accelerate domestic production to improve the self-sufficiency ratio for a handful of materials (e.g. the CRM Act Strategic Projects, among which the "Metlen" landmark project in Greece enabling the EU to become a full-self supply producer of primary Gallium (Ga), with production target of 50 metric tons annually by 2028, which is enough to cover all the EU's current Gallium demand and entirely substitute imports). Despite this, Europe will remain a **net importer from not-EU countries and highly dependent on global markets** for most critical minerals for the foreseeable future. This is also an effect of EU´s and

Member States' policies (e.g. high energy prices and higher costs for CO_2 certificates) having made in the last decades the access to raw materials and the development of mid- and downstream industries within the EU more difficult, causing a decline of domestic raw materials production capacities up to today, depleting Europe's ambition to build resilient, competitive, and environmentally responsible supply chains for CRMs.

- Scrap and primary raw materials are distributed to most consumers via globally active traders. **Traders** sell internationally to any buyer able to pay and clear the transaction. Commercially, they act to maximise profit and minimise risk, selling to the highest credible bidder worldwide, so long as transactions meet legal standards and compliance rules. This means there is no preferential treatment for the EU. **Mining is for money**.
- In mining, revenues result after a very long time when break-even is reached. Investment decisions are led by pure **profitability** considerations: *which raw material can generate profits the fastest with comparatively low CAPEX and OPEX*. And, in this regard, CRMs are inferior to base metals and therefore influence the investment decisions of large mining operators.
- Mining projects have **long development lead times**. This hinders the rapid supply of Europe from domestic sources, as most projects have not yet reached the status of a robust, i.e., financially creditable, bankable feasibility study. **EU mining finance** is now closely linked to the sustainability criteria of the EU taxonomy regulation: only projects that meet demanding technical and environmental standards qualify as sustainable, allowing access to green financing but also raising compliance hurdles. To benefit, mining companies must conduct comprehensive ESG assessments and fulfil stringent transparency and reporting requirements. By contrast, **outside the EU**, mining projects often access financing with fewer environmental or reporting requirements, making capital acquisition faster and generally less complex, hence making these locations more attractive for international mining investment.
- Mining **investments** globally has **steadily declined** over the past 15 years due to asset write-downs and lost investor confidence, even as profits recovered and demand forecasts remain strong. In 2022, the world's 40 largest miners invested only 75 billion USD, down from 130 billion USD in 2013, with returns on new projects at around 7%—a figure that is insufficient to attract investors back to the sector.
- The supply of many critical raw materials is **highly concentrated**, with China near-monopoly and dominant role in CRMs refining and processing (e.g. China provides 100% of the EU's supply of heavy rare earth elements (HREEs), but EU is also dependent on Türkiye, which provides 99% of the EU's supply of Boron (B), on South Africa, providing 71% of the EU's needs for Platinum (Pt) and an even higher share of the platinum group metals (PGMs), etc.).
- The risks associated with the concentration of CRMs production are in many cases compounded by **low substitution and low recycling rates**.
- This concentration of power creates an inherent **vulnerability** for Europe, as any disruption—whether due to geopolitical tensions, trade restrictions, or economic policies—can have cascading effects on Europe's industrial agenda.
- The global scramble for CRMs is intensifying as the small handful of players who dominate their extraction and processing look set to use these resources as both an **economic tool** and a

geopolitical weapon: the securitisation of CRMs is **reshaping global power dynamics**. Access to and control over CRM supply chains gives strategic leverage over import-dependent countries in a similar way to how control of fossil fuel supplies has been in recent history.

Semiconductors

- Semiconductors are critical to modern life, as the **foundation of modern electronics**, enabling data processing, control, and communication in virtually every device.
- A semiconductor is a material that falls somewhere on the continuum between conductor and insulator, enabling a controlled flow of electrical current. Manufacturers process **semiconductor materials** such as Silicon (Si) and other materials into **wafers**, which are then lithographically printed with various functionalities. The wafer is then cut into **chips** that make up semiconductor **devices**, which enable all kinds of machines to harness electricity for processing power.
- In the semiconductor industry, the wafer—usually made of Silicon Metal (Si)—serves as the layer on which materials are processed and formed into chips. Each chip is essentially a highly engineered semiconductor device that is crucial to powering countless electronic devices. As semiconductor technology advances, these chips continue to **shrink in size and grow in computing power** because manufacturers can pack more transistors into the same area ("higher density"). A smaller technology node ("nm node", i.e. nanometre dimension) generally means 'more transistors per chip', allowing more operations per second (higher performance), lower energy per operation (better efficiency), more functionality per chip (AI accelerators, 5G, data centres, etc. E.g., compared with a 5nm chip node, a 3nm can deliver ~10–15% performance gains or ~25–35% lower power, plus large density improvements).
- Semiconductors are **in greater demand than ever**: Industry 4.0 and, more generally, digitalisation of industry and global business, are enabled by smart computers and connected devices, and these require semiconductors.
- While semiconductors can create a wealth of opportunities for industries around the world, reliance on semiconductors could also introduce **vulnerabilities**. Reasons for this include: **(i)** The making of semiconductors is **one of the most complex and sophisticated processes** in all manufacturing. **(ii)** Chips needed for the Digital and Green Transition require **more complex and more critical materials** such as **Gallium (Ga)** (enabling compound semiconductors (GaAs, GaN) for high-speed & high-power devices needed e.g. for 5G RF components, satellite communications, power electronics, defence systems, radar), **Germanium (Ge)** (used in high-speed electronics and photonics (SiGe), and some infrared optics needed for telecommunications, sensing and imaging, photonics and optical interconnects), **Tungsten (W)** (used in contacts and interconnects because it is stable and conductive at very small dimensions. It is present in essentially all advanced logic chips, and indirectly enables AI processors, data centres, mobile SoCs), **Cobalt (Co)** (used in advanced interconnect schemes and barrier layers as it helps reduce resistance and improve reliability at small scales. For this it is used in high-performance computing, mobile processors, GPUs/AI accelerators), **Tantalum (Ta)** (used in barrier layers and capacitors, automotive electronics, servers, smartphones and laptops), **Hafnium (Hf)** (essential for controlling leakage at tiny transistor

dimensions, i.e. used essentially in every modern advanced logic chip). **(iii)** Semiconductors value chain is heavily influenced by **geopolitics** (e.g., **Taiwan** manufactures over 60% of the world's semiconductors and over 90% of the most advanced nodes. A blockade, cyberattack, or kinetic conflict in the Taiwan Strait can upend the entire global chip supply overnight. Much worse, a Chinese invasion of Taiwan would cripple the planet, with entire industries facing shutdowns within weeks and the global economy arguably spiraling into recession. Before the war, **Ukraine** supplied more than half of the world's purified Neon (Ne), a gas essential for the lasers used in photolithography for chips. Russia's invasion disrupted this supply. Meanwhile, **Russia** produces about 40% of the world's Palladium (Pd), another key element in chip manufacturing. Sanctions, export bans, and logistics breakdowns in the Black Sea have complicated access to these materials, extending procurement cycles. The **United States**' export controls on advanced chips to China, enacted in 2022 and updated multiple times, has reshaped trade flows. **China**'s own countermeasures, including restrictions on Gallium (Ga) and Germanium (Ge), which are critical for chips, hint at just how strategic the semiconductors have become).

- **Access to semiconductors is vital to Europe's competitiveness, security and industrial future**. These components are crucial to many industrial sectors and consumer products and play a key role in the global technology competition and in geostrategic interests. Yet geopolitical risks, primarily the US-China rivalry but also China's threats to Taiwan and Russian threats to the European security order, are placing the security of semiconductor supply at risk (one ongoing example of this is the **"Nexperia crisis"**, arisen after last September the Netherlands took control of Nexperia chipmaker claiming the Chinese owner, Wingtech, was seeking to relocate European production to China, hence the need to ensure chip supplies. China retaliated by blocking the export of Nexperia's chips, most of which are packaged in China and are used in cars and consumer electronics, causing a global shortage of chip supply).
- The global semiconductor shortage triggered by COVID-19 highlighted the **sector's structural inelasticity**: capacity cannot be scaled up quickly, so shocks translate into prolonged disruptions. Average lead times, normally around 12–20 weeks, increased to around 40 weeks and, in some cases, reached up to 99 weeks.
- Europe's dependence on supply from a limited number of chips companies, hence its **vulnerability to any type of disruptions** as well as export restrictions from third countries in the current geopolitical context. The EU's share of the global semiconductor market is currently 13% by value, far below its economic weight. EU's effort to establish and relocate productions in Europe is pairing global players' **changing strategies to relocate from Taiwan** to securer countries to reduce the increasing risks of China's attack. However, at least 5/6 years are necessary to start new productions. In the meantime, chips traders are offering **increased stock possibilities** to 'protect' their customers.

2. Supplies Disruptors

Military Conflicts

- Conflicts disrupt supply chains not only by damaging infrastructure, but by converting 'normally efficient' trade routes and critical inputs into strategic chokepoints, as they trigger immediate logistics rerouting, price spikes, and cascading production slowdowns across industries, resulting in **systemic disruption multipliers** (e.g., not only major conflicts can trigger this, but also regional ones: e.g., in the framework of ongoing Myanmar's civil war between military junta regime and various ethnic armed groups, the Kachin Independence Army's takeover of key mining zones in the northern of the country made collapse supply of heavy rare earth (HREE) compounds to China (−89%), triggering a sharp price rise (e.g., Terbium Oxide (Tb_4O_7) +21.9%), which impacted not only China's but the world's supply chains).
- It's **easy to overlook the ripple effects of conflicts** happening far from home. But when Russia invades Ukraine, when a drone strike shuts down a port, when tensions flare near the Taiwan Strait, when Myanmar rebels invade an unknown-to-many mining region, the consequence isn't just political, it's practical: critical materials vanish from inventory forecasts, semiconductors lead times stretch, and delivery windows become guesswork.

Trade Controls

- In this cycle, as **globalisation stalls and countries turn increasingly inward**, trade control measures are increasingly adopted by many countries.
- Trade controls are **policy instruments** that restrict, condition, or redirect trade and investment flows to protect economic security, enforce rules, or secure strategic supply chains. They can consist in (i) Price tools (tariffs, duties, export taxes), (ii) Quantity tools (quotas, bans, licensing caps), (iii) Strategic tools (sanctions, export controls, investment controls, procurement restrictions), (iv) Compliance tools (standards, rules of origin, customs enforcement).
- **Export controls** such as bans, quotas or end-use restrictions on exporting strategic raw materials or chip-related technologies (e.g., China's restriction on Gallium and Germanium export; USA's control on advanced chip equipment and AI chips) are aimed to retain domestic supply, gain leverage, or limit adversaries' capability building. Their impact on supply chains can be sudden supply shortfalls, price spikes, forced sourcing shifts, stockpiling.
- According to the OECD, the global stock of export restrictions on industrial raw materials rose to **nearly 18.000 measures in place** by end-2023, representing a more than fivefold increase since 2009, with an acceleration in 2023 that saw more than doubling of the growth rate compared to 2022. In and with about 14% of global trade in non-waste & scrap industrial raw materials facing at least one restriction, with Cobalt and Rare Earths particularly affected. In 2023, seven countries—The People's Republic of China, Viet Nam, Burundi, the Russian Federation, Democratic Republic of Congo, Zimbabwe, and Laos—accounted for 94% of new export restrictions.

- **Tariffs and reciprocal tariffs** as import duties are designed not only to protect industry and rebalance trade, but also to obtain concessions, or shape industrial relocation. Beyond the direct impact on the country to which the tariff is applied, indirect impacts include rerouting of supply chains to alternative destinations, reshoring and preferential sourcing with aligned partners, which can tighten supply for third parties. (e.g., as a result of US tariffs on China, the EU may face stronger competition from US buyers of critical materials, who can offer higher prices or long-term offtake contracts to secure volumes. This can worsen lead times and raise costs).
- **Anti-dumping & countervailing duties** (TDIs) as duties on goods judged to be dumped or subsidised (steel, aluminium, solar, chemicals, some electronics inputs). They protect domestic capacity and reduce dependence on unfairly priced imports, reshaping supplier base and up to accelerating nearshoring or shift imports to third countries.
- **Sanctions & embargoes** (sectoral + secondary sanctions) consist in restrictions on trade and finance with certain countries/entities, including sector-level bans. Reasons include national security, foreign policy, and control of strategic industries. They impact supply chains bringing to abrupt supplier exclusion, compliance costs, "shadow trade" risk.
- **Import restrictions / prohibitions for security reasons** such as quotas/caps, bans or heightened requirements on imports from specific origins (risk-based). Their goal is to reduce dependence, protect strategic infrastructure, prevent infiltration of critical tech.
- **Rules of origin tightening & anti-circumvention** include stricter origin certification, customs enforcement and anti-transshipment measures. They prevent tariff/sanction evasion via third countries. Impacts on supplies include changes sourcing choices and re-labelling practices, raising compliance costs.
- **Customs controls & enforcement tools** such as inspections, seizures, hold/release orders, forced-labour bans, extended checks. They can produce shipping delays, supplier switching, traceability requirements.
- **Technical Barriers to Trade (TBT) & cybersecurity / standards controls**, including mandatory certification, security requirements, eco-design rules, "right to sell" conditions, such as sustainability due diligence rules affecting raw materials. De facto, they excluding non-compliant suppliers.
- **Dual-use technology restrictions** as restrictions on export/import of technologies that have civilian + military use (chips, machine tools, advanced materials). Examples include controls on advanced lithography and chipmaking equipment; restrictions on high-end GPUs.
- **Outbound investment controls** (new generation of trade controls), as restrictions or reporting requirements on domestic firms investing in adversary sectors (chips, quantum, AI, advanced materials). They are aimed to prevent capital and know-how from strengthening strategic competitors.
- **Inbound investment screening (FDI controls),** blocking or conditioning foreign acquisitions or investments in strategic sectors/mines to protect strategic assets, critical infrastructure and tech. their impact on the supply chain includes ownership, access rights, and long-term control over mines/refineries.

- **Subsidy-linked trade conditions ("trusted supply chains")**, as eligibility for subsidies/tax credits depending on sourcing from allied countries or excluding "foreign entities of concern". Their goal is to reshape supply chains away from rivals and build domestic ecosystems.
- **Public procurement restrictions ("Buy national / trusted supplier" rules)** restrict suppliers for government procurement in rail, defence, energy, telecoms to reduce security risks and build domestic capacity. This produces shifts in demand, creates large secured domestic markets and excludes some global competitors.
- **Export taxes / raw material retention policies** as taxes or restrictions on exporting unprocessed minerals to force domestic value addition. Their goal is to develop processing industry and capture more value. Examples include export bans/taxes on nickel ore or bauxite in producing countries (common in minerals industrial policy).
- **Strategic stockpiling + export restrictions (crisis mode)**, consisting in accumulation of reserves of rare earths, metals, or semi-inputs, often paired with export licensing; they are aimed to reduce vulnerability and manage supply shocks even if it may raise market tightening, price volatility, "race to stockpile" among states.

Logistics

- Increasingly, global or continental logistics is being disrupted for different reasons and with impacts going from longer delivery times to higher transport costs.
- Causes of logistical disruption include: (i) **geopolitical instability** (e.g., because of Russia's aggression to Ukraine, container traffic through the **Black Sea** has dropped sharply, delaying deliveries of raw materials and finished semiconductors alike; Houthi rebels' attacks on shipping vessels in the **Red Sea** have triggered widespread re-routing of goods along Africa, with ~14 days-longer, more expensive paths); (ii) **climate events** (e.g., slowdowns at the **Panama Canal** in 2023/2024 caused by canal drought, produced higher shipping costs, long waits, rerouting; **Canada** wildfires damaging or shutting down **rail lines**, halted freight movement and caused railcar backlogs, with re-routing and capacity constraints affecting shipments of mining materials, forestry products, fuel; China's **Yangtze River** "Mega" Drought & Heatwave in 2022 forced modal shifts, raising costs, and delaying intermediate goods, which propagated outward along global value chains; **Rhine River** low water in 2021 reduced freight capacity, disrupting chemical, energy, and manufacturing supply chains across Europe); (iii) **incidents** (e.g., **Suez Canal** blockage for six days in March 2021 by a container ship that had run aground in the canal, with global delays impacting industries with existing shortages, thereby influencing markets already at risk of collapsing; **Port of Baltimore**'s shipping channel blocked for weeks in March 2024 after a container ship struck a support pier causing a bridge to collapse); (iv) **cyberattacks** (targeting shipping lines (e.g., **Maersk/NotPetya** in 2017), global forwarders (e.g., **Expeditors** in 2022), and port operators (e.g., **DP World Australia** in 2023) paralyse operations and trigger digital-based global supply chain disruptions, producing congestion, delays, and knock-on failures across global value chains); (v) **labour strikes and workforce shortages**.

- Countries with heavy manufacturing activity and long supply routes (e.g., Italy, Austria, Germany) suffer higher transport challenges and are more subject to this kind of risks.

Military Mobility

- Although it could be framed as a sub-category of logistics bottlenecks, Military Mobility differs from the previous category for its ***intentionality***, i.e. the freight bottleneck is *created* due to a **capacity-prioritisation shift** for transportation of military personnel, material and assets in a framework of scarce rail slots.
- For the EU, Military Mobility must ensure the **rapid and seamless movement** of personnel, material and military assets within and outside the EU, **at short notice and on a large scale**. The pillars to implement it combine the removal of physical obstacles (e.g. adaptation of rail, road, port, weight, height, gauge infrastructures), the de-bureaucratisation and digitisation of processes for cross-border transit (the so called "Military Schengen"), and the security and resilience of essential elements such as communications, networks, energy, and fuels.
- **The Netherlands** is moving toward giving urgent military transports priority on the rail network, placing **freight at the lowest priority level**, potentially delaying or displacing regular rail cargo flows. The expected impact is increased unpredictability for rail-based delivery of industrial inputs moved by rail and port hinterland flows (e.g. chemicals, steel products, components, fuels, containerised goods from ports). In parallel, the Port of Rotterdam has reportedly put contingency plans in place to **reroute and reallocate commercial freight flows** to free up priority berths and space for military vessels and defence-related cargo movements when required.

Severe and Extreme Climate Events

- While most extreme weather events are localised, their economic impacts **reverberate through global value chains** (GVSs) given the high degree of interconnectedness (e.g., Thailand floods in 2011 disrupting major industrial estates in electronics and automotive produced effects across Japan, the EU and North America, affecting the production of cars, hard disk drives, air conditioners, refrigerators, and causing 40 billion USD of economic damages. *Globally*, they resulted in significant delays in car manufacturing and a reduction in industrial production of 2,5%. Prices of hard disk drives increased by 80%-190% and did not return to pre-flood levels for six months).
- The importance of this is widely recognised, but the potential scale of economic risks to GVSs from "fast onset events" (i.e. environmental hazards or disasters that happen quickly, with little to no warning, causing immediate and severe impacts) is **still poorly understood**.
- The intensifying effects of climate change produce severe to extreme events like heavy precipitation and pluvial floods, river floods, more frequent landslides, extreme storms including tropical cyclones, droughts, more frequent wildfires, as well as compound events (i.e. multivariate and concurrent extremes that, with increasing global warming, will have an increasing likelihood of frequency than in the past).

- What were once classed as isolated incidents are now **becoming regular disruptions**, increasingly **affecting different phases of global value chains**: not only logistics (as seen in cases of *Logistics disruptors* above), but also mining extraction (e.g. heavy rainfalls and floods closing opper, platinum, iron ores, gold, etc. mines from Australia to Chile, from South Africa to Brazil, from Indonesia to Peru, and wildfires repeatedly closing gold mines in Canada), upstream and downstream production (e.g. cyclones and typhoons and even drought in Far-East semiconductors' factories, or floods in OEMs and Tiers in Europe).
- **Asia** remains the region **most impacted** and **most likely to be impacted in the future** by natural disasters. For the World Meteorological Organisation, Asia is currently warming nearly twice as fast as the global average, fuelling more extreme weather and wreaking a heavy toll on the region's economies, ecosystems and societies. As these regions are the global hubs for critical raw materials, semiconductors and Western's low-cost productions, the **disruption risk for critical industrial inputs is increasing** year after year.

3. Supply Disruptions Costs and Outlook 2026

- The **cost of global supply chain disruptions** is very high. Swiss Re estimates it in 184 USD billion annually, driven by raw materials volatility, delays, increased logistics costs.
- According to Prewave, supply chain disruptions cost businesses 6% of annual revenue, but McKinsey research shows that companies can **lose** *up to* 42% of a year's EBITDA due to a single major disruption, especially those without diversified sourcing or agile production strategies. These costs include (i) lost revenue from delays in production or delivery, (ii) increased costs from premium prices for alternative suppliers or expedited shipping, (iii) inventory shortages leading to dissatisfied customers, (iv) reputational damage from frequent disruptions. Beyond the immediate financial impact, supply chain disruptions can also have long-term consequences, such as reduced competitiveness, strained supplier relationships, and regulatory penalties.
- Most companies are employing **multiple tactics** to build resiliency and diversification of their supply chains. Major rail OEMs increasingly frame procurement and supplier management in terms of resilience, flexibility and business continuity, including the need to maintain robust supplier networks and reduce exposure to supply disruptions. Advanced technologies such as Internet of Things (IoT), Big Data analytics, Artificial Intelligence (AI), Robotics etc. are helping better understand and predict supply chain behaviour and disruptions (e.g., supply chain monitoring, tracking and visibility, forecasting, analytics).
- However, technology alone is not a silver bullet. True supply chain resilience requires a strategic, proactive approach that fosters **cross-industry collaboration** and embeds **risk mitigation at every stage**.
- In fact, Gartner predicts **92% of companies** will **lack full end-to-end supply chain resiliency by 2026**, leaving many unprepared for ongoing disruptions. Indeed, lower-tier suppliers—especially SMEs and highly specialised sub-suppliers—remain, even today, less visible, less supported, and more exposed to disruptions and material shortages. As a result, resilience gaps are expected to persist

precisely in the 'hidden' layers of the value chain where critical components and processing steps are frequently concentrated.

- Per Goldman Sachs, the **risk of supply disruptions will raise** due to the very high geographic concentration of commodity supply (i.e. critical raw materials, oil, gas), the increasing geopolitical, trade, and AI competition, which lead to a more frequent use of commodity dominance as leverage. Beyond rare earths, in coming years supply disruptions risks are seen for other critical minerals such as lithium, copper, aluminium, given China's near-monopoly not only in exploitation but also dominance in refining of many minerals.
- Finally, in terms of commodities impacting Europe's industrial capacity and competitiveness, Goldman Sachs expects the LNG supply wave to reshuffle but not reduce Europe's **natural gas** import dependence. While the outlook base case is that a surge in US and Qatari cargoes will end Europe's energy crisis, the potential rise in US/Qatari exports to 70/10% of European imports by 2030 recreates the potential for using gas as geopolitical leverage. For **oil**, while the outlook base case is excess oil supply and still low price, disruptions from Russia, Venezuela, and Iran are risks to watch, especially with a moderation in OPEC+ spare capacity. For Gzero Media, however, 2025's geopolitical shocks involving those oil producers only threatened oil supplies but never disrupted them physically, given the continued flow of sanctioned ('dark') oil, higher non-OPEC supply (notably the USA), and OPEC+ buffers. However, if any disruption were to physically remove significant volumes from the market at a time when OPEC+ spare capacity is more limited, prices could still react sharply. However, any new event such as US attack to Venezuela of the past days show how things may change swiftly, disclosing new doubts on oil market management in the coming months both as Venezuela production and as retaliation from producing countries supporting Venezuela's current government.

4. Minerals Diplomacy and Geopolitics for Minerals and Semiconductors

- As minerals demand skyrockets globally, key global players are more and more committed to what is named "Minerals Diplomacy" to secure their access to these critical production inputs.
- **China**, intent to solidify dominance in rare earth elements and other critical minerals essential for the global energy transition, is using the "International Economic and Trade Cooperation Initiative on Green Mining and Minerals", a supply chain bloc to counter the West, with its minerals-rich allies like Zimbabwe, Cambodia and Nigeria.
- **USA**, under both the Trump and Biden Administrations, has signed deals with Ukraine, Kazakhstan, Rwanda-Democratic Republic of Congo, Peru to secure access to critical minerals.
- **India** is building minerals diplomacy through state-led overseas acquisition, bilateral MoUs, and coalitions with like-minded partners, to reduce dependence on China and power its manufacturing/energy transition.
- **USA, the EU and other partner countries have initiated,** under the Biden Administration, the **Minerals Security Partnership (MSP)** as a government-to-government partnership among like-

minded economies aimed to secure and diversify critical mineral supply chains, promoting projects that meet high ESG standards. MSP partners created the MSP Forum engaging select minerals-producing countries (Argentina, Democratic Republic of the Congo, Dominican Republic, Ecuador, Greenland, Kazakhstan, Mexico, Namibia, Peru, Philippines, Serbia, Türkiye, Ukraine, Uzbekistan, and Zambia) committed to advancing and accelerating individual projects that adhere to the MSP's strategic goals of diverse and resilient supply chains, local value-addition, and beneficiation to advance the economic objectives of all involved countries.

- Beyond the 'pure', 'labelled', Minerals Diplomacy, other Geopolitical actions may 'hide' the will to access to critical minerals and commodities, such as:
  - **China and the Belt and Road Initiative:** Mining is the second largest destination for the Belt-and-Road Initiative (BRI), with an investment of 95 billion USD since 2013. Almost half of it is concentrated in 4 countries – Indonesia, Democratic Republic of Congo, Peru, Guinea – securing a further dominant position.
  - **USA and Ukraine:** The "Agreement on the Establishment of a United States-Ukraine Reconstruction Investment Fund" signed in 2025 is designed as a joint reconstruction investment structure that preserves Ukraine's formal ownership of resources while granting the USA preferential access and shared governance over new critical minerals (i.e. subsoil use conditions and production) and relevant infrastructures essential for these projects, including roads, rail, pipelines, ports, terminals, logistics hubs, and processing plants (like refineries or LNG facilities).
  - **USA and Greenland:** The USA has been expressing its interest over Greenland since World War II (Truman Administration). In more recent times, both Trump Administrations have refreshed such interest as seeing Greenland a geopolitical shield and a potential critical-minerals hedge, combining hard security with supply-chain strategy. Although the USA frames its interest in Greenland mainly as a security issue (its location is pivotal for monitoring Russia, controlling emerging sea routes, and supporting US defence infrastructure), US strategic logic is of economic-security, as Greenland holds significant critical minerals (including rare earths, graphite, etc.) that are key for defence tech and the green transition.
  - **USA and Venezuela**: The USA current war 'over narco-traffic' in Venezuela and the military operation to remove Maduro is increasingly supposed to also be driven by the country's abundant deposits of gold, bauxite, and rare-earths such as coltan and thorium, as well as oil, gas, diamonds, iron ore, processed aluminium and steel products.
  - **USA and Nigeria**: The "US Christmas attack" to Isis in Nigeria, claimed as retaliation to murders of Christians, can be read under this lens.
  - **USA and Travel Bans**: Trum Administration travel ban policy, forbidding the entry of foreign nationals from certain countries into the United States, has been expanded in 2025 to many countries rich in critical minerals and oil, claiming national security needs, concerns about weak vetting, unreliable records, and corruption in some countries. This can be however read as having 'tools to relax' during negotiation phases in exchange for access to other

elements of interest. Nigeria, Africa's most populous nation, as **retaliation** has threatened mineral trade retaliation to jeopardise US access to West Africa's mineral resources.

- **USA and diversified tariffs policy**: US 'better tariffs' under the Trump Administration are increasingly offered – after sometimes harsh negotiations – to 'aligned partners' as part of wider economic-security deals, and the strongest, most explicit cases link tariff relief to critical minerals access (Indonesia) and to semiconductor supply-chain statecraft (China as well as allied chip partners Japan, South Korea, Vietnam, Malaysia, Thailand).

5. Efforts to increase Resilience and Autonomy

Cross-industry Collaboration

- Across strategic industrial ecosystems, a **growing number** of cross-industry initiatives are emerging to strengthen value chain resilience by improving transparency, coordination and collective risk management across all tiers, offering also a scalable pathway to mitigate critical material and semiconductor vulnerabilities and to strengthen supply autonomy, especially for SMEs that otherwise lack the scale and visibility needed to absorb shocks independently.
- Similar efforts typically create **shared governance frameworks, common data standards and trusted collaboration mechanisms** that allow companies to exchange relevant supply-chain information without compromising commercial confidentiality.
- By enabling **earlier detection** of bottlenecks, improving **traceability and compliance**, and facilitating **faster reconfiguration** of sourcing options during disruptions, such initiatives help reduce the structural 'blind spots' that often affect Tier-2 and Tier-3 suppliers. They also support more coordinated approaches to supplier qualification, integrity checks and lifecycle management, which are particularly important in safety-critical sectors with long product lifetimes and limited substitution possibilities.

Good practice | Policy + Industry: *Catena-X*

Catena-X is a global, industry-driven data ecosystem for the automotive value chain explicitly **designed to improve supply chain resilience by turning fragmented, opaque supply networks into connected "data chains"**—so disruptions can be detected earlier and managed better. It serves as a blueprint for future industrial data spaces in Europe.

Catena-X was initiated in Germany by major automotive and industrial actors, including BMW Group, Mercedes-Benz, Volkswagen, and others, and was supported as an internationally relevant industrial-policy flagship initiative by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) with more than 100 million € of EU support (NextGenerationEU / recovery package).
Catena-X supports value chain resilience through:

- a standardized, interoperable data ecosystem that enables **cross-industry alignment of demand and capacity in real time**, based on validated data, while preserving data sovereignty
- tools that allow OEMs up to suppliers, even at Tier-n levels suppliers and downstream partners, to **efficiently exchange and synchronize their demand forecasts and available production capacities**. The result is robust, predictable supply chains – even during volatile phases
- **end-to-end traceability of components, materials, and processes across the entire supply chain**. Through the use of digital twins and standardized data models, components can be uniquely identified—from raw material source to finished product.

Catena-X therefore **enables**:

- Early detection of **capacity bottlenecks and demand fluctuations**
- Accurate **traceability** of products, components, and production steps
- **Shorter response times** to supply disruptions or quality issues
- Efficient **coordination** between OEMs and suppliers–**even at Tier-n levels**
- **Reduced inventory costs** through better planning accuracy.

Catena-X uses a federated model based on principles associated with GAIA-X, so companies share only what is necessary via agreed standards and open interfaces, while keeping data sovereignty.

The ecosystem is **governed by the Catena-X Automotive Network Association**, while technical building blocks are developed in open source via Eclipse Tractus-X.
Catena-X is frequently presented as one of the first large-scale "data space" implementations in European industry and a blueprint for other industrial ecosystems (e.g., Manufacturing-X), precisely because it links digital collaboration to resilience and sustainability outcomes.

Link: Catena-X

Good practice | Industry: *Stellantis supply-assurance measures*

As the auto industry's demand for semiconductors accelerates, since 2023 Stellantis has been implementing a multifaceted strategy designed to **manage and secure the long-term supply of vital microchips**.
Key vehicle capabilities directly depend on the innovation and performance of single devices, therefore in Stellantis cars are installed hundreds of very different semiconductors. Stellantis' strategy was therefore adopted to deploy all innovation potential and to avoid that one missing chip can stop their lines.

Developed by a cross-functional team, the strategy was **created through a rigorous assessment of customer desires for advanced technology features** and a keen focus on delivering the Stellantis 2030 objectives. The strategy, which is **refined continuously**, includes:

- implementation of a semiconductor database to provide full transparency on the semiconductor content
- systematic risk assessment to avoid and proactively remove legacy parts
- long-term chip level demand forecasting to support capacity securitization agreements with chip makers and Silicon Foundries
- implementation and enforcement of a Green List to reduce chip diversity and – in case of future chip shortages – to put Stellantis in control of the allocation
- the purchasing of mission-critical parts at chip makers including a long-term securitization of chip supply.

Therefore, Stellantis' policy introduces **direct upstream procurement of mission-critical chips** from chip makers **instead of leaving it entirely to suppliers**, to **avoid shortages and price escalation** for Tiers.

Stellantis has entered into direct agreements for semiconductors with a purchasing value of more than 10 billion € through 2030. The **supply agreements cover a variety of vital microchips**, including:

- Silicon Carbide (SiC) MOSFETS, which are fundamental to the range of EVs
- Microcontroller Unit (MCU), a key part of the computing zones for the STLA Brain electrical architecture
- System-on-a-chip (SoC), where performance is essential for the high-performance computing (HPC) units that deliver the in-vehicle infotainment and autonomous driving assist functions.

Link: [*Stellantis Implements Multifaceted Semiconductor Strategy to Ensure Supply Security, Drive Innovation*]

In 2023 Stellantis made a 155 million USD **investment in the Los Azules copper mining project** in Argentina. As one of top ten international copper projects in development, it is expected to produce 100,000 tons per year of green copper for EVs cathode at 99.9% purity, starting in 2027 and whose resources can secure the operation for at least 33 years.
Stellantis investment is aimed at **ensuring strategic supplies of raw materials necessary**

for the success of its global electrification plans.

Link: [Stellantis Strategic Copper Investment in Argentina]

Circularity for Resilience

- Circular economy strategies aim to keep materials longer in use in the economic system. Despite the EU is probably one of the most advanced regions in end-of-life management of waste products, the options for circularity that are possible in the current situation are **vastly under-used** (e.g. the provisions of the Waste from Electrical and Electronic Equipment (WEEE) Directive of 2003 did not provide enough incentives to establish recycling processes for all WEEE materials, while recycling of specific CRMs from WEEE is mainly economically driven. Likewise, the WEEE 2 Directive of 2014 does not specifically require the recovery of CRMs).
- Critical materials are not easily recoverable at scale today or require advanced processes. Beyond technology readiness for most complex separation, **reaching critical mass** to ensure sustainable business cases is still challenging for many materials (e.g., electronics already provide a vast waste outflow containing significant amounts of critical raw materials, but collection lags behind and recovery is focused only on major or high-value material flows; rare earths and other critical raw materials used in small volumes are lost).
- As many innovative technologies requiring critical and strategic raw materials are only at the beginning of their life-cycle, circularity cannot help counterbalancing the increasing demand of primary materials. And since many key innovations for industrial sectors typically will be used for decades before they reach end of life (e.g. aerospace technologies, clean energy technologies, new generations of trains with battery or hydrogen propulsion), circularity strategies can only be applied in the future.
- However, critical raw materials have been **used in significant quantities in the past in other than novel critical technologies and products** (e.g., not only Copper, Tungsten or Aluminium, common in grid distribution, household, roofing, tooling components, etc., and whose recycling rates are already high in the EU, but also Neodymium magnets were common in computer hard disks, that now largely have been replaced with solid state memory). If recovered, these can be a source for critical materials needed in today's more advanced applications.
- Circularity has a significant **territorial dimension**: territories are where environmental impacts, material flows, and recovery opportunities concretely arise. For this reason, fostering value-chain resilience requires **place-based regional policies** to shorten supply chains and embed circular practices within local and cross-regional ecosystems. Regions are best positioned to connect end-of-life assets, industrial demand, recycling capacity, skills, and infrastructure, transforming waste streams into locally available secondary resources while reducing exposure to external shocks.
- Defining clear and 'low red-tape' **regulatory layers** on circularity and avoiding regulatory fragmentation is a key step, as well as avoiding unjustified differences between regional regulatory frameworks to ensure a level-playing field and equal opportunities throughout Europe.

Good practice | Industry: *Apple*

To scale its efforts—and help identify broader market opportunities for decarbonization and circularity—Apple worked with McKinsey to realize a deeper understanding of circular value chains across multiple industries for materials like copper, aluminium, and rare earth elements, among others. To help strengthen broader industry momentum for circular materials, Apple and McKinsey have chosen to make a number of quantitative research findings publicly available, calling for industry partners to help increase the overall use of circular materials.

Apple experts from across functions, including **operations**, **engineering**, and **environmental** teams, collaborated with McKinsey to complement existing work to further explore the current landscape and new opportunities for circular materials: What materials get lost in production after reaching end-of-life; which untapped scrap pools have the most potential; and what actions, alliances, and regulatory conditions are needed to get there.

Apple wanted to make these results as practical, concrete, and actionable as possible by identifying measures to unlock these untapped materials, looking to understand and share what exact scrap reservoirs exist by region and industry, what form the scrap comes in, and how to operationally unlock it.

To get a granular view of the materials market, one element of the work involved use of MineSpans, a McKinsey tool that pools data on all the mines in the world, using supply-and-demand models, carbon footprints, and scrap pool data. This data complemented Apple's own work in key material value chains and their circularity opportunities, supply-and-demand dynamics, and the products that contain these materials, such as copper in electrical devices and underground cables.

The research is helping Apple identify further ways to unlock these materials, such as e-waste management and regulatory measures, ensuring materials that would otherwise be lost can be recovered and recycled. The goal is for industry players and policy makers to forge a viable path toward recovering them.

In this spirit of collaboration, Apple is actively rallying partners and adjacent industries to drive change across materials supply chains. Now that they've helped build a recycled material end-to-end market perspective within the electronics industry, Apple **is looking to team up with other off-takers with shared ambitions, as well as materials producers and equipment manufacturers working on ways to disassemble, sort, or recover materials**. This effort is part of the World Business Council for Sustainable Development's Critical Materials Collective initiative. From offtake agreements to scrap collection, this collaborative approach ensures the entire ecosystem works together toward sustainability and circularity goals.

To scale quickly enough to solve for this challenge in the short term, players will need to invest in accelerating research and development of the technology needed, much of which still must be built and proven at industry scale. For example, Apple has invested in recycling innovations including Taz, a machine that separates magnets from audio modules to recover rare earth elements and Dave, a robot that disassembles Taptic Engines on Apple devices to recover valuable rare earth magnets, tungsten, and steel. In July 2025, Apple announced a deal with MP Materials for rare earth magnets that includes plans for an all-new recycling facility capable of taking in recycled rare earth feedstock and reprocessing it for use in Apple products.

Collaboration across the value chain is a long-term approach to help solve this challenge. For example, producers and original equipment manufacturers help recyclers focus their efforts by

providing transparency on magnet locations such as Apple's recycler guides—an effort regulators now require.
Such insights help effectively devise strategies for unlocking and making use of untapped circular materials pools. But to increase recycled content in their products, players need a detailed understanding of current barriers and unlocks to tap new secondary pools instead of competing for already scarce supply.

Link: How Apple is helping unearth a path toward increasing the global use of circular materials|

Good Practice | Policy: *Achieving Circularity Experimentation Journey*

The "Achieving Circularity Experimentation Journey", facilitated by the JRC, brings together regions aiming to make circularity a prominent element of their industrial transition, developing business models and environmental conditions to make it competitive by fostering demand for circular products as a driving force for innovation and territorial transformation.
The involved EU regions are Central Macedonia (EL), Dalarna (SE), Järva (EE), Kanta-Häme (FI), Navarra (ES), Normandie (FR), East-North Region (FI), and the region of Murcia (ES).
The journey operates on two levels:

- At the **local level**, each region aims to develop its own local experimentation process, fostering collaboration and learning from others and creating their "transition teams" to guide the circularity process across administrations and local ecosystems.
- At the **Journey/European level**, drawing from the collective experiences of regional practitioners, collaboration with colleagues from JRC and external experts, the journey aspires to influence and drive change.

E.g., Dalarna is promoting public procurement processes that generate demand for circular products, encouraging horizontal and vertical coordination among administrations and involving businesses. Normandie is deeply committed to improving circularity in the plastics and packaging industry, which is one of its major sectors. In addition, Navarra pushes for the creation of transition teams among administrations for better coordination on transforming circularity, while Murcia and Kanta-Häme closely collaborate with companies, particularly SMEs, to create ecosystems with start-ups and exploring new AI opportunities. East-North Finland looks into working on circularity in mining and bioeconomy, and Central Macedonia aims to develop its own regional circularity strategy.
The initiative aims to make circularity a reality by offering insights to the legislators, policymakers and territorial stakeholders that can contribute to remove the identified barriers and reinforce circularity in the European Union at all levels.

Link: Preparatory Action (2024-2026) - Innovation for place-based transformation

Advanced Materials

- Advanced materials, i.e. materials rationally designed to have new or enhanced properties, offer the possibility to substitute or reduce the use of critical and strategic raw materials **in technology supply and value chains** while maintaining performance in high-demand applications.
- The **maturity** of substitution and reduction solutions varies across sectors and applications. Some sectorial applications have distinct requirements, so the **coexistence** of several technologies alternative to the current benchmark may be desirable. JRC analyses these factors **in clean energy technologies**, finding that: (i) in batteries and electric-vehicle motors, many innovative technologies which reduce or eliminate the use of critical raw materials are already commercially available; (ii) in wind energy, commercial technologies such as induction generators are viable for onshore wind applications, but less so for offshore, where emerging technologies such as high-temperature superconductors are less mature; (iii) in the solar PV sector, many innovative technologies are in early commercialisation phase; (iv) in hydrogen electrolysers and fuel cells, reduction solutions could be available in the short term.
- The substitution of critical raw materials with advanced materials can, however, involve **trade-offs** in terms of durability, lifetime, cost, or environmental and social impacts.
- **Solutions for substitution** include: (i) 1-for-1 material substitution: Replacing critical materials within components with less- or non-critical alternatives. (ii) Technology/component substitution: Replacing entire components or adopting alternative technologies to eliminate the need for specific materials. (iii) Process substitution: Employing alternative process technologies that enable the substitution or reduction of certain materials.
- **Solutions for reduction** include: (i) Enhancing material properties: Improving material performance (e.g., higher efficiency or output per unit of material) to decrease the quantity required. (ii) Optimising component design: Refining the design of components to minimise material use without compromising functionality. (iii) Improving process efficiency: Adjusting process parameters to achieve greater material efficiency during manufacturing or assembly.

Supplies for Digital Sovereignty

- EU digital sovereignty can be defined as Europe's ability to act independently in the digital world and is related to the **capacity of maintaining control of the products, systems, and services with any digital elements** used by European citizens, undertakings, and public administrations. The meaningful control over the technological components and elements thereof should include the different phases including design, production, operation, use, improvement, sustainment and resilience, **throughout their entire life cycles**.
- EU digitalisation is quadrupling from 2010 the energy requested, to 8000TWh/year in 2030.
  Edge is seen as an enabler for reducing carbon usage by cloud; however, the expansion of cloud in Europe will be accompanied by significant energy efficiency gains compared to other alternatives, like on premises or private clouds. The increased provision of cloud and edge services will aggregate workloads on public cloud / edge services across Europe.

- The Technology Roadmap for Edge and Cloud confirms the attention and potential supply risks that, as suitable to impact on, may impact also the Railway sector. Supply chain disruptions are considered a key driver for the Edge-and-Cloud supply chain, as the current supply chain crisis could slow down technology development and deployment.
- **Ensure local options exist** for components critical to technology development and deployment is therefore critical, as digital components are largely dominated by non-EU companies and industry standards, and for the purpose of European technical sovereignty for edge and cloud it is useful to consider technological, organisational, intellectual property level efforts, which cover the following:
    - Hardware level including:
        - Chips (e.g. semiconductors: computing, power management)
        - Boards (aggregation of chips)
        - Devices/apparatus (e.g. connectors, routers, computers, switch, smartphones, embedded subsystems, and other components)
    - Software level including:
        - Embedded software
        - Basic operating software (e.g. operating system, cloud infrastructure software)
        - Application-related software (e.g. database management)
    - Data including:
        - Actual data
        - Meta data related to actual data
        - Inferenced data (from actual data and metadata)
    - Infrastructure topology taking into consideration centralised and distributed architectures towards edge and far edge.

EU efforts for supply autonomy and resilience

The European Commission is committed to adopting a broad series of policies and initiatives suitable to increase Europe's autonomy in accessing to critical raw materials and components necessary to its industry. The main 'horizontal' ones are:

Table 1 | EU's initiatives to increase industrial autonomy in accessing to CRMs and critical components

EU Initiative	Objective	Webpage
Economic Security Strategy (2023)	Sets the EU framework for 'de-risking', identifying sensitive dependencies and using trade, investment and export-control tools to reduce vulnerabilities, including supply chain security.	Link
Internal Market Emergency and Resilience Act (IMERA) (2024)	Formerly known as the Single Market Emergency Instrument (SMEI), it is designed to provide the EU with the flexibility to take rapid and effective actions in case of future crises (i.e. security concerns, natural disasters,	Link

	economic shocks, public health crisis), safeguarding critical supply chains and ensuring the continued free movement of goods, services, and people.	
Joint Communication on strengthening Economic Security (2025)	Sets out the EU's strengthened approach to addressing risks, using all the tools at its disposal in a more coordinated way for six main priorities, one of which is reducing strategic dependencies for goods and services. It will also enhance its information collection and analytical capabilities to inform EU decisions and improve coordination with Member States and businesses.	Link
Action Plan on Critical Raw Materials (2020)	Looks at the current and future challenges and proposes actions to reduce Europe's dependency on third countries, diversifying supply from both primary and secondary sources and improving resource efficiency and circularity while promoting responsible sourcing worldwide. Adopted with the 2020 List of Critical Raw Materials (CRMs) and a foresight study on CRMs for strategic technologies and sectors from the 2030 and 2050 perspectives.	Link
European Raw Materials Alliance (ERMA) (2020)	Aims to make Europe economically more resilient by diversifying its supply chains, creating jobs, attracting investments to the raw materials value chain, fostering innovation, training young talents and contributing to the best enabling framework for raw materials and the Circular Economy worldwide.	Link
Raw Materials Diplomacy (2021)	Part of the Raw Materials Strategy (2011), consists in Strategic Partnerships with resource-rich countries, typically formalised through Memoranda of Understanding (MoUs) and followed by implementation roadmaps. So far, the EU has signed 15 Strategic Partnerships and has relationships in place with 10+ more countries.	Link
European Union Free Trade Agreements (FTAs) → *in place and under negotiation*	EU FTAs increasingly support the EU's critical-inputs security by combining market access with disciplines on raw-material export restrictions and with cooperation frameworks that diversify sourcing and underpin investment across mining, processing and strategic component value chains	Link
Global Gateway Strategy (2021)	The EU's multi-billion investment vehicle to advance European geo-economic interests with partners across the globe can be seen as both the external arm of the EU's new industrial policy and a response to China's Belt and Road Initiative (BRI). It is implemented through projects. A prominent example linked to secure and	Link

	resilient CRM supply chains is the "Lobito Corridor", to connect by rail the Southern regions of the Democratic Republic of the Congo (DRC), northwestern Zambia and Angola to regional and global trade markets via the port of Lobito.	
Minerals Security Partnership Forum (2024) – *former CRMs Club* (2023)	Co-led by the EU and the USA, the Forum is a multilateral cooperation platform within the framework of the MSP, bringing together raw materials producing countries and raw materials consuming countries at various stages of development. It focusses on advancing and accelerating individual projects and promoting policies that contribute to resilient value chains and to bringing local value-addition	Link
Critical Raw Materials Act (2024)	EU's comprehensive response to its increasing demand and dependence on critical raw materials supplied by third countries, to create more secure and resilient supply chains.	Link
Steel and Metal Action Plan (SMAP) (2025)	Customs surveillance system to monitor the import and export of metal waste and scrap into and out of the EU, covering ferrous waste and scrap (including steel), aluminium and copper. The Commission will use import and export data to assess if any further action is necessary to help reduce reliance on imports, increase recycling and secure a more reliable supply of essential metals for key industrial sectors.	Link
Raw Materials Mechanism (2025)	Mechanism open to (i) undertakings consuming raw materials established in the Union, (ii) central buyers who purchase on behalf of other undertakings consuming raw materials established in the Union (iii) suppliers of raw materials, (iv) storage suppliers. The Mechanism enables connection between these organisations, facilitating demand aggregation and transparent, joint purchasing of raw materials, hence reducing price volatility and supply insecurity –however it does not directly provide financing or support negotiations (these take place outside of the EU Platform, following the connections created through it).	Link
IPCEIs (Important Project of common European interest) on Microelectronics (2018, 2023)	Large, cross-border state-aid approved projects that pool public funding to accelerate breakthrough microelectronics and communication technologies across the full value chain.	Link
Alliance on Processors and Semiconductor Technologies (2021)	Aims to identify current gaps in the production of microchips and the technology developments needed for European companies and organisations to thrive, no matter their size.	Link
Chips Act (2023)	Aims to reinforce the semiconductor ecosystem in the EU, increase the resilience of supply chains and reduce	Link

	external dependencies.	
Chips Joint Undertaking (2023)	EU public-private partnership (PPP) created under the European Chips Act to strengthen Europe's semiconductor ecosystem, fund R&I and pilot lines, and support tools like a design platform, competence centres and skills development.	Link
European Commission Expert Group "European Semiconductor Board" (2023)	Serves as governance mechanisms of the European Chips Act and its three pillars of action. The aim of the ESB is to facilitate a smooth, effective and harmonised implementation of this Regulation, cooperation and the exchange of information	Link
EU–India Semiconductor Business Cooperation (2023)	Working arrangements on semiconductors ecosystem, its supply chain and innovation under the framework of EU-India Trade and Technology Council (TTC)	Link
Semiconductor Competence Centres (2024)	Promoted by Chips JU, it is a Europe-wide network of national and regional competence centers (CCCs) for semiconductors aiming to be a first entry point for users (mainly SMEs and startups) towards the design platform and the pilot lines to reduce cost barriers and encourage growth in Europe's fabless sector; to facilitate skill development activities; to support companies in accessing the Chips Fund.	Link
EU Semiconductor Diplomacy Network (2025)	Consortium aimed to support a more coherent European economic foreign policy in semiconductors, reducing vulnerabilities and managing external dependencies in a geopolitically tense environment	Link
Other relevant Industrial Alliances (since 2017)	"European Battery Alliance", "European Alliance for Industrial Data, Edge and Cloud", "Critical Chemicals Alliance", "Circular Plastics Alliance", "European Clean Hydrogen Alliance" and others also contribute to building a more autonomous and resilient European industrial ecosystem with reference to key materials, components and systems.	Link
Battery Regulation (2023)	Introduces due diligence, traceability and recycled-content requirements; supports a more secure and sustainable supply chain for key battery materials and reduces reliance on primary imports.	Link
Ecodesign for Sustainable Products Regulation (ESPR) (2024)	A major framework to extend product lifetimes, improve reparability, recyclability and recycled content-ultimately to reduce raw-material demand and dependency over time.	Link
RESourceEU Action Plan (2025)	Provides financing and concrete tools to protect industry from geopolitical and price shocks, promote projects on critical raw materials in Europe and beyond, and partner with like-minded countries to diversify supply chains	Link
European Circular Economy Act	Aims to create one single market for secondary	Link

(CEA) → *forthcoming (2026)*	resources, cutting through regulatory complexities, and unlocking investments in the technologies and infrastructure.	
European Advanced Materials Act → *forthcoming (2026)*	Puts forward measures to achieve open strategic autonomy on advanced materials. This will help reduce dependencies on critical resources and boost EU competitiveness.	Link

PART II

RAIL INNOVATIONS RISKS: A SNAPSHOT

The Project Research and Its Conclusions

The methodology followed

As the LEADER 2030 ultimate project goal is ensuring that Europe's rail value chain remains resilient, sustainable, and competitive:

- The European rail value chain was, first, analysed within the more general disruptions affecting the European economy, and then directly surveyed (data directly gathered from companies throughout the entire rail value chain from 37 regions in 16 countries) to identify current disruptions (of what; where along the value chain; for what reasons; resilience plans; etc.) to understand supply and value chain dynamics, and to identify alerts for the future.
- A similar analysis was then conducted in other high-technology sectors (Automotive, Aerospace, Defence, Clean Energy Technologies) with whom the rail sector shares certain technological evolutions and certain supply dynamics, to verify if specific disruption or resilience patterns existed.
- Then, the EU-Rail target innovations were comprehensively mapped, identifying necessary technologies, raw materials, and supply chain requirements across various tiers (OEMs, Tier 1, 2, 3) to make a first 'criticality assessment'. Also, subsystems and components that will become obsolete or significantly reduced due to technological advancements were also identified, for signaling key areas of industrial transformation due to affect part of the rail value chain. This was done through (i) desk analysis of the EU-Rail key documents (MP, MAWP) and available data from the Flagship Projects, (ii) a direct consultation of Flagship Project Coordinators and Partners to obtain first-hand insights into the status, outcomes, and future technological requirements of their projects, including raw material dependencies and supply chain implications–although 3 didn't participate, and (iii) targeted interviews to 24 key industry players.
- In parallel, it was carried out a desk research on raw material supply distortions from past crisis resulting in availabilities constraints of raw materials; a desk research on disruptions of the raw materials supply chains induced by energy politics and energy shortages; the analysis of most affected Member States' raw materials sourcing agenda, e.g. by their raw material strategies, here specifically those countries with a strong rail economy. When the previous analysis of critical raw materials and critical components needed for EU-Rail innovations was ready, it was carried out the review to map their provenance/supply chain information as well as sourcing possibilities within Europe and from overseas, together with: desk study on global (including EU) framework conditions regarding the accessibility of raw materials and conditions of economically viable domestic sourcing including EU regulation and directives that impact these supply schemes; desk research on geopolitical analysis and outlook in terms of envisaged short-term strategic partnerships, backward integration and competing supply schemes of other industry sectors; stakeholders' consultation on sustainable sourcing and supply schemes to contribute to fostering a resilient rail supply chain for the implementation of the future needed rail innovations and energy grids up to 2030.

Supply disruptions risks

According to the results of the LEADER 2030 survey carried out on ***past and current*** disruptions in the European rail value chain, **company size** is not an element that automatically affects the ability to avoid or better resist such disruptions. The ability to manage these difficulties through

structured forms of risk management (stockpiling, contingency planning, suppliers' vulnerability assessment, suppliers' diversification, …) varies from case to case. The survey results show that (i) large companies have in general more tools to manage this but they are affected by many disruptions in parallel, which can also create and multiply cross-dependencies; (ii) SMEs, being more vertical, are affected by more specific disruptions, but usually resort to stockpiling and continency planning as their main strategy. Substitution of non-EU disrupted supplies with EU ones is not always possible due to the objective lack of closer and more certain alternatives (raw materials and electronics first and foremost), and, whenever possible, the cost difference - on average +30% in the EU - does not make this substitution possible due to the non-acceptance of the 'cost increase for greater security' by the end customer. In addition, to date, forms of intra-supply chain circularity are hardly considered at all.
Going into some detail:

- 58,1% of the surveyed European companies–representing a well-balanced sample in terms of size, provenance, role in the rail value chain and business segment– suffered disruptions, in most cases concerning "*both standard and innovative supplies*" (55%), which calls for a **first 'alert'**, as this – summed to the 9% of disruptions hitting "*more innovative supplies only*" – is exactly the 'fear' behind the EU-Rail call funding this project. However, as those *not suffering disruptions* consisted by 41,8% of *engineering companies* and *enterprises without critical supplies*, the number of "real problem-free supply companies" was 23,8% only.
- Disruptions are **mainly Supply-related** (87% of respondents reported them with *high+very high impact*); the main ones concern **Raw Materials** (with Iron (Fe), Aluminium (Al) and Copper (Cu) the most hit, but also Rare Earths (both LREE and HREE) as well as other metals representing high-performing conductors), followed by **Processed Materials** (all steel types, composites and aluminium-based alloys the most hit, as well as more innovative materials such as Glass-based and Composites) and **Components** (semiconductors, chips and a wide variety of electronic components by far the most disrupted, however followed by a broad range of components related to rolling stock, signalling and communication systems, infrastructure); **Assemblies** are the least disrupted.
- Disruptions concerning **Economic/Financial aspects** are the second most important problem suffered by the rail value chain (71% of respondents reported them with *high+very high impact*), followed by **Logistics** (increased costs and delays) and by **Manufacturing-related** disruptions (both with 58% of respondents reporting them with *high+very high impact*). Being logistics strictly related to supply chain management, a **second alert** to be considered in the assessment of future rail supply vulnerabilities is the frequency of logistic disruptions with global impact. The surveyed companies source in large majority also from outside Europe, hence the likelihood that this type of disruptions will continue to impact them is very high.
- Given that major disruptions in supplies however concerned *sourcing from own country and from inside Europe*, a **third big alert** – and indication for action – concerns the **need to connect** as much as possible European value chains.
- Demand-driven disruptions exist (35% of respondents reported them with *high+very high impact*) and represent a **fourth alert** about disruptions that could affect the rail value chain as result of the upcoming innovation-driven transformations in the rail sector. The main reason for such

disruptions was in fact *change in the products/services requested*, which also highlights the risk of **obsolescence** management.

- The **low substitution potential** of many supplies and the **price gap** between substitutable supplies 'made outside the EU' vs 'made in the EU' (worth of an **average +30%**) represents a **fifth alert** to be considered in identifying possible policy and industrial mitigation/solution strategies, such as boosting circularity along the value chains or fostering the adoption of criteria in customers' procurements/purchases **rewarding the 'made in EU'**. In fact, in the background remains the risk that the deployment of all the (macroeconomic) policies and actions useful and necessary to increase the autonomy and resilience of European supplies in the years to come will be frustrated by the (microeconomic) policies and actions of the firms that determine the supply and demand for those supplies. Supply chain policies that continue to focus on the lowest price, moreover in parallel with the demand to source - however - from reliable suppliers, run the risk of appearing like 'having your cake and eating it'. This is a **sixth alert** to be considered. A crucial work should be done for bringing such considerations into the Procurement process of Public Buyers, first, and as a beneficial consequence this would go all along the value chain purchases. Some EU policies and tools are already there to avoid the 'misuse' of lowest price criterium and fostering the broad use of the MEAT-Most Economic Advantageous Tender principle. Strategic considerations to make the best use of this and other tools to enable the best performances for the target users while helping EU industry long-term resilience should be done at value chain level.
- The **companies with resilience policies in place** (both the companies having not suffered any disruption and those affected) are the huge majority (75%) of the surveyed companies. On average, more than one policy is adopted by each company, this showing that to mitigate *different* types of disruptions produced by *different* types of crises companies need to put in place a set of solutions. For example, stockpiling is a good practice to reduce (i) risks of scarcity due to wars (because productions are suspended) or inbound logistics bottlenecks (whatever their reason), as well as (ii) risks of high fluctuations in prices (analysing the price trends and global trends, one can decide to buy larger stocks when prices are lower). However, the participants' answers also show a major attention to diversification of supplies both inside and outside Europe, for redundancy reasons. Stockpiling and diversification/duplication of suppliers, however, are both **expensive choices**: this raises a **seventh alert** concerning the economic sustainability of such policies in the long-term. Companies may have initially viewed these as temporary measures, but we are living in an era of "permacrisis", and all companies must now make the most of **advanced technologies** to try to understand and predict behaviour and supply chain disruptions to achieve an optimised balance between *resilient-only* and *lean-only* status.

Then, the results of the LEADER 2030 analysis carried out on ***past and current*** disruptions in other possibly relevant sectors showed that:

- The other sectors analysed –Defence, Aerospace, Clean Energy Infrastructures, Automotive–have also experienced in the most recent years **similar levels of supply disruptions**, being affected by **dependencies on many production inputs**.

- The expectation of finding 'special' resilience patterns to learn from in the Defence and Aerospace sectors–as considered 'prioritised'–was therefore unmet. Findings also show that high investments in R&D have not shielded these sectors from even the most ordinary metal supply problems, which confirms both the **'globalised' risks** and the **importance of *any* production input**, even those not marked as being "critical" according to mainstream methodologies.
- **Common disruption patterns** could be found between the **Defence and Aerospace** and the railway sector, not only in the field of the three special segments analysed, i.e. *Defence electronics*, *Advanced materials* and *UAVs*. This makes the effort towards resilience of these industrial ecosystems more similar.
- The **Clean Energy infrastructures** sector didn't provide resilience patterns either. Many dependencies are common to the railway sector, given its utilisation of energy infrastructures and clean technologies. Special disruption patterns were instead identified, mostly related to price volatility.
- The **Automotive** sector didn't provide supply resilience patterns either, despite its huge dimension could help a stronger position on supply markets. Its key lessons, instead, have to do with the huge transformation of its value chain following to transition from conventional to electric vehicles. As transparency on technology roadmaps and planning by OEMs was called by several consultancies to increase the sector resilience and delivery capacity–and this was then done through "Catena-X"–, this should also be followed by the railway sector in its transformation towards 2030.

The overall findings of this first set of research showed also the **importance of also 'more ordinary' production inputs** and that **even *small components* can become critical** *if* their supply is delayed or scarce/insufficient.
This corresponds with the 'alert' raised in 2022 by the European Commission Expert Group "Industrial Forum" in its "Strategic Dependencies Interim Paper", where it specifically mentions the **"relevance of small components"**, reporting that:

> *"(…) the innovative or highly specialized nature of a good should not be the sole criterion to define what was strategic or not to the EU industry, quoting current shortages of semiconductors of different complexities, widely used by the EU industry. Products which are essential for many sectors but which are no longer produced in the EU, such as screws, cables or bolts, could also be considered".*

Moving to the future, the following analysis carried out on Europe's Rail target innovations mapped several transformative innovations essential for the future of the European railway system and currently delivered through the following Flagship Projects:

- **Network Management & Mobility (FP1 - MOTIONAL):** Advanced traffic management systems, real-time data analytics, and digital platforms enhance operational efficiency and network capacity.

- **Digital & Autonomous Train Operations (FP2 - R2DATO):** Automatic Train Operation (ATO), AI-driven control systems, and advanced sensor technologies improve safety, reliability, and cost efficiency.
- **Intelligent & Integrated Asset Management (FP3 - IAM4RAIL):** Predictive maintenance systems, Digital-Twins, and IoT-based sensors optimize asset lifecycle and reduce maintenance costs.
- **Sustainable & Green Rail Systems (FP4 - RAIL4EARTH):** Energy-efficient propulsion, sustainable materials, and emissions reduction technologies drive sustainability efforts.
- **Competitive Digital Green Rail Freight (FP5 - TRANS4M-R):** Digital Automatic Couplers (DAC), intelligent freight systems, and smart grid integration enhance efficiency and sustainability for seamless rail freight.
- **Regional & Capillary Rail Services (FP6 - FUTURE):** Modular vehicles, cost-efficient infrastructure, and customer-centric digital services improve accessibility and affordability.
- **New Approaches for Guided Transport (FP7 - Pods4Rail):** Automated multimodal transport systems and ultra-high-speed trains introduce innovative mobility solutions.

The steps of the research conducted followed this sequence:

1. **Identify Innovations:** Each FP's main innovation (and its more advanced version when the case) was identified based on EU-Rail documentation and industry inputs.
2. **Break Down Functionalities** For each main innovation, core functionalities and sub functionalities were outlined.
3. **Detail Products and Components:** From the identified functionalities, relevant products were broken down into sub-assemblies and their respective hardware and software components, isolating hardware for further analysis.
4. **Extract Raw Materials:** Components were mapped to their required raw materials, focusing on rare earth elements crucial for advanced rail technologies.
5. **Categorize Needs and Potentially Obsolete Components:** Each FP was analysed for new material requirements compared to previous technologies, as well as components likely to become obsolete.
6. **Likelihood of Technology Implementation by 2030:** Assessed the probability of each innovation reaching operational status by 2030 based on its projected Technology Readiness Level (TRL), as detailed in EU-Rail MAWP.
7. **Criticality of Raw Material Demand on the Sourcing Chain by 2030:** Analysed the criticality of raw materials based on demand trends and the likelihood of related innovations being implemented, identifying potential supply chain risks by 2030.

This comprehensive approach not only mapped the material and technological needs essential to LEADER 2030 objectives but also introduced a forward-looking analysis. By linking technology readiness with material demand, the methodology highlighted critical areas of impact on the sourcing chain. Altogether, this structured approach provided a thorough, actionable framework aligned with LEADER 2030's strategic goals.

Here below is provided the estimated overall risk represented by these innovations according to three categories of risk:

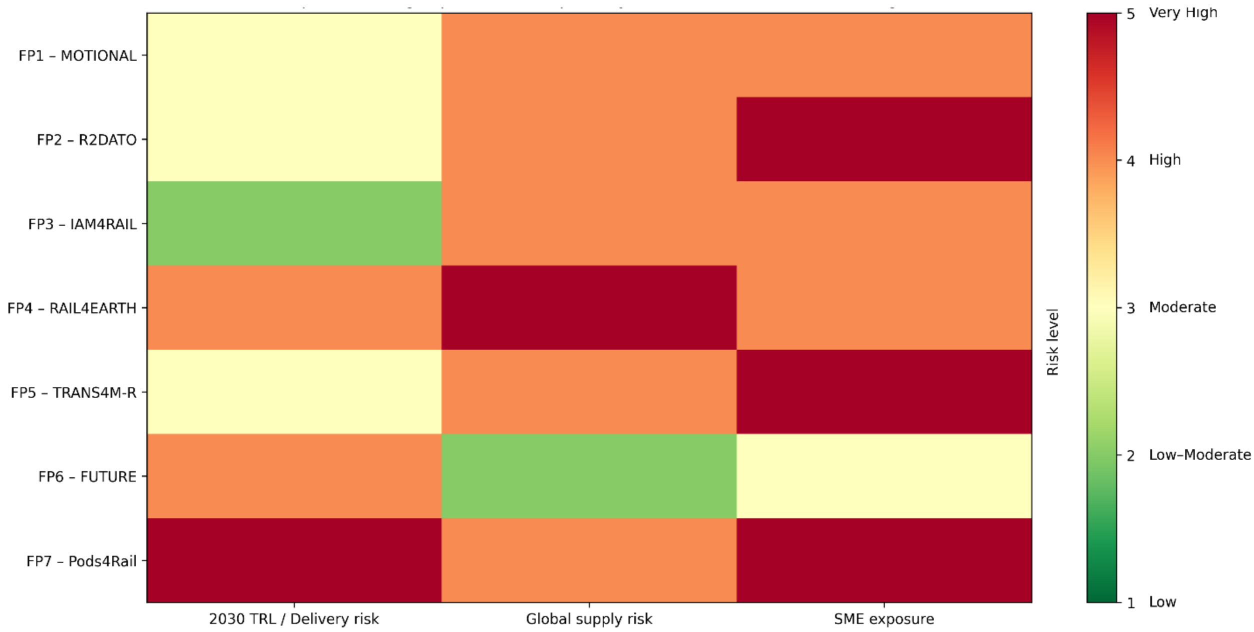
- ***(A) Materials risk (CRMs + semiconductors)***:
  It captures the **likelihood that EU-Rail innovations face delays, cost increases, or redesign needs because of limited availability, price volatility, export restrictions, or concentration of supply for** critical raw materials and semiconductor components**.**
  Rail innovations increasingly depend on materials and components that have high geopolitical, industrial and logistical sensitivity (e.g., batteries, power semiconductors, rare-earth magnets, sensors, advanced electronics). When shortages occur, the rail sector often struggles to substitute quickly due to safety certification constraints and long qualification cycles.

- ***(B) Digital dependency risk (cloud + firmware + platform sovereignty)***:
  It captures the **risk that EU-Rail innovations remain structurally dependent on non-EU controlled digital infrastructures, software stacks and vendor ecosystems**, reducing long-term autonomy and increasing vulnerability to disruptions or strategic constraints.
  Many digital rail innovations (traffic management, digital twins, predictive maintenance, communications) rely on cloud services, data centres and cybersecurity toolchains, proprietary firmware and vendor-controlled updates, software platforms and data governance frameworks dominated by external actors. This can create **vendor lock-in**, **shorten usable lifetimes of equipment** (forced obsolescence), and **increase exposure to geopolitical tensions or compliance restrictions**, even when physical components are available.

- ***(C) SME exposure (Tier-2/Tier-3 vulnerability)***:
  It captures the **extent to which supply-chain risk concentrates in lower-tier suppliers**, especially SMEs, which are often responsible for specialised components, assemblies, electronics modules, and niche subsystems that enable rail innovations.
  Many critical bottlenecks occur below Tier-1, where SMEs have less bargaining power and visibility, cannot easily stockpile or multi-source, and face high qualification costs; they are hit first by chip allocation, long lead times and price surges, and are frequently forced to absorb higher stockpiling or procurement costs (e.g. for semiconductors) as these increases cannot be readily passed upstream or renegotiated with OEMs.
  This can turn small disruptions into major programme delays for OEMs, because a single missing subcomponent can block delivery of an entire subsystem.

In the Figure below are summarised the overall results. Here the risks (A) and (B) are summed in the *Global Supply Risk*, while it is also included the *2030 TRL / Delivery risk* to specify at what actual TRL each FP is estimated to be in 2030 – which can delay the occurrence of the *Global Supply Risk* or make it occur, as initially estimated in the project scope.

Figure 1 | Risk-exposure Heat Map of EU-Rail Flagship Projects based on the risk categories considered



More details are provided in this table of synthesis:

Table 2 | Summary of risk assessment of each FP based on the different types of risks as well as identifying what value-chain actors will be mostly impacted, while highlighting SMEs exposure

Flagship Project	2030 TRL / Delivery risk	Global supply risk (materials + digital > A+B)	Top 10 CRMs (incl. semiconductors)	(A) Material risk — Top 3 point-of-failure components	(B) Digital dependency risk — Top 3 point-of-failure components	Value-chain actors most impacted	(C) SME exposure
FP1 – MOTIONAL (ERTMS)	**3 (Moderate)**	**4 (High)**	**Si (Silicon), Ga (Gallium), Ge (Germanium), As (Arsenic), Hf (Hafnium), Nd (Neodymium), Dy (Dysprosium), Tb (Terbium), Li (Lithium), Cu (Copper)**	1) Trackside/wayside **IoT sensors** & monitoring hardware (rare-earth magnets + semiconductor content) 2) **Safety-critical signalling electronics** (on-board/trackside computing, interlocking/RBC hardware) 3) Dense **cabling + power distribution** for upgraded infrastructure (Cu/Al)	1) **Safety-certified compute** (MCUs/SoCs) for ERTMS/traffic management 2) **Telecom / radio modules** for secure connectivity 3) Cybersecurity primitives (secure elements/HSM-class modules)	Tier-1 signalling/CCS integrators + OEM onboard integration; Tier-2 electronics/PCB/module suppliers; Tier-3 passive components/connector/cable suppliers	**High** (many critical parts sit below Tier-1: sensors, PCBs, connectors, harnesses; limited bargaining power)
FP2 – R2DATO (ATO over ETCS)	**3 (Moderate)** (GoA2 closer; higher autonomy less mature)	**4 (High)**	**Si, Ga, Ge, As, Hf, Nd, Dy, Tb, Li, Cu**	1) **Perception sensor suites** (radar/LiDAR/cameras) & associated magnetics/optics 2)	1) High-integrity **AI/edge compute** (accelerators/SoCs) 2) **Safety-certified firmware stacks** &	OEM (integration) + Tier-1 ATO/CCS integrators; Tier-2 sensor and compute module suppliers; Tier-3 passive	**Very High** (autonomy stacks depend on specialised Tier-2/3

Flagship Project	2030 TRL / Delivery risk	Global supply risk (materials + digital > A+B)	Top 10 CRMs (incl. semiconductors)	(A) Material risk — Top 3 point-of-failure components	(B) Digital dependency risk — Top 3 point-of-failure components	Value-chain actors most impacted	(C) SME exposure
				Redundant power electronics supporting onboard autonomy compute 3) **High-integrity wiring/harnessing** for redundant architectures	toolchains 3) **V2X/FRMCS-adjacent comms chipsets** (baseband/RF front-ends) — D2.1 example shows V2X as an enabling tech with TRL expectations by 2027 for GoA2	components	suppliers; allocation/lead-time shocks hit them first)
FP3 – IAM4RAIL (Asset Monitoring)	**2 (Low–Moderate)**	**4 (High)** (D2.1: all technologies in FP3 show high overall criticality by 2030)	**Si, Cu, Al, Au (Gold), Li, Nd, Dy, Tb, Ga, Ge**	1) Distributed **trackside sensing networks** (accelerometers, condition monitoring nodes) 2) **Inspection drones/robotics** & onboard diagnostic gear (battery + sensor BOM) 3) Spares for **high-failure-rate field electronics** (connectors,	1) **Edge gateways** (industrial compute + connectivity) 2) Cloud/analytics dependencies (servers, storage, networking) 3) Cybersecurity + identity modules for distributed	Tier-2 sensor OEMs + Tier-3 components dominate exposure; Tier-1 system integrators aggregate; infrastructure managers procure deployments	**High** (monitoring is "many-SME" by design: lots of niche sensor, integration, and maintenance suppliers)

Flagship Project	2030 TRL / Delivery risk	Global supply risk (materials + digital > A+B)	Top 10 CRMs (incl. semiconductors)	(A) Material risk — Top 3 point-of-failure components	(B) Digital dependency risk — Top 3 point-of-failure components	Value-chain actors most impacted	(C) SME exposure
				boards, enclosures)	monitoring		
FP4 – Rail4Earth (Green Rail Systems)	**4 (High)** (several energy/storage solutions in D2.1 are TRL6-type by 2027 → weaker 2030 likelihood)	**5 (Very High)** (battery + power-electronics CRM bundle)	**Li (Lithium), Co (Cobalt), Ni (Nickel), Mn (Manganese), Cu (Copper), Al (Aluminium), Si (Silicon), SiC (Silicon carbide), Ga (Gallium), Ge (Germanium)**	1) **Traction / stationary battery systems** (cells, modules, packs) 2) **High-power converters/inverters** (SiC/GaN power modules) 3) **High-current cabling & busbars** (Cu/Al)	1) **Energy management + BMS controllers** (embedded compute, firmware) 2) Smart-grid / SCADA connectivity dependencies 3) Cybersecure control electronics	OEM propulsion integration + Tier-1 traction/energy system suppliers; Tier-2 battery and power-module suppliers	**High** (SMEs exposed in power-electronics sub-tiers, BMS/software, specialised cooling, connectors; capex/qualification barriers are steep)
FP5 – TRANS4M-R (Seamless Rail Freight)	**3 (Moderate)**	**4 (High)** (DAC high/very-high; overall moderate; strong exposure to batteries + semiconductors, with very high Li demand and high Cu/steel)	**Li, Al, Cu, Si, Nd, Dy, Tb, Ga, Ge, Co**	1) **Digital Automatic Coupler (DAC)** mechatronics (actuation + sensing) 2) **Freight integrity / condition monitoring** nodes (distributed sensors) 3) Wagon-level **power & energy storage** for “always-on” monitoring	1) Wireless comms modules (IoT/rail comms) 2) Microcontrollers + secure elements in wagon electronics 3) Platforms for data exchange / predictive logistics	Freight wagon OEMs and Tier-1 subsystem suppliers; Tier-2/3 electronics module, sensor, connector suppliers	**Very High** (freight tech stacks are often supplied by smaller specialised vendors; allocation shocks can stop whole retrofit programs)

Flagship Project	2030 TRL / Delivery risk	Global supply risk (materials + digital > A+B)	Top 10 CRMs (incl. semiconductors)	(A) Material risk — Top 3 point-of-failure components	(B) Digital dependency risk — Top 3 point-of-failure components	Value-chain actors most impacted	(C) SME exposure
				(batteries)			
FP6 – FUTURE (Capillary lines)	**4 (High)** (D2.1: FP6 among those struggling to exceed TRL7; timelines extend)	**2 (Low–Moderate)** (D2.1: criticality assessed low due to focus on low-cost solutions; adoption of expensive tech/materials unlikely)	**Cu, Al, Si, Li, Nd, Mn, Ni, Co, Ga, Ge** *(indicative "baseline electronics & power" set; FP6 aims to minimise expensive CRM-intensive solutions)*	1) Cost-sensitive **onboard energy storage** (if hybridisation/backup required) 2) Essential **communications & control electronics** (COTS-heavy) 3) Lightweight/low-maintenance subsystems (materials depend on chosen concept)	1) Reliance on **COTS industrial compute** availability 2) Vendor lock-in on firmware/updates for low-cost platforms 3) Connectivity modules for regional digitalisation	Regional OEMs/system integrators + Tier-2 suppliers for cost-optimised subsystems; infrastructure managers	**Moderate–High** (SMEs are prevalent, but "supply-critical" niche CRMs are intentionally minimised by design/cost constraints)
FP7 – Pods4Rail (Future Mobility)	**5 (Very High)** (D2.1: TRL around 5–6; unlikely to reach TRL7 by 2030)	**4 (High — latent)** (2030 exposure low due to TRL, but if scaled, it inherits autonomy/monitoring/energy CRM stacks)	**Li, Co, Ni, Mn, Si, Ga, Nd, Dy, Cu, Al** *(inherited "system-of-systems" set: energy + autonomy + comms)*	1) **Pod battery & small traction** systems 2) **Permanent-magnet motors/actuators** (REE exposure) 3) Sensor kits for localisation & safety	1) Autonomous navigation compute & perception SW/HW stack 2) Connectivity modules (fleet management, V2X-type comms)	Early stage: innovators/SMEs + Tier-2 module suppliers; later: OEMs integrate	**Very High** (innovation-heavy ecosystem; dependence on specialised suppliers while volumes are initially low)

Flagship Project	2030 TRL / Delivery risk	Global supply risk (materials + digital > A+B)	Top 10 CRMs (incl. semiconductors)	(A) Material risk — Top 3 point-of-failure components	(B) Digital dependency risk — Top 3 point-of-failure components	Value-chain actors most impacted	(C) SME exposure
					3) Safety certification / software toolchains dependencies		

Obsolescence in the Rail Value Chain

The shift towards digital, automated, and sustainable rail systems under EU-Rail not only increases reliance on Critical Raw Materials but also will phase out legacy components. Obsolescence has always been the case with innovation, but the magnitude of the transformation of the European railway system pursued through the EU-Rail programme is unprecedented, and therefore the impact of obsolescence will be greater across more parts of the rail supply chain as a whole and can generate disruptions.

In detail, by 2030, manual coupling, non-digital signaling, condition monitoring, diesel propulsion, and conventional HVAC should be largely replaced by Digital Automatic Couplers (DAC), AI-driven systems, electrification, and energy-efficient technologies. Of course, this comes together with the management of obsolescence of electronics, which is a critical issue to be handled. **However**, supply chain risks—such as semiconductor shortages, rare earth dependencies, and cybersecurity vulnerabilities—could **slow deployment**, **delaying the switch to new innovations** and therefore requiring the relevant part of the supply chain to continue supplying the current systems and components.

Spoiler: Do not overlook risks from the innovation phase

As the Europe's Rail programme positions its innovations within European strategies whose milestones are set by 2030 (i.e. *doubling of high-speed rail traffic* and *large-scale deployment of automated mobility* set in the "Sustainable and Smart Mobility Strategy"; *cutting emissions by at least 55%* set in the European Green Deal; *full digitalisation* set in the "Digital Decade" Communication; ERRAC *R&I Priorities for 2030*), the time horizon of the "LEADER 2030" research and roadmapping extended to 2030, but the outcomes of the desk research and the stakeholders' interviews switched several innovation roadmaps beyond 2030.

As a result, some consulted stakeholders advocate for an increased use of Commercial-Off-The-Shelf (COTS) products for EU-Rail innovations, as they perceive some criticalities as moderate or low by 2030. Yes, this can be explained because only part of EU-Rail innovations will reach the market by then, but – as researchers – our 'feeling' is that some stakeholders interviewed (and they were interviewed *because* involved in EU-Rail FPs) mostly work in R&D teams (hence 'far from the market') and are not fully aware of 'real world supply dynamics'. This 'feeling' was also 'informally' proved during the LEADER 2030 presentation at WCRR 2025, where R&D teams in the audience, despite working in 'big rail leaders', were not aware of the picture presented in Part I of this document, neither of field data resulting from the Survey shortly summarized in the previous pages. This conducts to one of the most powerful industrial recommendations provided in Part III of this document, which is: *Aligning R&D teams with 'real world supply criticalities' to include a 'design for resilience analysis' since the first phases of the innovation process*.

In fact, **not everything can be COTS**, **both *by* and *beyond* 2030**, and **however also COTS have proved to be subject to supply disruptions**; **hence criticalities will remain strategically important**, **as shown in Part I, and thanks to Part II we know where they will hit**. Therefore, **ensuring long-term supply chain resilience, industrial autonomy, and adaptability to future technological shifts remains a priority for Europe's rail ecosystem**.

PART III
INDUSTRIAL AND POLICY RECOMMENDATIONS

AIMED AT SUPPORTING THE RAIL VALUE CHAIN DIRECTLY

(A) To foster Value chain's resilience

- **A.1 - POLICY / INDUSTRY:** Foster R&D projects as follow-up to "LEADER 2030" in parallel to all Europe's Rail Flagship Projects to allow for a coordinated, detailed identification of FPs' needs and risks, and specific potential 'de-risking' solutions for upcoming rail innovations.

- **A.2 - INDUSTRY / POLICY:** Foster a whole rail value-chain preparedness model to reduce systemic vulnerabilities, strengthen supply continuity for critical materials and components, and ensure that SMEs—often the most exposed actors—are not left as weak links in increasingly fragmented global trade environments.
  Major European and global rail OEMs have increasingly strengthened their supply-chain readiness policies, including supplier governance, risk monitoring, and continuity planning. However, it is crucial to avoid that an 'OEM-centric approach' can have limited reach beyond the first tiers of the supply base, leaving lower-tier suppliers less visible, less supported, and more exposed to disruptions, trade restrictions, tariffs, material shortages, as resilience gaps persist precisely in the 'hidden' layers of the value chain where critical components and processing steps are frequently concentrated—as proved in major global value chains (GVSs) crisis. This should be achieved through targeted policy and industrial actions, which may include:
    - SME-focused resilience toolkits and support schemes, helping lower-tier suppliers assess exposure to trade controls and design multi-regional sourcing strategies for critical inputs
    - Tier-n visibility requirements, encouraging OEMs to expand transparency and risk monitoring beyond Tier-1 suppliers through structured data-sharing arrangements and "critical sub-supplier mapping"
    - Collective procurement and demand aggregation mechanisms, allowing SMEs to access diversified suppliers and long-term contracts that would otherwise be out of reach. This should happen fostering a coordinated, sectorial usage of the "EU Raw Materials Mechanism" but also through similar initiatives on Electronics.

- **A.3 - POLICY / INDUSTRY:** Strengthen rail supply chain resilience through a European, SME-inclusive rail data ecosystem.
  In line with the objectives of Europe's Rail Joint Undertaking and the EU's broader industrial and economic security agenda, the European rail sector should build on the *Catena-X* experience to develop a European, rail-specific, federated data ecosystem enabling secure and standardised data sharing across the rail value chain. Such an ecosystem would support the resilience, competitiveness and sustainability of the European rail system by improving multi-tier visibility of supply chains, enabling earlier identification of disruptions affecting critical materials, components and subsystems, and facilitating coordinated mitigation actions. In particular, it would address structural vulnerabilities faced by SMEs, which play a key role in rail innovation and specialisation

and are placed but often lack visibility, bargaining power and resources to manage supply shocks. The initiative could:

- Adopt a federated, sovereignty-preserving data architecture, aligned with European data-space principles, ensuring that companies—especially SMEs—retain control over their data while participating in trusted value-chain collaboration
- Develop common rail data standards and interfaces, coordinated at European level, to lower entry barriers and integration costs for SMEs
- Prioritise resilience-oriented use cases, such as demand and capacity forecasting, early-warning systems for supply disruptions, traceability of critical inputs, and coordinated response mechanisms in crisis situations
- Mobilise EU and national support instruments (R&I funding, Digital Europe, Regional and Cohesion funds) to support SME onboarding, skills development and interoperability with existing industrial data spaces.

By embedding these principles within Europe's Rail governance (and its successor's) and innovation activities, the EU can reinforce the resilience of rail supply chains, reduce strategic dependencies in a critical sector, and ensure that SMEs remain fully integrated contributors to Europe's innovation, manufacturing and deployment capacity up to and beyond 2030.

(B) To foster Companies' internal resilience

- **B.1 - INDUSTRY:** Invest in advanced technologies that enable real-time visibility across the supply chain, strengthening resilience and responsiveness to disruptions. This may include:
  - Digital platforms and IoT solutions to monitor material flows, inventory levels, and logistics in real time
  - Predictive analytics and AI-driven risk assessment tools to anticipate shortages and identify alternative sourcing options before disruptions occur
  - Blockchain or secure data-sharing frameworks to ensure transparency and traceability of critical raw materials and components
  - Interoperability of digital systems across OEMs, Tier suppliers, and operators, aligned with EU data governance and cybersecurity standards.

- **B.2 - POLICY:** Adopt policies and funding mechanisms supporting SMEs to invest in advanced technologies for real-time supply chain visibility, since these threats increasingly exceed the normal business risks associated with entrepreneurship. This may include:
  - Dedicated financial instruments (e.g., grants, low-interest loans, tax incentives)
  - Sector-wide or regional shared platforms where SMEs can access real-time supply chain data collectively, reducing individual investment costs through economies of scale.

- **B.3 - POLICY:** Introduce targeted support measures to help SMEs offset the financial impact of maintaining higher buffer stocks in response to supply chain turbulence and materials shortage. This may include:

- Temporary financial relief schemes or risk-sharing mechanisms to cover additional inventory costs
- Tax credits or subsidies linked to resilience-building actions, such as strategic stockpiling of critical raw materials
- Pooling and shared storage solutions coordinated at regional or sectoral level to reduce individual SME costs.

(C) To increase Critical Raw Materials availability

Circularity of materials

- **C.1 - POLICY:** Turn regions into active nodes of resilient and sustainable value chains rather than passive endpoints of global supply networks strengthening territorial circular-economy strategies that support shorter, more resilient value chains, notably by:
  - Developing interregional circular hubs that link dismantling, recycling, remanufacturing and manufacturing activities across sectors (e.g. rail, automotive, energy, construction)
  - Encouraging local and interregional sourcing of secondary materials, reducing reliance on long-distance imports of critical inputs
  - Supporting industrial symbiosis between infrastructure managers, manufacturers, recyclers and SMEs to retain material value within the territory
  - Aligning regional innovation, skills, and investment policies with circular objectives, ensuring that recovery and processing capacities are available close to where materials are consumed.

- **C.2 - POLICY:** Deploying public policy initiatives to support R&D investments to fill the technological gap in recycling both traditional products and innovations, and scale quickly enough the implementation, following a value chain approach, i.e. clusterising territorial value chains for inputs gathering and outputs usage.

- **C.3 - POLICY / INDUSTRY:** Promote performance-based standards and tiered qualification/certification protocols for secondary materials—starting with high-volume streams such as steel, aluminium and copper—combined with traceability requirements (material passports/chain-of-custody) and procurement incentives, so that certified secondary materials become easier to specify, approve and use in rail applications without compromising safety or interoperability.

- **C.4 - INDUSTRY:** Fully integrate Eco-design principles across all stages of the rail value chain, ensuring that systems and components are designed from the outset for future repairability, remanufacturing, and recycling. This approach should:
  - Embed design-for-disassembly and material separation criteria in rolling stock, signaling equipment, and infrastructure components.

- Prioritise modular architectures and standardised interfaces to facilitate component reuse and upgrade.
- Ensure that critical raw materials and other valuable resources can be efficiently recovered at end-of-life, supporting circularity and reducing dependency on primary raw materials.

- **C.5 - INDUSTRY:** Building on existing practices in sectors such as electronics and emerging initiatives within the rail industry, OEMs and Tier suppliers should broaden and standardise the provision of professional guidance for recyclers by:
  - Ensuring comprehensive, sector-wide adoption of disassembly guides for all major rail systems and components, not just selected products
  - Including clear, step-by-step instructions for safe dismantling, highlighting methods to maximize recovery of critical raw materials and other valuable resources
  - Providing recommendations for appropriate downstream recycling processes or partners, ensuring compliance with environmental and safety standards.
  - Making these guides accessible, regularly updated, and harmonised across the industry, aligning with EU circular economy objectives and all applicable requirements.

(D) To reduce dependence on Critical Raw Materials

Alternative design

- **D.1 - INDUSTRY:** Establish "Resilience Teams" within companies to ensure a structured and continuous exchange of information among departments responsible for design, engineering, industrialisation, and procurement. These teams should promote awareness of supply chain vulnerabilities, including risks linked to disruptions and dependencies on specific materials and components, and support proactive identification of alternative solutions to strengthen resilience and prevent shortages. It is essential that R&D personnel are informed of such vulnerabilities early, so that product and solution designs can be adapted promptly to mitigate risks. Likewise, procurement and supply teams should actively engage with R&D to seek technical support in identifying alternative materials or components when shortages occur, fostering a two-way collaboration for preventive and corrective action.

- **D.2 - POLICY / INDUSTRY:** Streamline regulatory frameworks to allow greater flexibility in substituting critical materials subject to higher risks by:
  - Leveraging the "EU-Rail Standardisation and TSI Input Plan" (STIP) to facilitate and fast-track material substitutions topic into the regulatory environment to also benefit material swaps in live products.
  - Encouraging cross-sector expertise exchange, ensuring that R&D and procurement teams are involved early in the standardisation revision process, helping to anticipate and address material constraints.

- **D.3 - POLICY / INDUSTRY:** Promote coordinated initiatives aimed at developing rail components that do not rely on rare earth elements (REEs) or other highly critical raw materials, thereby reducing strategic dependencies and enhancing supply chain resilience. These efforts should draw inspiration from best practices in other sectors, such as the European electric vehicle industry's successful development of permanent magnet-free electric motors. Such initiatives should encourage cross-sectoral knowledge transfer, research collaboration, and innovation funding, ensuring that rail value chain adopts sustainable and resource-efficient technologies while maintaining high performance standards.

- **D.4 - POLICY / INDUSTRY:** Design equipment to extend lifetime of components.
  While rail already has formalised obsolescence management practices and Europe has established general methods for assessing repairability and upgradeability, these tools should be consistently translated into systematic, rail-wide "lifetime-extending design" requirements (long-life, upgradeable and substitutable) for electronic and digital rail systems. Requirements may include mandating:
  - modular architectures (replaceable boards / line-replaceable units) as a default design principle
  - hardware–software separation and long-term software support
  - standardised recertification pathways for replaced electronics modules
  - procurement requirements that–in a first phase–reward and–then–request suppliers to demonstrate long-term availability, upgradeability and substitution planning.

Alternative materials

- **D.5 - INDUSTRY:** Foster substitution with Composites.
  Rail is a 'conservative' market and should be more open-minded towards Composites. In taking substitution decisions, the Composite price compared to the material to substitute should take into account Life Cycle Cost Analysis, as Composites ensure longer life as well as much higher fatigue resistance. Combinations of materials to produce Composites can be thousands, and resins will evolve in the future: innovation is the gateway. Also, the freedom of design of Composites allows also the re-cyclability and re-usability of the materials, as "Eco-Design" is at the centre of these materials. Moreover, as a lot of glass fiber is ending its life now, and many start-ups are growing to manage this, further evolution and increase in Composites recycling will allow for more sustainability and for lower costs for Composites use.
  As there is a lack of knowledge in the sector about their potential, OEMs role is key in explaining and driving the change in the market, as answers to key challenges such as Safety, Maintenance, as well as to make improve passenger experience can also come through the introduction of Composites.

Alternative production

- **D.6 - INDUSTRY:** Industries should embed "alternative production" pathways into their supply strategies to reduce exposure to global disruptions in critical materials, components and logistics, by combining these practices:
  - *Scale additive manufacturing (AM) and advanced manufacturing* to shift from "wait for spare parts" to "produce what you need, when you need", reducing inventories, shortening lead times and lowering material use (hence lowering disruption exposure)
  - *Deploy "print-and-go" local production*, including small CNC/3D printing and (where feasible) local PCB manufacturing, to bypass long overseas supply chains, reduce transport dependence and improve security for sensitive digital equipment
  - *Expand remanufacturing and R-cycle services (repair, refurbishment, reuse)* to retain up to ~80% of the original "core" material value, reduce dependence on virgin CRMs, and strengthen regional supply autonomy through local operations
  - *Adopt MaaS (Manufacturing-as-a-Service) networks* to access distributed European manufacturing capacity on-demand, enabling rapid switching of suppliers, resilience through redundancy, and better SME participation in high-tech supply chains.

  Implementation priority in the rail sector should start with spare parts and low-volume components (where Additive Manufacturing and remanufacturing already show success), then extend the approach to electronics housings, selected mechanical assemblies, and certified critical items through shared qualification frameworks and trusted data-sharing ecosystems.

(E) To secure intra-EU freight logistics

- **E.1 - POLICY:** Several mitigation instruments are already embedded within the EU rail regulatory framework and can be further reinforced. Regulation (EU) No 913/2010 establishes Rail Freight Corridors (RFCs) with governance structures that include Corridor One-Stop Shops (C-OSS) and mechanisms for the allocation of pre-arranged train paths and reserve capacity for international freight services. In addition, RailNetEurope (RNE) and the RFC network implement harmonized International Contingency Management (ICM) procedures and predefined rerouting scenarios to ensure coordinated responses to major operational disruptions. These existing mechanisms should be strengthened and adapted to guarantee the continuity of critical supply chains, particularly in view of emerging Military Mobility requirements, which may introduce priority access provisions during crisis situations. Possible measures might include:
  - Define a "critical freight" category beyond Military/Defence needs (e.g., Critical Raw Materials, semiconductors, energy equipment, medical/chemical essentials) and embed it into existing corridor capacity rules, contingency plans and rerouting scenarios.
  - Expand and standardise existing reserve-capacity and contingency train paths for critical freight flows on key corridors, while strengthening corridor governance to ensure capacity optimisation even under exceptional priority regimes.
  - Enhance real-time corridor-level performance monitoring and predictive disruption management for critical freight trains, building on existing tools.

AIMED AT SUPPORTING THE RAW MATERIALS VALUE CHAIN DIRECTLY

(F) Improve framework conditions of the EU single Market for Energy Intensive Industries

- **F.1 - POLICY:** Reducing Bureaucracy And Regulatory Burdens.
  To enhance the competitiveness and resilience of Energy-Intensive Industries (EII), the COM should urgently streamline administrative procedures and reduce regulatory burdens across the sector. Current frameworks often impose contradictory requirements, with overlapping and sometimes conflicting obligations stemming from different regulations, undermining legal certainty and delaying vital investment decisions. It is insufficient to introduce new acts—such as the CRMA, which aims to accelerate permitting—if these are accompanied by additional bureaucratic obligations that offset their intended benefits. Instead, the COM should ensure regulatory coherence between existing and forthcoming measures, eliminating duplicative or antagonistic requirements while harmonizing rules to enable industry to comply efficiently with a single framework. Such an approach will allow European EIIs to invest in decarbonisation and innovation, strengthen strategic autonomy, and better compete globally without unnecessary regulatory complexity.

- **F.2 - POLICY:** Financing.
  Unlike the arms industry, the EU taxonomy has not yet made a U-turn on mining. It remains difficult for project developers, most of whom are small, to obtain financing from European banks. Mining developers, often junior mining companies, usually do not have sufficient capital resources. But they are taking the important first step in exploration and development. It is not uncommon for volatile price developments to lead to abandonment. Market participants (sometimes with political support from their governments) often try to knock competitors out of the field by influencing commodity prices. China in particular has become "famous" for this practice. This leads to the next recommendation.

- **F.3 - POLICY:** Establishing New Value Chains, Compensating For Know-How Deficits, Price Protection.
  European companies have situated themselves at the higher end of the value chain. They use to buy components and semi-finished products rather than raw materials. Little incentive exists for European companies to move to lower rungs of the value chain when cheaper, already-manufactured components and products from China are available. For European companies to build out processing capacity in parallel to China will be costly and will take time – posing a challenge to urgent decarbonisation demands. China may use its supply chain domination as a tool of retaliation. It could ban the export of CRM products to certain countries, or it could intentionally trigger a supply glut of any CRM product at any time in order to depress global prices and collapse

the profitability of ex-China operations. In the worst case it could send European companies active in ex-China CRM supply chains into financial distress or bankruptcy. Given these challenges, it is evident that financial mechanisms are needed to improve the commercial viability of ex-China CRM opportunities and to persuade European companies to participate in ex-China CRM supply chains.
First, European companies participating in either mining or local processing need some form of price protection. This could be provided by European public financial institutions extending guarantees to producers to establish a minimum price (floor) and maximum price (ceiling) for ex-China products. This would remove some price volatility – on the upside as well as the downside – protecting producers against price drops by China while facilitating more long-term offtake agreements made possible by greater price certainty. The USA is showing how to nurture and cultivate the delicate seedlings of its revived REE value chain. The government is buying into mines and guaranteeing minimum prices that are higher than the discounts offered by competitors (China). Hedging European mining investments and bridging price slumps should therefore also be part of the financing instruments of a CRMA. This also applies to ensuring the operational viability of existing raw material extraction and production, provided that this is justified on economic policy grounds.

- **F.4 - POLICY:** Deployment Of Political Risk Insurance.
  Greater deployment of political risk insurance is needed to support European companies entering more difficult contexts. This would protect companies against the risks arising from arbitrary actions by the host government, including expropriation, confiscation, and selective discrimination. Such risks are comparatively high in the mining sector. The European Investment Bank and the European Bank for Reconstruction and Development are able to provide political risk insurance, as are several European development finance institutions. More extensive use of these facilities is needed, with the institutions providing these products scaling up resources dedicated to them.

- **F.5 - POLICY:** Reducing Electricity Costs.
  Measures to reduce Europe's electricity costs will be vital to enable greater processing and refining capacity to be developed in Europe. European electricity costs are currently two to three times higher than those in the US and China, which poses a significant barrier to expanding processing capabilities in Europe. Reducing electricity costs in Europe will take concerted efforts from a number of actors, including private sector investments in renewable energy supported by incentives from the EU and Member State governments.

- **F.6 - POLICY:** Enhancing EU–Private Sector Dialogue for Effective CRM De-Risking.
  EU and Member State institutions will need to develop better consultation platforms with the European private sector to understand their concerns about entering CRM supply chains in overseas and to more engage in the European Strategic Raw Materials Partnerships. This understanding should inform the nature of the support extended to European companies active in CRM supply chains in Africa, thereby ensuring that de-risking initiatives are more effective.

(G) Strengthen Existing and Building Adequate New Institutional Capacity

- **G.1 - POLICY:** Strengthen European Economic and Social Committee.
  To safeguard the institutional role and expertise of the European Economic and Social Committee (EESC), the European Commission should ensure that EESC recommendations receive greater prominence in critical legislative consultations, such as those for the Critical Raw Materials Act. The Commission could achieve this by formally prioritizing EESC opinions in its reporting and drafting processes, systematically highlighting how EESC recommendations are considered and integrated into proposal texts before broader consultation with civil society and NGOs. Such an approach will reinforce the EESC's function as the representative body of organized civil society and economic actors, maintaining a balanced and structured consultative process that builds on institutional expertise while still engaging wider stakeholders.

- **G.2 - POLICY:** Raise Raw Materials Awareness And Building Institutional Capacity.
  The European Commission should raise raw materials awareness among political decision makers at both the Member State level and within its own ranks by implementing targeted education and outreach initiatives. This could include regular high-level briefings and workshops emphasising the strategic importance of raw materials for industrial competitiveness, climate objectives, and supply chain security. Integrating raw materials risk assessments into all relevant policy portfolios would ensure shared understanding and prioritization across institutions. Furthermore, direct engagement with decision makers through dedicated networks, annual forums, and joint monitoring platforms would foster a culture of continuous awareness and cooperation around raw materials challenges and solutions.
  To improve raw materials awareness and policy effectiveness, the European Commission should also ensure that the relevant Directorates-General (DGs) are adequately staffed with expert personnel and provided with the necessary resources to coordinate strategy, implement policy, and support Member State engagement. Investing in capacity—both in terms of numbers and specialist expertise—will enable DGs to deliver robust analysis, coordinate across EU institutions, and efficiently address raw materials challenges. This strengthened staffing should extend to DGs directly responsible for industrial, trade, environment, and research policy, ensuring that raw materials considerations are integrated and prioritized in all pertinent policy domains.

- **G.3 - POLICY:** Set Up EU Market Intelligence Capacities.
  Establishment of new market intelligence capacities on CRM value chains for strategic, economic and technical monitoring of CRM supply chains as a unit of EU Raw Materials Agency, comparable to the German Deutsche Rohstoffagentur (DERA).

- **G.4 - POLICY:** Set Up State-Supported Investment And Procurement Organisation.
  Set up a new European, state-supported investment and procurement organisation acting as lead buyer and pooler of raw materials demand across European countries. Similar to the Japan Oil, Gas

and Metals National Corporation (JOGMEC): Direct investment or guarantor of private sector investments.
Japan secures critical raw materials with a law on economic security. When raw materials are in short supply, a sovereign wealth fund helps by investing directly in mining all over the world. Raw Materials Sourcing as part of a state service is organized in JOGMEC, the Japan Organization for Metals and Energy Security, established in 2004. JOGMEC has over 600 employees, maintains offices in 18 mining countries and has an annual budget of the equivalent of over twelve billion euros. It maintains a ruling party task force on economic security, which anchors the tasks of supply chain differentiation and circular economy in the day-to-day work of the party, and includes a new ministerial office for economic security, which centrally coordinates the work of all ministries on economic security issues, including raw material procurement and recycling.

(H) Review the Critical Raw Materials Act

- **H.1 - POLICY:** Ensure a Level Playing Field at global level.
  The Critical Raw Materials Act (CRMA) is not the only law of its kind. Other players have also deeply intertwined their economic policies with strategic raw material security. In a multipolar world of raw material security systems, this will also give rise to a new quality of competition based also on applicable rules, which become an integral part of global systemic conflicts.

- **H.2 - POLICY:** Determine Realistic Benchmarks.
  The implementation periods and scales of the CRMA benchmarks until 2030 are ambitious and not very useful for achieving the goal. The “final reckoning” will take place in only six years after which the CRMA was set into force, according to the current procedure. A lot can happen between now and then. It would make more sense to set milestones until 2030 and continuously adjust them in line with the overall framework conditions. In the case of recycling, these will also be the quantities of scrap available. It is unlikely that sufficient secondary raw material flows of certain CRMs will be available on the market by 2030. Quotas are static and may be exceeded more quickly than expected in the future, for example when the recycling industry and smelting begin to scale up. The benchmarks could seriously jeopardize the competitiveness of European industry.
  The benchmarks are understood to refer to extraction, processing, and recycling capacities. This means that the percentages represent not only quantities, but also physical production facilities and thus capital investments. Given the current difficult conditions, it remains questionable how these can be expanded (financed and approved) so quickly by 2030. The BDI rightly pointed this out.

- **H.3 - POLICY:** Funding For Infrastructure in External Diversification.
  It will depend on, first, European funding for infrastructure investments in third countries through programmes like Global Gateway, tied to privileged access to these resources. This will, again, require money and the CRMA does not spell out sufficiently where this money should come from.

And the CRMA does not adequately incorporate geoeconomic risks in the section criteria for these projects.

(I) Improve support mechanisms for European companies

- **I.1 - POLICY:** Align Private Sector Interests With The EU´S Ambitions For Strategic Raw Materials Partnerships.
  The EU pinned much hope on its strategic partnerships with African countries increasing its access to CRMs. Yet the lack of European private sector participation means this is access is failing to materialise. Will the CRMA (Critical Raw Materials Act) Strategic Projects approach be more effective? This will depend on whether the benefits extended to these projects succeed in aligning private sector interests with the EU's ambitions. This seems unlikely in the current market circumstances.

- **I.2 - POLICY:** Incentivise The Private Sector.
  The level of financing required for European companies to get in front of competitors in CRM mining and processing in Africa far exceeds the funding the EU and other European partners have made available to date. While other powers are speeding ahead, leveraging significant available resources to aggressively pursue opportunities, the cost of catching up is growing for Europe.
  Finally, the EU and Member State institutions will need to develop better consultation platforms with the European private sector to understand their concerns about entering CRM supply chains in Africa, what they could be incentivised to do, and what support it would take. This understanding should inform the nature of the support extended to European companies active in CRM supply chains in Africa, thereby ensuring that de-risking initiatives are more effective.
  Geopolitical and geoeconomic ambitions cannot wish away market dynamics and the need for the commercial viability of projects. However, well designed policies that target clear interventions can help overcome these factors. Turning the needle on CRM project viability in Africa is essential if European companies are to pursue these opportunities. This will come down to the nature and scale of support extended to European companies. It will undoubtedly be costly to develop incentives that can motivate European companies to enter CRM supply chains in Africa and deploy them at some degree of scale. But Europeans cannot afford not to act if they are to address this vital aspect of de-risking. Not only is their energy security at stake, but so is the EU's future political, economic, and military strength.

- **I.3 - POLICY:** Decrease Regulative Risk Potential Regarding The Implementation Of The CRMA Strategic Projects.
  Strategic projects should rightly provide sufficient information to demonstrate that they are socially responsible, sustainable, and designed to create a win-win situation. Many of the demands made by social, environmental, and human rights organizations during the consultation phase were taken into account here. Nevertheless, they were unable to push through their demand for a control function, e.g., by representatives of the indigenous communities affected. The European

Commission refers to the applicable law of the third country. Recognition as a strategic project in the EU should apply without prejudice to the approval conditions applicable to the projects concerned. This means that they are not granted special status in the sense of suspending conditions. For example, under German law, they are not equivalent to the construction of LNG terminals or wind turbines. On the contrary, new EU requirements, such as the EU Industrial Emissions Directive or the EU Nature Restoration Law, are likely to impose even higher substantive legal requirements on CRMA projects or further tighten limit values (mining BREF and substance regulations), which may even prevent projects altogether (failure to obtain a permit). Newly created conflicts of interest are likely to complicate administrative enforcement, minimize predictability, and delay procedures at the expense of innovation and investment.
Furthermore, legal action is still a possibility and may be particularly relevant in the case of EIAs. Reason 32 of the CRMA states: *"In exceptional cases related to the nature, complexity, location or size of the proposed project, Member States should have the possibility to extend the time limits. Such exceptional cases may include unforeseen circumstances that require environmental assessments related to the project to be supplemented or completed."*

- **I.4 - POLICY:** Simplify CRMA Strategic Projects Application.
  The scope of the application for strategic projects is reasonable. This is demonstrated by the 169 applications received in response to the first call. Nevertheless, some of the information required in the application raises questions about the cost-benefit ratio. For example, Article 7(g) states that a 'work plan to support further training and retraining and to promote inclusive representation of the workforce' should be provided. It would probably have been more sensible to request information on the resilience and robustness of the relevant value chain.

- **I.5 - POLICY:** Incentivise Strategic Project Owners.
  Projects given Strategic Project status can receive assistance from the CRM Board to identify potential funding sources, including private investors, the European Investment Bank, European Bank for Reconstruction and Development, international finance institutions, and programmes and initiatives of member states and the EU (including the Global Gateway). However, the CRMA does not itself make new funding sources available, so financing options are limited to what other sources of funding can offer. The act also promises to facilitate offtake agreements, with the European Commission undertaking to establish a bidding process that could match buyers and sellers of CRM products based on the volume and quality of CRMs being sought or sold, intended price at which to buy or sell, and desired duration of the offtake agreement. CRMA Strategic Projects can only receive advice on potential funding sources and the proposed bidding process for CRM offtake can only attempt to match buyers and sellers. This makes receiving financing and offtake facilitation potentially both uncertain and not very time sensitive. This will be a challenge for European companies looking to take quick advantage of an emerging opportunity, particularly when competitors are able to move faster".

- **I.6 - POLICY:** Don´t limit CRMA granted strategic projects to a sufficiently mature stage.

CRMA Projects must also be at a sufficiently mature stage, requiring them to have progressed to that point in the absence of Strategic Project benefits. This excludes projects that could have reached viability if financial support from the EU had been available at an earlier stage.

(J) Amend Regulations and better balance the interest of strategic mining and private investments in projects in Europe with the EU's supposed attempts to expand Nature Protected Areas

- **J.1 - POLICY:** Amend REACH.

  According to its Competitiveness Compass, the European Commission plans to propose a Chemicals Industry Package for the last quarter of 2025. The package will reaffirm the REACH revision postponed repeatedly under von der Leyen I. The EU is under pressure to reverse steadily declining market shares. Most goods manufactured in the EU contain chemicals. Chemical industries also represent 5–7% of the EU's total industry turnover and employ more than 1.2 million people. Many such industries produce products aimed at improving sustainability, such as electric vehicle batteries, and solar and wind technology.

  EU chemical policy stakeholders hold different positions and expectations for the revision. Even the timing of the revision is contentious. German chemical industry association VCI opposes a rapid overhaul. It argues that 'no quick decisions on a revision are necessary', and favours changes to annexes or guidance documents over amendments to the legal text. Conversely, environmental NGOs criticised the postponement of the REACH revision during the von der Leyen I Commission. The NGO ClientEarth calls for 'urgent' revision, citing 'very high' non-compliance with REACH obligations. It also highlights new scientific findings, not recognised in current regulation, on chemicals' harmful effects. Chemical industry stakeholders favour changes to annexes or appropriate guidance rather than legal amendments. Environmental groups, meanwhile, are demanding urgent revision of current regulation. Compromises needed to link pollution and competitiveness. Industry advocates are calling for 'reducing regulatory burden' and call for cutting red tape — but a focus on deregulation alone risks ignoring the urgent need to tackle chemical pollution.

  With the REACH revision proposal, the European Commission could, therefore, try to better connect pollution and competitiveness, instead of trying to solve them independently or treating them as conflicting interests. CEFIC mentions US policies as a good example of business friendliness through incentives. Perhaps the European Commission could create incentives for initiatives that address pollution while enhancing EU competitiveness. In an era of PFAS and nano plastics, chemical simplification offers market opportunities. Indeed, some large brands and consumers demand materials and products that are chemically simpler and safer to recycle. Putting these ideas into practice, however, requires significant innovation in science and engineering, and new design principles. The EU could therefore use the REACH revision to create incentives — such as tax cuts, dedicated funding, and subsidies — for companies that invest in or intend to increase their efforts in these directions. Continuous monitoring would ensure that such initiatives do not simply result in greenwashing. Linking economic incentives to chemical simplification efforts is one way the

European Commission could reduce chemical pollution and enhance competitiveness, while attempting to keep bureaucracy manageable.

- **J.2 - POLICY:** Amend the Carbon Border Adjustment Mechanism (CBAM).
  Industry stakeholders across the EU have identified several areas where the CBAM could be improved to better achieve its goals, reduce administrative burdens, and ensure competitiveness:
  - *Close Loopholes and Protect Against Carbon Leakage:* **Fix loopholes**: Existing loopholes allow foreign producers to sidestep carbon costs, risking increased carbon leakage (relocation of production outside the EU) and undermining EU decarbonization investments. Strengthening CBAM to close these loopholes is viewed as vital to prevent deindustrialization and make the policy effective in cutting global emissions.
  - *Streamline and Simplify Administration:* **Reduce bureaucracy**: Companies face high administrative burdens due to complex reporting and frequent technical issues with the CBAM registry. Recommendations include simplifying reporting procedures, extending reporting deadlines, providing multilingual guidance, and improving user interfaces for data entry and corrections. **Raise de minimis threshold**: Many businesses must report on very small, low-emission imports, which inflates costs and workload disproportionately. Raising or introducing a weight-based exemption threshold could reduce unnecessary reporting for minor imports.
  - *Ensure fair competitiveness, especially for exporters:* **Export solutions**: Industry calls for mechanisms (such as rebates or adjustments) to avoid disadvantaging EU manufacturers in foreign markets, which currently pay for carbon costs not borne by competitors abroad. This adjustment must remain compatible with WTO rules. **Address downstream Impacts**: CBAM should be designed to mitigate negative effects on industries not directly covered by the mechanism, but which face increased costs due to higher input prices.
  - *Improve Policy Transparency and Predictability:* **Outreach and dialogue**: Launch large-scale outreach and consultation with affected industries and third countries to clarify CBAM requirements and gather feedback for future reviews. **Regular review and engagement**: Use the scheduled 2025 CBAM review as an opportunity for structured dialogue between the European Commission and industry to address strategic issues, carbon leakage risks, and technical challenges.
  - *Technical improvements and its reliability:* **Stabilize registry systems**: Resolve persistent IT errors and system instability in the transitional registry. Ensure users have reliable access, can correct errors, and download their reports without difficulty.
  - *Revenue use and global fairness:* **Revenue recycling**: Redistribute revenues generated from CBAM and ETS to support EU industry and offset competitiveness losses, helping downstream sectors adapt to increased costs.

- **J.3 - POLICY:** Amend the Net Zero Industry Act.

Industry stakeholders have offered several recommendations to make the Net Zero Industry Act more effective and competitive. These improvements focus on addressing global market realities, regulatory bottlenecks, funding gaps, supply chain risks, and workforce needs:

- *Enhance Global Competitiveness:* **Support Comparable to Global Rivals**: Increase EU funding and subsidy support to match levels seen in the United States (Inflation Reduction Act) and China, ensuring a level playing field for clean tech manufacturers. **Streamline Export and Market Access**: Foster international agreements and facilitate export opportunities for EU-made net-zero technologies to scale up demand.
- *Simplify Regulation and Cut Red Tape:* **Simpler and Faster Permitting**: Further accelerate and clarify permitting processes for strategic projects, aiming for true "one-stop-shops" and guaranteed maximum approval timelines. **Reduce Administrative Burdens**: Make reporting and compliance procedures more transparent and accessible, especially for SMEs, to minimize resource drain and delays in obtaining "strategic project" status.
- *Strengthen Supply Chain Security:* **Broaden Support for Critical Raw Materials**: Invest in diversified sourcing, domestic mining, and processing, as well as robust recycling infrastructure, to cushion against supply disruptions and increase strategic autonomy. **Include More Materials and Components**: Expand the scope of NZIA to cover a wider range of essential inputs and technologies, closing gaps in coverage identified by industry.
- *Expand and Target Funding:* **Increase Public and Private Investment**: Boost direct funding for technology deployment, capacity scaling, and R&D, making funds accessible to a broader range of companies—not just large ones. **Prioritize Innovation and Commercialization**: Target incentives at bringing new technologies from lab to market and facilitating investment in gigafactories and supply chain resilience.
- *Build the Workforce of the Future:* **Invest in Skills and Training**: Launch EU-wide programs for rapid training and upskilling in clean technology manufacturing, engineering, and supply chain management for both new entrants and current workers.
- *Align Procurement and Market Access Rules:* **Effective and Fair Public Procurement**: Clarify public procurement criteria so that preference for EU-made clean technologies translates reliably into market access, balancing resilience and cost competitiveness. **Remove Barriers for SMEs**: Make procurement accessible and fair to smaller, innovative firms, not just large incumbents.
- *Increase Predictability and Transparency:* **Clear Guidelines and Implementation Pathways**: Provide detailed information on technology, component scope, project selection, and evaluation so that businesses can plan investments and operations confidently. **Set Measurable Benchmarks**: Establish regular review milestones to track progress and adapt policies as needed, engaging industry in the process.

- **J.4 - POLICY:** Better balance of strategic mining projects in Europe with the EU's supposed attempts to expand Nature Protected Areas.

  Locations of mining operations are intrinsically linked to the geographical distribution of mineral deposits. In the EU, this factor presents unique challenges due to the region's high population

density and the prevalence of protected areas. More than 80% of CRM deposits are located in the vicinity (less than 5 km) or inside environmentally protected area. Moreover, there is a growing push to expand EU environmentally protected areas, and most protected areas prohibit mining activities, further complicating the EU's efforts to source raw materials domestically.
To address the fundamental conflict between high environmental standards and the goal of CRM autonomy, the European Commission should recognize that pursuing both objectives simultaneously will inevitably raise costs and hinder the competitiveness of EU mining operations and will less attract private investments. A more pragmatic approach is needed—one that openly acknowledges these trade-offs and fosters compromise where strategic interests and sustainability goals intersect.
The European Commission should develop clear criteria for prioritizing CRM projects in areas of lower ecological sensitivity and introduce flexible permitting rules where overriding strategic value is evident, while maintaining robust standards in cases of high biodiversity risk. This means designing policies that allow for responsible mining in selected protected areas only when the supply risk is critical and mitigation measures are scientifically validated.

(K) Improve Macro Indicators

- **K.1 - POLICY:** Raise Productivity and Foreign Direct Investments (FDI) in the EU.
  European policymakers should increase expenditure on R&D and create better incentives for private-sector R&D spending. Policymakers in Europe should also focus on closing the gap in technology adoption and productivity across firm-size classes and making it easier to diffuse technology to SMEs.

- **K.2 - POLICY:** Stimulate Private Investments.
  European policymakers should also pursue policies that lead to a greater share of European savings being invested in growth funding for firms and that allow for faster growth in venture capital. European companies, especially in the Energy-Intensive Industries (EII), can be incentivized to attract investment and enhance competitiveness by advancing the Capital Markets Union (CMU) and engaging private savers and pension funds in equity markets.

- **K.3 - POLICY:** Stimulate R&D For Technological Leadership.
  In its analysis of the Horizon Europe Work Programme for the 2025-2026 calls for projects, the European Technology Platform on Sustainable Mineral Resources (ETP SMR) expressed some disappointment that important parts of the CRM value chain (exploration, refining) were no longer fully taken into account. Furthermore, the latest calls to strengthen the European Strategic Raw Materials Partnerships are underfunded and granted projects will ultimately only include four out of eight countries.

- **K.4 - POLICY:** Priorise funding R&D close to market uptake.

Above all, however, it is important to promote applied research that has proven to have great potential for market uptake and technological leadership. Parallel to research questions on substitution, fundamentally new technologies with simpler raw material inventories are a major step not only towards technological leadership, but also towards easier-to-achieve raw material autonomy. In this context, it is important to look ahead to new raw material dependencies arising from new raw material requirements.

Note: Increasingly short-lived technology cycles place great demands on raw material production and supply, which is generally much slower than the introduction of new technologies. It is therefore not only necessary to meet the needs of existing technologies, but also to identify emerging technologies at an early stage and take precautions. This also offers advantages for Europe's efforts to achieve autonomy, provided that we do not knowingly miss the boat again.

- **K.5 - POLICY:** IPCEI for Rare Earth Mining and Processing?
  Europe does not need to develop a home-grown substitute for the entire Chinese rare-earth industry to reduce the threat China's monopoly poses. Instead, "significantly derisk" by cutting the reliance on China to 60-70% of consumption to provide sufficient alternative sources of supply for the most critical uses could be worth. Recycling, thrift and innovation could sort out the rest.

- **K.6 - POLICY:** Encourage The Private Sector To More Invest In The Midstream Segment.
  Europe's critical raw materials strategy focuses heavily on securing upstream resources but neglects the midstream segment such as pCAM (precursor cathode active material) and CAM production. Due to limited investment, Europe remains underdeveloped in this area and reliant on partnerships. Meanwhile, Chinese companies are rapidly expanding, especially in Morocco and Indonesia. By 2030, they are projected to control about 82% of global pCAM capacity, while Europe may cover only up to 30% of its own demand, leaving it exposed and undermining its broader resource security strategy.