# Deliverable D1.2
# Lessons on disruptions and resilience from other sectors

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# 1. Executive Summary

The analysis concerns advanced sectors whose experience is considered of help for the LEADER 2030 project, as possible differences or similarities can have a teaching effect. The sectors primarily targeted are **Defence** and **Aerospace**. Their choice was based on several elements:

- for their advanced nature, which could inspire the Railway sector with some lessons
- for the heavy use they make of metals and critical raw materials
- because they apply/develop solutions highly interesting to the Railway sector, such as highly reliable electronics, advanced materials, drones (UAVs)
- because their market is not "mass-market", and the numbers of product units are somehow limited
- for the fact that they cover both military and 'special' civil applications; this was important for the goal of the research to understand if any 'special channels to production inputs' are put in place for these sectors to increase the resilience of their supply chains.

The analysis then considers other two sectors, in search for further possible useful inputs:

- the **Clean Energy Infrastructures sector** – therefore a segment of the wider Energy sector suitable to be of interest to the Railway sector given the green transition challenges it is also living, and the long life cycle
- the **Automotive sector**, despite (a) it is a mass-market targeting the general public, and such numbers can influence the resilience of the sector *because of* its negotiation power on the supply markets. Instead, the Railway sector is based on smaller numbers, like Defence and Aerospace; (b) the life cycle of cars is much shorter than rolling stock and airplanes, and this has an influence on the ultimate goal of the analysis. However, relevant Automotive specificities have been included in the analysis to draw useful conclusions.

This version of the research includes a broader set of direct talks to companies and clusters operating in the target advanced sectors and in the horizontal Electronics Industrial Ecosystem. This was useful to integrate the desk research and make it easier to summarise the key outputs considered useful by the research team for the following project phases.

The Deliverable is composed by:

- Analysis of the Defence sector, of the Aerospace sector, of the Clean Energy Infrastructures sector, and of the Automotive sector under the point of view of dependencies, disruptions as well as policy and industrial measures adopted to reduce such vulnerabilities
- Cross-references between these sectors and the Railway sector or the previous LEADER 2030 analysis, where relevant
- Summary of take-aways/inspirations considered more relevant for the prosecution of the project tasks.

## 2. Abbreviations and acronyms

| Abbreviation / Acronym | Description |
|---|---|
| ASAP | Act in Support of Ammunition Production |
| BCG | Boston Consulting Group |
| CRM(s) | Critical Raw Material(s) |
| EDIRPA | European Defence Industry Reinforcement through common Procurement Act |
| EDIS | European Defence Industrial Strategy |
| EU | European Union |
| EU-RAIL / EU-RAIL JU | Europe's Rail Joint Undertaking |
| EU-RAIL AWP | Europe's Rail Annual Work Programme |
| IEA | International Energy Agency |
| JRC | Joint Research Centre of the European Commission |
| LEADER 2030 | "Learning for European Autonomy to Deliver Europe's Rail in 2030" |
| HCSS | Hague Centre for Strategic Studies |
| NM | Nanometres |
| OECD | Organisation for Economic Co-operation and Development |
| R&D | Research and Development |
| REE(s) | Rare Earth Element(s) |
| SIPRI | Stockholm International Peace Research Institute |
| UAV(s) | Unmanned Aerial Vehicle(s) |

# 3. Background

The present document constitutes the Deliverable D1.2 “Lessons on disruptions and resilience from other sectors” in the framework of the Exploratory Research Project LEADER 2030 as described in the EU-RAIL AWP 2022. Ultimately, it aims to contribute with intelligence information to the execution of all Flagship Projects.

## 4. Objective/Aim

The purpose of the “Lessons on disruptions and resilience from other sectors” is to study some advanced industrial sectors to search for useful lessons and best practices on disruptions and resilience concerning components and key raw materials they use and that the Railway sector will/can adopt as well for its innovations (e.g. light materials where Aerospace sector is ahead; advanced electronics where the Defence sector is ahead; etc.).

Its results, together with the ones emerging from the D1.1 “Map of disruptions experienced so far by the Rail Supply industry and lessons for the future” and D1.3 “Supply alerts for the future”, bring a further contribution to the project for the understanding of state-of-the-art disruptions in supplies, showing current vulnerabilities that could harm also the future Rail supplies, and for the identification of measures to be considered to reduce supply risks in the future.

Initially, the aim was to deliver this analysis prior to D1.3, to help a better framing of the risk concerning the detailed disruptions affecting the Rail supply chain as resulting from the LEADER 2030 survey run between end 2023 and beginning 2024. Instead, the broader knowledge gained drafting both the D1.1 and D1.3 could make this last analysis ‘less theorical’ – having to do with third sectors – and more specific to patterns emerged in the Railway sector.

# 5. The sectors under analysis

## 5.1. Overview of Defence and Aerospace

Defence and the Aerospace are very often considered as one single sector, both within the EU, where "Aerospace and Defence" represents one of the 14 EU industrial ecosystems[1], and at global level, where they are coupled in industrial outlooks[2] and in industrial lobby representation[3].
The sectors in fact have:

- common stakeholders
- very often comprising companies that produce for both segments and for both military and civilian use
- often using so-called "dual-use" products, software, and technology, i.e. that can be used for both civilian and military applications. The list of dual-use items for which the EU controls the export, transit, brokering, and technical assistance to contribute to international peace and security and prevent the proliferation of Weapons of Mass Destruction (WMD) is amended periodically and includes, in fact: Nuclear materials, facilities and equipment; Special materials and related equipment; Materials processing; Electronics; Computers; Telecommunications and information security; Sensors and lasers; Navigation and avionics; Marine; Aerospace and propulsion systems[4]. Such aspects may have an impact on supply disruptions when it comes to import needed dual-use components, software or technologies in the EU. The list of foreign countries also applying export restrictions to comply with WMD controls includes among others USA (which the analysis will show being a big source of dependence for the EU in these sectors. Good trade, technological and geopolitical relationships between EU and USA help reduce the likelihood that such dependence may have a blocking impact on EU productions), China (which applies a comprehensive set of controls on the export, import, and re-export of dual-use items, including electronics that can be used for both civilian and military applications[5]), Australia, Canada, Iceland, Japan, New Zealand, Norway, Switzerland, Liechtenstein, United Kingdom.

In this analysis, however, the two sectors are addressed separately, with:

[1] *European industrial strategy*.
[2] See for instance Deloitte (2024), *2024 Aerospace and Defense industry outlook*.
[3] See for instance in Europe "ASD" (https://www.asd-europe.org) and in the USA "AIA" (https://www.aia-aerospace.org).
[4] EU export controls reflect commitments agreed upon in key multilateral export control regimes such as the Australia Group, the Wassenaar Arrangement, the Nuclear Suppliers Group, and the Missile Technology Control Regime. The Regulation (EU) 2021/821 (Regulation 2021/821 (europa.eu)) governs the EU's export control regime, which includes common export control rules, a common EU list of dual-use items, controls on brokering and technical assistance relating to dual-use items and their transit through the EU.
[5] Mayer Brown (2024), *Key Changes and Updates to Chinese Export Controls in 2023*, 1st February.

- the Defence sector part covering military production and paying special attention to Defence electronics, to which the railway CCS-Control Command Signalling systems are compared because of the level of reliability they also must guarantee
- the Aerospace sector part being analysed, whenever the segmentation is possible, for non-military/commercial aspects, with special attention to the use of advanced materials – which the Railway sector is looking at with increasing attention in terms of increased lightness, comfort, maintainability, and of course safety – and to Unmanned Aerial Vehicles (UAVs) – whose usage is fostered in the Railway sector.

The ultimate aim is therefore to analyse the two sectors both in general terms and with specific focus on productions having a special relevance for the Railway sector, while trying to separate the measures used to reduce the vulnerability of *military vs civilian* supplies.

## 5.2. Defence sector

Within the European Union, and despite the overall competitiveness of the sector, years of Member States' underinvestment in Defence resulted into both capability and industrial gaps[6]. According to SIPRI-Stockholm International Peace Research Institute, in fact, around 55% of arms imports by European States in 2019/2023 was supplied by the USA, whereas the level was 35% in 2014/2018. However, Europe is responsible for about 1/3 of global arms exports[7]. Also China plays a key role in supplying EU countries with the raw materials and equipment they need for their defence industries[8].

According to data gathered, such *dependence* for supplies matches with a level of *disruptions* in supplies the sector suffered globally: production delays, delivery delays, unavailability of materials and parts, and increased pricing for both raw materials and components. Since the COVID-19 pandemic, these factors have been causing an increase in material lead times and supplier decommits, resulting in increased volatility in operating, program, and financial performance.

This analysis also intending to test the hypothesis *whether a sector that is not only highly technological but also highly critical for states is more resilient than other civil sectors due to specific support measures justified by "state priority"*, finds that the difficulties in sourcing supplies are totally similar to other similar sectors. In fact, despite the Defence sector benefits from 'special treatment' in several aspects, still it suffers e.g. from the *limited size* of supplies it requires – which make it very similar to the Railway sector – and this represents a cause of disruption, as reported by the American Defence and Aerospace Industry Association: "…Defence grade minerals are purchased in smaller quantities than those of industrial grade (e.g., automotive applications). Automotive and other commercial industries enjoy large purchasing power which often takes

[6] European Commission (2022), *Defence Investment Gaps Analysis and Way Forward*, Joint Communication to the European Parliament the European Council, the European Economic and Social Committee and the Committee of the Regions, JOIN/22/2024/final, point 2.

[7] SIPRI (2024), *European arms imports nearly double, US and French exports rise, and Russian exports fall sharply*, 11 March.

[8] Politico (2024), *China is a threat to Europe's gunpowder supply, defense boss warns*, 18 April.

priority over small-quantity – and often higher-quality material – buys regardless of the national security imperative"[9].
Indeed, also according to JRC the Defence "demand for raw materials, which is low in terms of volume, may also be much less elastic than the civil sector's, which means that they may acquire raw materials at a higher price than the competitive civilian market can afford"[10].

Therefore, from these very first results, disruption patterns in the Defence sector look very similar to those in the Railway sector. The following paragraphs will elaborate more on the specific problems and the measures taken to reduce them.

### 5.2.1. Supply disruptions and dependencies

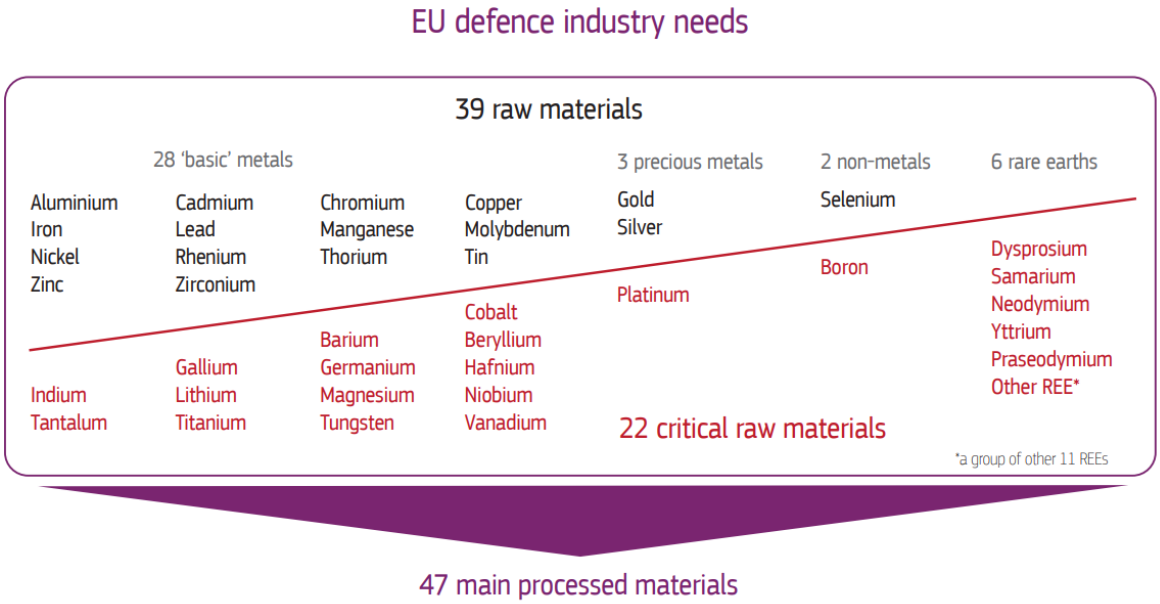
In a research paper dated 2016, the JRC stated that "information about the defence industry's dependence on raw materials is scarce, being bound by confidentiality. However, limited information is available on some countries, 8 mainly related to strategic industrial stockpiles"[11].
Despite this, the JRC could identify the list of both processed materials and raw materials used in defence applications, as well as measure EU's dependence towards specific states (China ranks first, 34%, and USA ranks second, 15%)[12]. Based on such lists, the JRC could declare that "USA, the EU and other major industrialised countries are being confronted by serious global competition for several materials"[13].
While all the above was already reported in 2016, the series of recent crises have certainly made such competition tougher.
Part of the confidentiality around sector's supplies has somehow been overcome by the crises induced by COVID-19, global shipping disruptions, and lately to the war in Ukraine etc., which brought also the Defence industrial stakeholders to publicly claim supply bottlenecks and to call for support actions from their states. According to SIPRI, "many parts of the arms industry were affected by pandemic-related disruptions in global supply chains in 2021, which included delays in global shipping and shortages of vital components. Russia's invasion of Ukraine in February 2022 has added to supply chain challenges for arms companies, as Russia is a major supplier of raw materials used in arms production"[14].

According to JRC studies[15] the *European Defence industry* needs **39 raw materials** (for about half of them, the EU Defence industry relies **100%** on imports from countries **outside** the EU; 22 of them are included in the EU's Critical Raw Materials list). However, being defence equipment mainly made from processed and semi-finished materials rather than raw materials in their elemental form, their importance is related to their use to produce **47 advanced materials**

[9] AIA-Aerospace Industry Association (2023), *AIA Critical Minerals Supply Chain White Paper*.
[10] JRC (2020a), *Critical Raw Materials for Strategic Technologies and Sectors in the EU. A foresight study*, p. 69.
[11] JRC (2016), *Raw materials in the European defence industry*, European Commission, p. 7.
[12] Ibidem, respectively at p. 39-49 and at p. 50-56.
[13] Ibidem.
[14] Op. cit., SIPRI (2024).
[15] Op. cit., JRC (2016) and JRC (2020a).

**(different alloys, compounds and composites materials)** important to the European Defence industry. Given the very high level of performance and special properties of these materials, that cannot be matched by readily available substitutes – **their potential supply risk is much higher compared to the supply risk of the constituent raw materials**.

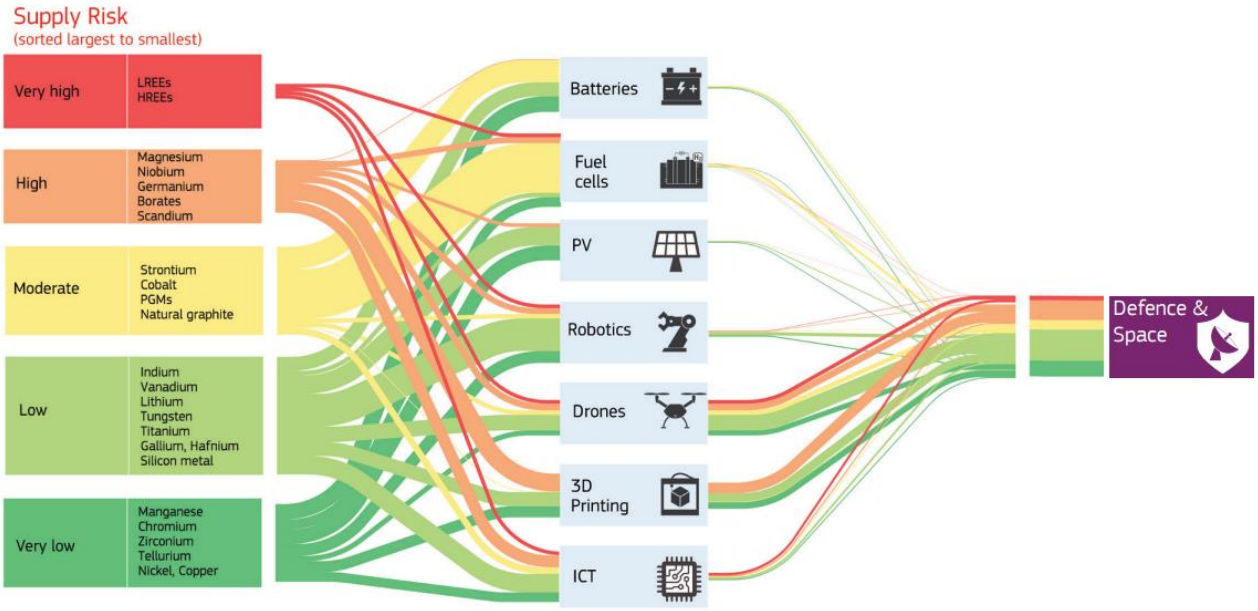
**Figure 1 | EU industry needs for raw materials (source: JRC[16])**




Focusing on the sector's supply risk based on the adoption of certain technologies and the raw materials they need to be produced, the JRC further contributed to the analysis. These results are of direct interest also to the Railway sector, as these technologies also apply in the Railway field:

[16] Op. cit., JRC (2020a), p. 70.

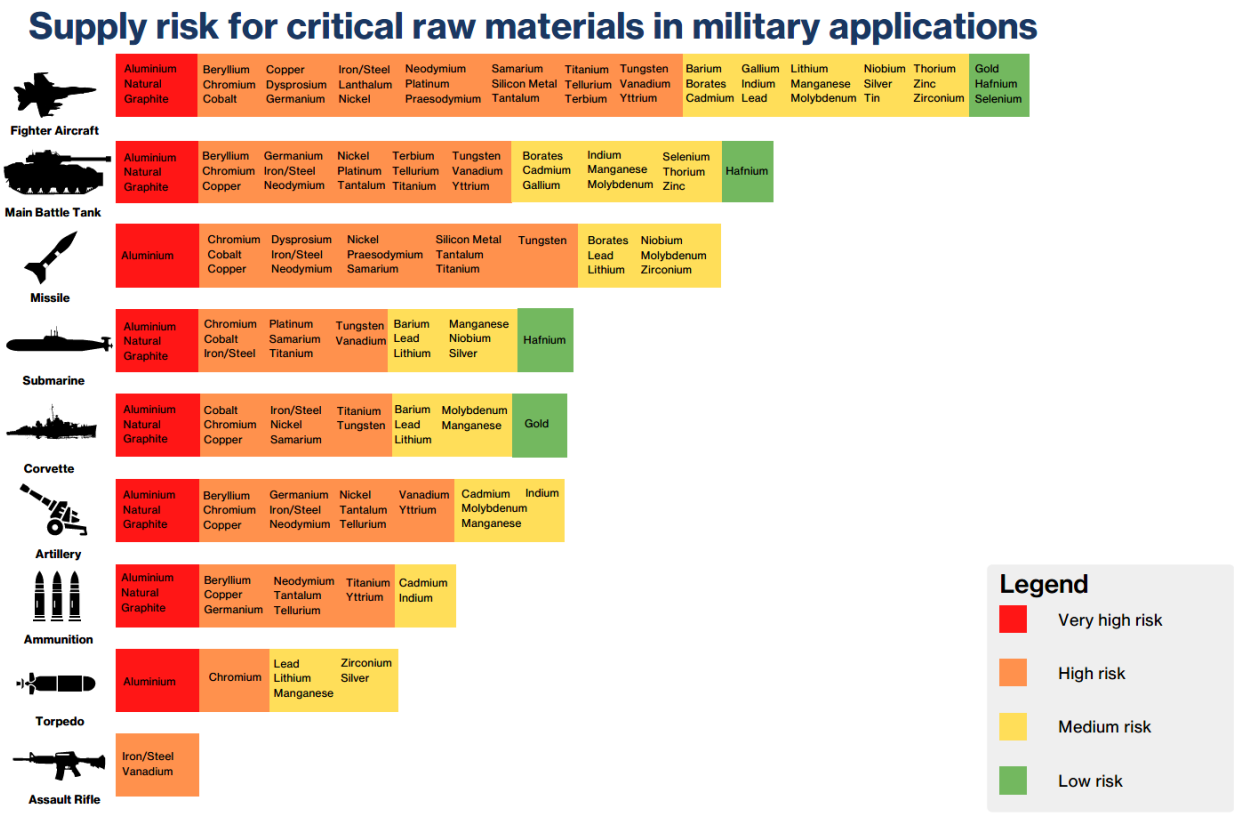
**Figure 2 | Relevant materials and technologies to the defence and aerospace sectors (source: JRC[17])**




More recently, the **Hague Centre for Strategic Studies (HCSS)[18]** discusses the importance of raw materials in *European defence applications* and provides a risk assessment of supply security and geopolitical risks, identifying **40 critical and 'soon-to-be' critical raw materials** that are strategic for the European defence industry. These materials are used across the air, sea, and land domains in various military applications and components. The report also ranks these materials according to their supply risk for European defence, based on an assessment of the probability and impact of supply disruptions:

[17] Op. cit., JRC (2020a), p. 69.
[18] Hague Centre for Strategic Studies (2023), *Strategic raw materials for defence | Mapping European industry needs*.

**Figure 3 | Supply risk for critical raw materials in military applications (source: HCSS[19])**




Such risk assessment, being based on *probability* and *impact* (the latter consisting in the frequency with which materials are used across defence applications, i.e., in how many defence applications a material is used), **highlights what had already emerged from the analysis of the LEADER 2030 survey on disruptions in the Railway industry** (see Deliverable D1.1):

- materials which the EU categorises as 'moderate criticality' – e.g. aluminium – or are even excluded by the CRMs list – e.g. iron - resulted as the most critical materials both in the Defence sector and in the Railway sector
- vice versa, materials such as Rare Earths are considered by the EU as 'very high criticality materials' given their fundamental role in the energy transition, but their limited use in the Defence sector has as a result that they are assessed as of medium criticality in the above assessment.

Because of this, **such approach will also be followed in the following steps of the LEADER 2030** project to weigh as more properly as possible the risk of future supplies for the Railway sector.

[19] Ibidem.

#### 5.2.1.1. Focus on Defence electronics

Electronics in defence systems is becoming increasingly important: today, electronic components and communication equipment are part of almost all weapons systems and pieces of equipment. The functions of weapons systems are increasingly dependent on the electronics subsystems for **guidance**, **communications** and **control**.
Electronic military equipment is not only manufactured as stand-alone sets of equipment but is increasingly integrated in all forms of weapon systems as **command**, **control**, **communication**, **computer**, **intelligence**, **surveillance**, and **reconnaissance** (C4ISR) technologies. A rise of **autonomous systems** including armed drones is also in the pipeline.
Therefore, the market for military electronics has grown continuously over the last decades[20].

The functionalities of Defence electronics are reminiscent of those required in Control Command Signalling (CCS) systems in the railway field. The level of complexity, criticality and reliability required in both fields for their respective applications makes the evolution of the former - but also its difficulties and possible mitigation solutions - particularly interesting to the latter.

According to JRC[21], the following raw materials required by Defence electronics fall under the list of CRMs. The table below:

- (columns A-B-C) summarises relevant key data provided by the JRC
- (column D) provides the result of the check made by the research team between A-B and the results emerging from the project Deliverables D1.1 and D1.3, to show if the *criticality* assigned by the JRC to Raw Materials used in Defence electronics matches the disruptions reported by the Rail Value Chain. This is aimed at **drawing further potential alerts for future development of Rail electronics**.
- (column E) shows whether export restrictions on the listed Raw Materials apply and from which countries, according to OECD data. This is aimed at better understanding if geopolitics has an impact on such criticalities, to **help draw further alerts driven by geopolitics suitable to impact future development of Rail electronics**.

**Table 1 | Overview of Raw Materials used for Defence electronics and their specific applications, criticality index, Rail criticality check, export restrictions applied (source: Authors with JRC and project data)**

| (A) Raw Material | (B) Criticality assigned by JRC[22] | (C) Applications for Defence electronics[23] | (D) JRC criticality *vs* Rail Value Chain alerts in D1.1 and D1.3 | (E) Restrictions on export of industrial raw materials |
|---|---|---|---|---|

[20] IndustryAll, Syndex (2022), *Defence Industry in Europe*.
[21] Op. cit., JRC (2020a), p. 71.
[22] Ibidem.
[23] Op. cit., JRC (2020a), p. 44-49, plus other sources.

| | | | | reported by OECD as in place at the end of 2022[24] |
|---|---|---|---|---|
| **Samarium (REE)** | Very high (6.12) | Electronic applications (general)<br><br>Used in microwave technology, enhancing the performance of radar and communication devices for command and control.<br><br>Samarium-cobalt magnets play an integral role in high-tech devices such as precision-guided missiles and satellite systems | It didn't result in the "alerts' list" of the Railway industries surveyed so far | - |
| **Neodymium (REE)** | Very high (6.07) | As component, control systems, actuators and amplifications (e.g. satellite communication, etc.) | It didn't result in the "alerts' list" of the Railway industries surveyed so far | - |
| ***Other REEs*** | *Very high (5.67)* | *Signal generation, surveillance and missile launch detection), lasers, sensors, other electronic components* | *REEs resulted in the "alerts' list" of the Railway industries surveyed so far (4% of companies said to be impacted by disruptions in its supply for power electronics and for on-board monitoring, maintenance,* | - |

[24] OECD (2022), *Methodological note to the Inventory of Export Restrictions on Industrial Raw Materials*.

| | | | | |
|---|---|---|---|---|
| | | | *surveillance and information systems)* | |
| **Yttrium (REE)** | High (4.20) | In composition, in equipment for signal generation, detection and surveillance | It didn't result in the "alerts' list" of the Railway industries surveyed so far | - |
| **Magnesium** | High (3.91) | Communication equipment, radar | It didn't result in the "alerts' list" of the Railway industries surveyed so far | Brazil, Israel, Kazakhstan |
| **Germanium** | High (3.89) | On-board electronics for inertial and combat navigation, IR tracking systems, binoculars (including night vision), GPS/SAL guidance system | It didn't result in the "alerts' list" of the Railway industries surveyed so far | China from 2023[25] (the OECD doesn't report it because covering up to 2022) |
| **Borates** | High (3.19) | Boron provides protection, conductivity, and durability in Defence electronics. Doping boron with aluminium creates a material with copper-like conductivity but without corrosion. | It didn't result in the "alerts' list" of the Railway industries surveyed so far | Argentina, Bolivia |
| **Indium** | Low (1.79) | Laser targeting, sensors, identification equipment for IR imaging systems and inertial navigation as well as in on-board electronics for phased array radar | It didn't result in the "alerts' list" of the Railway industries surveyed so far | - |
| ***Lithium*** | *Low* | *Lithium-ion* | *It resulted in the "alerts'* | Argentina, |

[25] CSIS (2023), *Understanding China's Gallium Sanctions*, 7 July.

| | | | | |
|---|---|---|---|---|
| | *(1.64)* | *batteries for energy storage, electric propulsion, electronics* | *list" of the Railway industries surveyed so far (4% of companies said to be impacted by disruptions in its supply power electronics and for on-board monitoring, maintenance, surveillance and information systems)* | Zimbabwe |
| **Tantalum** | Low (1.36) | Capacitors for on-board applications: binoculars, identification equipment/IR, inertial navigation, radars | It didn't result in the "alerts' list" of the Railway industries surveyed so far | Burundi, China, Dem. Rep. of Congo, Ethiopia, Nigeria, Rwanda |
| **Baryte** | Low (1.26) | Electronics (general) | It didn't result in the "alerts' list" of the Railway industries surveyed so far | India, Thailand, Vietnam |
| **Gallium** | Low (1.26) | Communication (e.g. transmitter) and electro-optical systems and on-board electronics | It didn't result in the "alerts' list" of the Railway industries surveyed so far | China from 2023[26] (the OECD doesn't report it because covering up to 2022) |
| **Hafnium** | Low (1.12) | Electro-optical systems for radar | It didn't result in the "alerts' list" of the Railway industries surveyed so far | - |
| **Silver** | Very low (0.68) | Electronics for transmitter, communication and identification systems | It didn't result in the "alerts' list" of the Railway industries surveyed so far | Bolivia, China, India, Kazakhstan, Mexico, Russia |
| **Selenium** | Very low (0.41) | Specialised electronics (e.g. phased array radar) and batteries | It didn't result in the "alerts' list" of the Railway industries surveyed so far | India |
| **Zinc** | Very low | Substrate (zinc | It didn't result in the | Bolivia, China, |

[26] Ibidem.

| | | | | |
|---|---|---|---|---|
| | (0.34) | sulphide and zinc selenite) in electronics for radar and infra-red detectors | "alerts' list" of the Railway industries surveyed so far | India, Kazakhstan, Russia, |
| ***Copper*** | *Very low (0.32)* | *On-board electronics for inertial navigation, binoculars, IR equipment, phased array radars, guidance systems* | *It resulted in the "alerts' list" of the Railway industries surveyed so far as one of the most hit (19% of companies said to be impacted by disruptions in its supply for many applications for rolling stock, command control signalling, and infrastructures, with heavy impact on power electronics, electric traction, level crossings, communication, and much more)* | *Argentina, Chile, China, Rep. Dem. of Congo, Indonesia, Kazakhstan, Mexico, Mongolia, Russia, Zambia* |
| **Gold** | Very low (0.19) | Electronics for radars (e.g. 3D medium range, guidance, navigation, air search, long-range air and tracking) and in surface detection | It didn't result in the "alerts' list" of the Railway industries surveyed so far | Colombia, Congo, Ghana, Guinea, Indonesia, Kazakhstan, Philippines, Russia, South Africa, Uzbekistan, Zimbabwe |
| **Lead** | Very low (0.09) | Batteries, electric motors and electric propulsion | It didn't result in the "alerts' list" of the Railway industries surveyed so far | Bolivia, China, India, Kazakhstan, Mexico, Morocco, Russia, South Africa |

### 5.2.2. Measures used to mitigate risks

At EU level, Russia's invasion against Ukraine led to the adoption of specific, unprecedented measures meant to mitigate risks of disruptions in supplies for defence systems and build up strongest research and industrial capability. Some were thought for the short/medium-term, others for the long-term. Among these, the following are especially relevant to this research:

- July 2022: European Defence Industry Reinforcement through common Procurement Act (EDIRPA) – *targeting the demand side*
- March 2023: Act in Support of Ammunition Production (ASAP) - – *targeting the supply side*
- March 2024: European Defence Industrial Strategy (EDIS).

**EDIRPA** (European Defence Industry Reinforcement through common Procurement Act)[27] is a new EU instrument that became Regulation in October 2023. It is meaningful to this research because it **incentivises cooperation in defence procurement** between Member States to **jointly coordinate and acquire the most urgent and critical defence product needs**, especially those amplified from Russia's aggression against Ukraine. It allocates a total budget of 310 million € to facilitate the joint purchase, offsetting the complexity often associated with common procurement.

**ASAP** (Act in Support of Ammunition Production)[28] represents the "industrial part" of the so-called three-track approach of the Ammunition Plan agreed by the European Council on 20 March 2023, to urgently deliver ammunition and missiles to Ukraine and to help Member States refill their stocks. According to Politico, in fact, Europe reliance on China to make powder for Ammunition can bring to supply crisis that could threaten the continent's security[29].
Acknowledging the critical need of **timely availability in sufficient volumes of such products** for EU security and continuous efforts to support Ukraine, the European Commission adopted ASAP to ramp up the EU's production capacity and addressing the current shortage of ammunition and missiles as well as their components. It aims to support the destocking from Member States (track 1) and the joint procurement for ammunition (track 2).
As it is of interest for this research, the Act introduces:

- An **instrument to financially support the reinforcement of the Union's industrial production capacities** for the relevant defence products. This consisted in open calls for projects, whose results have been announced in March 2024[30], worth of 500+ million €
- A **mechanism to map, monitor and better anticipate the existence of bottlenecks** in these supply chains
- The introduction of a **temporary regulatory framework to address the ammunition supply shortage**.

[27] European Commission, EDIRPA | Procuring together defence capabilities.
[28] European Commission, Act in Support of Ammunition Production (ASAP).
[29] Politico (2024), *China is a threat to Europe's gunpowder supply, defense boss warns*, 18 April.
[30] ASAP Results. Boosting ammunitions production (europa.eu).

**EDIS** (European Defence Industrial Strategy)[31] takes its steps from the acknowledgment that the EU is a competitive global player capable of producing world-class advanced systems, but its full potential is affected by years of underinvestment and fragmentation of defence demand along national lines. These trends have increased **dependencies on third countries**. Such a trend in fact has increased along the years, as shown above by SIPRI data, despite already in 2007/2008 the European sector committed to "less European dependence on non-European sources for key defence technologies" and "the reinforcement of the EDTIB [-European Defence Technology Industrial Base-] to satisfy needs for autonomy and operational sovereignty"[32].
Out of the five parts composing the EDIS, the following are relevant to this research:

- Investing more, better, together, European – which includes joint procurement, more cooperation, as well as preparation for a **European Military Sales Mechanism to enhance availability of EU equipment**
- A responsive and innovative European Defence Industry – which includes **EU Security of Supply regime to solve tensions along the supply chains and identify bottlenecks**
- Financing the Union's ambition for Defence industrial readiness – which includes the proposed **European Defence Industry Programme** (EDIP) with a budget of 1,5 billion €.

## 5.3. Aerospace sector

Civil aeronautics is one of the most successful EU's high-tech sectors. European industry is world leader in the production of civil aircraft, including helicopters, aircraft engines, parts and components. The civil branch of the Aerospace industry constitutes the backbone of the overall sector, representing 50% of its annual turnover. In terms of supplies, the European aeronautics industry relies on a global supply chain for various raw materials and components.

### 5.3.1. Supply disruptions and dependencies

The Aerospace sector has been disrupted by the COVID-19 pandemic, which – together with the heavy impact on the demand for air travel – has led to unforeseen levels of uncertainty regarding the supply of various technological goods. The sector also has been impacted by global dependence on countries specialised in the production of critical electrical, electronic, and electro-mechanical components, which resulted in slowdowns or stoppages in production lines. According to McKinsey[33], aerospace executives were about 18 times more likely to mention supply-chain-related terms, such as "shortages" in 2022 than they were in 2014.
Concerning steel and aluminium, their sourcing was also impacted for reasons due – earlier – to COVID-19 demand drop followed by quick skyrocketing, and – then – to the impact of Russia's

[31] European Defence Industry Strategy (europa.eu).
[32] European Defence Technology and Industrial Dependencies (europa.eu).
[33] McKinsey (2024), *Addressing continued turbulence: The commercial-aerospace supply chain*.

invasion of Ukraine, which led to reduced imports to the EU but also to an increased demand for such materials driven by Defence needs.

Because of the attractiveness of the sector advanced performances, the European Aerospace industry is also facing increasing competition from non-aerospace sectors for strategic aerospace metals such as titanium, vanadium, nickel, and cobalt.

#### 5.3.1.1. Focus on Advanced Materials

The evolution of the Aeronautics industry brought a shift from the use of traditional materials such as metals and metal-based alloys to new lightweight materials such as *titanium alloys*, *composite materials*, especially those made from glass and carbon-fibres, and *high-temperature-resistant plastics*.

In the field of Aerospace, **titanium** has been applied for many years. Commercially pure titanium and titanium alloy are used as a material having light weight (density being 60% that of steel), high strength, heat resistance, as well as excellent corrosion resistance. It is mainly used for the airframe (e.g. cockpit window frame, tail cone, wing box, fastener, landing gear, hydraulic pipe, track beam) and the engine parts (e.g. fan and the compressor in the fore half section), to reduce fuel consumption of aircrafts and increase maintainability[34].
Titanium properties make it an attractive material for various applications in the railway industry, e.g. to achieve weight reduction in vehicles, or for components that are exposed to harsh environmental conditions. However, the use of titanium in the Railway industry might not be as widespread as in other sectors like aerospace – and even automotive - mainly due to its relatively high cost compared to other materials like steel or aluminium[35][36].
However, according to the European Commission, imports of titanium metal in the EU are mostly in the form of wrought products (85% by value in 2020), and the EU is the world's top importer of it as it doesn't produce titanium sponge, which is the primary metal feedstock for wrought titanium[37]. Because Russia and Ukraine are key global suppliers of such materials, which makes the Aerospace sector vulnerable to supply chain disruptions. For such a reason, in Spring 2022, the European industries called for the EU Institutions not to sanction Russian titanium[38]. Likewise, no other CRM is included in EU's bans for Russia. However, the most plausible sources for the EU in order to shift supply from Russia in the medium term are its existing trade partners: Kazakhstan and Japan for unwrought titanium, and the USA and the UK for wrought products[39].

Today, for most commercial aircraft applications, **carbon fibre-based composites** are now the

[34] Nippon Steel and Sumitomo Metal (2014), *Application and Features of Titanium for the Aerospace Industry*. The paper also provides details about the types of Titanium used for the several parts.
[35] Ibidem.
[36] The average ratio between aluminium and titanium cost per kg is 2 to 20 USD, respectively.
[37] JRC (2022), *Titanium metal: Impact assessment for supply security*.
[38] Euractiv (2022), *Airbus urges EU leaders not to sanction Russian titanium*.
[39] Op. cit., JRC (2022).

leading materials on the market, with airplanes being made 50%+ from Carbon-Fiber Reinforced Polymer (CFRP) composites to decrease weight for increasing fuel efficiency (which is an achievement both for environmental aspects and for long-distance independency), while providing greater resistance. The market outlook for this type of materials is expected to increase steadily [40].

Such materials, today used in the Railway sector for specific applications (vehicles/modules, interiors, toilets, lineside furniture and platform systems, track-bed, gantries, etc.), could expand their use replacing up to structural components like train outer shells and bogies once the standard aspects are solved[41]. On such aspect, the FP7 project "REFRESCO", concluded in 2016, must be mentioned: it found that the current European railway certification process gives opportunities for applying new materials in train carbody shells; the set of technical standards needed to prove compliance for composite car bodies is not yet in place and thus has to be developed further; however, even if some standards need adaptation for composites material behaviour, most can be applied to a composite car body shell without jeopardising safety[42].

According to JRC[43], however, the EU lacks major manufacturers of aerospace-grade carbon fibres and their precursors, e.g. polyacrylonitrile (PAN), which are needed for composite materials and are currently mainly produced in Japan and the USA. As a consequence, at the present time there is a potential low-to-moderate supply chain bottleneck in the EU for such aerospace materials and other semi-finished materials.

**High-temperature resistant plastics** are used extensively in the Aerospace industry due to their light weight (e.g. they are about 50% lighter than aluminium), high strength, and excellent thermal stability, as they can withstand elevated temperatures without significant loss of mechanical properties. Also, they reduce manufacturing and operating costs and, in general, can be manufactured more economically than metals. Additionally, plastics stand up in harsh conditions better than other materials. Unlike metals, they are resistant to corrosion and more impact resistant than glass. Plastics also provide electrical insulation, with some having almost zero conductivity.

Being compounds produced specifically according to the sought performance, it cannot be measured a specific level of dependency for European industries. Surely, global leaders are based in Eastern Asia (Japan, South Korea), but also specialisations in techno-polymers are found in Europe (Germany, Italy, France).

Also the Railway sector makes use of such materials thanks to the benefits in terms of increased safety as well as reduced maintenance times, thanks to their high mechanical strength, corrosion and weather resistance, and high temperature resistance. Some of the high-temperature resistant plastics used in the Railway sector include Enhanced Plastics (e.g. for reducing on board noise emissions and vibrations), Thermoplastics (which can be melted and dissolved many times, making them ideally suited for recycling), High-Heat Plastics (e.g. for pneumatic tubes for pantographs, for short neutral sections in overhead lines).

[40] Get inside Scoop of Carbon Fiber Reinforced Polymer Market.
[41] Technologies of the future: composite materials.
[42] Lightweight materials provide opportunities for the next generation of railway vehicles (europa.eu).
[43] Op. cit., JRC (2020a).

### 5.3.1.2. Focus on Unmanned Aerial Vehicles (UAVs)

UAVs are defined by the JRC as "aircrafts that do not carry a human operator, use aerodynamic forces to provide vehicle lift, and can be expendable or recoverable". They are commonly known as drones. Like any modern aircraft, drones are composed of numerous components, often up to several hundred individual parts. As drones can basically be considered a special type of robot, the composition and components are similar[44].

The EU is increasing its efforts to create a large-scale drone market, also for commercial purposes[45], to enhance own capabilities and reduce reliance on non-EU suppliers (above all for an extremely sensitive domain of military operations); however, dependencies still exist and are due to a variety of factors, including the global nature of the supply chain and regulatory challenges.[46] Competition mostly comes from USA and Israel, which are leaders in the UAV market.

The UAVs value chain[47] requires tight supply chains, nowadays exacerbated by component shortages and increased import duties in Europe, while components sourced in the EU are said to be up to three times more expensive than Chinese supplies with very minimal differences in quality. Manufacturers struggle with delays and sourcing problems, greatly increasing costs and hampering timely production.

Dependencies in this segment concern the several components of UAVs that are not produced or sourced in Europe, and whose global production is concentrated in only a few countries: **Electronics** (Navigation and control systems, Inertial Measurement Units, Graphical Processing Units, Communications Systems, Microprocessors, Sensors, Actuators, GPUs, Gears, Microprocessors, often imported from other countries, mainly USA, Israel, and Japan), **Engines** (Magnets, Gears, Li-polymer batteries, Fuel cells), as well as **Industrial Equipment** for UAV production. The most important supplier by far of components for military drones is the USA (average 42%, with peaks up to 95% for GPUs), while China dominates the civil drones sector, and increasingly the share of professional drones.

Due to their complex systems, a wide range of materials are relevant for drone production. Compared to the other parts of the UAV supply chain, the EU is well positioned with regard to the supply of **processed materials**, with a share of more than 27%. These include 14 materials, namely: aluminium alloys, aluminium-magnesium alloys, magnesium alloys, nickel alloys, nickel-titanium alloys, titanium alloys, speciality steels, high-performance alloys, refractory metals, composites (CFCs), aramid (Kevlar) fibres, semiconductors, ferroniobium and magnetic alloys.

Concerning **raw materials**, 48 are identified as relevant, and the EU is fully dependent on the supply of 40 of these. China is the predominant supplier of most of the CRMs for UAVs, providing more than 39%. South Africa and Russia are the next major suppliers of CRMs, with a 13% and an 6% share of global production respectively. The supply of CRMs from European countries is 13%. However, as JRC highlights, opportunities for diversification of the materials supply is possible as more than 50% of the raw materials are supplied by numerous smaller supplier countries.

[44] Ibidem.
[45] Drone Strategy: Creating a large-scale European drone market.
[46] Defence Industry Europe (2023), *Developing a European UAV. Capabilities, ambitions, and role of the European defence industry*, 26 February.
[47] Its composition is provided by European Commission (2022b), *Report of the Drone Leaders Group*, p. 9.

According to JRC[48], the following raw materials required by UAVs fall under the list of CRMs. The table below:

- (columns A-B-C) summarises relevant key data provided by the JRC
- (column D) provides the result of the check made by the research team between A-B and the results emerging from the project Deliverables D1.1 and D1.3, to show if the *criticality* assigned by the JRC to Raw Materials used in UAVs matches the disruptions reported by the Rail Value Chain. This is aimed at **drawing further potential alerts for future development of UAVs for Railway applications**.
- (column E) shows whether export restrictions on the listed Raw Materials apply and from which countries, according to OECD data. This is aimed at better understanding if geopolitics has an impact on such criticalities, to **help draw further alerts driven by geopolitics suitable to impact future development of UAVs for Railway applications**.

**Table 2 | Overview of Raw Materials used for UAVs and their specific applications, criticality index, Rail criticality check, export restrictions applied (source: Authors with JRC and project data)**

| (A) Raw Material | (B) Criticality assigned by JRC[49] | (C) Applications for UAVs | (D) JRC criticality *vs* Rail Value Chain alerts in D1.1 and D1.3 | (E) Restrictions on export of industrial raw materials reported by OECD as in place at the end of 2022[50] |
|---|---|---|---|---|
| **Beryllium** | 2.22 (Moderate) | In alloys, communication equipment and integrated wire networks, electro-optical systems, landing gears | It didn't result in the "alerts' list" of the Railway industries surveyed so far | China, Madagascar |
| ***Other REEs (including scandium)*** | *Very high (5.67)* | *In (small) electric motors with electronic speed control (ESC); in AlSc alloys for* | *REEs resulted in the "alerts' list" of the Railway industries surveyed so far (4% of companies said to be* | - |

[48] Op. cit., JRC (2020a), p. 48.
[49] Op. cit., JRC (2020a), p. 71.
[50] OECD (2022), *Methodological note to the Inventory of Export Restrictions on Industrial Raw Materials*.

| | | | | |
|---|---|---|---|---|
| | | *lightweight-high strength non-structural parts and fittings* | *impacted by disruptions in its supply for power electronics and for on-board monitoring, maintenance, surveillance and information systems)* | |
| **Magnesium** | High (3.91) | In high-performance Al-Mg alloys | It didn't result in the "alerts' list" of the Railway industries surveyed so far | Brazil, Israel, Kazakhstan |
| **Niobium** | High (3.90) | Microalloying in high strength structural steel | It didn't result in the "alerts' list" of the Railway industries surveyed so far | - |
| **Germanium** | High (3.89) | On-board electronics, inertial navigation systems (5N) and combat identification equipment | It didn't result in the "alerts' list" of the Railway industries surveyed so far | China from 2023[51] (the OECD doesn't report it because covering up to 2022) |
| **Indium** | Low (1.79) | In compounds for electro-optical systems | It didn't result in the "alerts' list" of the Railway industries surveyed so far | - |
| **Gallium** | Low (1.26) | Communication and identification systems (GaAs and GaN, 5N), also in electro-optical systems | It didn't result in the "alerts' list" of the Railway industries surveyed so far | China from 2023[52] (the OECD doesn't report it because covering up to 2022) |
| **Titanium** | Low (1.26) | Armour, airframes and wings, fans & compressors | It didn't result in the "alerts' list" of the Railway industries surveyed so far | Brazil, China, India, Kenya, Madagascar, Malaysia, Senegal, Sierra Leone, Vietnam |
| **Hafnium** | Low (1.12) | Ni-based super-alloys, high strength-high | It didn't result in the "alerts' list" of the Railway industries | - |

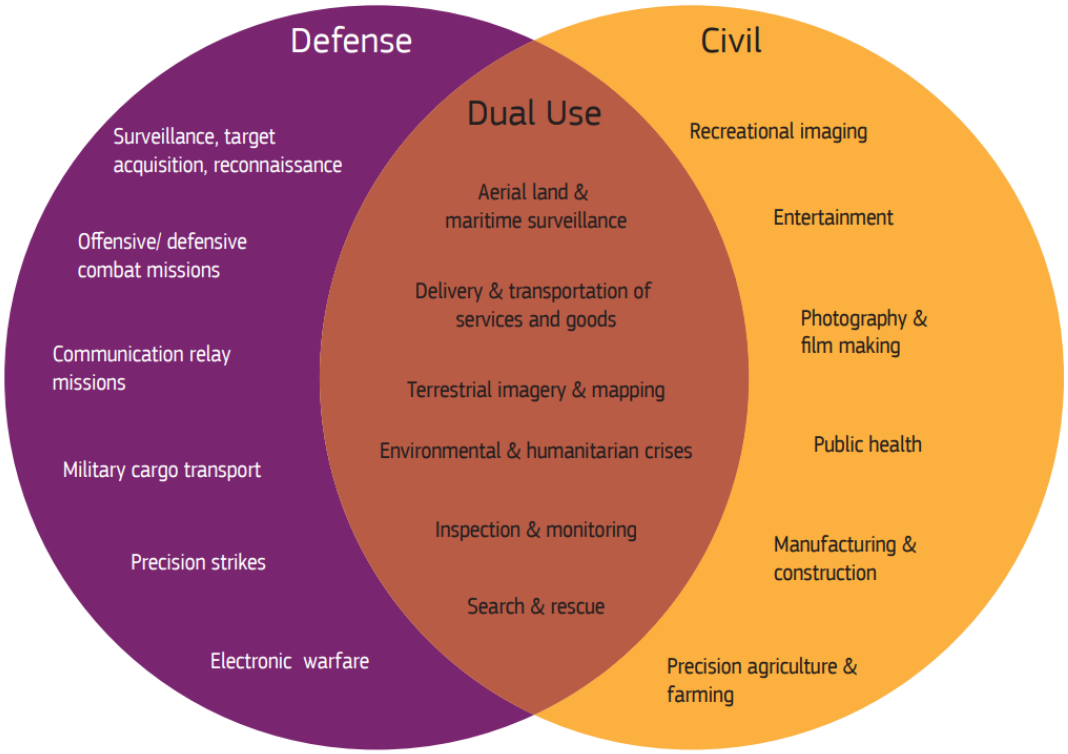
[51] CSIS (2023), *Understanding China's Gallium Sanctions*, 7 July.
[52] Ibidem.

| | | | | |
|---|---|---|---|---|
| | | temperature application | surveyed so far | |
| ***Aluminium*** | *Very low (0.59)* | *Alloys used for airframes, gear bodies, avionics* | *Aluminium resulted in the "alerts' list" of the Railway industries surveyed so far (22% of companies said to be impacted by disruptions in its supply both as pure aluminium and alloys in applications for lighter rolling stock, systems and infrastructures)* | *China, Egypt, Guinea, India, Indonesia, Jamaica, Kazakhstan, Malaysia, Russia, Tajikistan* |
| ***Nickel*** | *Very low (0.49)* | *Turbine and engine parts* | *Nickel resulted in the "alerts' list" of the Railway industries surveyed so far (4% of companies said to be impacted by disruptions in its supply, e.g. for braking systems, UPS-uninterruptable power supply, systems for stations)* | *Botswana, China, Colombia, Indonesia, Madagascar, Myanmar, Philippines, Russia* |
| ***Iron*** | Very low (0.46) | *In special steels in structural and engine parts* | *Iron resulted in the "alerts' list" of the Railway industries surveyed so far (22% of companies said to be impacted by disruptions in its supply for many applications for rolling stock, command control signalling, and infrastructures, with heavy impact going from braking systems to superstructures)* | *Argentina, Brazil, China, India, Malaysia, Mexico, Saudi Arabia, Ukraine* |
| ***Copper*** | *Very low* | *Alloying element in* | *Copper resulted in the* | *Argentina,* |

| | | | | |
|---|---|---|---|---|
| | *(0.32)* | *super-alloys and CuBe alloys, communication equipment* | *"alerts' list" of the Railway industries surveyed so far as one of the most hit (19% of companies said to be impacted by disruptions in its supply for many applications for rolling stock, command control signalling, and infrastructures, with heavy impact on power electronics, electric traction, level crossings, communication, and much more)* | *Chile, China, Rep. Dem. of Congo, Indonesia, Kazakhstan, Mexico, Mongolia, Russia, Zambia* |

UAVs are increasingly considered for Railway applications, above all for monitoring roles to increase safety, security as well as maintainability of railway transport and infrastructures.

**Figure 4 | Drone applications (source: JRC[53])**




All the above should be considered in the scale-up of its applications and reliance on UAVs for specific railway operations.

### 5.3.2. Measures used to mitigate risks

With reference to the specific aspects covered in the previous paragraphs, the following measures adopted by the EU to reduce supply dependency, address disruptions and increase autonomy of the European Aerospace/Aeronautical sector are to be mentioned:

- 2021: Observatory for Critical Technologies
- November 2022: Drone Strategy 2.0 for a Smart and Sustainable Unmanned Aircraft Eco-System in Europe.

The **Observatory of Critical Technologies (OCT)**[54] was set up by the European Commission with the aim to strengthen the resilience of the Aerospace (as well as of Defence and Security) industry across the value chain:

[53] Op. cit., JRC (2020a), p. 47.
[54] European Commission (2023a), *For a resilient, sustainable and digital aerospace and defence industrial ecosystem, Commission Working Document*, SWD(2023) 280 final. European Parliament (2023), *Follow up to the European Parliament non-legislative resolution on Critical technologies for security and defence: state of play and future challenges*, ITRE Resolution.

- identifying critical technologies in the interplay between the Civil, Space, and Defence industries
- **identifying and monitoring risks associated with strategic dependencies (technologies and their associated value chains and actors)**
- performing technology watch to identify emerging critical and potentially disruptive technologies with a significant potential impact on space and defence innovation and EU strategic interests.

In such a framework, a specific Sub-Group of Experts on "Critical Technologies and Supply Chain" was set up by the European Commission within the Expert Group on "Policies & Programmes relevant to EU Space, Defence and Aeronautics Industry (SDA)"[55].

The **new Drone Strategy 2.0**[56] adopted by the European Commission aims to support the development of a smart and sustainable unmanned aircraft eco-system in Europe. The Strategy identifies a number of actions to further develop the EU drone service market. They include, among others:

- measures to better **exploit synergies between civil and military drone technologies** to support the competitiveness of European industry: already today, many critical drone technologies for security and defence increasingly originate in the civilian domain and use critical components of a dual-use nature. To accelerate innovation across domains and foster technological sovereignty, better exchange between civilian and defence research and innovation communities is needed. This requires a more efficient use of resources and a readiness to explore the opportunities of dual-use. It also means **reducing strategic dependencies and vulnerabilities of the value and supply chains** associated with these technologies
- to develop a **Strategic Drone Technology Roadmap** in order to identify priority areas to boost research and innovation, **reduce existing strategic dependencies and avoid the emergence of new ones**.

## 5.4. Clean Energy Infrastructures

Clean Energy Infrastructures refer to the foundational systems and facilities necessary for the widespread adoption of clean energy technologies.
The group of technologies named "Clean Energy" include:

- Solar Energy (captured from sunlight using photovoltaic cells)
- Wind Energy (generated by wind turbines)
- Hydropower (derived from flowing water in rivers or dams)
- Geothermal Energy (tapped from Earth's internal heat)

[55] Register of Commission expert groups and other similar entities – Critical Technologies and Supply Chain.
[56] European Commission (2022c), *A Drone Strategy 2.0 for a Smart and Sustainable Unmanned Aircraft Eco-System in Europe*, Commission Communication, COM(2022) 652 final.

- Biomass Energy (produced from organic materials like wood, agricultural residues, and biofuels) Nuclear Energy (although controversial, it emits no greenhouse gases during operation)
- Ocean Wave Power (harnessing wave energy).

These energy sources are clean with regard to climate change as they do not emit greenhouse gases, the most important of which is carbon dioxide (CO2), so "clean" technologies can more precisely be referred to as low-carbon or carbon-free[57].

Infrastructure to transport and store electricity, hydrogen and CO2 is a critical enabler of clean energy transitions: in the NZE Scenario, the global length of power transmission lines increases by around 185% and distribution lines by almost 165% over 2021-2050. Trade in low-emission hydrogen, which is almost non-existent today, covers more than 20% of global merchant hydrogen demand by 2030. Annual CO2 storage injection capacity jumps from around 42 million tonnes (Mt) of CO2 per year today to around 1.2 gigatonnes (Gt) per year by 2030, requiring a huge expansion of CO2 transport and storage infrastructure[58].

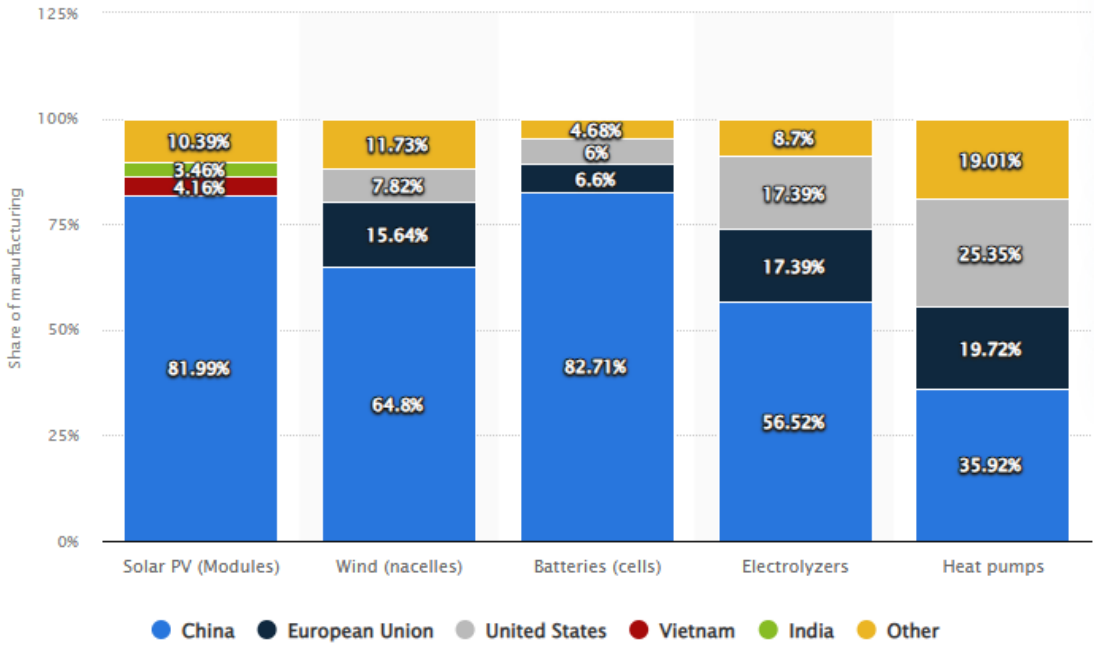
The infrastructures for Clean Energy encompass various components, such as **grids**, **transmission lines**, **charging stations**, and **batteries**[59]. These elements are critical for supporting the transition to clean energy sources as well as clean applications like fostered in the Rail sector.

### 5.4.1. Supply disruptions and dependencies

Europe is actively positioning itself as a leader in Cleantech infrastructure development. Many are the policy initiatives launched by the EU to achieve this (the "Green Deal", "Net Zero Industry Act", "Fit for 55", "Cleantech for Europe" and the EU bonds to leverage public funds to scale the clean technologies are among the best known[60]), and the European Cleantech industry is thriving.

[57] MIT Climate Portal (2024), *What is "clean energy"? Is any kind of energy completely clean?*, 7 May.
[58] IEA (2023a), *Enabling infrastructure – Energy Technology Perspectives 2023*.
[59] See World Economic Forum (2024), *Clean energy innovation points the way to net zero. But what about the underlying infrastructure?*, 11 January.
[60] For a complete overview, see European Commission (2023b), *Commission reports on EU policy initiatives to promote investments in clean technologies*, 24 October.

**Figure 5 | Distribution of clean energy technology manufacturing as of 2023, by region (source: Statista[61])**



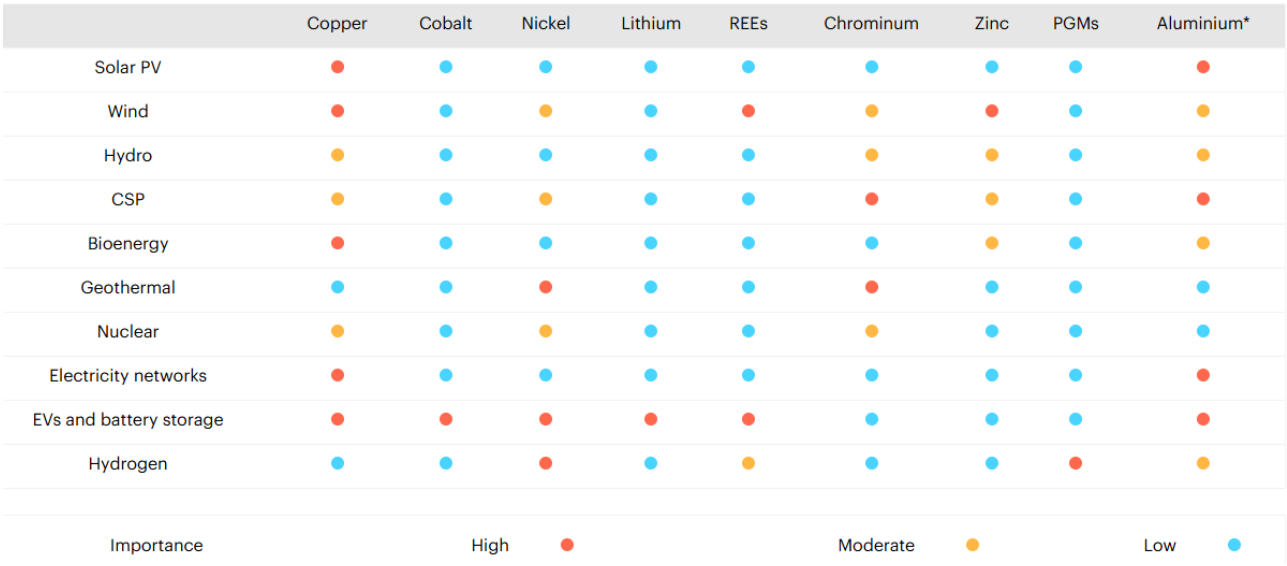

while the EU pioneers clean technologies like wind power and hosts major climate tech start-up hubs, the sector faces challenges such as permitting uncertainties and global competition with the US and China, as well as several **dependencies** in producing clean energy technologies not only at raw materials level but also at components level (e.g. China domination of solar PV technology supply market with about 89%).

Since 2010 the average amount of minerals needed for a new unit of power generation capacity has increased by 50% as the share of renewables in new investment has risen[62].

A specific analysis on what critical raw materials are necessary for Clean energy infrastructures and what importance each of them will have was made by IEA:

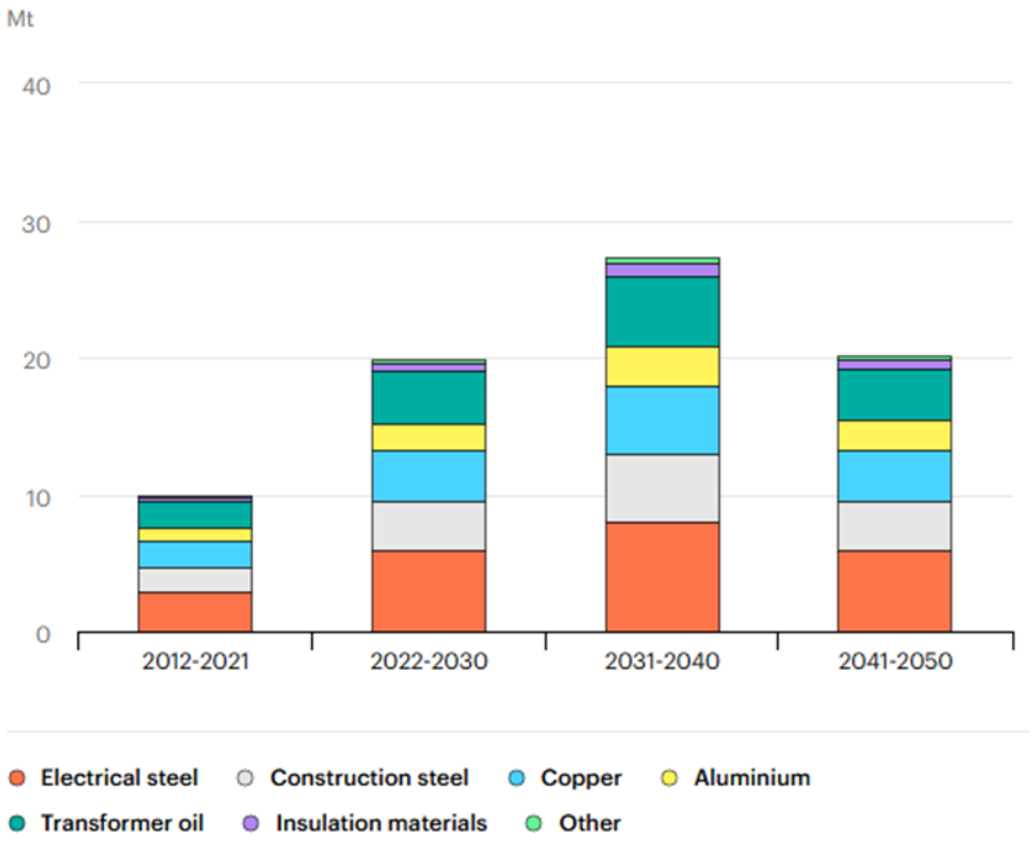
[61] Statista (2024), Clean energy technology manufacturing by region 2023.
[62] IEA (2021a), *The Role of Critical Minerals in Clean Energy Transitions*, Executive Summary.

**Figure 6 | Critical mineral needs for clean energy technologies (source: IEA[63])**



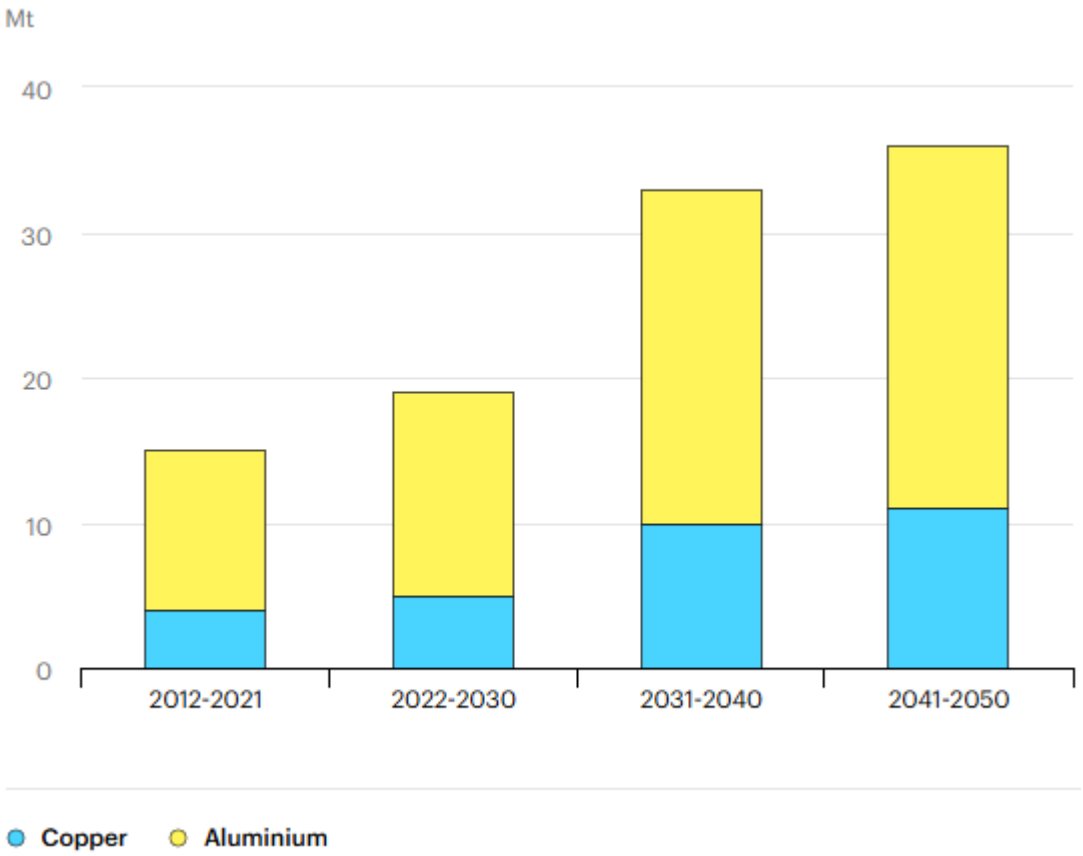

[63] IEA (2021b), *Mineral requirements for clean energy transitions – The Role of Critical Minerals in Clean Energy Transitions*, Introduction.

**Figure 7 | Average annual material needs for power transformers in the Net Zero Scenario, 2012-2050 (source: IEA[64])**




[64] Op. cit., IEA (2023a).

**Figure 8 | Average annual material needs for power transmission and distribution lines in the Net Zero Scenario, 2012-2050 (source: IEA[65])**




Further raw materials result necessary according to the JRC[66] for the above applications. These include both structural materials - concrete, steel, plastic, glass, aluminium, chromium, copper, iron, manganese, molybdenum, nickel, and zinc - and technology specific materials such as REEs and minor metals.

According to IEA, mineral demand for low-carbon power generation grows rapidly, doubling in the STEPS scenario (i.e. IEA's Stated Policies Scenario) and nearly tripling in the SDS scenario (i.e. the Sustainable Development Scenario) over the period to 2040.
Wind power plays a leading role in driving demand growth due to a combination of large-scale capacity additions and higher mineral intensity (especially with growing contributions from mineral-intensive offshore wind). Solar PV follows closely, with its unmatched scale of capacity additions among the low-carbon power generation technologies. Hydropower, biomass and nuclear make only minor contributions given their comparatively low mineral requirements and

[65] Ibidem.
[66] JRC (2020c), *Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system*.

modest capacity additions[67].
Such demand projections are however subject to considerable uncertainty, with different levels of climate ambition depending on Governments and various technology development pathways resulting in a wide range of mineral demand. These large uncertainties around possible futures may act as a factor that hampers mining and processing companies' investment decisions, which could in turn cause supply-demand imbalances in the years ahead. In fact, despite the promise of massive demand growth, mining and processing companies may be reluctant to commit large-scale investment given the wide range of possible demand trajectories. This is well understandable given the long lead-time necessary from mine discovery to production, assessed in 15,7 years[68] up to 16,5 years[69].

Similarly, supply **disruptions** have hit the sector in several ways:

- Prices for the materials needed to create wind turbines and solar panels have experienced significant volatility: e.g. the price of polysilicon (i.e. the starting material for wafers in solar cells) rose by 350% between 2020 and June 2022 due to events in China (which produces more than 79% of the world's supply) having sharply reduced availability: COVID-19 lockdowns, factory accidents, and floods.
- Cost inflation has also affected commodities needed for wind turbines. Due to the combination of rising global demand for wind energy and pandemic-related supply issues, the prices of steel, copper, and aluminium – which compose 40/50% of wind turbines – have experienced two- and threefold increases over the past few years.

Given the rules governing the sector, these causes have raised profitability warnings due to long-term contracts with customers containing fixed prices that do not allow adjustments.

The critical raw materials identified by IEA as necessary for Clean energy infrastructures have been:

- (columns A-B-C) summarised and classified against key data provided by the JRC
- (column D) checked against the results emerging from the project Deliverables D1.1 and D1.3, to show if the *criticality* assigned by the JRC to Raw Materials used in Clean energy infrastructures matches the disruptions reported by the Rail Value Chain. This is aimed at **drawing further potential alerts for further use of both Clean energy infrastructures and other relevant cleantech applications in the Railway sector**
- (column E) checked against export restrictions, according to OECD data. This is aimed at better understanding if geopolitics has an impact on such criticalities, to **help draw further alerts driven by geopolitics suitable to impact future utilisation of Cleantech in Railways**.

[67] Ibidem.
[68] S&P Global (2023), *Discovery to production averages 15.7 years for 127 mines*, 6 June.
[69] Op. cit., IEA (2021a).

**Table 3 | | Overview of Raw Materials used for Clean energy infrastructures and their specific applications, criticality index, Rail criticality check, export restrictions applied (source: Authors with JRC and project data)**

| (A) Raw Material | (B) Criticality assigned by JRC[70] | (C) Applications for Clean Energy Infrastructures | (D) JRC criticality *vs* Rail Value Chain alerts in D1.1 and D1.3 | (E) Restrictions on export of industrial raw materials reported by OECD as in place at the end of 2022[71] |
|---|---|---|---|---|
| ***REEs*** | *Very high (5.67)* | *Crucial for **permanent magnets** in wind turbines* | *REEs resulted in the "alerts' list" of the Railway industries surveyed so far (4% of companies said to be impacted by disruptions in its supply for power electronics and for on-board monitoring, maintenance, surveillance and information systems)* | - |
| **Magnesium** | High (3.91) | Magnesium-based materials are used for **hydrogen storage**. Magnesium alloys are used for **wind turbines** and **solar power systems** due to their corrosion resistance and lightweight properties | It didn't result in the "alerts' list" of the Railway industries surveyed so far | Brazil, Israel, Kazakhstan |
| **Niobium** | High (3.90) | *Wind Towers:* For **structural supports** to strengthen wind | It didn't result in the "alerts' list" of the Railway industries surveyed so far | - |

[70] Op. cit., JRC (2020a), p. 71.
[71] OECD (2022), *Methodological note to the Inventory of Export Restrictions on Industrial Raw Materials*.

| | | | | |
|---|---|---|---|---|
| | | tower components<br><br>Niobium-containing gear steels enhance the reliability and design life of turbine gearboxes, which represent about 25% of wind tower construction costs<br><br>Plays a role in **conversion components** like common mode chokes (CMCs), filters, transformers, and inverters<br><br>*PV Solar Panels:* Helps create reliable, ultra-compact **electromagnetic compatibility (EMC) components**, improving safety and grid stability, ensuring consistent clean electricity supply | | |
| **Cobalt** | Moderate (2.54) | Essential for **rechargeable batteries** for storing electricity generated by solar panels and wind turbines, enhancing grid stability and reliability. | It didn't result in the "alerts' list" of the Railway industries surveyed so far | China, Democratic Rep. of Congo, Indonesia, Madagascar, Philippines, Zambia, |

| | | | | |
|---|---|---|---|---|
| | | Plays a role in **hydrogen** production through **electrolysers** and **fuel cells** | | |
| ***Lithium*** | *Low (1.64)* | *Used in **energy storage** systems* | *It resulted in the "alerts' list" of the Railway industries surveyed so far (4% of companies said to be impacted by disruptions in its supply for power electronics and for on-board monitoring, maintenance, surveillance and information systems)* | *Argentina, Zimbabwe* |
| **Chromium** | Very low (0.86) | Chromium-based ferroalloys are especially important in wind turbines to enhance corrosion resistance<br><br>Chromium layers act as protective barriers, preventing corrosive materials from damaging underlying metals | It didn't result in the "alerts' list" of the Railway industries surveyed so far | China, India, South Africa, Zimbabwe |
| ***Nickel*** | *Very low (0.49)* | *Wind Turbines: in the construction of wind turbines to enhance their durability and resistance to corrosion, especially in offshore environments*<br><br>*Solar Panels:* | *Nickel resulted in the "alerts' list" of the Railway industries surveyed so far (4% of companies said to be impacted by disruptions in its supply, e.g. for braking systems, UPS-uninterruptable power supply, systems for stations)* | *Botswana, China, Colombia, Indonesia, Madagascar, Myanmar, Philippines, Russia* |

| | | | | |
|---|---|---|---|---|
| | | *in the production of certain types of solar panels, contributing to their efficiency and longevity*<br><br>*Hydrogen Production: used in electrolysers and fuel cells* | | |
| ***Copper*** | *Very low (0.32)* | *Copper is the cornerstone for all electricity-related technologies* | *Copper resulted in the "alerts' list" of the Railway industries surveyed so far as one of the most hit (19% of companies said to be impacted by disruptions in its supply for many applications for rolling stock, command control signalling, and infrastructures, with heavy impact on power electronics, electric traction, level crossings, communication, and much more)* | *Argentina, Chile, China, Rep. Dem. of Congo, Indonesia, Kazakhstan, Mexico, Mongolia, Russia, Zambia* |
| ***Graphite*** | *n.a.* | *Used in **lithium-ion batteries** and as a conductor in **fuel cells*** | *It resulted in the "alerts' list" of the Railway industries surveyed so far (it fell into "Other" materials, with 1% of companies saying to be impacted by disruptions in its supply for Railway Vehicles)* | *India, Zimbabwe* |

"The prospect of a rapid increase in demand for critical minerals – well above anything seen

previously in most cases – raises huge questions about the availability and reliability of supply. In the past, strains on the supply-demand balance for different minerals have prompted additional investment and measures to moderate or substitute demand. But these responses have come with time lags and have been accompanied by considerable price volatility. Similar episodes in the future could delay clean energy transitions and push up their cost"[72].

Under the point of view of disruption risks, in fact, for new clean technology supply chains, time is a critical factor. Project lead times are particularly long for enabling infrastructure for electricity, hydrogen, and CO2 management, as well as for mines. It is therefore essential to reduce permitting times and mobilise investment and financing for key supply chain elements, along with skills development in anticipation of future needs and faster innovation in early-stage technologies[73].

### 5.4.2. Measures used to mitigate risks

Crisis concerning the energy sectors addressed by the EU with own measures refer to enhancing energy security and reduce energy supply disruptions following the war in Ukraine and embargoes towards Russia, that was EU's main supplier. In such a context the following measures can be mentioned:

- **REPowerEU Plan**: the Plan, involving also emergency legislative measures, helped avoid energy supply disruptions, eased pressure on energy markets, and facilitated the structural reform of the energy system. The plan was executed through the European Green Deal legislation and increased deployment of renewable energy
- **Diversification of Energy supplies**: to reduce dependence on Russian fossil fuels, the EU phased out coal imports, significantly reduced oil imports, and decreased gas imports. Gas demand was also reduced by over 18% compared to the previous five years. Additionally, the EU diversified energy import routes and infrastructure
- **Energy Efficiency and Renewables**: The EU achieved record growth in solar photovoltaic (PV) capacity (+41 GW) and increased wind capacity. In 2022, 39% of electricity was generated from renewables, surpassing fossil fuels for the first time. Legislative targets were set for a minimum share of 42.5% renewable energy by 2030, with an ambition to reach 45%. Energy efficiency targets were also increased to reduce final energy consumption by 11.7% by 2030[74].

"Given the vulnerability of global supply chains, renewables developers may benefit from partnering with their suppliers to build additional manufacturing capacity. This could include the insourcing of critical components, the expansion of manufacturing facilities, or the creation of new facilities. In many countries, governments are eager to help in this effort and have created policies and incentives that seek to promote clean-energy manufacturing within their borders"[75].

[72] IEA (2021c), *The Role of Critical Minerals in Clean Energy Transitions*, p. 11.
[73] IEA (2023b), *Policy priorities to address supply chain risks – Energy Technology Perspectives 2023*.
[74] European Commission (2023c), *State of the Energy Union 2023: EU responds effectively to crisis, looks to the future and accelerates the green transition*, 24 October.
[75] McKinsey (2023), *Renewable-energy development: Disrupted supply chains*, 17 February.

## 5.5. Automotive

Automotive is a valuable example of **how an entire value and supply chain is being disrupted by technology change**. The shift to low-emission vehicles led by net-zero policies in Europe and worldwide has created a significant change in the market for auto components: demand for batteries and electric drives are growing, while conventional transmissions and engines will see a decline.

"In a net-zero scenario, first movers establishing the new supply chains and manufacturing capabilities would likely see increased competition, especially with batteries, as more players enter the market. Companies may find new opportunities across the value chain, including the creation and maintenance of the corresponding infrastructure"[76].

In fact, "an estimated 24 new battery gigafactories would be needed to meet the local demand for passenger EV batteries, and some 15,000 public chargers and semi-private chargers (those in multifamily homes) would need to be installed each week by 2030"[77].

### 5.5.1. Supply disruptions and dependencies

Three are the supply-led disruptions and dependencies in Automotive more meaningful for this research[78]:

- The disruptions in semiconductors in the years 2021/2022 – i.e. shortages in supply
- The disruptions led by the transition towards electric vehicles (EV) – i.e. change in the value chain
- The disruptions and dependencies in supplies needed for the EV market – i.e. shortages in supply.

*The disruptions in semiconductors in the years 2021/2022*

After recovery from demand drop caused by the COVID-19 lockdowns, concerns shifted to the supply side. Although vehicle orders surged to unexpected heights after 2020, a shortage of Automotive semiconductors forced OEMs to close production lines or remove some popular features, such as heated seats, from their offerings, because OEMs and Tier 1 suppliers could not procure sufficient quantities of chips and were forced to delay vehicle production.

Russia's invasion of Ukraine has introduced further uncertainties to both the semiconductor supply chain and automotive demand.

Moreover, many semiconductors are transported by air, but transport costs in those years significantly increased while available shipping volume dropped.

The result was that OEMs, as being unable to obtain critical vehicle components, reduced their production volumes in response, which added even more uncertainty by decreasing demand for

[76] McKinsey (2022), *The automotive sector's net-zero transition: Shifting to low-emission vehicles*, 1 August.

[77] Ibidem.

[78] The disruption led by COVID-19 is instead not considered because demand-driven (lockdowns truncated the consumer demand at global level, therefore supplies were slowed-down 'only' because manufacturing plants temporarily closed).

some semiconductor-based components[79].
"While manufacturers of laptops, white goods, and other devices have also cut production because of semiconductor shortages, the repercussions in the automotive industry have been more severe. Some premium OEMs were able to safeguard profits with selective manufacturing and sales strategies designed to optimize margins. This strategy, however, may result in a shortage of lower-margin vehicles and could cause extreme fluctuations in demand for automotive chips"[80].
In fact, this is what happened. The next paragraph will discuss this and the consequences.

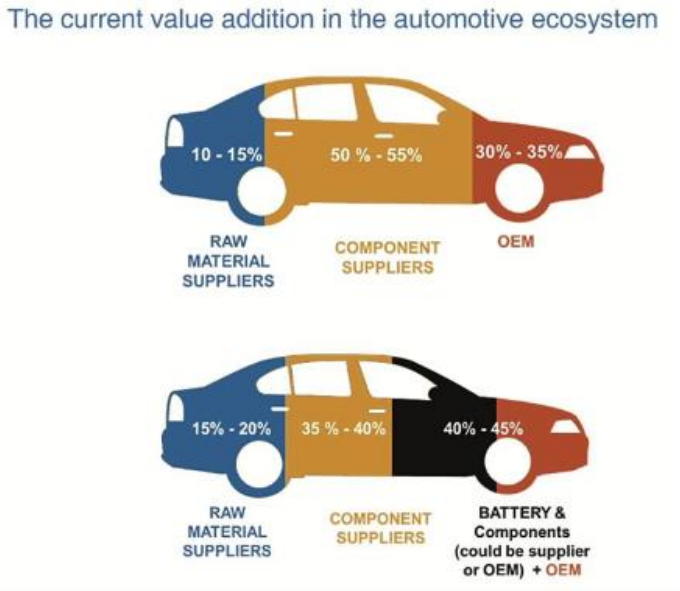
*The disruptions led by the transition towards electric vehicles (EV)*
"Firstly, as we move to EV, there will be a witnessed **change in the Bill of Materials (BOM)** because of the moving parts that conventional vehicles use"[81].
As well known, the traditional vehicle powertrain consisting of engine, transmission, and drivetrain are being replaced by batteries, motors, and other electronic components such as the control unit, battery management system, and thermal management system. But as there is no 'big bang', the value chain needs to remain productive for both types of vehicles, which boosts the challenge also in terms of financial investments.

This different demand in supply influences how the value chain looks like, with:

- an increasing role of raw materials suppliers (the Figure 11 | Minerals used in conventional vs electric cars per kg/vehicle (source: IEA) explains why)
- a decreasing role of standard component suppliers
- a large, brand-new role of suppliers of batteries and relevant EV components. On this new group, a study finds that they "have entirely different expectations around trust and its components: realistic expectations, accountability, and information transparency. Purchasing organizations need to develop and improve the capabilities and capacities to work with this new supply base"[82]
- the role of OEMs either decreased *if* the previous category is represented by suppliers, or increased *if* OEMs invest in self-manufacturing the needed batteries and components.

[79] McKinsey (2022), *Semiconductor shortage: How the automotive industry can succeed*, 10 June.
[80] Ibidem.
[81] FinShiksha (2022), *Electric Vehicles vs Conventional Vehicles: Is it cannibalization or new opportunity?*, 30 March.
[82] Plante Moran (2022), *Auto supplier and OEM relationships: Insights from the 2022 WRI® Study*, 3 June.

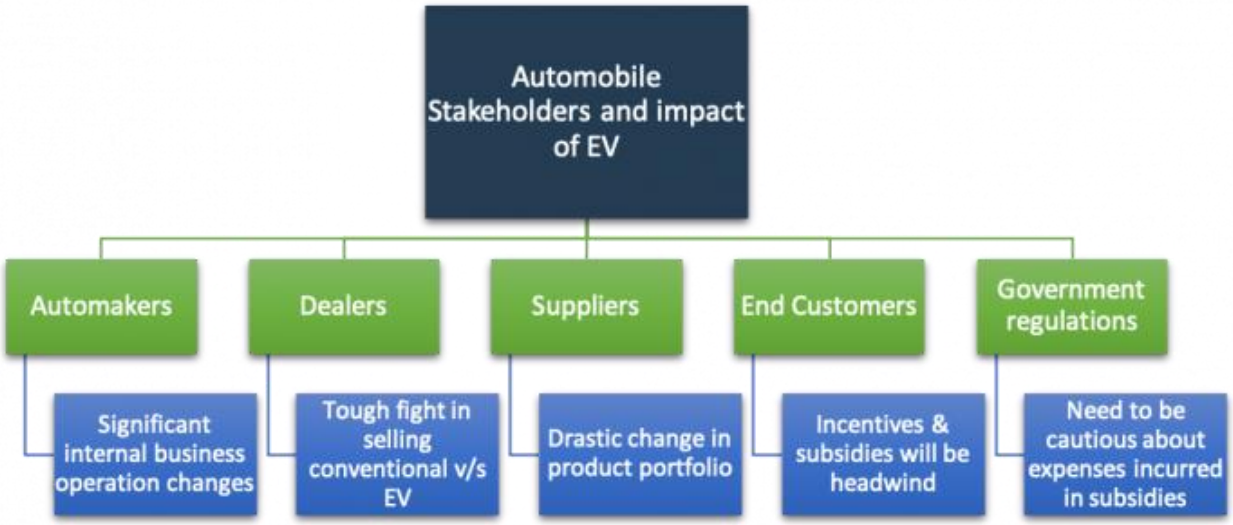
**Figure 9 | The Automotive Value Chain composition in the conventional cars case (above) vs electric vehicles case (below) (source: FinShiksha[83])**




Such a transformation represents one of the elements where the Railway sector can learn most from the Automotive experience, and this in fact represents one of the goals the LEADER 2030 project has: to inform the European SMEs of the Rail Supply Industry that there will be a change in the future Bills of Materials due to the innovations under development by the EU-RAIL programme; to inform them how the BOMs will differ from the current ones; to help shape the new needed value chain for the most disruptive innovations such as Hyperloop or Maglev.

[83] Ibidem.

**Figure 10 | The impact of the transition towards EV on the Automotive Value Chain: Suppliers are experiencing a drastic change in their product portfolio (source: FinShiksha[84])**

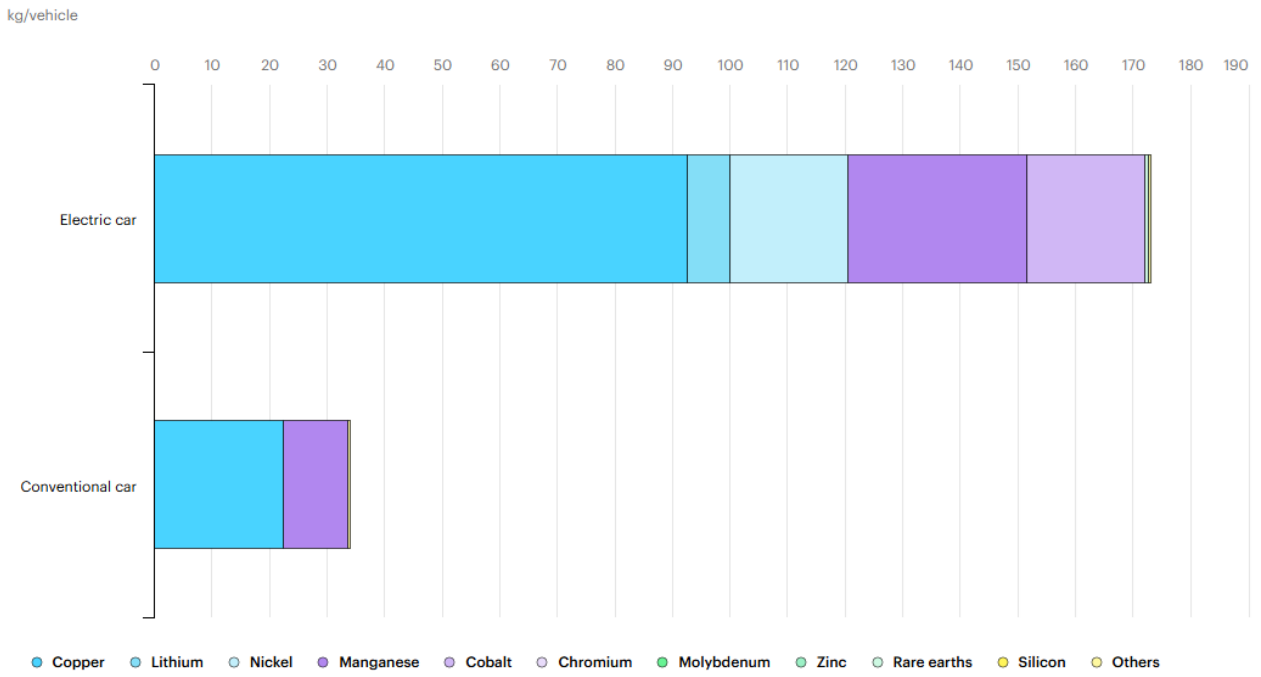



*The disruptions and dependencies in supplies needed for the EV market*

The complexity of cars evolution towards e-Mobility is represented in the following Figure. EU and global policies for road transport decarbonisation are leveraging the demand for electric vehicles, that will **heavily increase the demand for a wide series of Critical Raw Materials**, boosting dependencies. "In the new EV equilibrium, raw materials are estimated to contribute 15-20% of the vehicle's value compared to 10-15%"[85].

[84] Ibidem.
[85] Ibidem.

**Figure 11 | Minerals used in conventional vs electric cars per kg/vehicle (source: IEA[86])**




### 5.5.1.1. Focus on Semiconductors in Automotive

As shown in the following Figure, nodes greater than 90 nanometres (nm) are in high demand in the automotive industry. This kind of nodes are a **mature type**; therefore, they have low profit margins, which explains why the semiconductor industry is unlikely to address the structural reasons for their shortages. On the other side, Automotive OEMs appreciate the attractive price point of mature nodes and have a limited incentive to migrate to lower node sizes, because of the additional development and qualification costs, as well as the limited availability of R&D staff.

Why are nodes characteristics so important?
A node "refers to a specific semiconductor manufacturing process and its design rules. (…) Different nodes often imply different circuit generations and architectures. Generally, the smaller the technology node means the smaller the feature size, producing smaller transistors which are both faster and more power-efficient"[87].

The demand for most advanced chips with smaller node sizes is soaring, in search for the right mix of priority performances. E.g., "the smallest structures in chips, which are 5 nm and 3 nm in size, confer important benefits within select market segments and application areas, including data centers, 5G smartphones, edge computing, and machine learning. Semiconductor customers in

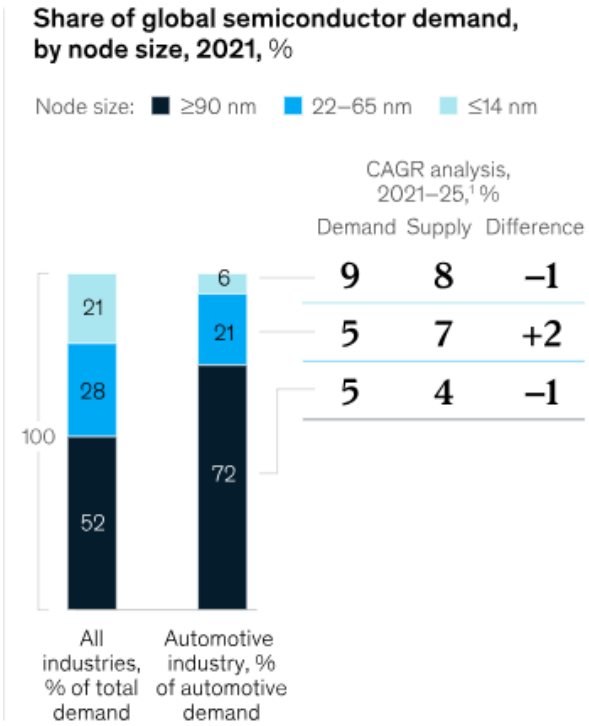
[86] IEA (2020), *Minerals used in selected transport technologies*, 6 May.
[87] Technology Node - WikiChip.

these segments will pay a premium for leading-edge chips, since they need a combination of strong performance *and* low power requirements to win their markets. The resulting sales boost will more than compensate for higher chip costs"[88]. In fact, according to McKinsey, the cost from validation to IP qualification of:

- designing a 5 nm chip is approximately 540 million USD
- designing a 7 nm chip is about 300 million USD
- designing a 10 nm chip is around 175 million USD.

Therefore, companies not searching for the highest computational capabilities or low power requirements have little incentive to move to smaller chips due to their much higher cost.

**Figure 12 | Share of global semiconductor demand by node size, and the Automotive demand (source: McKinsey[89])**




The above Figure shows the state-of-the-art with the semiconductor demand in the Automotive sector, mostly represented by larger nodes chips. However, the Automotive industry's demand is shifting significantly towards smaller nodes due to the rise of advanced driver-assistance systems (ADAS) and autonomous vehicles (AVs), which require **more advanced chips**:

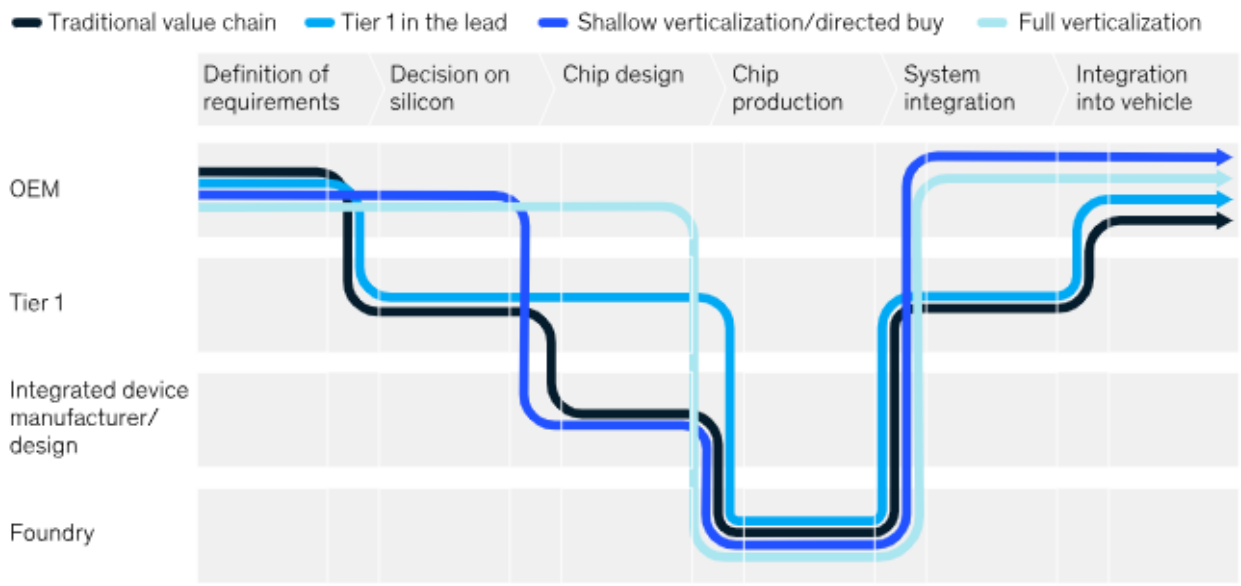
- ADAS systems, which handle critical functions like braking and object detection, require high-performance chips. These systems rely on specialty silicon—customized chips tailored to specific

[88] McKinsey (2020), *Semiconductor design and manufacturing. Achieving leading-edge capabilities*, p. 3.
[89] Ibidem.

applications. OEMs are increasingly designing these chips in-house to gain more control and reduce development timelines

- Centralized E/E Architecture: ADAS-equipped vehicles have a more centralized electrical and electronic (E/E) architecture compared to traditional vehicles. They incorporate more sensors and compute-electronics content, necessitating multiple interconnections within the vehicle
- Levels of Automation: The type and number of semiconductors required depend on the AV's level of automation. The Society of Automotive Engineers (SAE) classifies AVs into six levels, from 0 (no automation) to 5 (full automation). Each level has specific requirements for sensor fusion, processing power, and connectivity
- Revenue Potential: Autonomous chips (used for AV functions) are expected to generate $29 billion in revenue by 2030. As AV technologies evolve, semiconductor companies must stay ahead to remain competitive[90].

**Figure 13 | According to McKinsey, Automotive OEMs will likely follow one of four models/paths to acquire or produce semiconductors (source: McKinsey[91])**




A McKinsey survey of more than 100 leading automotive and semiconductor specialists showed that 68% of respondents believed that OEMs would favour the above *shallow-verticalization/directed buy* approach to navigating the value chain. This path makes sense for many companies, since use case requirements are similar across OEMs and chip-development costs are higher when smaller volumes are produced.

The *Full verticalization* approach is instead just emerging: this model gives OEMs the most

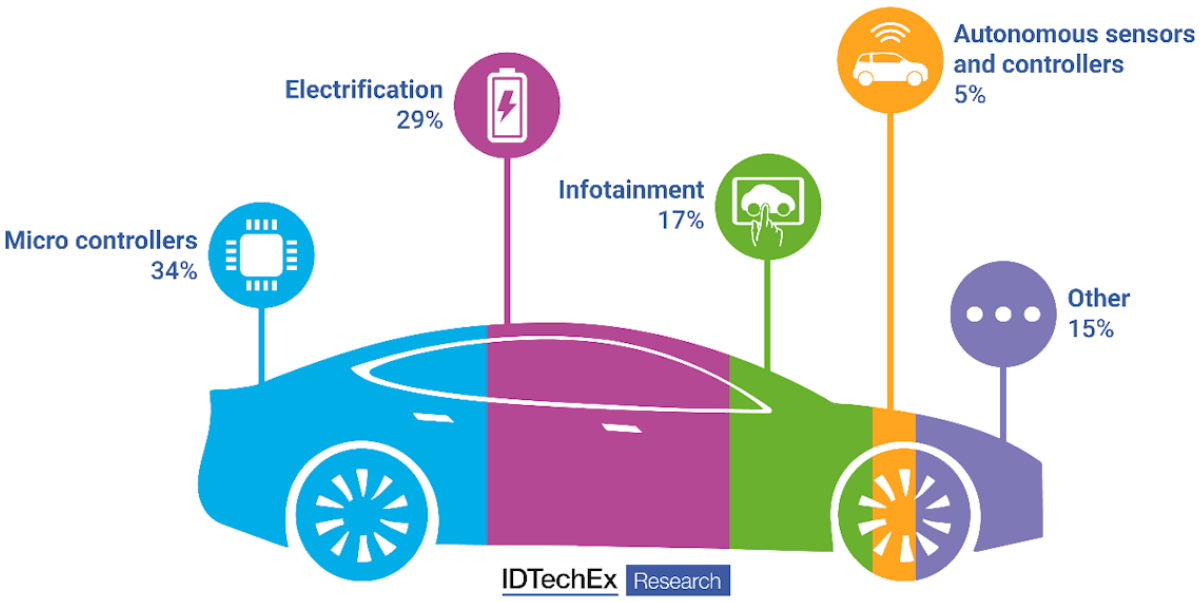
[90] McKinsey (2021), *Automotive semiconductors for the autonomous age*, 3 August.
[91] Ibidem.

independence, since they define requirements and oversee chip design before commissioning production at a foundry. There are two potential strategies for full verticalization:

- The formation of a **cross-OEM consortium**, in which multiple companies collaborate on chip design and architecture. *Pros*: OEMs share both development costs and risks, reducing the burden on individual companies. Consortium members can also pool their staff, which may reduce the competition for top talent. *Cons*: While individual companies might be able to incorporate some of their own specifications into the chips, compromises are inevitable and there are limited opportunities for differentiation. In some cases, it may be difficult to reach an agreement about joint requirements and priorities or to align on processes.
- The **independent route**, in which OEMs develop their own silicon, architecture, and chip design—all while keeping material costs relatively low. *Pros*: By working independently, OEMs can create specialized chips that differentiate their products from competitors. *Cons*: Independence comes with greater risks, since a single OEM bears all costs and has complete responsibility for meeting timelines and ensuring quality. OEMs may also encounter some delays, at least initially, since many lack employees with strong expertise in chip design and architecture.

  The most famous case of OEM following the independent route is Tesla, whose move on semiconductors is changing the paradigm in the sector. Tesla started designing controllers as far back as the Model S (year 2012; 20% of controllers designed in-house), and has risen through the years, with the Model Y (year 2019; 61% internally designed controllers) and the Cybertruck (year 2021/23; internally design controllers going up to 85%); at the Tesla's 2023 Investor Day, the company stated that the next-gen vehicle will have 100% internally designed controllers.[92]

**Figure 14 | Semiconductor distribution in a Tesla like vehicle (source: IDTechEx[93])**




[92] IDTechEx (2023), *Tesla's Trendsetting Semiconductor Move and Why You Should Care*, 11 May.
[93] Ibidem.

The suitability of similar approaches should be assessed also within the European Rail Supply Industry at least for the most advanced applications, and not only at OEM level. As dependency risks are expected to grow, "to remain strong, tier-one suppliers could benefit from a clear semiconductor strategy, especially in the R&D-intensive areas" – suggests McKinsey[94].

### 5.5.2. Measures to mitigate risks

At policy level, the transition towards EV of the European Automotive industry has been supported by the European Commission with several initiatives. Under the point of view of ensuring supplies for such transition, it can be mentioned:

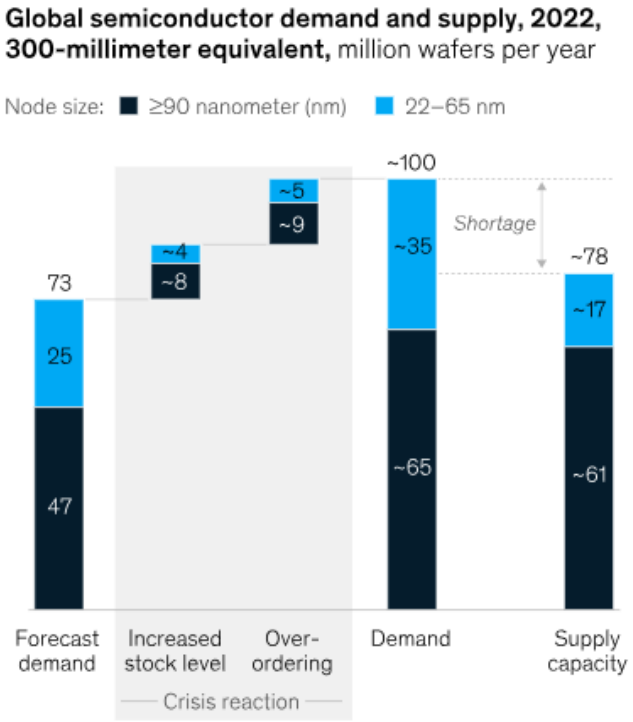
- **EU Battery Alliance (EBA)[95]**: launched in 2017 to specifically support both the EU Twin Transition and the competitiveness of the Automotive sector. According to the EU Court of Auditors, thanks to this: "production capacity of lithium-ion battery cells is developing rapidly within the EU-27 and could rise from 44 gigawatt hours in 2020 to approximately 1.200 by 2030. However, the actual deployment of such capacity is not ensured and may be put at risk by geopolitical and economic factors"[96] – the last comment confirms the fears at the basis of the LEADER 2030 project and the need to consider all elements.

Apart from this, no other specific initiatives have been adopted with the specific goal to reduce the sectoral disruptions.

At industry level, different behaviours were identified following the different sources of disruption. During the semiconductor shortages, the Automotive sector opted for **over-ordering and stockpiling**. Given the global dimension of the Automotive industry, such a decision provoked a major turbulence in the semiconductor industry.

[94] Op. cit., McKinsey (2021).
[95] European Battery Alliance - European Commission (europa.eu).
[96] European Court of Auditors (2023), *Special report 15/2023: The EU's industrial policy on batteries: New strategic impetus needed*, 19 June.

**Figure 15 | Global semiconductor demand and supply per specific types of chips, and the impact of the crisis reaction boosted by the Automotive industry (source: McKinsey[97])**




Such behaviour is 'stigmatised' in a BCG survey, where automotive companies were reported prioritizing near-term crisis response over longer-term resilience, while they should gear up for future crises through roadmaps for resilience and rewiring their organizations for risk management[98].

Similarly, McKinsey suggests that "companies can start by focusing on the implications of three critical activities that form the foundation for strategic shortage management: the **creation of strong technology maps**, **reliable short-term demand planning**, and **guidance for long-term demand planning**"[99]. Several factors may complicate the creation of such technology mapping and planning, but solutions exist, and are proposed here below:

[97] Ibidem.
[98] Boston Consulting Group (2023), *How Auto OEMs Can Build A Resilient Supply Chain*, 27 June.
[99] Op. cit., McKinsey (2022).

**Figure 16 | Suggestions to strategic shortage management (source: McKinsey[100])**

| | Technology road map | Short-term demand planning | Long-term demand planning |
|---|---|---|---|
| **Typical challenges** | Unclear technology road maps, making it difficult to predict development of **semiconductor content for next-generation products** | OEMs frequently making changes that affect semiconductor demand, **even after production has begun** for their order<br>Semiconductor suppliers **requiring commitment** on product mix and allowing little flexibility | Limited ability of OEMs to determine their **custom orders** that largely affect demand for specific semiconductors<br>Semiconductor suppliers requiring guidance to decide on **long-term capacity investments** |
| **Best-practice solution** | Tier 1 suppliers—and in certain circumstances, OEMs—**develop strong technology road maps** | **Share information on demand and supply** through the full value chain based on:<br>• Commonly agreed-upon nomenclature<br>• Increased accuracy through data-driven forecast algorithms | **Extend demand planning** to 3–5 years |
| **Strategic management levers** | **Strategic product development:**<br>• Identification of re-engineering needs for chips<br>• Identification of potential for drop-in components<br>• Reduction of semiconductor variance across products to reduce the fluctuations in demand resulting from custom-vehicle orders | **Trusted partnerships:** Resulting from increased transparency<br>**Binding orders:** Potential commitment to the integrated device manufacturer (and even the foundry) by the Tier 1 supplier, and to the Tier 1 supplier by the OEM, on volumes<br>**Improved inventory management:** Midterm inventory strategy based on demand–supply matching | **Strategic investments:**<br>• Assessment of co-development opportunities<br>• Strategic coinvestment in nodes in short supply |

All of these arguments are in the focus of the LEADER 2030 project.

[100] Ibidem.

# 6. Lessons for the Railway sector

## 6.1. Defence vs Railway sector

The European Defence sector's growing dependence from external supplies looks very similar to what the European Railway sector is experiencing. However, the former's dependence on one single country – i.e. the USA – represents, in theory, a higher risk, only mitigated by the fact that USA is a like-minded country. The evolution of Presidential administrations, however, may decrease or increase such theorical risk. In fact, as SIPRI emphasises, "many factors shape European NATO states' decisions to import from the USA, including the goal of maintaining trans-Atlantic relations alongside the more technical, military and cost-related issues. If trans-Atlantic relations change in the coming years, European states' arms procurement policies may also be modified"[101].

The European Railway sector, instead, imports from many countries, even though for specific raw and processed materials and electronic components quasi-monopolistic dependencies exist. Also, another difference seems to be that decisions about sourcing are taken at industry level, and 'only' answer the specific industry's policies (e.g. multinationals can source either in relation to headquarters policies, or in response to rules set out in contracts won e.g. Build America, Buy America Act, Local content requirements, etc., or on the basis of the search for the lowest price, etc.).
As a result, some measures defined for the Defence sector *might* not be applicable to the Railway sector.
In this respect, it is interesting to take note of some of the premises underlying the above-mentioned European Commission Joint Communication on "Defence Investment Gaps Analysis and Way Forward". With due differences, some of them could be kept in mind for possible measures to be thought of to support the resilience of the supplies for the Railway sector.

> *Based on the historical record, there is nonetheless a* ***risk that Member States opt for national solutions, because of industrial and security of supply considerations****, or,* ***when not available privilege "off-the-shelf" non-EU solutions given the sense of urgency****, at the expense of possible EU solutions that may have equivalent lead times. Defence industries may be inclined to* ***serve as a matter of priority their national government as opposed to a more European-wide client-base****.* ***Without coordination and cooperation, the increased investments would deepen the fragmentation of the European defence sector, limit the potential for cooperation throughout the life cycle of the equipment****,* ***intensify external dependencies*** *and* ***likely hamper interoperability****.* ***Short term acquisitions will have a longer-term impact in this regard, resulting into a reduction of market strength and foregone opportunities for***

[101] Op. cit., SIPRI (2024).

***the next decades***[102].

## 6.2. Aerospace vs Railway sector

Both sectors share the challenge to reduce the weight of their vehicles, and the research and application of advanced materials to substitute more traditional metals/materials is a common trend. Such a trend, however, has to take into account differences in the costs the two sectors can afford to manufacture their vehicles, i.e. what the Aerospace can afford, Railways cannot.
Apart from the hoped-for trends of cost reductions in production inputs once they are mature - which can soon or later also happen to advanced materials used in Aerospace -, cost reduction in *sourcing* such materials – if not in manufacturing – could be achieved with cross-sectoral joint purchases thanks to a higher contractual power.
Both sectors are also highly regulated in terms of materials use, which lead to very low flexibility both for materials substitution and for suppliers' substitution. For such a reason, one field of action should concern standardisation aspects.

Concerning UAVs, any advancement planned by the EU to strengthen the European industry, above all under the regulatory point of view, certainly will also benefit the Railway sector, which is planning – also through the EU-RAIL programme – their use to increase automated inspection with no or minimal service disruptions, being non-invasive tools capable of self-diagnostics.

## 6.3. Clean energy infrastructures vs Railway sector

The further greening of the Railway sector is demanding an increasing utilisation of renewable energy for railway infrastructures and stations, of green traction power for trains (batteries, hydrogen, etc.), etc.. For such a reason the challenges affecting the Clean Energy infrastructures sector are common to a part of the Rail Value Chain, and this goes beyond the different types of disruptions typical of the Energy sector.

Beyond the supply risks all the sectors surveyed experience, the main risk threatening the Clean Energy sector – and therefore also Clean Energy utilisation in the Railway sector - is uncertainty about actual Governments' climate ambitions. Given the huge investments required by the sector, and the long lead-time from initial investment to operations, this fact represents a major limitation to the development of the relevant supply chain.

## 6.4. Automotive vs Railway sector

Both sectors are living an unprecedented transformation, but not comparable for the impact on

[102] Op. cit., European Commission (2022a), point 1.

their value chains. While the revolution in the Automotive sector is driven by the CO2 reduction needs, followed by automation, the Railway sector is working to deliver a more holistic transformation that will re-shape the European Railway system in 2030 under several points of view.

Joint challenges include:

- the introduction of batteries in their vehicles
- the shift towards more advanced semiconductors to support higher performances towards the introduction of ADAS and autonomous driving.

In both these segments disruptions have already taken place, and all analysis agree that more will come given the high dependence of Europe for the needed critical raw materials and also – for the semiconductors part – for the manufacturing process, given the limited and heavily concentrated number of chip foundries at global level.

Differences in how the two sectors will actually approach such transformations and supply risks lie in their different magnitudes both as value chain and as market size.

## 6.5. Ideas transfer to the Railway sector?

'Suggestions' and alerts from stakeholders of the sectors analysed were gathered along the desk research; they are summarised below as bases for further considerations when the project LEADER 2030 will have to draft policy and industrial recommendations for the Railway sector:

| Area | Possible inputs | Project Comment |
|---|---|---|
| **Policy** | (source: Politico/SAAB) *Cut environmental rules to make it easier for companies to diversify their supply chains for critical military components.* | While it is impossible, for a EU deeply committed to become the greenest continent in the world to accept a similar step back, **simplification** of rules and/or the creation of an **international level playing-field** could be pursued. |
| **Policy** | (source: AIA) *Defence applications typically require high-purity, grade materials that rely on qualified 2 processing and smelting operations. Due to the risk and complexity of these applications, it can take up to ten years to transition and certify new suppliers.* | Standardisation of materials and qualification/certification of suppliers pose strict rules. Effort towards **simplifications** should always be sought at the relevant level to reduce duration and impact of this type of supply bottlenecks. |

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| **Policy** | (source: IndustriALL/Syndex) *Duplication in development and production of weapon systems still remains a problem, however. Compared to the US, significantly more types of weapons are deployed in the EU armed forces for the land, air and sea sectors. The fragmentation this creates is visible in Europe's weapon systems, where several variants are typically in use at any one time - in fact, six times as many as in the US.* | With due differences, this statement is somewhat reminiscent of the subject of **Modularisation** in the railway sector, the application of which, starting with signalling systems and extended to other areas, would bring benefits in terms of less fragmentation and more elasticity of supplies. |
| **Policy** | (source: IndustriALL/Syndex) *Military exports have a significant share in the total turnover and are important for the industry because the home markets are too small to reach the production volumes necessary for efficient production.* | While the development of the SERA-Single European Railway Area and the transformations undergoing in the railway sector in Europe are providing enough home market to European industries, still export is key for their competitiveness. The EU is still the main world exporter of railway solutions, but ad hoc measures could be adopted to support such **export**, similarly to what other extra-EU countries do. |
| **Policy** | (source: Modern Diplomacy) *While having resources and mines is essential, it is not enough to control the entire value chain for critical minerals. Mastery of the various mineral processing technologies is also essential. This is an area where Europe and the United States are lagging far behind, making them highly dependent on China.* | Clearly identify **industrial, technological and skills gaps** within key relevant value chains should be the first, essential step of a holistic strategy to be developed jointly by the EU Institutions together with the national and regional ones to build long-term resilience. |
| **Industry + Policy** | (source: McKinsey) ***The lead times for chip manufacture*** *average a minimum of four months if capacity is available and no expansion is required; otherwise, it will likely take a minimum of 18* | Given, on the one side, the overall increasing global demand for semiconductors, and on the other side EU effort towards "made in Europe" semiconductors manufacturing, |

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| | *months. Increasing production might seem like the obvious answer, but it takes more than three years to build a new fab and ramp up wafer production.* | this information should be taken into consideration for any **strategic decision** both at company and at value chain level. |
| **Industry + Policy** | (source: SEMI[103]) *The SEMI Smart Mobility initiative brings together community stakeholders in the microelectronics and mobility ecosystems to identify and address technical issues and supply chain dynamics that are best addressed collectively.* | As semiconductors are critical also for the transformation of the Railway sector, a **similar initiative** could be fostered along with the EU-RAIL projects implementation, as it is crucial to do innovation having in mind the supply chains constraints. |
| **Industry** | (source: Roland Berger[104]) *Aerospace supply chains have reached their limits – a new supply chain setup with increased collaboration and new ways of working across all tier levels is needed* | Despite the sector-specific reasons bringing the source to suggest this, certainly new ways of more collaborative working should also be pursued in the Railway sector, as multiplier of transparency, efficiency, and ultimately of innovation. |
| **Industry** | (source: Withum[105]) *Deepening existing relationships includes sharing more detailed forecasts and committing to higher levels of inventory than previously to ensure delivery metrics are met. Further, OEMs are developing more strategic relationships with tier two and three suppliers that previously have not been a priority to avoid unexpected disruptions and limit exposure as much as possible. They will need to ensure the products they manufacture are reliable, safe and cost-effective.*<br><br>(source: Plante Moran) *Improving OEM-supplier working relationships will be critical as the* | This is a key action recommended to the Automotive sector given its transformation towards new EV value chain.<br>The Railway sector is living an important transformation, too. The LEADER 2030 project is right here for assessing beforehand how the value chain will be transformed, knowing that it will surely be, and what the smaller suppliers should do to not being hit by such transformation. For such a reason, the Railway sector should **adopt this recommended action**, now more than ever before. |

[103] SEMI, Connecting Mobility and Microelectronics.
[104] Roland Berger (2023), *Resilience in aerospace supply chains: Why transparency is the key*.
[105] Withum (2023), *How Supply Chains Are Changing the Automotive Industry*, 5 November.

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| | *industry shifts from internal combustion engine (ICE) vehicles to battery-electric vehicles (BEV). First, strong supplier relationships can minimize costs as OEMs end their ICE programs. Clearly communicating technology roadmaps with suppliers will help them navigate an orderly transition to other products, industries, or even ultimately exit operations.* | |
| **Industry** | (source: McKinsey) *The ongoing **[semiconductors]** shortage is partly a result of long-standing structural factors, such as insufficient capacity, but the recent behavior of automotive companies—overordering and increasing stock levels— **is also contributing to the problem.*** | Overordering and stockpiling is – as seen the Deliverable 1.1 – one of the main solutions adopted by the Rail Value Chain. Its smaller dimension however has not the 'power to impact' the overall market, while this is the case for Automotive. This *could* mean that overordering and stockpiling in the Railway sector *could* be a practice to be considered for the long-term. However, as already concluded in the Deliverable 1.1, stockpiling increases company costs, and AI can help optimise the balance. |

# 7. Conclusions

The analysis showed that:

- Both the Defence and Aerospace sectors experienced in the most recent years **levels of supply disruptions like other industrial ecosystems**. Similarly, they are affected by **dependencies on many production inputs**. The expectation of finding 'special' resilience patterns in these 'special' sectors to learn from was therefore unmet.
- Their high investments in R&D have not shielded them 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.
- Russia's aggression against Ukraine has made it a **matter of utmost urgency** to address - from the beginning of 2022 - the problem of supply disruptions and dependencies in these sectors, in particular in the Defence sector, leading the EU to adopt new measures, including forms of monitoring bottlenecks in supply chains, increasing production capacity, creating new domestic value chains, as well as orchestrating joint purchases – in the case of Defence – to increase EU's negotiation capacity on materials' and components' markets. The recipe of EU joint purchases proved, so far, to work effectively for medical reasons during the COVID-19 pandemic and is now also promoted by the new Critical Raw Materials Act for such materials[106]. This last step will certainly help all industrial sectors in Europe.
- **Common disruption patterns** could be found between the Defence/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. This is also proved by the funding by Horizon Europe programme of the CSA project "IDEALIST"[107], aimed at tackling supply chains disruptions and boosting advanced technologies uptake in the EU Aerospace & Defence industrial ecosystem, the Mobility-Transport-Automotive ecosystem, and the Energy-Intensive Industries ecosystem. Two LEADER 2030 partners participate in such project, therefore mutual spillovers will take place between the two initiatives.
- The **Clean Energy infrastructures** sector didn't provide resilience patterns either. Many dependencies are common to the Railway sector, given the utilisation of energy infrastructures and clean technologies by the Railway sector. Special disruption patterns were instead identified, mostly related to price volatility, that in the most recent years has hit extremely high levels.
- 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 is called by several consultancies to increase the sector resilience and delivery capacity, this should also be followed by the Railway sector in its transformation towards 2030.

[106] Q&A: European Critical Raw Materials Act (europa.eu).

[107] 3 InDustrial Ecosystems tAckLing supply chains dISrupTions and boosting advanced technologies uptake | IDEALIST | Project (europa.eu).

- The **lessons/take-aways/suggestions** gathered may offer ideas, in the following project analysis and for the final project recommendations, to increase the future availability of supplies and the autonomy of Railway industries; their actual technical/political feasibility will have to be duly assessed during the remaining course of the project.

Ultimately, the analysis was meant to gather from highly advanced sectors valuable information on most advanced materials and components as the focus of the LEADER 2030 project is to identify disruption/dependency patterns in production inputs for the new railway innovations. The findings show instead the **importance of also 'more ordinary' production inputs**. This matches with the results emerged from the LEADER 2030 Survey to the Railway industries (see specifically the D1.3), which showed that **even *small components* can become critical** *if* their supply is delayed or scarce/insufficient.
This in turn corresponds with the 'alert' raised in 2022 by the European Commission Expert Group "Industrial Forum"[108]: in its "Strategic Dependencies Interim Paper", in fact, it specifically mentions the **"relevance of small components"**, reporting that:

> "some stakeholders (…) underlined 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 (for instance according to the Cycling Industry Association, due to component supply disruptions, over 1 million bikes could not be produced/assembled in the EU in 2020)"[109].

The following project analysis will therefore continue to keep also this take-away in mind, to avoid any possible 'derubrication' by importance of even the smallest components or 'non-critical/strategic' materials, according to the mainstream classifications.

This analysis (D1.2) will be used to complement the list of alerts (D1.1, D1.3) affecting production inputs for the target EU-RAIL innovations. Therefore, the next project output "Map of Rail industry needs in 2030" (D2.1) –which consists in the mapping of all materials and components necessary to produce the innovations where EU-RAIL and the European Rail industries are investing, and in mapping materials and components no more necessary because of the turnover the innovations will generate– will include the indication of all these already-known alerts.

The presentation of highlights from the D2.1 will take place during a conference at the world railway fair "InnoTrans 2024" (Berlin, 24-27 September 2024).

[108] Register of Commission expert groups and other similar entities – Industrial Forum.
[109] European Commission Expert Group "Industrial Forum" (2022), *Strategic Dependencies Interim Report*, p. 4.

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