European Military Independence - Material Dependencies and Supply Chain Resilience in EU Military Technology Development

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"Working and conceptual papers" are analytical reviews of existing resources, including academic literature, think tank analyses, and inputs from formal institutions such as the World Bank, European Commission, and OECD. They are not intended to present original research but rather to build a background for developing research concepts used in data-driven analytics. Originally intended as internal working material, these papers are published when they are deemed to be of broader public interest. This paper is part of a series of "conceptual papers" produced as part of a project supported by the International Visegrad Fund and Konrad Adenauer Stiftung in Prague.

Executive Summary

This chapter dives into the European Union's recent expression of the will to become militarily independent from other major powers. With geopolitical tensions on the rise after Russia invaded Ukraine in 2022, the EU has gotten a taste of modern warfare with a major military power and its requirements. Its ammunition reserves have barely been able to keep up with the intensity of the ongoing combat. While being the biggest monetary supplier to Ukraine, the US is still the biggest supplier of military equipment. Ammunition and conventional weaponry aside, the contemporary military industry is marked by technologies whose production requires more complex materials and processes, which could be a decisive factor in a country's or bloc's military power. The chapter is an overview of the most important modern military technologies and their material requirements. Since the European Union is highly dependent on other countries for rare materials at essentially all stages of the supply chain, this poses a massive challenge to the goal of European independence and security.

With this analysis, I am attempting to identify the technologies expected to be most crucial to the current and future military industry. This includes know-how and software developments related to AI, the operation of chemical lasers, and production methods for metamaterials, as well as tangible technologies like advanced materials, propulsion systems, 3D printing, and robotics and their material requirements. Most importantly, I am identifying the raw materials most at risk for the EU. The EU depends on the materials or goods of many different countries. For example, a key component of most modern military equipment are semiconductors, for which the EU is highly dependent on East Asian countries, such as China, Japan, South Korea, and Taiwan. In fact, China, a geopolitical opponent of the EU, dominates the processing of most critical raw materials. On the other hand, partners of the EU, such as the USA, present less of a problem due to their friendly relations but are still a massive obstacle to European military independence. On the lower end of the supply chain, most of these critical raw materials originate from Africa - practically inaccessible to the EU directly if there is a higher bidder (such as China).

Most of the imported military equipment by the European Union comes from the United States, being the biggest arms dealer in the world. The policy of independence, even from allies, has been controversial. The level of independence the EU is striving for is certainly not in the interest of the US, as it has an interest in making an impact in Europe politically. It also doesn't want to lose such an important economic partner. Lower trade relations between Europe and the USA could have significant geopolitical implications.

In terms of raw materials, certain CRMs are essential to the modern military industry, such as germanium, magnesium, neodymium, yttrium, and graphite, to name a few. The supply of these materials poses a large supply chain risk for the EU, being dependent on China for most of them. Without alternatives, the European Union cannot hope to become militarily independent. If it did so at the cost of some modern technologies, it would lag significantly behind other major world powers, the biggest concern being Russia.

Additionally, the joint defense procurement of EU member states remains an issue to be tackled. While defense collaboration within the EU has grown significantly since the start of the century, the system is still quite decentralized. Countries still wish to keep their autonomy and protect their manufacturers. Thus, joint defense collaboration and procurement are still inefficient in the EU. In the paper, I point out the mechanisms currently in place and their development, as well as recommendations for a smoother collaboration between member states (and what drives it).

Introduction

According to the Vice President of the EU Commission Margrethe Vestager, for 16 months since the start of the Russia-Ukraine war 'member states spent more than €100 billion on defence acquisitions. Almost 80% of that was spent outside of the European Union and the U.S. alone accounted for more than 60% of this spending. This is no longer sustainable'. In fact, according to data from the State Department the US has by far the biggest share of arms deliveries in the world, around 80% (Figure 1).

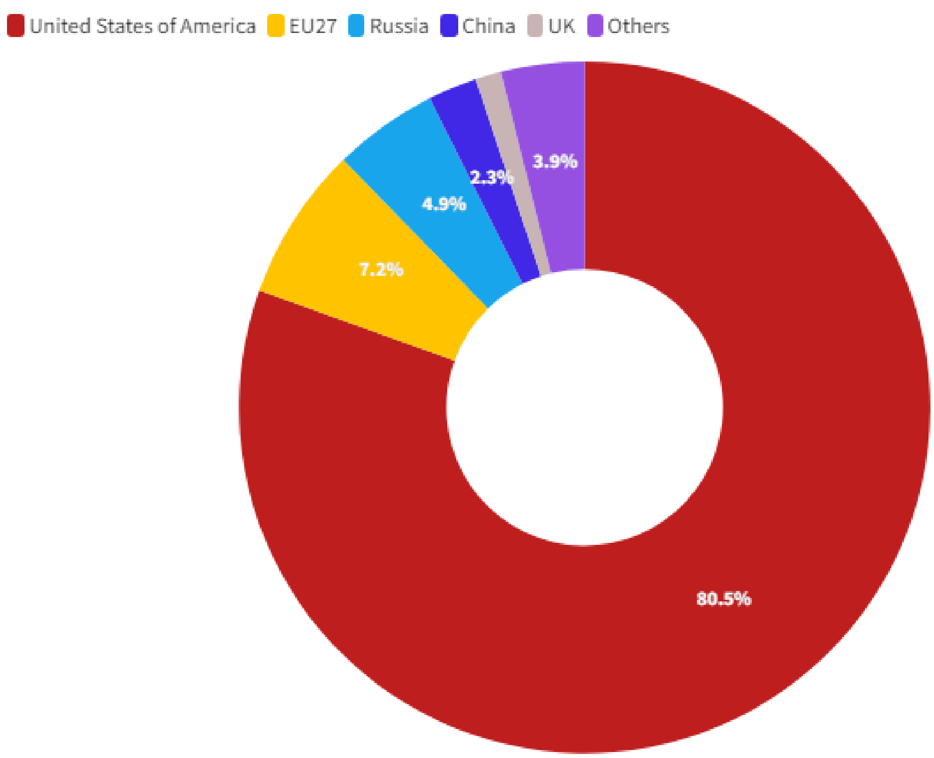


Figure 1 - Share of arms (value) transfer deliveries by supplier (2019)

A sense of political estrangement from Washington is highlighted by the necessity for some degree of strategic independence from the EU's top NATO ally. This has been furthered by former President Donald Trump's success in the US presidential campaign and his scathing remarks about the amount of money spent on European defense. Through the NATO alliance, the EU's member states have been sleeping beneath the US nuclear umbrella for decades, while their defense budgets and crisis management capabilities have stagnated. The main proponent of a more robust EU defense sector, EU Commissioner Thierry Breton, stated that the bloc must rely on its own industrial base.

On March 5, 2024, the European Commission presented its first-ever Defence Industrial Strategy. It proposes breaking the EU's dependence on US military equipment and establishing a new European Defence Industry Programme (EDIP) which is intended to increase weapons production and collaboration between manufacturers. The EU plans to invest €1.5 billion in EDIP between 2025 and 2027. It is expected that by 2030, member states will purchase at least 40% of their equipment collaboratively (up from 18% presently), allocate half of their procurement budget to EDTIB purchases, and increase the proportion of "intra-EU defense trade" to 35% of the EU defense market's total value.

There are several issues the EU faces concerning its military industry - at two different levels of analysis: import of arms and import of materials.

The EU is very dependent on other countries for its military hardware. As expected, the crisis in Ukraine deepened that dependency. As expected, to meet the needs of Ukraine and supply it with the necessary amount of arms and ammunition the EU had to import (Figure 2).

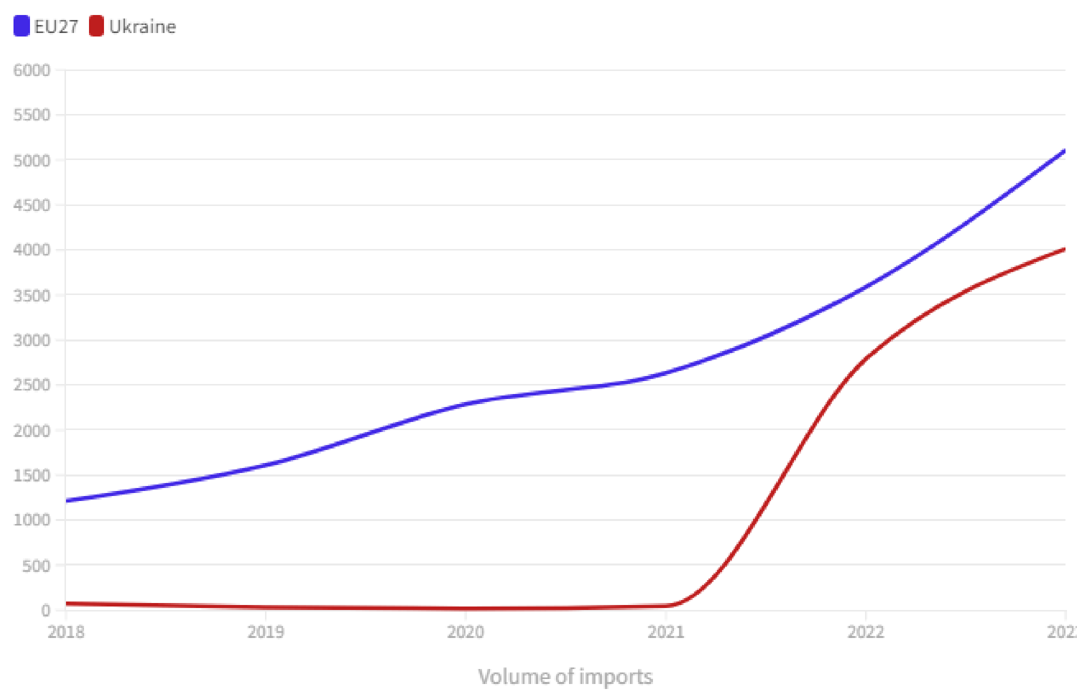


Figure 2 - Arms imports (Source: SIPRI 2024)

However, it seems that even with the imports, as well as the planned increase in military equipment production, the EU is not likely to outgun Russia. Therefore, it is questionable (a) if the EU can afford to massively reduce imports, and (b) whether even if they don't they will be able to satisfy their military needs. While Russia is also partially militarily dependent on other countries, the EU, as previously mentioned, is mostly dependent on one country, the USA.

There should also be real concern among the EU officials regarding their trade connection with the USA. By severely reducing imports of arms from the US, the US would be losing out on a long-lasting partnership and reconsider the EU's importance as a trading partner and ally.

Additionally, as will be further discussed, the security of supply might be restricted due to geopolitical tension. A big share of the military production supply chain depends on China, an issue that is to be urgently addressed.

1. Current European Military Capabilities

The European defense industry is a multifaceted network comprising large multinational companies, mid-sized firms, and over 2,000 small and medium-sized enterprises (SMEs). In 2021, the industry reported a turnover of €84 billion and provided direct employment to approximately 196,000 highly skilled workers, with an additional 315,000 jobs indirectly supported by the sector. The European Defense Technological and Industrial Base (EDTIB) is particularly concentrated in France, Germany, Italy, Spain, and Sweden. Among the largest companies in the EU by defense revenue are Italy's Leonardo, the European multinational Airbus, and French companies Thales, Dassault, and Safran.

The industry, however, faces significant challenges even apart from supply chain dependencies. One of the most pressing issues is the substantial under-investment in defense budgets by EU member states over the past decade. Despite commitments to increase defense spending, many countries have failed to allocate sufficient funds, exacerbating dependencies on third-country suppliers. Notably, over 60% of European defense procurement budgets have been spent on military imports, highlighting a critical dependency on non-European sources for certain defense products.

In terms of global standing, only 17 of the top 100 defense companies are headquartered in the EU, compared to 46 in the United States. The top five US defense companies alone had combined revenues of $203.5 billion (€193 billion) in 2021, more than double the total revenue of the entire EU defense industry. Lockheed Martin, the most profitable US defense company, recorded $64.5 billion (€60.7 billion) in revenue that year, nearly three-quarters of the total revenue generated by the EU-based defense companies.

The European defense industry also grapples with issues related to workforce skills and manufacturing capabilities. A significant portion of the industry's workforce is nearing retirement, and there is a notable shortage of young talent entering the field. This shortage is particularly acute in high-tech areas, where the defense sector competes with the civilian technology industry for skilled personnel. To address these challenges, the European Commission has launched various initiatives, including the European Defense Skills Partnership and the European Year of Skills 2023, aimed at developing and retaining necessary skills within the sector.

In response to the increased demand for defense products following Russia's war on Ukraine, the EU and its member states have taken steps to reinforce the defense industry. These measures include significantly boosting defense budgets, which are projected to reach a total of €290 billion annually by 2025, and investing in research and technology (R&T). In 2021, member states allocated a record €3.6 billion to defense R&T expenditure, though this still falls short of the 2% benchmark set within the European Defense Agency (EDA) framework.

Europe's defense industry produces a comprehensive array of conventional capabilities required by its armed forces. However, this production capacity comes with notable dependencies. Due to years of insufficient national demand, manufacturers have increasingly relied on exports to non-EU and non-NATO countries to sustain their skills and production lines. Additionally, the pressure to economize defense spending has led to significant dependencies on imports for raw materials and key components like semiconductors. These dependencies are now under scrutiny as the security of supply becomes a critical concern for European nations and their militaries.

The European Defense Technological and Industrial Base (EDTIB) extends well beyond the EU and its member states. Despite EU initiatives such as the Permanent Structured Cooperation (PESCO), the European Defence Fund (EDF), and the European Peace Facility, the majority of defense industrial investments by EU member states occur outside the EU framework. Countries outside the EU, including the United Kingdom, Norway, and Türkiye, significantly contribute to this landscape through both cooperation and competition. Additionally, non-European companies, particularly from the US and South Korea, have integrated into Europe's defense industrial ecosystem by supplying components and complete systems.

Despite over two decades of efforts to foster closer development and procurement cooperation within the EU, the EDTIB remains shaped by national decisions made decades ago, especially post-Cold War. Defense needs and broader domestic economic policies and philosophies, including state ownership of defense companies influenced these decisions. Consequently, each country has its unique narrative regarding its defense industrial base and ambitions. Eastern and Central European countries faced the additional challenge of integrating into NATO, necessitating adaptations to new equipment standards and interoperability. The dissolution of the Soviet Union and the Warsaw Pact further complicated matters, as these countries lost their traditional supply bases and economic links, leading many companies to cease production or focus on maintaining legacy equipment and exports to former Soviet states (DGAP 2023).

Recent history underscores the importance of forthcoming decisions for the EDTIB. Europe's entry into a new historical phase, spurred by the Russian war of aggression, has placed security of supply for armed forces at the forefront of the political agenda. European countries, regardless of size, now recognize the cost of their dependence on global supply chains. While governments share the aspiration to ensure national security of supply, their interpretations of what this entails vary significantly. Some countries limit their national supply definitions to basic elements like ammunition and maintenance, while others aim to maintain a technological edge in components or entire weapon systems. These choices indicate that armed forces may need a new balance of quantity and quality. Not every aspiration can be met nationally, necessitating a trade-off between ambition and feasibility that could foster cooperation. Current practices reflect a pragmatic approach: countries view their national bases as crucial to their defense efforts while continuing to engage in EU or multinational cooperation. The sustainability of this approach will become clear as economic and financial pressures necessitate tougher decisions regarding the future of the defense industrial base (DGAP 2023).

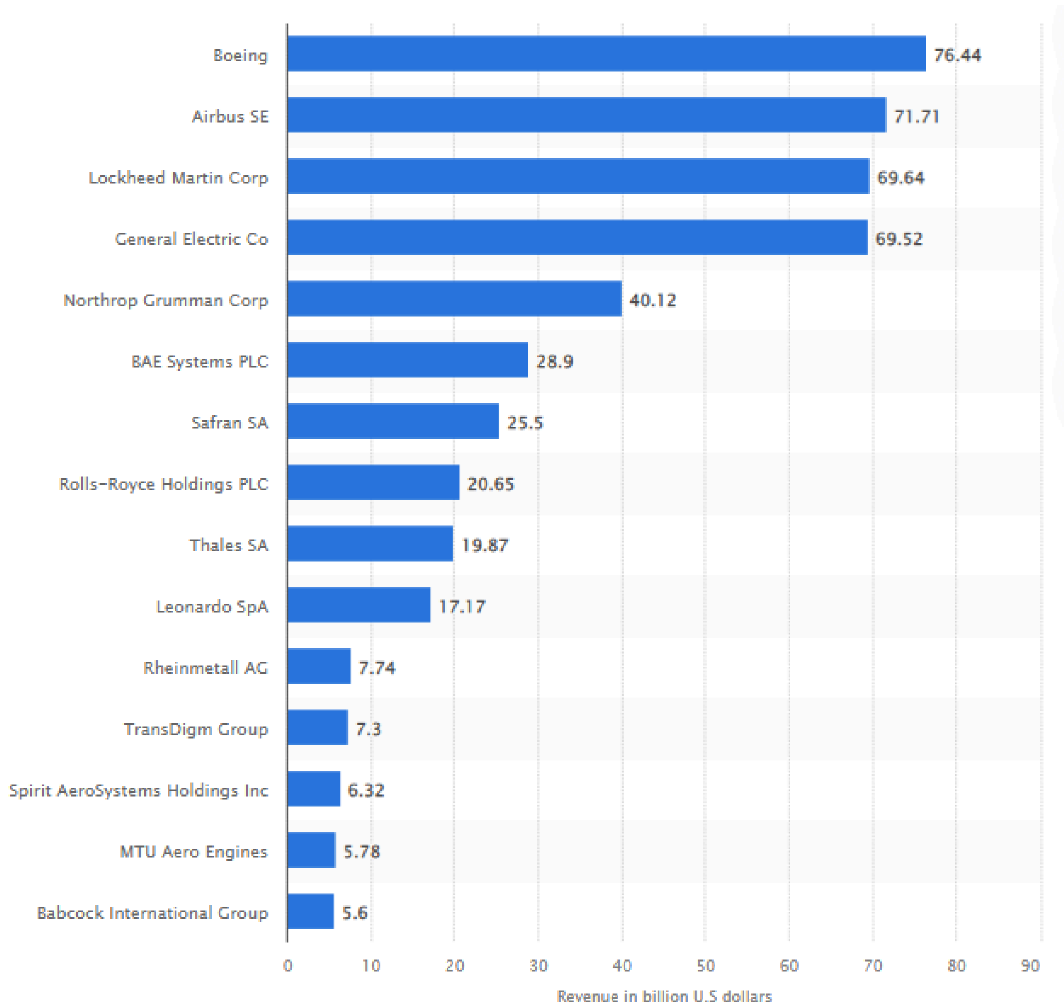


Figure 3 - Leading defense aerospace and defense companies in Europe by revenue (*Source: Statista 2024*)

As the European defense industry is heavily fragmented, the level of military capability, lucrative companies, and supply chain dependencies vary from country to country.

a) France

France's defense industry is a cornerstone of its national defense policy, marked by a robust technological and industrial base capable of developing and producing nearly the entire spectrum of weapon systems and armament technologies. This comprehensive capability encompasses major land, naval, and air platforms, electronics, command and control (C2) systems, as well as space and nuclear technologies. This capacity distinguishes France from other major European players who are more willing to rely on American technologies. Central to France's strategy is the preservation of its independence on the global stage, achieved through a self-sufficient defense ecosystem.

Among the major French defense companies, six stand prominently in the global arena. Airbus Group, including its Airbus Defence and Space division, is a leading multinational aerospace and defense company involved in military aircraft, helicopters, satellites, and other defense-related systems. Despite its broad portfolio, defense accounts for less than 20% of Airbus's total revenue, which stands at approximately $10.85 billion. Thales Group is another key player, specializing in defense, aerospace, transportation, and security systems, with a defense revenue of about $10.21 billion. Dassault Aviation, known for its production of military aircraft such as the Rafale fighter jet, reports a defense revenue of $5.31 billion. Safran, a multinational company involved in various sectors including aircraft engines, aerospace propulsion, defense systems, and avionics, has a defense revenue of $4.98 billion. MBDA, a joint venture between Airbus Group, Leonardo (Italy), and BAE Systems (UK), specializes in missile systems, including air defense systems and precision-guided munitions, with a defense revenue of $4.96 billion. Naval Group, formerly known as DCNS, focuses on the design and construction of submarines and surface vessels, boasting a defense revenue of $4.85 billion. Lastly, KMW-Nexter Defense Systems (KNDS), a Franco-German defense company specializing in land defense systems, armored vehicles, and artillery, has a defense revenue of $3.17 billion.

These companies form the backbone of France's defense industrial base, supported by a network of over 4,000 small and medium-sized enterprises (SMEs) involved in defense, employing between 150,000 and 200,000 people nationwide. This extensive industrial network ensures that France can meet most of its defense needs domestically. However, the French defense industry is heavily dependent on defense exports, primarily outside Europe. According to the SIPRI database, France was the world's second-largest exporter of defense equipment in 2021, with exports ranging between €2 billion and €4 billion annually, often secured after fierce competition with American and European competitors. Despite its strengths, the French defense industry is not entirely self-sufficient and maintains dependencies on certain imported components and systems. For instance, major contracts with the United States include air surveillance systems, MALE drones, transport aircraft, and critical components such as aircraft carrier catapults, with annual defense procurements from the US amounting to approximately one billion euros. This reliance highlights a strategic challenge for France, which strives for greater European integration and reduced dependency on non-European suppliers (DGAP 2023).

In terms of materials and components, the French defense sector, like much of Europe, faces dependencies on imports for raw materials and key components such as semiconductors. These dependencies are increasingly scrutinized as the security of supply becomes a critical issue. The economization of defense has pressured prices, exacerbating these dependencies. France is a strong proponent of a unified European Defense Technological and Industrial Base (EDTIB) and has pushed for initiatives like the European Defence Fund to encourage European countries to "buy European." Despite these efforts, French companies continue to face challenges related to European cooperation, with past programs often needing more time and effort (DGAP 2023).

The war in Ukraine has acted as a catalyst, significantly changing the European debate on defense and defense spending. France views this as an opportunity for the European Union to deepen its defense integration and strengthen the EDTIB. French leaders have high expectations for European partners and hope for significant progress in joint defense projects. France's commitment to a more integrated European defense industry remains strong, driven by both strategic goals and the need to secure its defense supply chain against global uncertainties.

b) Germany

In Germany, the defense industry is marked by a robust network of major companies, each specializing in various sectors such as aerospace, land systems, electronics, and naval systems. Among the biggest defense companies, Airbus stands out as a key player in aerospace, with a total revenue of $61.67 billion, of which $10.85 billion is derived from defense activities. Airbus is heavily involved in projects like the Future Combat Air System (FCAS) and the Eurofighter, which are collaborative efforts with France and Spain. Diehl and Hensoldt are prominent in the electronics and missile sectors. Diehl, with total revenue of $3.745 billion and $870 million from defense, and Hensoldt, which generates almost all of its $1.743 billion revenue from defense, integrate critical components into larger systems.

In the land systems domain, Krauss-Maffei Wegmann (KMW) and Rheinmetall are major players. KMW, part of the KNDS group, focuses on land systems and has a revenue of $3.193 billion from defense. Rheinmetall, which operates across land systems, munitions, electronics, and soldier systems, generates $6.691 billion in revenue, with $4.450 billion coming from defense (SIPRI 2022).

The naval sector is dominated by companies like ThyssenKrupp Marine Systems (TKMS) and Lürssen. TKMS, with total revenue of $40.226 billion and $2.39 billion from defense, and Lürssen, generating between $1.3 billion and $2.1 billion, are involved in the construction and integration of surface and underwater naval systems (SIPRI 2022).

MBDA is a significant player in the missile sector, with a total revenue of $5.007 billion, of which $4.960 billion is defense-related. This company focuses on integrating missile systems and components (SIPRI 2022).

German defense companies are significantly dependent on foreign suppliers for many raw materials, certain alloys, and components such as semiconductors, which are primarily sourced from Asia. Additionally, Germany relies on the United States for medium to long-range air defense components, 5th-generation fighter aircraft, and heavy transport helicopters. This dependency extends to some types of missiles, naval guns, radars, and UAVs sourced from different global suppliers. Despite concerns about dependencies on China, Germany does not view imports from the United States as problematic (DGAP 2023).

c) Italy

In Italy, the defense industry is a significant sector, with the largest company being Leonardo. In 2021, the Italian defense technological and industrial base (DTIB) achieved a turnover of 17 billion euros, with 66 percent of this revenue coming from exports. The industry employs about 52,000 workers directly and approximately 210,000 indirectly. Leonardo ranks 7th in the world and 2nd in Europe for defense revenue. Its divisions focus on helicopters, fixed-wing aircraft, defense electronics, and multidisciplinary armament systems. Leonardo also owns a stake in Avio, a manufacturer of small launch vehicles, and collaborates with Thales in the "Space Alliance" through joint ownership of Telespazio and Thales Alenia Space.

Fincantieri is another major player, renowned for shipbuilding. It constructs various classes of warships and submarines, including the Cavour aircraft carrier, Orizzonte and FREMM frigates, and Vulcano logistic support ships, often in cooperation with international partners like the French Naval Group and German TKMS. Elettronica is prominent in defense electronics, providing electromagnetic and cyber solutions. Iveco Defence Vehicles is notable for producing a range of wheeled military vehicles, and Beretta supplies small arms to the Italian Army and other international customers. Rheinmetall Italia and Avio Aero (a GE company) are also significant contributors to the sector.

d) United Kingdom

Despite not being a member of the EU anymore, the military companies situated in the UK are of great importance to the overall EU defense framework. The biggest defense companies in the United Kingdom include BAE Systems, Rolls-Royce, Babcock International, and QinetiQ. These companies are integral to the UK's defense capabilities and have significant roles in various defense sectors.

BAE Systems, the dominant player in the UK defense industry, leads the development and delivery of the Astute and Dreadnought submarines, with Rolls-Royce responsible for the reactors. BAE Systems is also the prime contractor for the Type 26 Global Combat Ship, which includes a power and propulsion system managed by Rolls-Royce. In addition, BAE Systems plays a crucial role in the Eurofighter Typhoon program and the Global Combat Air Program, collaborating with Rolls-Royce, Leonardo, and MBDA. BAE Systems was ranked 7th in the Defense News Top 100 Defense Companies in 2022, with significant turnover from its defense operations. Rolls-Royce is a key player in the development of gas turbines for military aircraft and warships, and it manufactures the nuclear reactors that power British submarines. The company's civil businesses are larger than its military operations, but it remains a vital contributor to the UK's defense capabilities. Rolls-Royce was ranked 27th in the Defense News Top 100 Defense Companies in 2022.

Babcock International, an engineering enterprise, builds and supports surface ships and submarines, maintains land equipment, and is part of a consortium delivering flying training. It is also expanding into military communications and mission systems. Babcock International was ranked 43rd in the Defense News Top 100 Defense Companies in 2022. QinetiQ, a privatized spin-off from the former Governmental Defense Evaluation & Research Agency (DERA), focuses on a wide range of technologies and frequently acts as an advisor to the government on technology matters. It also has a long-term contract to manage the UK's missile ranges in Scotland. QinetiQ was ranked 64th in the Defense News Top 100 Defense Companies in 2022.

The UK defense industry also benefits from significant involvement by foreign companies such as Leonardo, Thales, Airbus, and MBDA, which have extensive operations in the UK. Leonardo has taken over Westland, the UK's helicopter company, and is central to the Typhoon and Future Combat Air System projects. Thales is a key player in UK sonar capabilities, including for the nuclear submarine fleet, and Airbus is crucial to UK space capabilities and builds both civil and military wings in the UK. MBDA, a joint venture involving France and Italy, is the predominant missile enterprise in the UK and develops and produces a wide range of missile systems. The UK is also home to subsidiaries of several major US defense companies, including General Dynamics, Raytheon, and Lockheed Martin. These companies contribute to various projects, such as tactical communications, the Ajax armored vehicle program, IFF and radar systems, Paveway bomb production, and missile components (DGAP 2023).

e) Spain

In Spain, the defense industry is defined by several major companies, notably Indra and Navantia, which are important for various defense sectors. Indra, a leading company in the defense and information technology sector, is known for its advanced technological solutions and services. It specializes in areas such as radar systems, electronic warfare, command and control systems, and cybersecurity. Indra's defense segment is integral to its operations, contributing significantly to its revenue, which in 2022 was approximately €3.851 billion. Indra's capabilities extend to air traffic management systems, simulation, and training, making it a key player in both national and international markets. Navantia is another cornerstone of the Spanish defense industry, focusing on naval construction. It produces a wide range of naval vessels, including frigates, submarines, and amphibious ships. Navantia is involved in significant international projects and partnerships, highlighting its role in global naval defense. In 2022, Navantia's revenue was €1.28 billion, underscoring its substantial contribution to Spain's defense sector.

Spain's defense industry also includes other notable companies like Airbus, which has a significant presence in Spain's aerospace sector, producing military transport aircraft such as the A400M, and collaborating on European defense projects like the Eurofighter Typhoon. Airbus is a critical player, contributing to Spain's capabilities in both civil and military aerospace (Infodefensa (IDS) 2023).

The Spanish defense industry, much like its European counterparts, relies on a diverse supply chain that includes foreign suppliers for various components and materials. Dependencies exist particularly for advanced technologies and raw materials, which are sourced from global markets. The industry is integrated into the broader European defense framework, participating in multinational projects and leveraging collaborations to enhance its capabilities and reduce dependencies (DGAP 2023).

f) Turkey

Turkey is also on its way of becoming a big military partner for the EU. Turkey's defense industry is characterized by several major companies that play crucial roles in both national defense and international markets. Leading the sector are ASELSAN, Turkish Aerospace Industries (TAI), Roketsan, and BMC.

ASELSAN is the largest defense company in Turkey, specializing in advanced electronics and systems integration. It produces a wide array of defense products, including communication systems, radar systems, electronic warfare, electro-optics, and missile systems. In 2023, ASELSAN reported a revenue of approximately USD 2.74 billion, reflecting its substantial contribution to the defense sector. ASELSAN's capabilities in developing and producing high-tech defense electronics have positioned it as a key player in the global defense market. Turkish Aerospace Industries (TAI) is another cornerstone of Turkey's defense industry, focusing on the design, development, and production of aerospace systems. TAI produces a variety of military aircraft, including the T129 ATAK helicopter, the ANKA unmanned aerial vehicle (UAV), and is involved in the development of the TF-X, Turkey's indigenous fighter jet. TAI's revenue in 2022 was around USD 1.8 billion, underscoring its pivotal role in enhancing Turkey's aerospace capabilities.

Roketsan is known for its expertise in missile and rocket systems, producing a range of products including the SOM cruise missile, the Cirit laser-guided missile, and various artillery rockets. Roketsan's revenues and production capacities reflect its strategic importance in supplying advanced missile systems to the Turkish Armed Forces and export markets. BMC is a leading producer of armored vehicles and military trucks. It manufactures a variety of armored solutions, including the Kirpi mine-resistant ambush-protected vehicle and the Altay main battle tank, which is expected to become a cornerstone of Turkey's armored forces. BMC's contributions are critical to Turkey's land defense capabilities and its exports of military vehicles.

The Turkish defense industry relies on a combination of domestic production and international collaborations to meet its equipment and material needs. While Turkey has made significant strides in achieving self-sufficiency in many areas, it still depends on imports for certain high-tech components and raw materials. For instance, advanced avionics, jet engines, and certain electronic components are sourced from international suppliers. However, the ongoing efforts to develop indigenous technologies and expand local production capacities aim to reduce these dependencies and enhance Turkey's strategic autonomy in defense manufacturing.

1.1 Strengths and Weaknesses in Production

The EU excels in the production of military aircraft and helicopters. Airbus Defence and Space is a major player, producing the Eurofighter Typhoon, a versatile and advanced multirole combat aircraft used by several European air forces. The A400M Atlas, another product of Airbus, is a tactical airlifter that meets a broad spectrum of transport requirements. Additionally, Leonardo's AW101 and AW139 helicopters are widely used for military applications, including transport, search and rescue, and anti-submarine warfare. The European aerospace sector, therefore, ensures that the EU has sufficient capabilities in terms of military aviation.

Naval capabilities are another strong area for the EU, with significant production of advanced naval vessels. Companies like Navantia, Naval Group, and Fincantieri lead in this sector. Navantia's portfolio includes frigates like the F-100 and submarines such as the S-80. Naval Group in France is known for its sophisticated submarines, including nuclear-powered models, and surface vessels like the FREMM multipurpose frigates, developed in cooperation with Fincantieri. On land, the EU produces a wide range of armored vehicles and artillery systems. Rheinmetall, KMW, and Nexter are key manufacturers in this domain. Rheinmetall's Leopard 2 main battle tanks and Boxer armored vehicles are widely deployed across Europe. The joint venture KNDS, formed by KMW and Nexter, produces various armored platforms, including the Leclerc and Leopard tanks. This strong industrial base in land systems ensures that European armies are well-equipped with modern armored and artillery systems. The missile and aerospace sectors are well-supported by companies like MBDA, which produces a wide range of missile systems, including the Meteor, Exocet, and Aster missiles. These systems provide critical capabilities for air-to-air, surface-to-air, and anti-ship engagements. In the realm of defense electronics and communication systems, Thales and Hensoldt are leaders. They develop advanced radar systems, electronic warfare capabilities, and command and control systems.

It's important to note that the Defense-industrial capacity encompasses far more than just factories and shipyards. It relies on a complex array of elements: not only the physical buildings and docks, but also the necessary tooling, systems, and software; an extensive network of facilities throughout the supply chain; workers with specialized skills; and access to specific materials and components. All these elements must be in place and active for defense-industrial assets to function effectively. Restarting a factory or dockyard that has been idle is particularly challenging, and recruiting or reallocating personnel from other business sectors on short notice is not easy.

Media reports have highlighted significant defense-industrial capacity issues in both Europe and the United States, including difficulties in scaling up or restarting production quickly. Lead times of two to three years are commonly cited for delivering complex systems from active production lines, as well as for reactivating dormant ones. For instance, BAE Systems informed the US Department of Defense that restarting M777 howitzer production would take 30–36 months. Similarly, Rheinmetall's CEO, Armin Papperger, noted that specialized steel for tank armor would require eight to twelve months for delivery, and lead times for certain electronic components used in tank production could be up to 24 months. These extended lead times are primarily due to supply chain bottlenecks, resulting from the limited number of specialized suppliers in Europe.

Even increasing the production of relatively simple systems like artillery rounds is proving challenging. There are reported shortages of chemicals for explosives and propellants, as well as metals and plastics for fuses and casings. Jiří Hynek, head of the Association for Weapons and Defence Industry of the Czech Republic, mentioned that most raw materials necessary for military production are either not mined or minimally mined within the EU, leading to astronomical prices for scarce items. A French parliamentary report indicated that the delivery time for unguided 155-millimeter artillery shells ranged from ten to twenty months and 24 to 36 months for guided shells. Mike Ord, CEO of Chemring, a supplier of explosive materials, stated that some customers have requested output increases of 100–200%.

The disparity between demand and production capacity is stark. Russia and Ukraine have sometimes collectively fired around 200,000 artillery shells per week, whereas the US currently produces about 20,000 155 mm rounds per month, with plans to increase to 90,000 per month by 2024 following a $2 billion US Army investment. War-gaming scenarios have revealed that the UK would deplete its ammunition stocks in just eight days during a high-intensity conflict, and German media in 2022 suggested that Bundeswehr stocks would last only a few hours to a few days in such a scenario. The situation is similarly dire for missiles. The French Ministry of Armed Forces has requested that MBDA Missile Systems increase production of the Mistral short-range air-defense missile from 20 to 40 per year by 2025 (IISS 2023). Meanwhile, Lockheed Martin plans to nearly double Javelin anti-tank missile production from 2,100 to 4,000 per year, yet the Ukrainian Armed Forces required some 500 Javelins per day during the war's early stages.

The root causes of these capacity problems are deeply embedded. For many systems, industrial capacity has been scaled down to match the low demand levels of domestic and core export markets. Ramping up production requires expanding facilities and recruiting skilled workers throughout the supply chain, which is both costly and time-consuming. For products no longer in manufacture, restarting production is often difficult and expensive, if possible at all. The need for spare parts for repairing and refurbishing existing hardware is particularly pressing. Leopard 1 and Leopard 2 tanks destined for Ukraine need restoration, but some spare parts are no longer available, necessitating hand repairs that can take up to six months. Any dormant facilities and tooling would likely need significant upgrades and refurbishment. Supply-chain constraints are only gradually becoming apparent, with some suppliers having redeployed resources or gone out of business. Certain parts may need to be updated, requiring redesign, while new systems are often only in the early stages of their development cycle and cannot be rapidly deployed.

2. Military Technology Trends and The Supply Chain

Military technology is getting increasingly more complex. Therefore, having an advanced military industry complex mostly independent of other countries is tricky. New technologies in the military such as advanced AI, 3D printing, UAVs, smart materials, and many types of energy-using equipment require an immense amount of special materials, such as Critical Raw Materials (CRM). Such equipment requires technologies such as nanomaterials, metamaterials, graphene, manganese, and magnesium, as well as many different advanced material composites like metal, polymer, and ceramic composites, aluminum and magnesium alloys, and carbon nanotubes. A whole different issue is the semiconductors, which Europe struggles to produce, but are crucial for this type of tech, particularly when even military clothing and non-electronic equipment is being equipped with electronic devices.

The US has recognized the aforementioned problem of China's supply chain domination quite early, but members of the EU, whose Common Security and Defense Policy is still in its infancy, have not yet accepted the reality of the challenges they confront and will face going forward. Defense companies are hardly an exception to how neoliberal globalization has altered supply chains throughout the world. These businesses embraced a "just-in-time" production philosophy, cutting down on or doing away with material and component inventories to lower overhead expenses for the finished good. The importance of strategic independence for the European military supply has diminished as globalization has increased the focus on maximizing corporate competitiveness. To put it bluntly, protecting domestic supply chains in support of national defense has been subordinated to corporate maximization. Figure 3 represents the EU's worldwide dependence on CRMs.

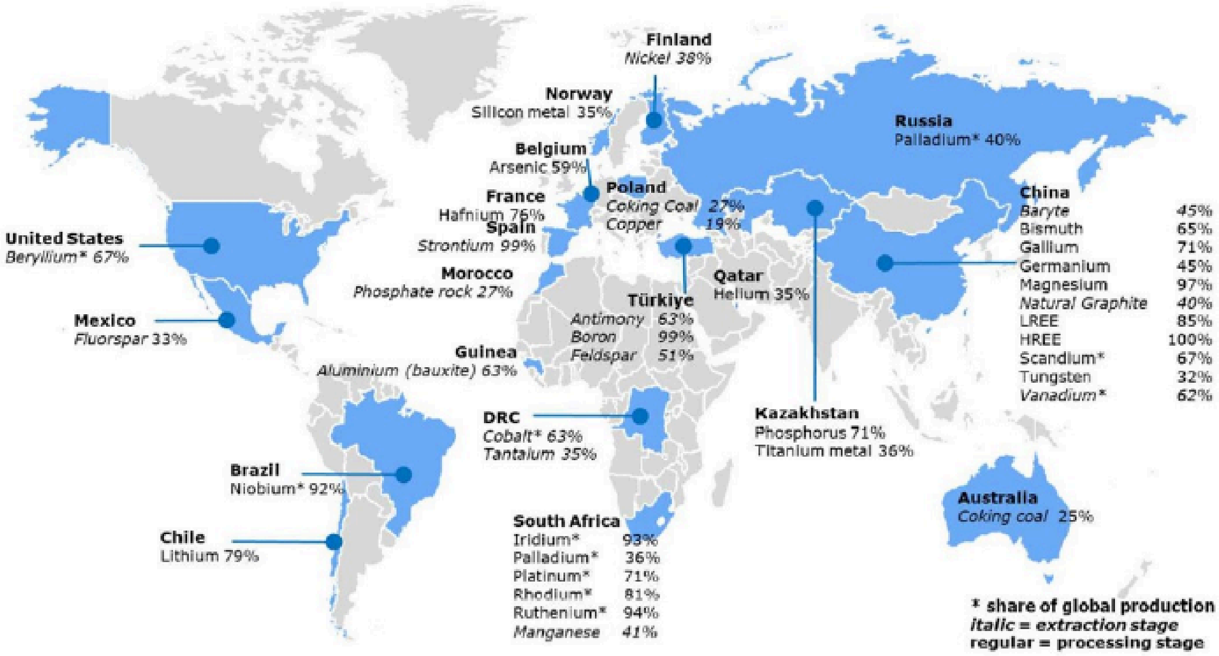


Figure 4 - Major EU Suppliers of CRMs (Source: The EU Commission final report on Critical Raw Materials 2023)

The existing state of the EU's supply chain poses a serious risk to the military forces of its members since there is no mandatory legislation on essential goods required for national defense at the interstate or national levels. What's more concerning is that by 2025, the European Commission itself predicts a very high risk of a shortage of rare earth materials and a high probability of critical material shortages. However, when one realizes that a large number of these resources are in the hands of China, the scenario becomes more worrisome. It is no coincidence that China currently holds a monopoly on the extraction and processing of the elements cobalt, lithium, manganese, tungsten, antimony, bismuth, graphite, fluorspar, and germanium, accounting for more than half of the world's supply. With a 90% market share, China is the EU's biggest supplier of rare earths. This monopoly extends to nearly 100% of the metals when it comes to heavy rare earths, which are used in many of the most modern weapon systems.

Given this dependency, China can, by imposing sanctions, severely limit Europe's military capabilities. A change in China's strategy of backing Russia in its current conflict with Ukraine is another possible effect of dependence. Western nations that impose sanctions on China may face retaliatory actions from the Chinese government, such as a restriction on rare earth exports. The EU, Japan, and Australia seem to be strengthening their alignment with US foreign and security policy as geopolitical tensions rise. Consequently, the previously restricted sanctions interactions between these countries and China may broaden and impact even more domains, including vital resources required for the defense industry. The reliance of the Western defense industry on Chinese rare earths across its supply chain poses a serious threat to its strategic independence, both domestically and concerning the Quadrilateral Security Dialogue and NATO alliance. It restricts the West's technological sovereignty and might eventually make it harder for it to maintain military operations and respond to emergencies.

For good reason, many defense analysts have already called this decade "the terrible twenties" because of issues with supply chains and manufacturing. The foundation of national defense has always been national-scale logistics, without which international security also disappears. For better or worse, private corporations supply and equip Western militaries, and no defense company in the West would willingly operate at a loss to ensure countries' independence from China or the necessary war reserves for armed forces. This implies that Western governments are accountable for quickly modernizing industrial bases and supply chains, beginning with the most essential components and resources, particularly rare earths.

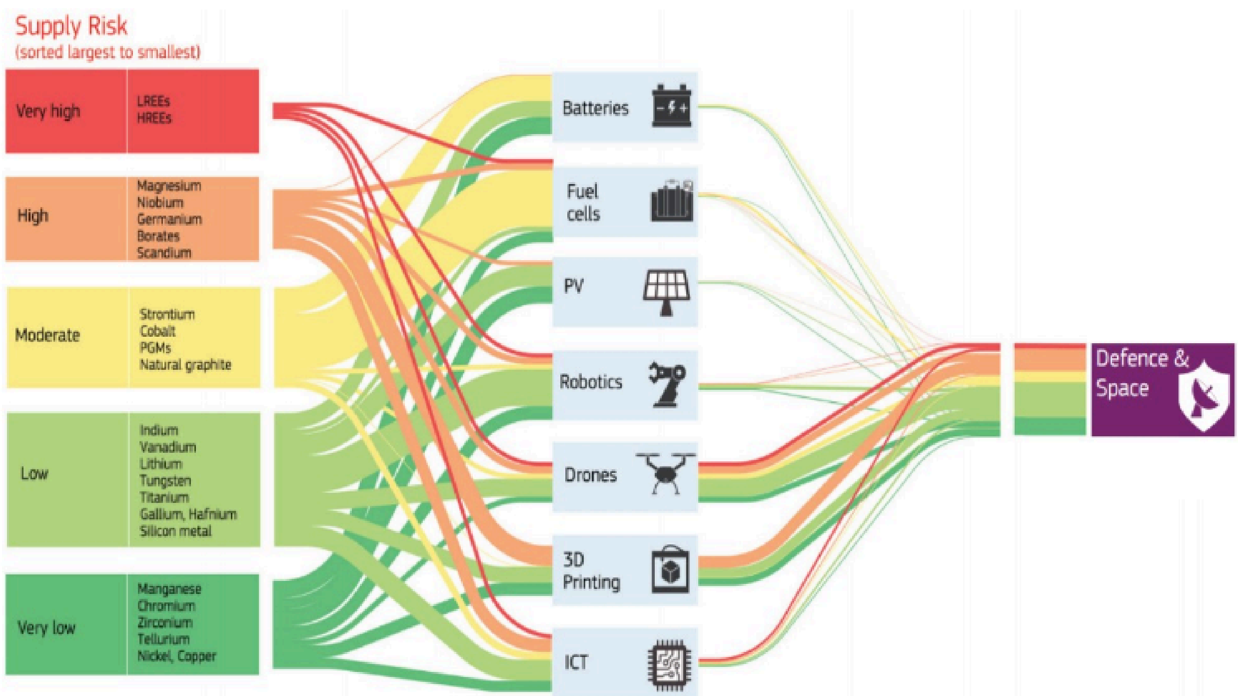


Figure 5 - EU's Supply Risks (Source: European Commission)

The supply of minerals is monopolized in a few countries, not just China. 34 raw materials have been designated as "critical" by the European Commission due to their significance to the economy and supply security. The origin of all 34 of these CRM imports into the EU is depicted in Figure 6. Eight components stand up as being especially troublesome when considering market concentration using the Commission's 65 percent threshold. In the case of bismuth, cobalt ore, magnesium, manganese, and strontium, imports from China surpass this limit.

Beryllium from the United States and feldspar and borates from Turkey display similar import concentration levels.

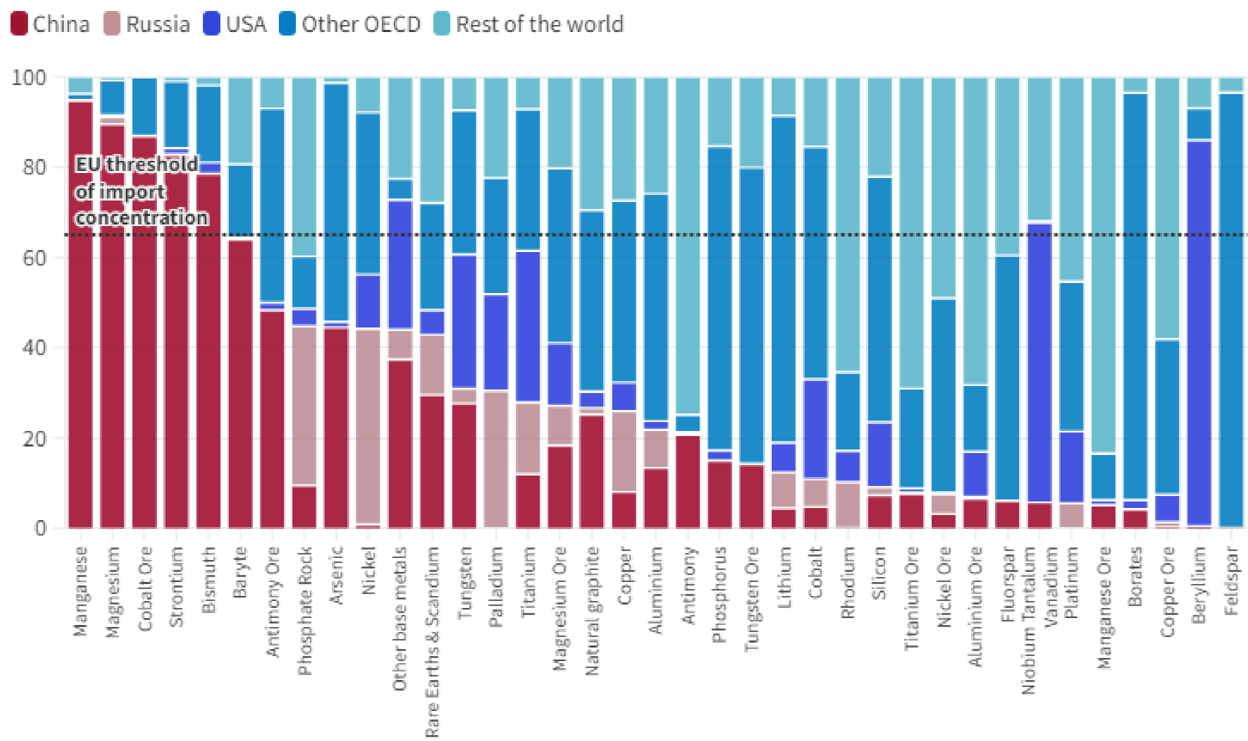


Figure 6 - Origin of EU imports of critical raw materials (2021) (Source: Eurostat)

Most of these materials are very important in the military industry, used for the production of helmets, ballistic missiles, ammunition, incendiaries, and most importantly, the creation of alloys that are necessary for modern military equipment.

There are many alarming examples of the EU's material dependency on China, such as with solar panels and batteries for electric vehicles. It's important to note that China does not necessarily extract these materials, but it plays a crucial role in the value chain. China is key for material processing, as well as manufacturing and assembling, which allows it to sell much higher-cost goods. China has an absolute monopoly on the processing of aluminum, polysilicon, graphite, lithium, cobalt, and many other metals. The same goes for the manufacturing of Batteries, solar panels, and electric vehicles.

The main way that Europe is exposed to CRMs is through the importation of manufactured products. For instance, the EU's imports of permanent magnets in 2021 were worth 12 times more than the total amount of rare earth imports. Imported lithium batteries were worth 75 times more than imported lithium, and imported solar panels were worth 13 times more than imported silicon. This is mostly caused by the fact that the EU does not produce many of these commodities locally, in addition to reflecting the higher added value of goods further upstream in value chains. For instance, local production of solar panels only meets roughly 10% of the demand in the EU.

1.1 Artificial Intelligence

In the dynamic landscape of modern warfare and the foreseeable future, the integration of artificial intelligence (AI) stands as a center point, revolutionizing the capabilities and strategies of military forces. AI, with its capacity to process colossal volumes of data, discern intricate patterns, and execute autonomous decisions, serves as the cornerstone of innovation in military technology, offering unparalleled opportunities for efficiency, precision, and adaptability in combat scenarios.

The utilization of AI in contemporary and anticipated military technologies spans a diverse spectrum of applications, each set to redefine the nature of warfare. Central to this paradigm shift is AI's role in intelligence, surveillance, and reconnaissance (ISR) operations. AI-powered systems are adept at analyzing vast data streams from satellites, unmanned aerial vehicles (UAVs), and ground-based sensors, empowering military commands with real-time situational awareness, threat detection, and target identification capabilities. This enhanced intelligence framework enables preemptive responses to emerging threats, granting military forces a decisive edge in dynamic and contested environments. It could be revolutionary in situations that require a fast response, while other, slower, tasks would be done by humans for a deeper level of analysis.

Furthermore, AI revolutionizes decision-making processes within military hierarchies, augmenting human cognition with data-driven insights and predictive analytics. Advanced algorithms and machine learning models enable AI systems to scrutinize vast repositories of historical data, simulate diverse operational scenarios, and furnish commanders with actionable intelligence for strategic planning and tactical execution. Given its predictive uses and preemptive action, it could completely change the way decision-making is done in the military. Beyond its role in ISR and decision support, AI is increasingly integrated into next-generation weapons systems, amplifying their lethality, autonomy, and operational efficacy. Autonomous drones, unmanned ground vehicles, and robotic weaponry imbued with AI algorithms exhibit enhanced capabilities for autonomous navigation, target acquisition, and engagement, transcending the limitations of human-operated platforms. These AI-enabled systems boast the ability to operate in complex and contested environments, execute precision strikes with unparalleled accuracy, and adapt dynamically to evolving threats, thereby extending the reach and potency of military forces while minimizing human exposure to danger.

1.1.1 Semiconductors

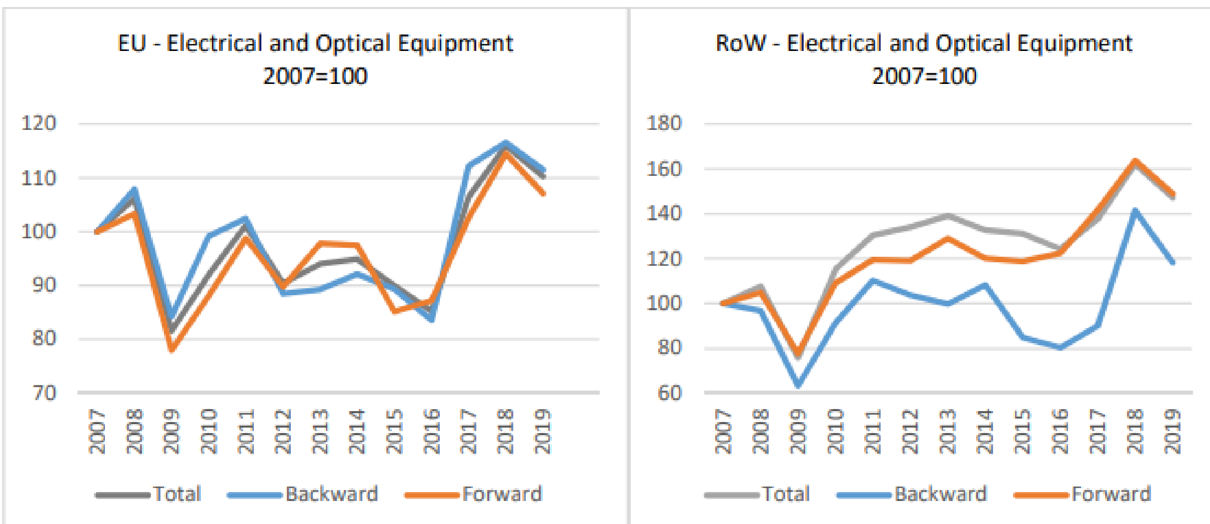
Semiconductors play an integral part in the contemporary economy, serving as the fundamental building blocks of various industries driving the ongoing digital revolution, including that of the military industry. Apart from AI, it involves essentially all modern military technologies - manufacturing, propulsion systems, UAVs, and even military clothing, which is bound to have microelectronics of all kinds integrated into it. All modern military equipment involves some degree of electronics, for which semiconductors are essential. Therefore, this analysis of the supply chain of semiconductors applies to all technologies mentioned in this paper. On the other hand, more conventional industries are also depending more and more on semiconductors. A few countries control the majority of the semiconductor production chain. However, because of the high level of company specialization, no country is independent or autonomous throughout the whole chain; instead, each nation maintains a dominant position in a particular chain segment.

Electronic devices known as semiconductors rely on certain properties of semiconductor materials to function. Semiconductors fall into seven main categories: memory, discrete, optoelectronics, logic, micro, analog, memory, and sensors. Memory, logic, micro, and analog semiconductors are the first four categories that are frequently grouped under the term integrated circuits (ICs). IC sales accounted for 328 billion EUR or 80% of the total 410 billion EUR in semiconductor sales in 2020. The remaining 20% of industry sales were made up of sensors (like MEMS, and microelectromechanical systems), optoelectronics (like LEDs), and discrete semiconductors (single transistors).

Given that semiconductors are essential to the operation of the modern economy, interest in them has skyrocketed in recent years. The semiconductor industry's global market capitalization increased from 438 billion euros in 2005 to over 2.5 trillion euros in 2021, with an average annual growth rate of more than 30% over the previous five years and a record increase of +53.7% in 2021 over 2020. However, the world has recently started experiencing a shortage. According to McKinsey, the semiconductor industry has expanded its production capacity by around 180% since 2000, yet at the current pace of usage, its whole capacity is almost depleted (McKinsey 2021). In the medium term, it is unlikely that the increasing demand will find supply. The major global producers are now increasing their production capacity, but this will take time for them to become operational because, despite the billions of euros required for the investment, it takes between 18 and 24 months for a manufacturing facility to start producing.

Ambitious national investment plans are centered on the semiconductors industry's global value chains (GVC). The US government authorized a $52 billion investment plan for domestic semiconductor production in June 2021. The goal of the European Commission's 2022 adoption of the European Chips Act is to double the EU's semiconductor market share from 10% to at least 20% by 2030. Intending to lure over $450 billion in investment from the private chip industry, South Korea approved up to US$65 billion in support for the semiconductor supply chain by 2030.

The World Bank's World Integrated Trade Solution (WITS) sector-level data on global value chain (GVC) integration offers insights into the degree of connectivity between the EU and GVCs in this particular industrial sector. The total GVC index calculates the amount of output (in million euros) that can be attributed to GVC links, indicating how connected a nation-industrial sector is to global value chains. This index is calculated for each country by averaging pure forward integration (the amount of domestic output exported overseas) and pure backward GVC integration (the amount of domestic output in the electrical and optical equipment sector that depends on imports, expressed in million euros). A country or region's dependence on foreign suppliers and clients increases with its level of backward GVC integration; it is the opposite with forward integration.



Source: JRC elaboration on World Bank data (WITS), data access Nov. 2021. Backward integration: amount of domestic output that depends on foreign imports. Forward integration: amount of EU output exported. Figures report the rescaled value for sums of the various indexes for all EU27 member states.

Figure 7 - The EU’s total forward and backward GVC integration

It is visible from these charts that the EU has become more dependent on other countries for electrical equipment in general. The next few figures show the EU’s trade balance and imports by country for specific products: (a) Diodes, transistors, and similar semiconductor devices, (b) Electronic integrated circuits, (c) Machines for the manufacture of semiconductors, and (d) Metals for the production of semiconductors. The source for all the data in these charts is compiled from Comtex.

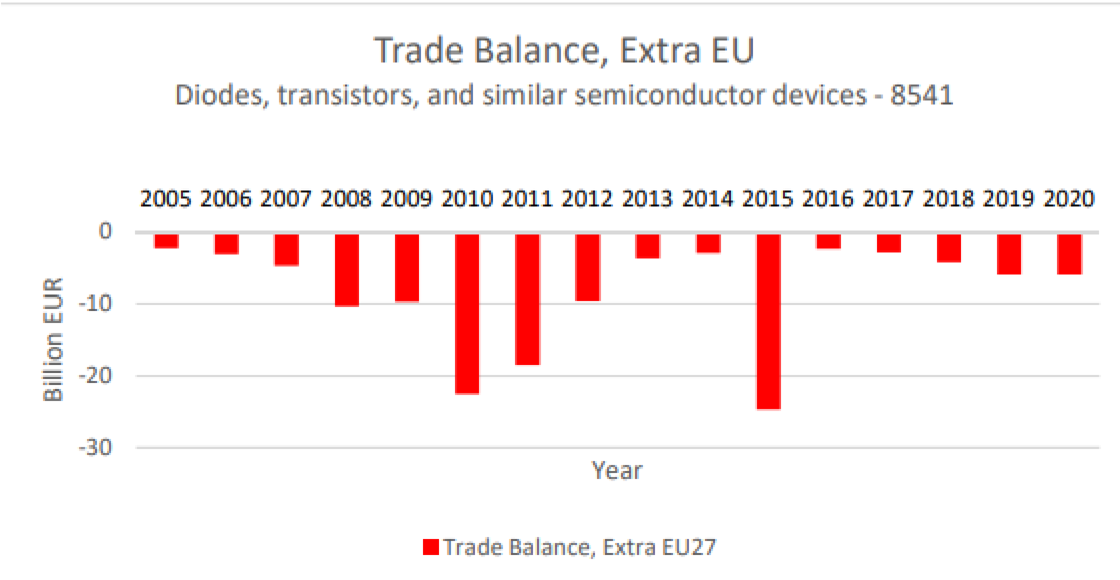


Figure 8

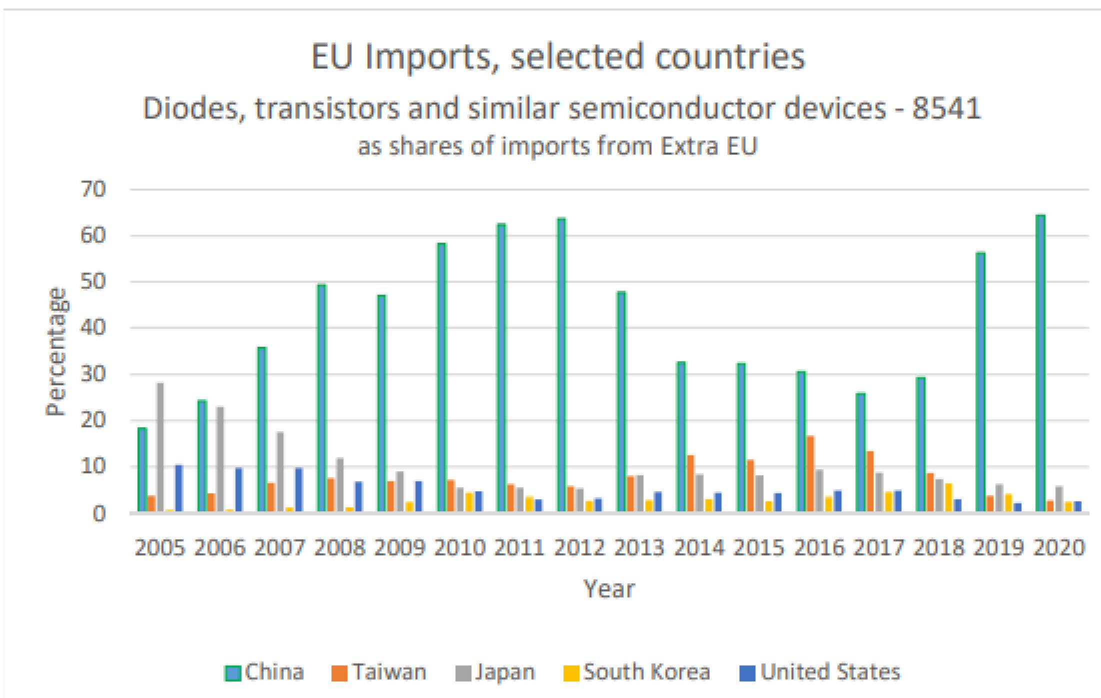


Figure 9

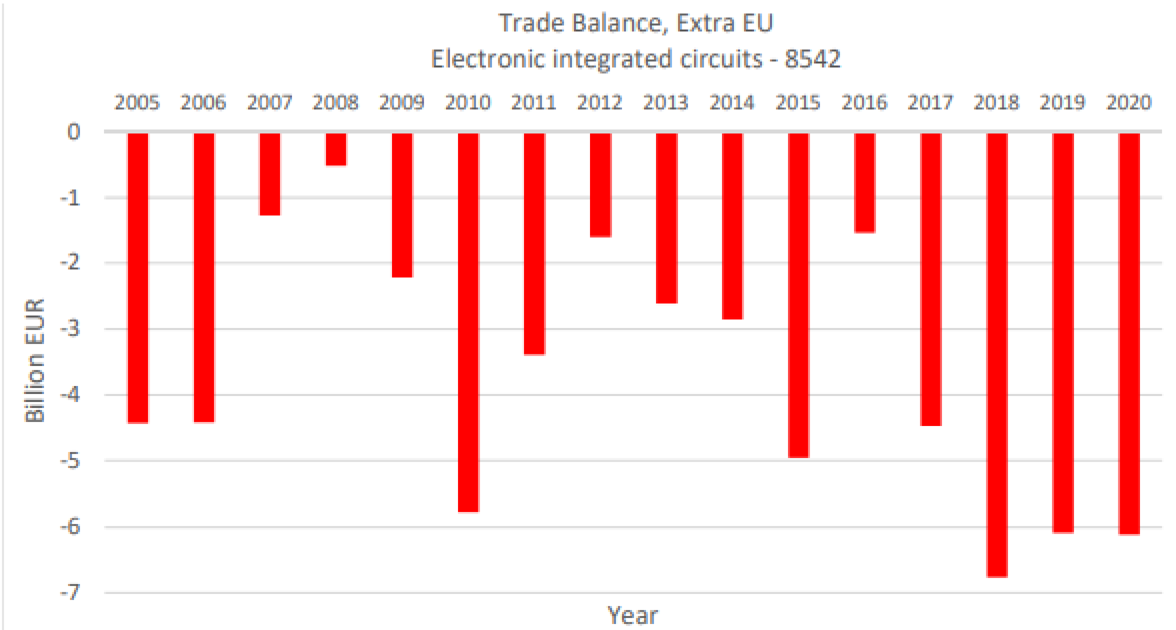


Figure 10

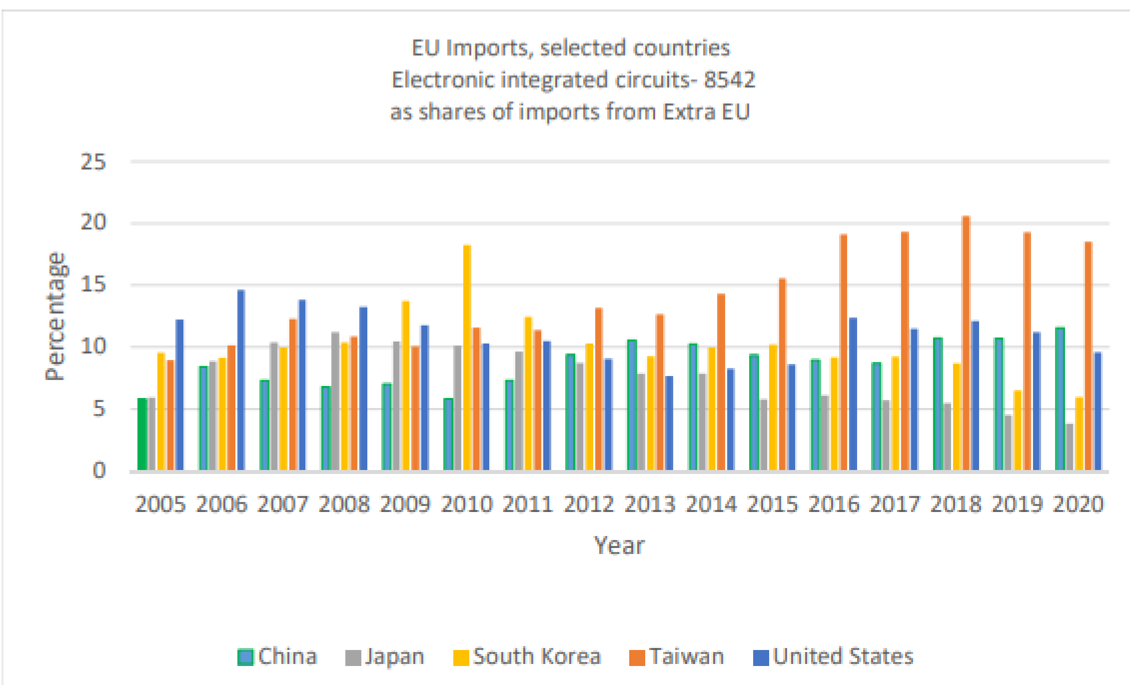


Figure 11

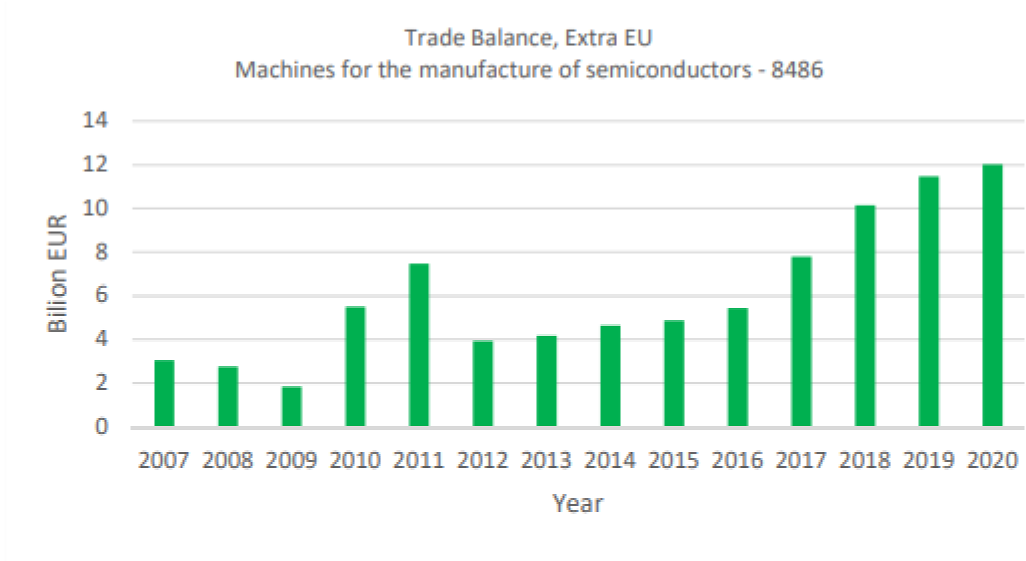


Figure 12

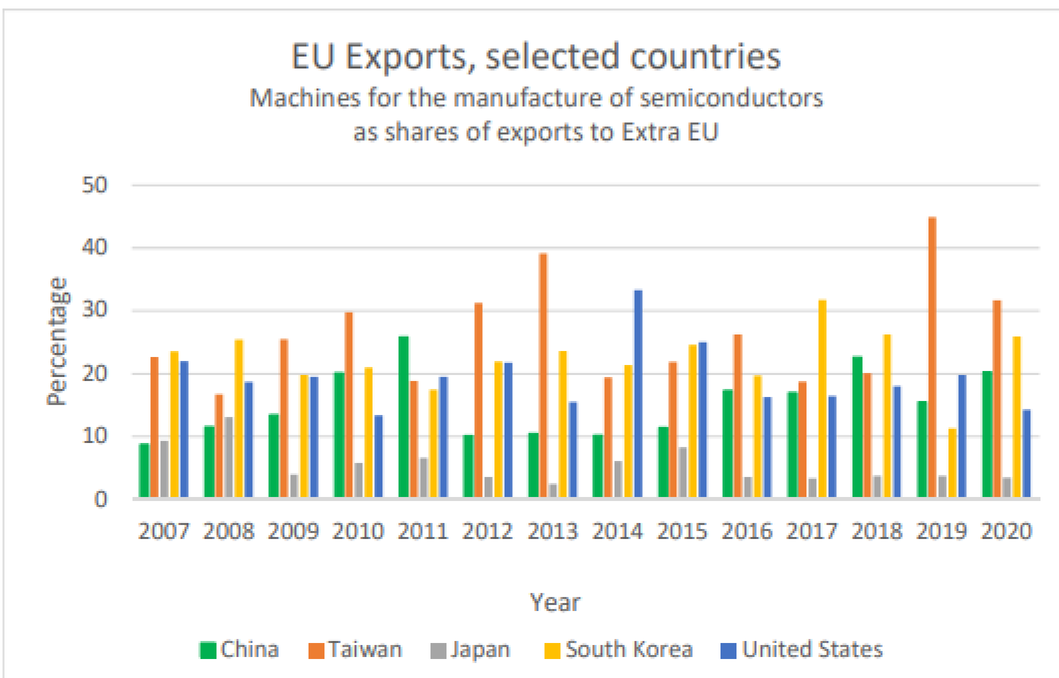


Figure 13

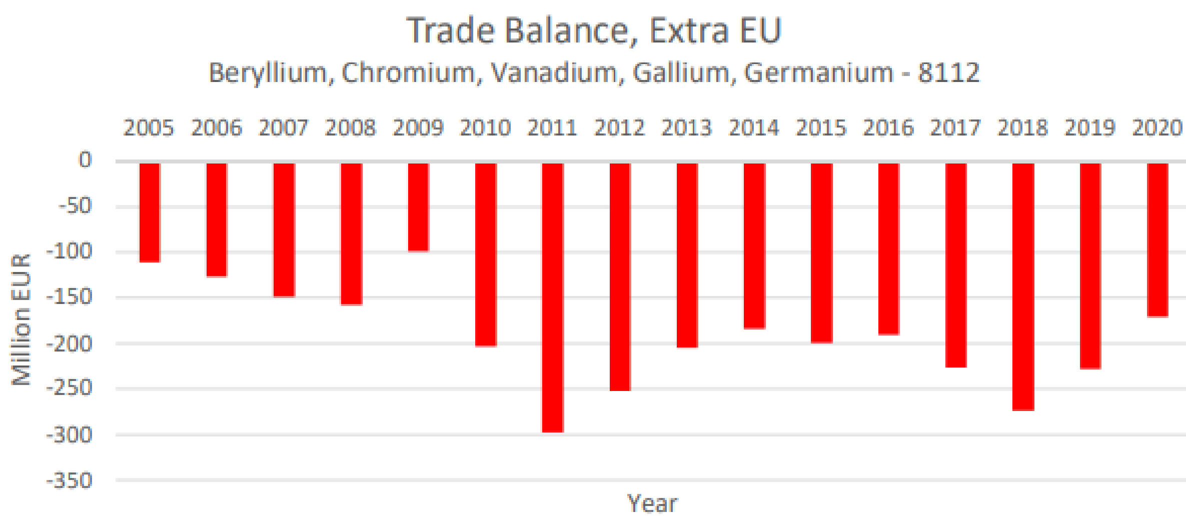


Figure 14

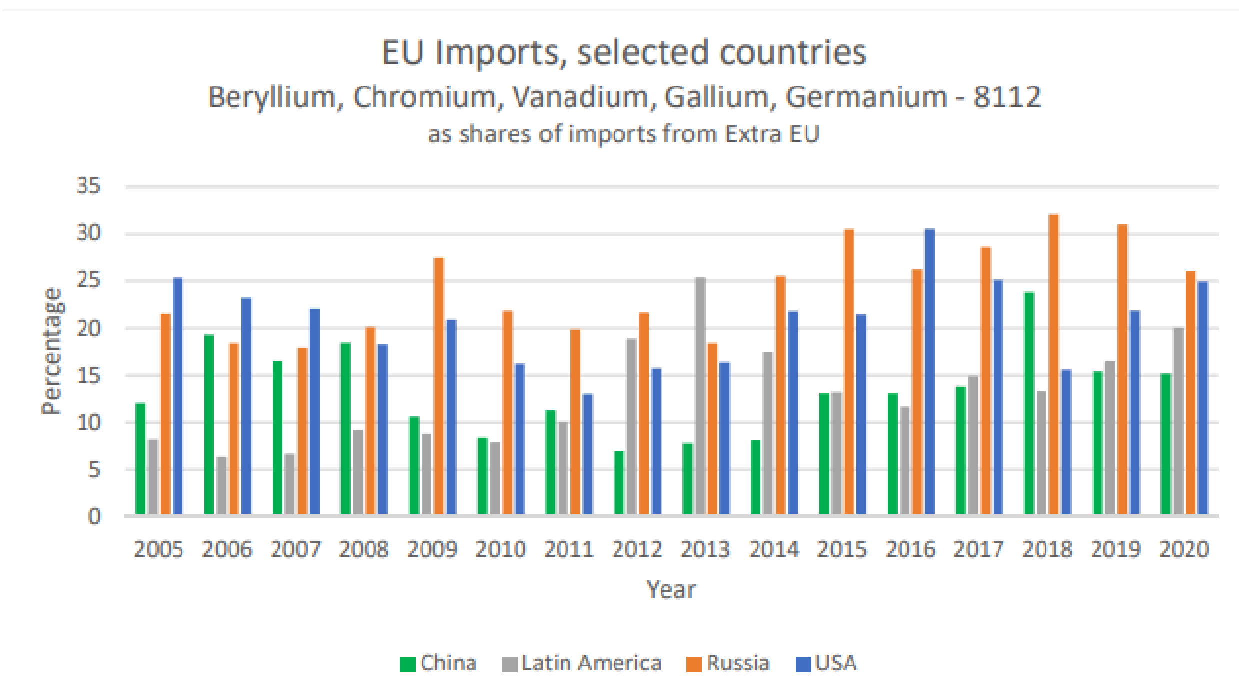


Figure 15

The EU is thus highly dependent on all but one category listed: machines for the manufacture of semiconductors, which it has been exporting increasingly more of in the past few years, with a value of 12 billion euros in 2020. This is primarily because of the contribution of several European manufacturers (including Trumpf, ASML, ASM, and Rhode and Schwarz), who have become industry leaders in machine production during the past ten years. Furthermore, the limited number of foundries now operating in the EU (mostly the German NXP and the French-Italian STM) explains the lack of machine imports from countries outside the EU and encourages European machine manufacturers to target East Asian markets.

Ambitious investment plans aim to enhance Europe's semiconductor industry and reduce dependency. Initiatives like the European Chips Act and national investment plans signal a commitment to bolstering domestic production. The Act seeks to increase Europe's share of global semiconductor production capacity from below 10% to 20% by 2030, thereby enhancing the region's technological sovereignty and competitiveness. Key components of the Chips Act include the establishment of the Chips Joint Undertaking, which builds on and renames the existing Key Digital Technologies Joint Undertaking. This public-private partnership aims to mobilize €43 billion in investments, including €3.3 billion from the EU budget, to support semiconductor research, innovation, and production. Short-term measures focus on crisis response and coordination between member states and the European Commission to mitigate the impact of the current semiconductor shortage. Medium-term measures aim to strengthen manufacturing activities within the EU and support the scale-up and innovation of the semiconductor value chain. Long-term measures prioritize maintaining Europe's technological leadership in the semiconductor industry through innovation and knowledge transfer. However, achieving self-sufficiency will take time due to the lengthy process of establishing manufacturing facilities.

The Chips for Europe Initiative, a significant part of the funding package under the Chips Act, aims to reinforce Europe's semiconductor technology and innovation capabilities. It will support initiatives such as deploying advanced semiconductor design tools, pilot lines for next-generation chips, testing facilities for innovative applications, and investments in quantum chip technology. To address the skills shortage in the semiconductor industry, the Chips for Europe Initiative will invest in education, training, and competence centers to develop a skilled workforce. Scholarships, incentives, and partnerships with academia and industry will promote diversity and inclusivity in the sector.

However, achieving self-sufficiency will take time due to the lengthy process of establishing manufacturing facilities, amongst other things. While the EU may be taking steps to increase its semiconductor production, so are other countries, especially the ones already mentioned are some of the main global suppliers (China, Taiwan, Japan, South Korea, USA, etc.). As was shown, the EU is dependent, but there are some upsides. As it's a big producer and exporter of machines for manufacturing semiconductors, there's hope that strategic independence can be achieved if obstacles such as the lack of CRMs necessary for semiconductors can be overcome.

1.1.2 Information and Communication Technologies

ICT serves as the backbone infrastructure for facilitating the collection, processing, transmission, and dissemination of vast amounts of data generated from various sensors, platforms, and command centers across the military ecosystem. AI algorithms rely on access to diverse and real-time data sources to analyze patterns, detect anomalies, and make informed decisions in support of military operations, intelligence gathering, and situational awareness. Secondly, ICT enables seamless connectivity and interoperability between disparate military systems, platforms, and stakeholders, allowing for the integration and coordination of AI-driven capabilities across different domains and operational environments. Thirdly, ICT facilitates the development and deployment of AI-enabled command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems, which serve as the nerve center for orchestrating and orchestrating military operations. ICT also facilitates the development and deployment of AI-enabled autonomous systems, unmanned platforms, and robotic technologies in military operations, including drones, unmanned ground vehicles (UGVs), and autonomous ships. These autonomous systems leverage AI algorithms to perceive, navigate, and adapt to dynamic environments, enabling them to perform a wide range of missions, including reconnaissance, surveillance, logistics support, and target engagement, with minimal human intervention.

While the criticality of materials holds for the entire European military-industrial landscape, modern electronics, and information and communication technology (ICT) devices, in particular, require a lot of CRMs. Europe is becoming more dependent on foreign technology and digital components as it lags in producing essential digital technologies. Large imports from China were a major factor in the EU's €23 billion total trade deficit for high-tech goods and components in 2017 (European Political Strategy Centre, 2019). The digital ICT industry has three primary characteristics when looking at raw materials (Ku, 2018). Firstly, it makes use of an ever-widening range of elements to provide the required mechanical, optical, magnetic, or electrical features for chips and devices. Second, the sheer volume of chips and devices that must be produced annually to achieve independence suggests that even small amounts of material can be used in some elements to meaningfully increase quantities compared to existing supplies. Thirdly, the pace at which new technologies are introduced can surpass the time frame linked to existing aspects of the supply chain.

To guarantee the correct operation of ICT equipment, other raw materials that are not employed in it are equally important and could even become crucial for the implementation of next-generation computing. Helium, for instance, is used to achieve the low operating temperature required for semiconductors, supra- and quantum computing technologies, which is very close to absolute zero. The massive volume of data generated and stored in data centers, enterprise infrastructures, and endpoints will be one of the key effects of the digitalization of equipment. The "global datasphere," which is the culmination of all of this data, is rapidly expanding and will be essential to the hyperconnectivity of military equipment. The requirement for more data will have a significant impact on data storage technology, particularly the need for more materials to produce memory. Based on (Ku, 2018) using cutting-edge technology like ferroelectric RAM would require up to 40 kilotonnes of platinum, or around 600 times the EU's current yearly consumption.

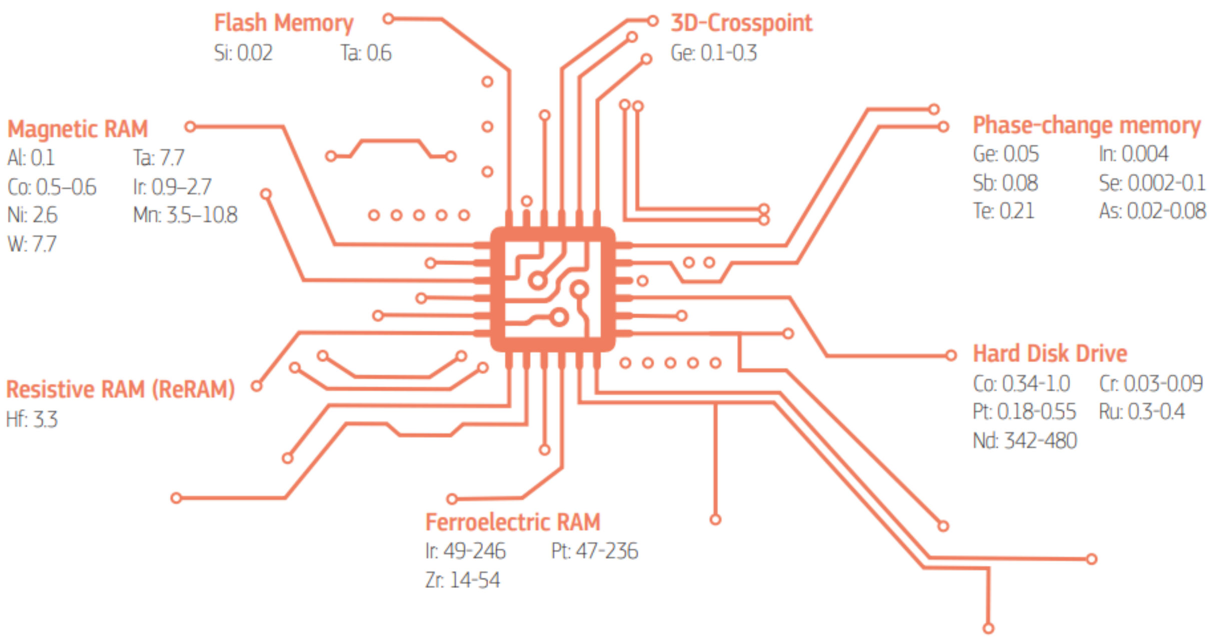


Figure 16 - Estimated materials intensity factors for different memory technologies. Amounts are in tonnes per Zetta-byte (Source: Ku 2018)

a) Metamaterials

Very important for modern antennas, as well as other advanced military communication technologies, are metametals. Future systems will have enhanced communication capabilities that better utilize the electromagnetic spectrum thanks to the employment of metamaterial-based communication technologies. Metamaterial-based antennas will be helpful in both offensive and defensive electronic warfare since they will boost power output, enhance directionality, and increase frequency range.

Moreover, metamaterials improve the fidelity and wide-area coverage of optical and infrared sensors, resulting in improved detection and identification. These materials also protect against a range of hazards, including weather, kinetic impacts, radioactivity, biological, and chemical agents, as well as stealth characteristics for protection and survivability.

As for the materials, we've established that the EU is heavily dependent on other countries. The other aspect of metamaterials, the production, also seems to be lagging behind major countries. While there are initiatives by the EU to address metamaterials (such as METRAMAT, and CoMetaS), there are long-term issues behind their production. There is a fundamental lack of knowledge of their design, integration at the component and system level, and reliability. The EU accounts for around 15% of the total metamaterial article and conference proceedings publications and citations, but it is still far behind in manufacturing. According to Figure 17, EU countries are nowhere to be seen as the top metamaterial patent publishers in the world.

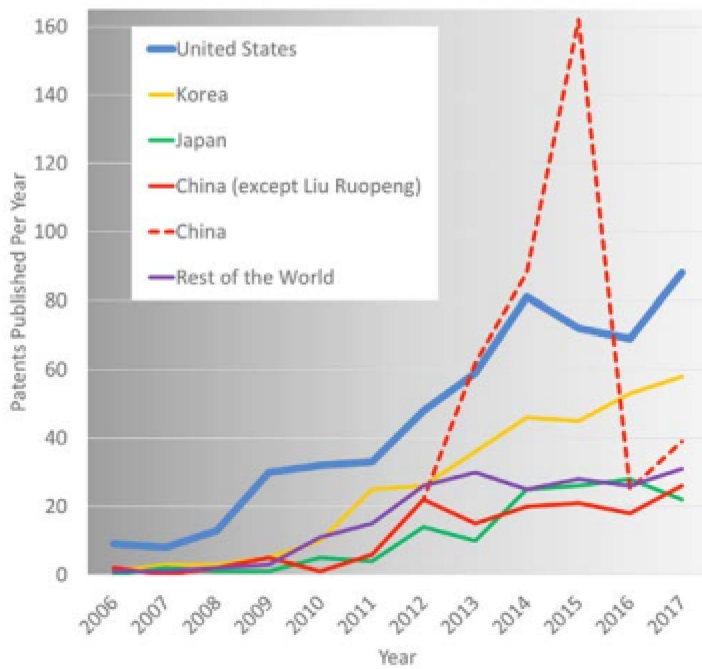


Figure 17 - Metamaterial patents published per year by country of origin

1.2 Advanced Materials and Manufacturing

The EU defense industry depends on a variety of materials with special qualities that make them indispensable for the production of parts used in military applications because using alternatives does not always ensure the same level of performance. For instance, REEs are essential to satellite communications, targeting lasers, precision-guided munitions, and remotely piloted aircraft systems. Specific basic elements like molybdenum, vanadium, or niobium are needed to make high-performing alloys that are used, for example, in the fuselages of combat aircraft. Titanium serves as the foundation for other alloys and offers excellent specific strength and resistance to corrosion while weighing just half as much as super-alloys based on nickel and steel. They are essential in aeronautical applications because of these qualities. Because beryllium is six times lighter and stronger than steel, it can be utilized as a lightweight alloy in jet fighters, helicopters, and satellites to save weight and increase maneuverability and speed. Beryllium is also used in gimbals, inner stage element joining in missile systems, and gyroscopes for missiles. Because of its exceptional stability, low coefficient of thermal expansion, high strength, high stiffness, low density, and excellent abrasion resistance, carbon fibers are also an essential component of military aircraft, strategic missiles, and satellites.

A top-down approach is used to identify the raw materials and processed materials used in the production of relevant European defense applications. The defense applications from the land, air, naval, space, electronic, and missile sectors are first broken down into subsystems and components. Upon examining the raw materials as the building blocks of alloys and compounds, 39 raw materials are found to be primarily required for their manufacturing, and therefore for the production of defense-related subsystems and parts. These basic materials are divided into four groups based on their chemical makeup and characteristics: metals, precious metals, rare earth elements, and non-metals. According to the most recent 2020 assessment by the European Commission, 22 of these 39 basic resources are crucial for the EU defense industry (Figure 18) (EC 2020).

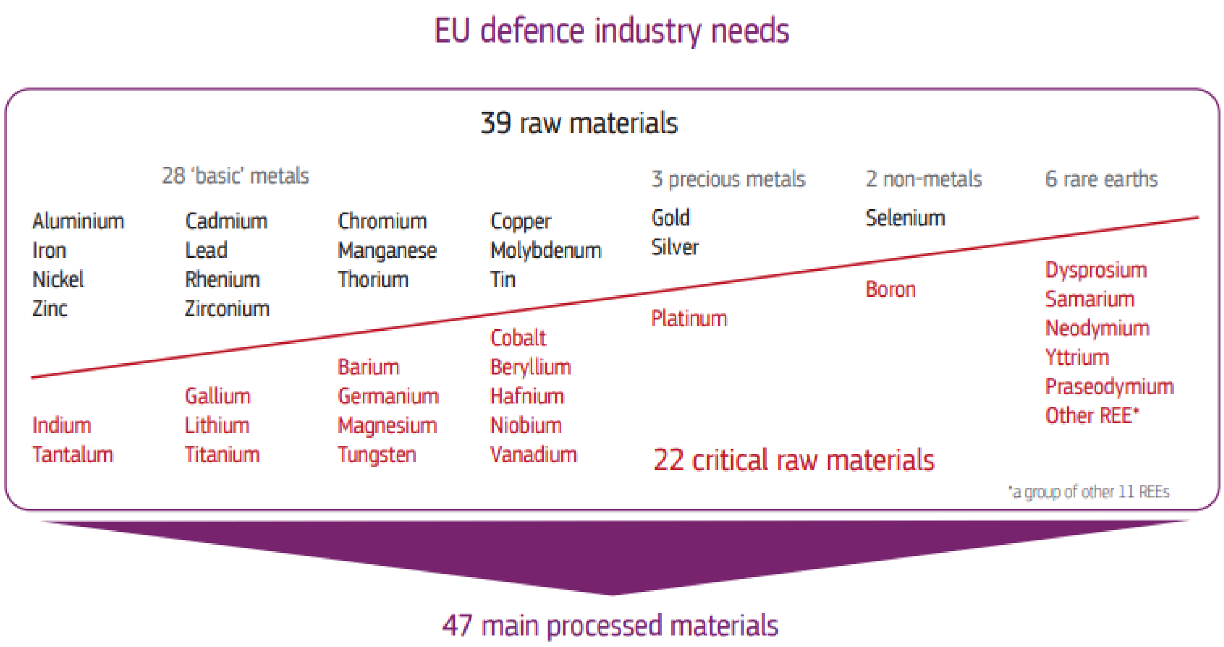


Figure 18 (Source: European Commission 2020)

Even though the amount of raw materials required for production in defense is generally small, some are exposed to supply security problems. The downstream provision of processed materials, including the know-how and transformation capabilities associated with materials processing, presents a unique challenge to the European defense sector. Although the EU has limited production capacity for specialty composite materials and their precursors, it is a major producer of alloys and special steel. Thirteen out of the 39 raw materials—namely, boron, dysprosium, gold, magnesium, molybdenum, neodymium, niobium, praseodymium, samarium, tantalum, titanium, yttrium, and other REEs—are entirely imported into the EU. In total, imports account for more than two-thirds of those raw materials. Aeronautics and electronics are the industries most susceptible to potential limits on the supply of materials (EC 2020).

On the next page is **Figure 19**, which shows the use in defense applications and the supply risk of raw materials used by the EU defense industry. The most critical materials are dysprosium, samarium, neodymium, praseodymium, and yttrium.

Supply Risk	Material	Aeronautics	Naval	Land	Space	Electronics	Missiles
6,20	Dysprosium	●		●	●		●
6,12	Samarium	●	●		●	●	●
6,07	Neodymium	●		●	●	●	●
5,67	Other REEs	●				●	
5,49	Praseodymium						●
4,20	Yttrium				●	●	
3,91	Magnesium	●	●	●	●	●	●
3,90	Niobium	●	●				●
3,89	Germanium			●	●	●	
3,19	Borates	●				●	●
2,54	Cobalt	●	●	●			●
2,22	Beryllium	●	●	●	●		
1,84	Platinum	●		●			
1,79	Indium	●			●	●	
1,69	Vanadium	●	●	●			●
1,64	Lithium	●	●	●		●	●
1,61	Tungsten	●	●	●	●		●
1,36	Tantalum	●				●	●
1,26	Titanium	●	●	●	●		●
1,26	Baryte	●		●		●	
1,26	Gallium	●			●	●	
1,12	Hafnium	●			●	●	
0,94	Molybdenum	●	●	●			●
0,93	Manganese	●	●	●	●		
0,90	Tin	●					
0,86	Chromium	●	●	●	●		●
0,83	Zirconium	●	●		●		●
0,68	Silver	●				●	
0,59	Aluminium	●	●	●	●		●
0,49	Nickel	●	●	●	●		●
0,46	Iron ore	●	●	●	●		●
0,45	Rhenium	●			●		
0,41	Selenium	●				●	
0,34	Cadmium	●					
0,34	Zinc	●	●		●	●	●
0,32	Copper	●	●		●	●	
0,19	Gold	●			●	●	
0,09	Lead	●	●			●	●

1.2.1 3D Printing (Additive manufacturing)

A new technology called 3D printing (3DP) is replacing existing manufacturing processes and challenging traditional supply chains. The term "3D printing" (3DP) refers to a broad range of technologies, including systems based on electron beam and laser melting, binder jetting and nozzle operations employing metal powders, wire and arc additive manufacturing (cladding) using metal wire, different types of laser polymerization, and other methods addressing the creation of polymer-based components (JRC 2019). 3DP offers a great chance of lowering supply risk for high-performing, low-weight assemblies and components. Particular benefits of 3DP include more design freedom and prototyping, significant weight reductions through optimized designs and more complicated geometries, and the ability to integrate customization into serialized production. Additionally, 3DP provides flexible decentralized production and the ability to fix existing parts. Due to the new technology's ability to eliminate numerous manufacturing phases, there have been substantial adjustments in several manufacturing sectors. The aerospace weight-saving potential is already rapidly developing, and in the defense sector, producing highly customized parts in remote places has numerous advantages that support tactical and strategic planning as well as troop field support. 3DP is developing quickly. Achieving adequate quality, cutting manufacturing costs, and maintaining production consistency—especially to fulfill industrial certification—are the main concerns.

The primary technologies for metal-based 3DP are electron beam manufacturing (EBM), binder jetting/nozzle systems (3DP and droplet deposition), direct energy deposition (DED) technologies, and powder bed fusion (PBF) using lasers. Except for 3DP of polymers and associated technologies, metal powders are used in most processes. The principal benefit of metal wire products, despite their lower level of development, is a more uniform dispersion of alloying materials and the ability to manufacture customized alloys through dual-wire feeding systems. Powders of aluminum-magnesium, titanium, nickel, stainless steel, and special alloys are the most commonly used alloy families. Specific amounts of extra alloying elements are used in these alloy families to provide a variety of material characteristics. Cobalt, hafnium, niobium, magnesium, scandium, titanium, vanadium, tungsten, and zirconium are the alloying elements that are most closely related to 3DP (EC 2020).

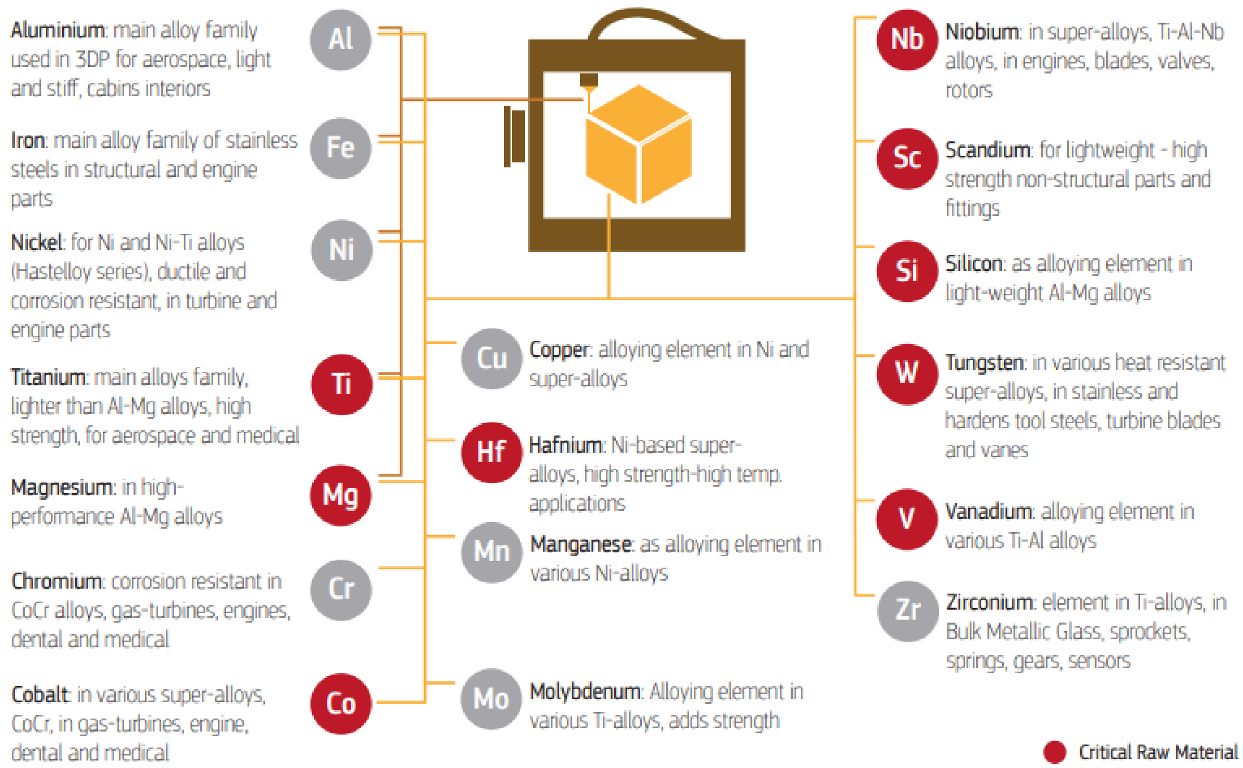


Figure 20 - Raw materials used in 3D printing (European Commission 2020)

About 30% of the raw materials needed for 3DP come primarily from China, which includes 7 of the 16 raw materials used for 3DP. According to the EU 2017 CRM list, 4 of the 7 CRMs identified for 3DP—magnesium, vanadium, tungsten, and scandium—come from China. Two other important suppliers of CRMs are Brazil and South Africa. There is very little (1%) supply of 3DP-relevant CRMs from European countries. For titanium, cobalt, magnesium, vanadium, tungsten, and niobium, supply threats are very significant. Furthermore, there exist noteworthy risks associated with scandium, hafnium, and zirconium, particularly in super-alloys meant for space applications.

The EU can supply processed materials because of its robust metallurgical capabilities. This is especially true for special alloys, stainless steel, and nickel alloys. But there aren't many suppliers of metal powder in the world. The availability of a large number of components is likely to be directly and severely impacted by any supply issues in one of these early phases of material manufacturing. In the past, the European Union has been comparatively well-represented, accounting for roughly one-third of the providers of 3D printing systems, including polymer systems. Any raw material disruptions would greatly diminish the EU's position regarding additive manufacturing (EC 2020).

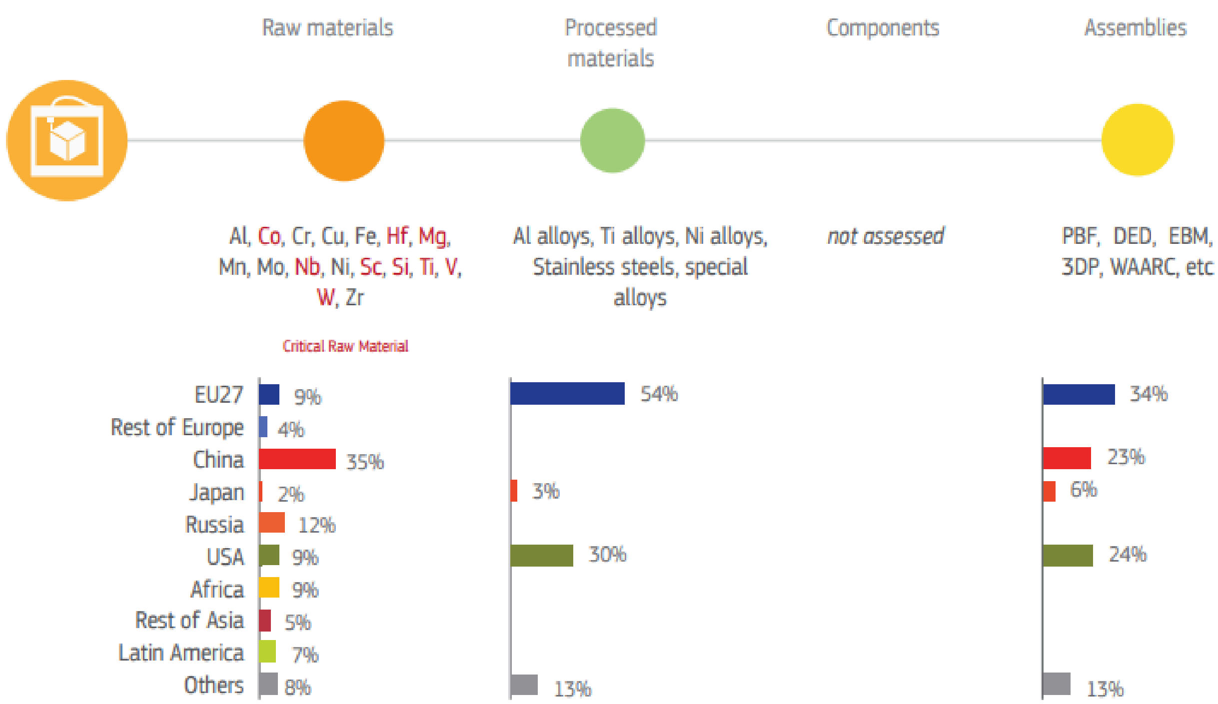


Figure 21 - 3D printing: Supply chain issues, bottlenecks, and key players (European Commission 2020)

1.3 Energy and Propulsion

1.3.1 Energy Weapons

Energy weapon systems, like [directed energy weapons](#) (DEWs) offer several distinct advantages over traditional kinetic weapons, including precision targeting, rapid engagement, reduced collateral damage, and enhanced effectiveness against a wide range of threats. By harnessing electromagnetic energy in various forms, such as lasers, microwaves, or particle beams, energy weapons can deliver destructive force with unparalleled speed and accuracy, making them valuable assets in modern warfare scenarios. One of the primary uses of energy weapons in the modern military industry is for air and missile defense. DEWs and laser weapons are capable of intercepting and neutralizing aerial threats, including aircraft, drones, missiles, and artillery shells, with precision and efficiency. By delivering high-energy beams at the speed of light, these weapons systems can disable or destroy incoming threats in real-time, providing a critical layer of defense against airborne and ballistic threats. Additionally, energy weapons are employed for ground-based applications, including perimeter defense, force protection, and counter-unmanned aerial system (C-UAS) operations.

Furthermore, energy weapons offer unique advantages in asymmetric warfare and counterinsurgency operations. Their ability to deliver precise and scalable force enables military forces to engage adversaries with minimal collateral damage and civilian casualties, thereby reducing the risk of escalation and public backlash. Energy weapons also play a critical role in space-based applications, including satellite defense, space surveillance, and anti-satellite (ASAT) operations.

There are multiple different types of lasers, and not all of them require rare earth elements to operate. For example chemical lasers utilize exothermic chemical reactions to produce a population inversion necessary for lasing. This inversion occurs when the chemical reaction favors higher internal energy states, leading to more excited molecules than ground state ones. One example is the reaction between atomic fluorine and molecular hydrogen, producing vibrationally excited hydrogen fluoride. Key requirements include: efficient mixing of reactants, such as hydrogen and fluorine, at high pressure and temperature, followed by supersonic expansion to cool the flow and maintain dissociated fluorine atoms. The laser cavity is designed perpendicular to the gas flow, enabling efficient lasing. Chemical lasers, like HF and DF lasers, operate in the infrared spectrum, with wavelengths typically opaque to the Earth's atmosphere, although DF lasers offer atmospheric transmission advantages. Successful implementations include MIRACL and THEL, achieving megawatt-class power outputs, showcasing their potential for both military and space-based applications.

Another example are Free Electron Lasers (FELs), which harness the kinetic energy of accelerated electrons to generate coherent laser radiation by passing them through a wiggler, a series of magnets. This induces energy modulation in the electron bunch, leading to coherent radiation emission across a wide range of wavelengths. FELs offer versatile tunability by adjusting either the electron beam's kinetic energy or the magnetic field strength. They boast high peak powers without thermal lensing issues, making them attractive for various applications, including laser weapons. However, FELs face challenges in terms of size, weight, and cost, particularly as the required electron beam energy increases for shorter wavelengths (G. Perram 2004).

However, the ones most commonly used are Solid-state lasers (SSLs), which encompass various designs including heat-capacity, fiber, and continuously cooled lasers, with key material requirements revolving around the host crystal, commonly yttrium aluminum garnet (YAG). YAG offers high thermal conductivity and mechanical strength, ideal for SSL applications. Optical transitions occur on energy levels of rare-earth ions like neodymium (Nd) and ytterbium (Yb) doped into the crystal, enabling efficient pumping with laser diode arrays. SSLs find applications in laser weapons, track illuminators (TILL), and beacon illuminators (BILL), where Nd:YAG and Yb:YAG systems are commonly used. Challenges include thermal management to mitigate issues like thermal lensing, addressed through innovative designs such as slab lasers and heat capacity lasers, utilizing materials like gadolinium gallium garnet (GGG) and diode pumps with high electrical-to-optical efficiency (G. Perram 2004).

The following are the main components of energy weapons and their material requirements:

- Laser gain medium: synthetic crystals such as ruby, and yttrium), semiconductors, and gases
- Optical coatings: dielectric materials such as magnesium, fluoride, tantalum pentoxide
- Lenses and mirrors: glass, silica, and crystalline substrates such as silicon
- Beam splitters: gold, silver
- Mounting structures: aluminum, stainless steel, carbon fiber polymers
- Cooling systems: copper, aluminum
- Semiconductors
- High-voltage capacitors: ceramics, polypropylene
- Batteries
- Microprocessors
- Sensors

Out of these, yttrium, magnesium, and tantalum are considered critical raw materials in danger of supply chain dependencies for the European Union. Glass and ceramics are processed materials fairly restricted by the supply chain, produced about equally by the EU, China, and the USA. Silicon is not a particular supply chain risk. Crystalline and carbon fiber polymers are of critical economic importance in the EU since they are mainly refined in China (EC 2020).

Yttrium alluminium garner is crucial for the production of military lasers. There materials are used in small amounts, but are crucial to ensure specific physical properties, and are highly dependent on imports from outside the European Union. Neodymium is also at a high supply chain risk for the EU. As is illustrated in Figure 3, a majority of the EU's processed scandium is imported from China, which processes 67% of the world's scandium.

1.3.2 Nuclear Microreactors

Nuclear microreactors are integral to the modern military industry, offering unique advantages and applications. These compact nuclear reactors provide reliable power generation capabilities in remote or austere environments, enhancing energy independence and resilience for military installations and operations. Their compact size and mobility enable deployment on land, sea, or air platforms, supporting diverse mission requirements and operational scenarios. With nuclear energy becoming more popular again, combined with the recent technological progress and the amount of power new military technologies are going to consume, portable nuclear reactors might be increasingly more important for the modern military.

Microreactors, especially those designed with innovative concepts like graphite monolith cores, require specific raw materials tailored to their unique operational and safety requirements. Cladding materials, such as molybdenum, are essential for heat pipes within the reactor core to ensure thermal stability and structural integrity. Yttrium hydride serves as a solid high-temperature moderator, enabling controlled neutron reactions essential for power generation. For nuclear thermal propulsion systems, materials like uranium-titanium-carbon systems are crucial for fuel, providing efficient energy release for deep space exploration. Similarly, cermets composed of uranium nitride and molybdenum-tungsten alloys are studied for such applications due to their thermal stability and fuel retention capabilities. Molten salt reactors utilize materials resistant to corrosion by molten fluoride or chloride salts, necessitating careful selection of suitable metals. Finally, for compact reactors intended for remote or space applications, materials like thorium-uranium-nitrogen systems are explored for their neutronic behavior and thermophysical properties, essential for safe and efficient energy generation in constrained environments.

Main components of nuclear microreactors and their material requirements:

- Fuel: uranium, plutonium
- Coolant: hydrogen, oxygen, deuterium, sodium, lead
- Control rods: boron, cadmium, hafnium
- Reactor vessel: iron, chromium, nickel
- Heat exchanger: copper, aluminum
- Turbine and generator: steel, copper, iron, cobalt, other rare earths
- Shielding: concrete, lead, boron

Out of those mentioned, boron, hafnium, and cobalt are critical raw materials most lacking in the EU for the production of nuclear microreactors. Yttrium is also at a high value chain risk. As for uranium and plutonium, essential for the reactors, the supply is questionable. Over 91% of natural uranium in the EU in 2022 came from four producing countries: Kazakhstan, Niger, Canada, and Russia.

1.3.3 Hypersonic Missiles and Aircraft

Hypersonic missiles are characterized by their ability to travel at speeds exceeding Mach 5 (five times the speed of sound) or higher, making them significantly faster and more maneuverable than traditional ballistic or cruise missiles. This extraordinary speed and maneuverability enable hypersonic missiles to penetrate enemy defenses with reduced warning time, striking targets with unparalleled precision and lethality. Furthermore, hypersonic missiles offer enhanced flexibility and versatility in both strategic and tactical operations. Their ability to travel at hypersonic speeds enables rapid response and long-range strike capabilities, allowing military forces to engage time-sensitive targets with minimal risk and maximum precision. Similarly, hypersonic aircraft represent a revolutionary advancement in military aviation, offering sustained flight at hypersonic speeds within the Earth's atmosphere. These cutting-edge aircraft leverage advanced propulsion systems, such as scramjets or ramjets, to achieve hypersonic velocities and maneuverability, enabling rapid deployment, long-range reconnaissance, and precision strike capabilities.

Hypersonic missiles and aircraft demand materials with exceptional thermal resistance, structural integrity, and mechanical properties to withstand the extreme conditions encountered during flight. Refractory metals like tungsten, molybdenum, and niobium are vital for their high melting points and strength at elevated temperatures. Carbon-carbon composites provide excellent thermal resistance and structural integrity for leading-edge surfaces and propulsion components. Nickel-based superalloys offer exceptional mechanical properties and resistance to high-temperature oxidation for components subjected to extreme thermal and mechanical loads. Ceramic thermal protection systems, including ablative composites, silica tiles, and carbon phenolic, are crucial for thermal insulation and protection against aerodynamic heating. High-temperature polymers such as polyimides and polybenzimidazoles with enhanced thermal stability and mechanical strength are utilized for specific structural and thermal management applications. Additionally, heat-resistant coatings like ceramic-based coatings and thermal barrier coatings (TBCs) are applied to surfaces exposed to high temperatures to improve durability and thermal protection. Advanced alloys such as titanium aluminides and intermetallic compounds provide high strength, corrosion resistance, and lightweight properties for critical components in engines and airframes. Moreover, ceramic matrix composites (CMCs) offer a combination of high strength, stiffness, and thermal stability suitable for use in engine components, thermal protection systems, and structural applications.

Components and material requirements of hypersonic missiles/boosters:

- Airframe: carbon fiber polymers, epoxy resins, titanium, aluminum, and ceramic matrix composites
- Propulsion: nickel-based superalloys, ceramic composites, tungsten, molybdenum
- Thermal protection: silicon carbide, carbon composites, ceramic fibers
- Guidance and control system: aluminum, titanium
- Payload: steel & aluminum alloys

Carbon and ceramic composites are critical materials the EU is severely lacking. Tungsten, titanium, and silicon are classified as CRMs but are not considered a supply risk (EC 2020). Out of those not mentioned in the previous chapters, niobium is a CRM with a moderate supply risk.

1.4 Robotics

Robotics present both hardware and software technological challenges. Using complicated software systems to accomplish ever more intelligent tasks is one of the challenges associated with software. On the hardware front, more advancements in system (robot) and component-level design are required to tackle these challenges. Particularly for exoskeletons, main components like gears, motors, power units, etc., must get lighter and smaller. A further difficulty for exoskeletons is to develop electronics that are more compact, powerful, fast, and precise.

One vital part of robots are their sensors. [Components](#) can now be made lighter and smaller thanks to new materials. For example, the creation of novel materials (such as those based on vanadium) may aid in the development of miniature, multipurpose motors and artificial muscles. Electric motors and batteries, among other energy sources, need to be made smaller and more efficient because exoskeletons depend on them. Because of their advantageous strength-to-weight ratios, light metal alloys like titanium, magnesium, and aluminum alloys—which are typically used alongside composites like CFCs, Kevlar, polymer–metal composites, etc.—are particularly attractive for robotics applications. Other cutting-edge materials that could revolutionize the field of robotics include printed liquid metals, metallic glass, and liquid silicone rubber.

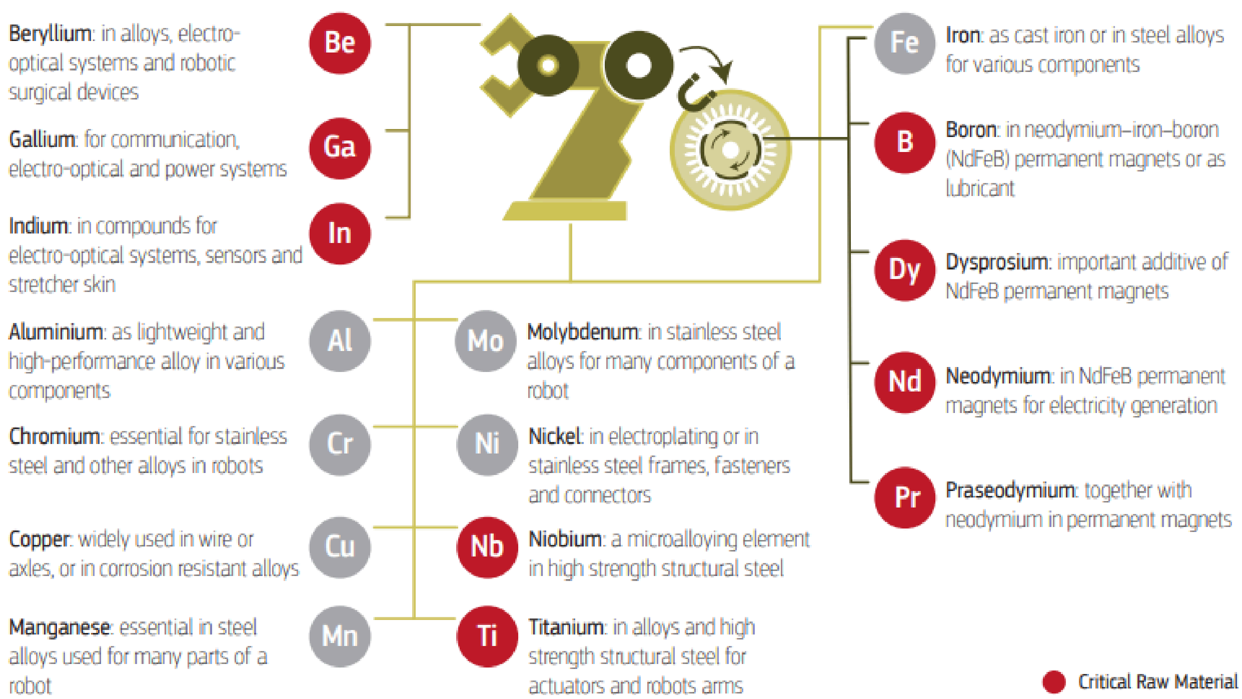


Figure 22 - Relevant raw materials for robotics (European Commission 2020)

For interactive robots, new materials and techniques for creating electronic skin are being developed. The synthesis of innovative materials, such as composites of soft materials with conductive fillers, or clever structural engineering and designs, such as serpentine-like architectures for interconnects or wires, are used to realize flexible (stretchable) electronics. The ability of the material to endure mechanical strain and retain sensing ability or electronic properties, such as the fragility of sensors, the time it takes for them to recover, repeatability, overcoming mechanical strain, and long-term stability, is one of the main challenges facing the development of electronic skin. Multifunctional materials that integrate functions like sensing, mobility, energy harvesting, and energy storage are necessary for more efficient robot designs. These materials can adapt and heal over time.

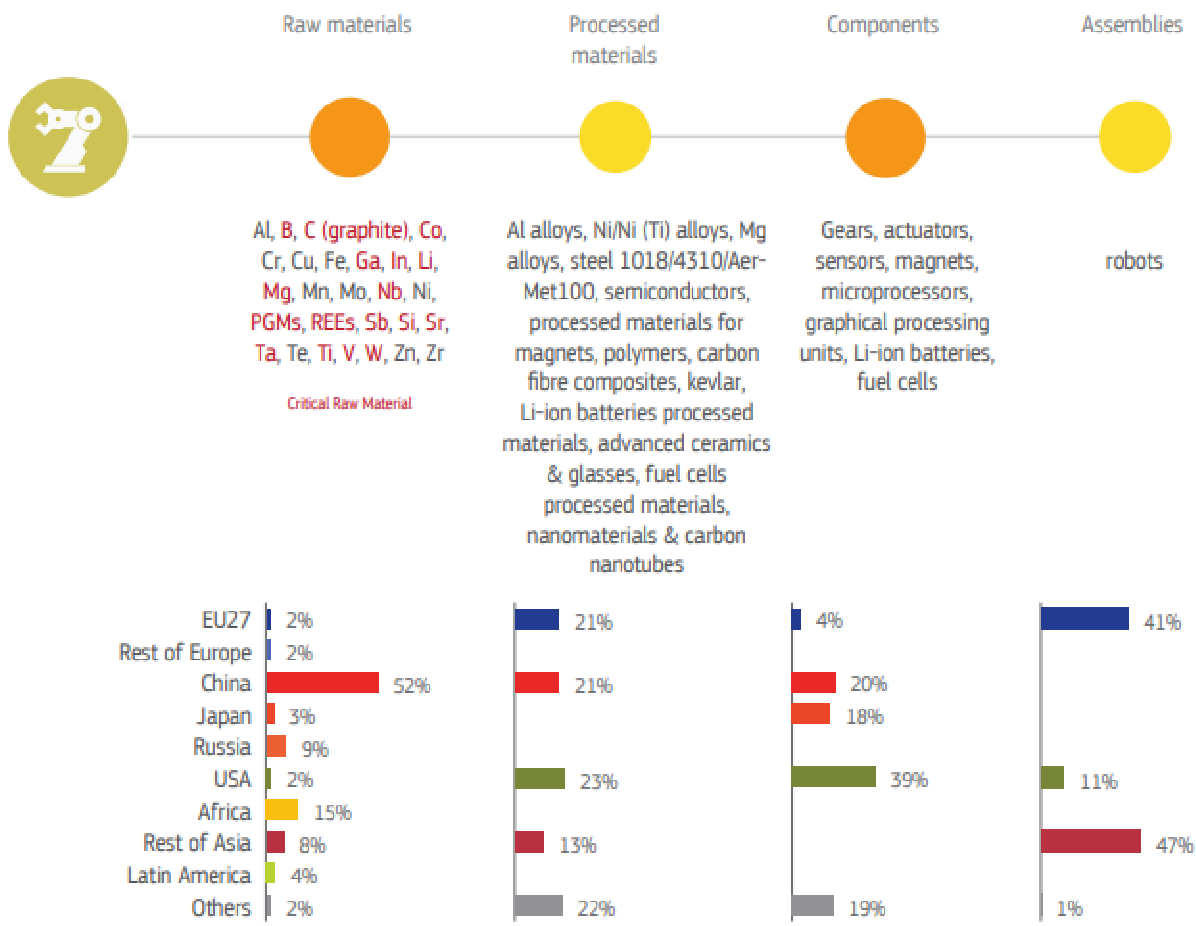


Figure 23 - Supply chain risks and bottlenecks for robotics (European Commission 2020)

There is a medium risk associated with the supply of processed materials and assemblies and a high risk associated with the supply of raw materials and components. 44 raw materials are essential to robotics. The EU depends entirely on outside sources for 33 of these. With 52% of the world's supply of raw materials for robotics, China surpasses South Africa and Russia in this regard. Merely 2% of the essential components are produced in the EU. Of the 44 raw materials, 19—titanium, tungsten, phosphorous, fluorspar, ruthenium, rhodium, gallium, indium, borate, palladium, platinum, REEs, bismuth, antimony, vanadium, magnesium, natural graphite, silicon metal, and cobalt—have been identified as essential to the EU military industry.

Together with the USA and China, the EU is among the top producers of processed materials (>20% share of production). Diversifying the source of the processed materials stands as an option. It should be pointed out, nonetheless, that the EU is entirely dependent on the supply of many processed materials used in robotics, including semiconductors, certain aluminum alloys, and aramid (Kevlar) fiber, the latter of which is mostly supplied by the USA and India. Furthermore, the supply of certain steels needed for robotics as well as processed materials for Li-ion batteries can encounter bottlenecks (EC 2020).

1.5 Aviation

1.5.1 Aeronautics

The aeronautics sub-sector of the defense industry is confronting the greatest obstacles since it needs a lot of highly specialized, complicated, and novel materials, like alloys and composites in addition to titanium, graphite, or fiberglass. The term "aerospace materials" also refers to materials used in aeronautic applications. The most important ones are the following: super-alloys, ceramics, glass laminate aluminum reinforced epoxy (GLARE), magnesium, and special alloys; alloys made of steel, titanium, aluminum, and composite materials. As the aeronautics industry has developed, new lightweight materials like titanium alloys, composite materials—especially those made of glass and carbon fibers—and high-temperature-resistant plastics have gradually replaced previously used materials like metals and metal-based alloys. To put it into perspective, up to 50% of modern aircraft are made of composite materials. When compared to conventional materials, these materials have stronger properties that result in greater resistance and lower weight. This results in increased maneuverability and long-range independence (low fuel consumption) of jet fighters for the defense sector.

The entire value chain of materials is covered by firms in the European alloy industry. These businesses produce, process, and distribute special high-performance alloys to a broad range of end users, including the defense industry. Unfortunately, the EU lacks significant producers of aerospace-grade carbon fibers and their precursors, such as polyacrylonitrile (PAN), which are presently mostly produced in the USA and Japan and are required for composite materials. There is now a possible low-to-moderate supply chain bottleneck for aerospace materials and other semi-finished materials required by the EU defense industry, even though the EU produces a small amount of all materials used in defense applications (EC 2020).

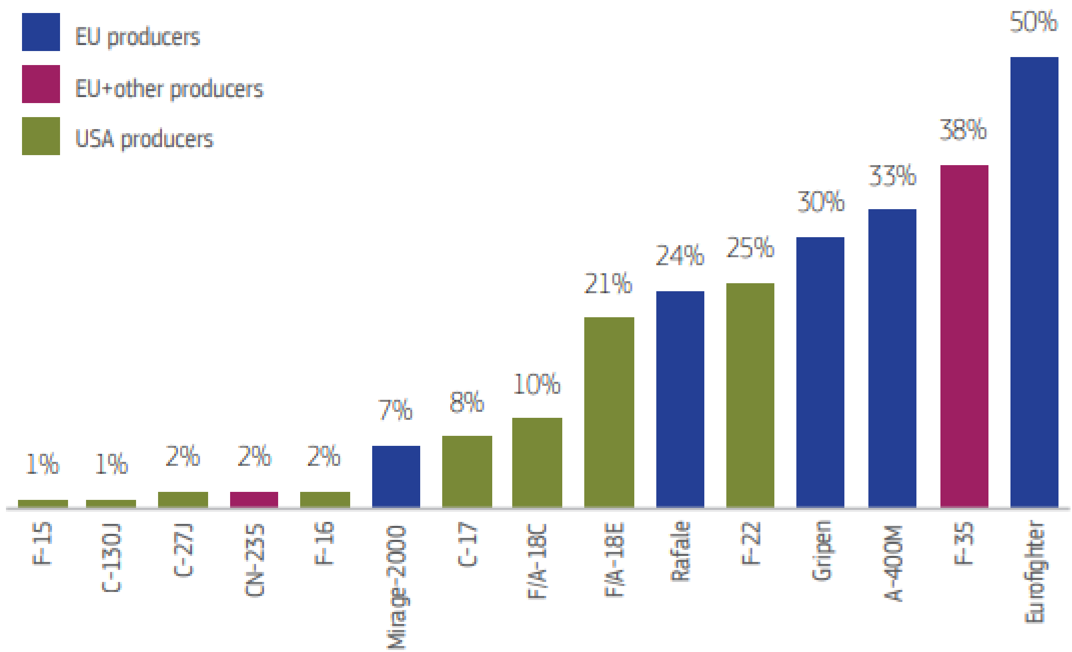


Figure 24 (European Commission 2020)

1.5.2 Unmanned Aerial Vehicles

Large Unmanned Aerial Vehicles (UAVs) already dominate the defense sector, and this is projected to continue for the next twenty years. The use of drones has increased in the defense sector in recent years. Embedded computing, cyber security, C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance), and UVs have important applications with potentially expanding markets. Drones, like any modern aircraft, are made up of several parts, sometimes as many as several hundred, to realize these applications. Given that drones are essentially a type of robot, their compositions are similar.

Larger UAVs' dimensions, technologies, and materials are similar to those of manned aircraft. Drone production involves a wide range of materials due to their sophisticated systems. 48 raw materials are considered relevant. Out of those 48, the EU is dependent on the supply of 40 of them. The materials of special significance are niobium, which is primarily supplied by Brazil, and REEs, magnesium, bismuth, and tungsten, all of which are primarily supplied by China. The EU has identified 15 materials as critical, including the materials groups of REEs and PGMs, as well as cobalt, lithium, titanium, silicon, natural graphite, magnesium, vanadium, antimony, bismuth, borate, indium, gallium, tungsten, tantalum, niobium, beryllium, and hafnium. China provides more than 39% of the CRMs for UVs, making it the main supplier. With a 13% and 6%

share of global manufacturing, respectively, South Africa and Russia are the next two largest exporters of CRMs. 13% of CRMs come from countries in Europe (EC 2020).

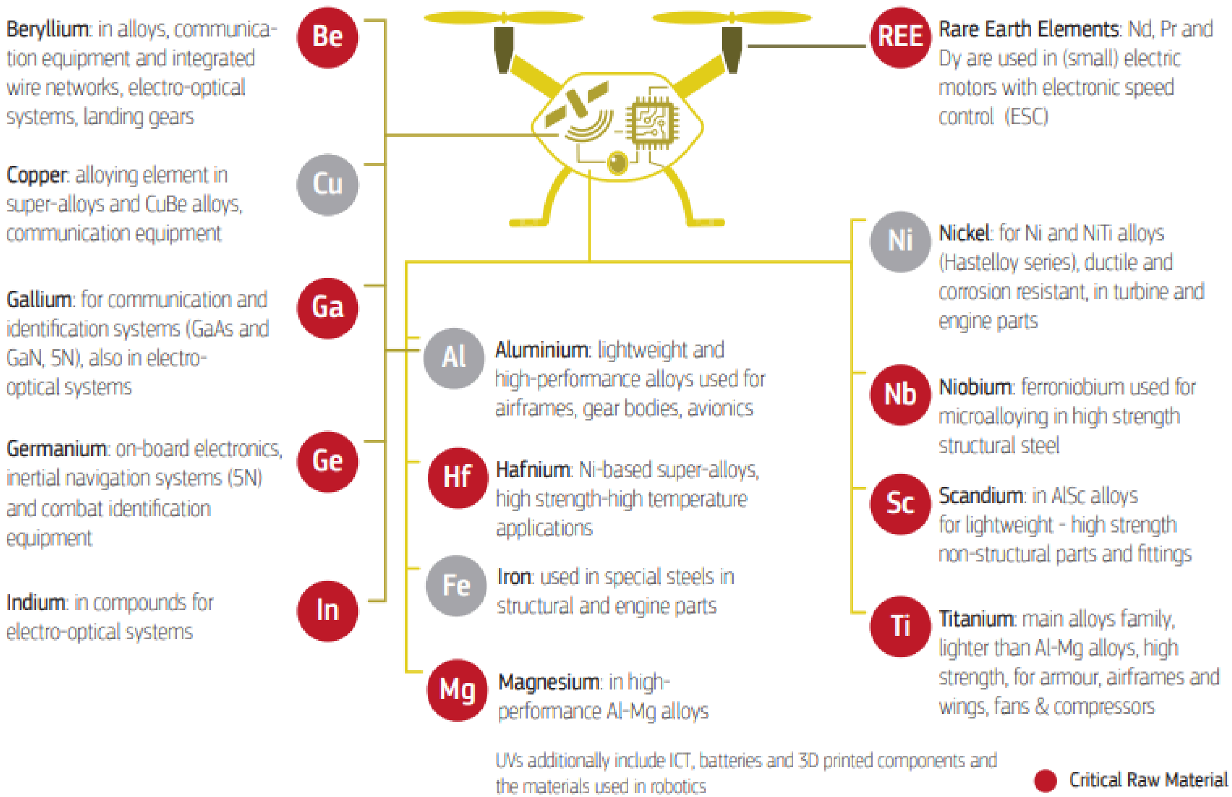


Figure 25 - Relevant raw materials for drones (European Commission 2020)

Aluminum alloys, magnesium alloys, nickel alloys, nickel-titanium alloys, titanium alloys, specialty steels, high-performance alloys, refractory metals, composites (CFCs), aramid (Kevlar) fibers, semiconductors, ferroniobium, and magnetic alloys are the 14 processed materials that have been identified to be relevant to drones. Processed materials for lithium batteries, motors, and FCs are also taken into account in the "processed materials" supply-chain step, much like in robotics (EC 2020).

With a share of more than 27%, the EU is in a strong position in the UAV supply chain when it comes to the supply of processed materials. The rest of the processed materials are supplied by other countries. The EU has a global manufacturing share of over 30% for seven relevant processed materials, and it even controls the majority of the global supply of some alloys (such as titanium, high-performance, and aluminum-magnesium alloys). Europe's worldwide production share for the remaining materials, however, is less than 20%, suggesting that supply sources may need to be diversified. Due to their small shares in worldwide production, the EU shows a large reliance on imports for several processed materials, including semiconductors, aramid fibers (Kevlar), and ferroniobium (EC 2020).

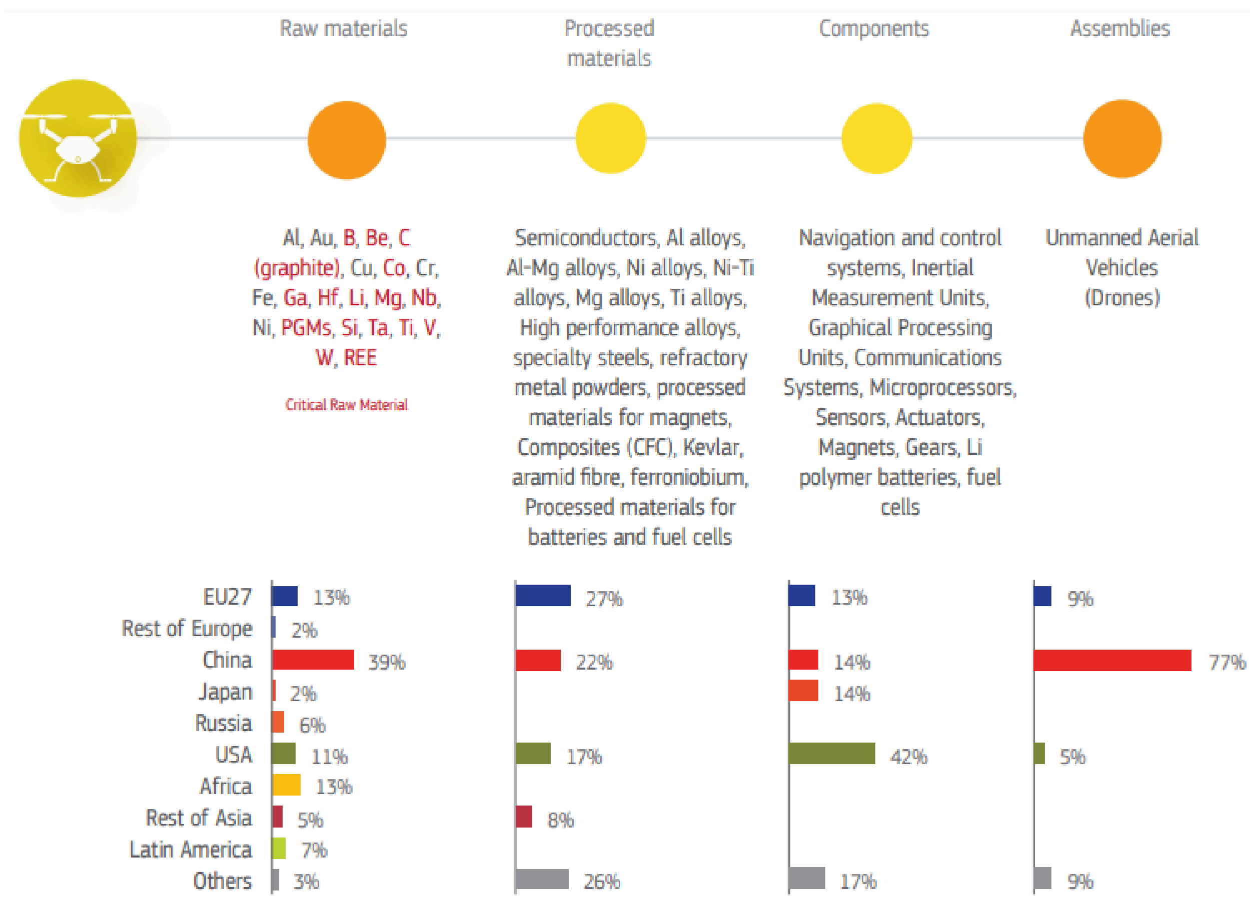


Figure 26 - Supply risks and bottlenecks for unmanned vehicles (European Commission 2020)

The USA (42%), by far, is the biggest producer of drone components. Depending on the particular component categories, the EU's picture is quite diverse. The European Union (EU) has a substantial global share of sensors, navigation and control systems, and Inertial Measurement Units (IMUs) (all >20%). It even leads globally in communications system production. The EU holds no less than 11% market share in actuators. Nonetheless, the EU is heavily dependent on imports for the remaining five components. The main provider of FCs, sensors, and gearboxes is Japan. Lithium polymer batteries and sensors are primarily supplied by China. Other important suppliers are Canada (FCs, IMUs, navigation and control systems), South Korea (microprocessors and FCs), and Israel (actuators). Potential supply bottlenecks relate to specific components, the manufacture of which is centered in a small number of countries worldwide.

Actuators, gears, GPUs, and microprocessors are all affected by this. Specifically, the USA accounts for an exceptionally high 95% of the global production of GPUs (EC 2020).

1.5.3 Space Applications

Space is increasingly vital for the military industry due to its critical role in enabling modern warfare capabilities, including reconnaissance, communication, navigation, surveillance, and missile defense. Military forces rely on space-based assets such as satellites to gather real-time intelligence, support precision-guided munitions, facilitate secure communications, and enhance situational awareness on the battlefield. Moreover, space-based platforms provide strategic advantages such as global reach, persistent surveillance, and rapid response capabilities, allowing military forces to project power and deter aggression across vast distances.

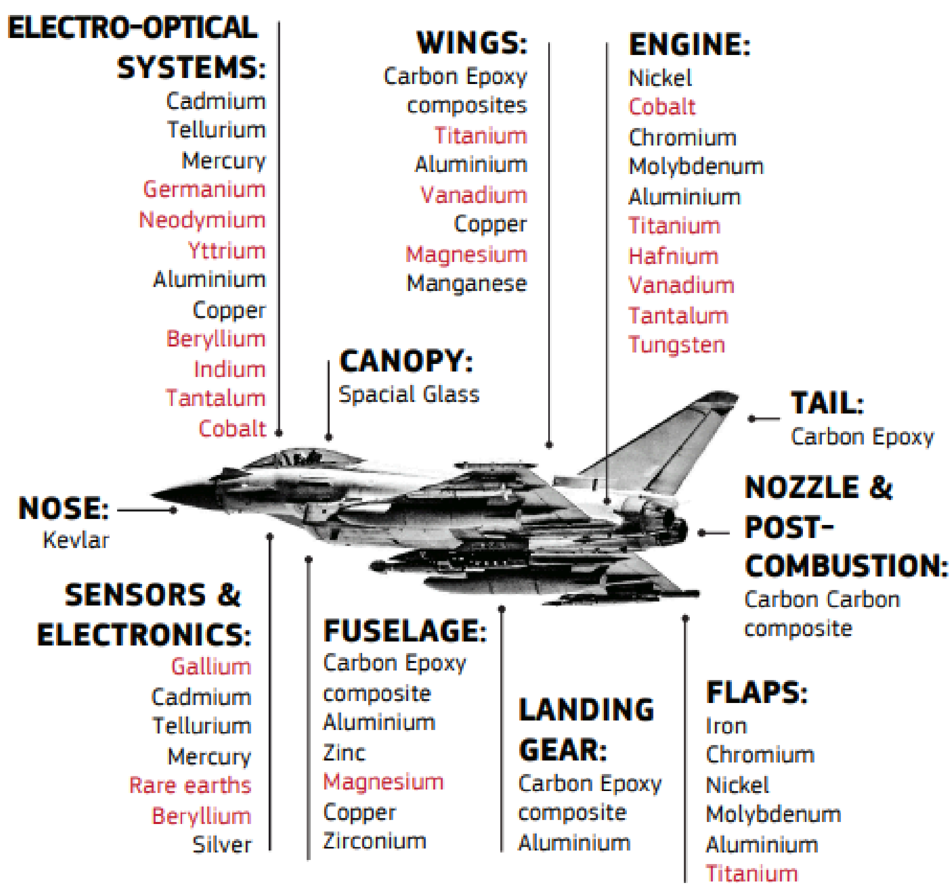


Figure 27 - Materials used in different parts of the combat aircraft Rafale (European Commission 2020)

The contemporary importance of the space sector is expected to have an impact on the availability of certain advanced materials like carbon fibers, precursors, resins, and special alloys. Materials are thus the main aspect of the construction of complex spacecraft, satellites, or launch systems. The design of a space product can occasionally be influenced by limits in the availability and qualities of materials. For instance, there were numerous material hurdles in the design of the Space Shuttle systems, including weight reduction, reusability, and space environment operation. Materials are also essential for the safety of space travel; the Challenger and Columbia Space Shuttle disasters, for example, were brought on by material failures.

1.6 Batteries

Batteries play an important role in the modern military industry by powering a wide array of critical equipment and systems used in military operations. From portable electronic devices and communication systems to unmanned aerial vehicles (UAVs) and armored vehicles, batteries provide the energy needed to operate effectively in diverse and demanding environments. Dependable and long-lasting batteries are essential for enabling soldiers to carry out missions without being tethered to fixed power sources, enhancing mobility, agility, and operational flexibility. Moreover, batteries contribute to reducing the logistical burden by enabling the use of lightweight and portable equipment, thereby facilitating rapid deployment and sustainment of forces in austere or remote locations. As military operations become increasingly technology-dependent and energy-intensive, the importance of advanced battery technologies, including high-energy-density batteries, rechargeable lithium-ion batteries, and ruggedized power systems, continues to grow.

Particularly, Li-ion batteries are becoming a more mature technology that could be crucial for the defense sector. The composition of Li-ion batteries is affected by many technological and financial factors. newer anodes (such as titanium, silicon metal, lithium metal, and niobium), coating materials (such as niobium and titanium), newer cathodes (such as niobium (CBMM report 2018)), and closer packing (less electrolyte, thinner separators, and thinner current collectors) are the main areas of recent battery research. Depending on the application, the primary goal is to increase specific energy to decrease weight and volume while retaining power capabilities to shorten charging times. Changing the cathode chemical mix reduces the overall proportion of cobalt in favor of alternative materials like nickel and/or aluminum to save money. This could therefore lessen durability and safety, both of which are becoming more and more crucial.

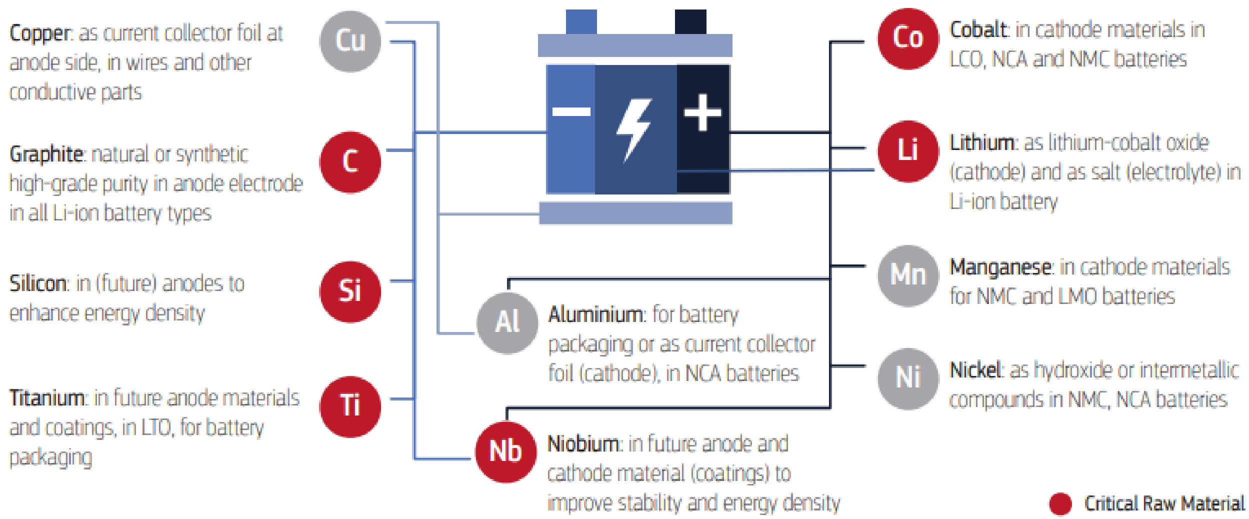


Figure 28 - Raw materials used in batteries (European Commission 2020)

In the 2020 list of CRMs, cobalt, natural graphite, and lithium are considered critical out of the materials currently used in battery manufacturing. Researchers are investigating the properties of silicon metal, titanium, and niobium to enhance future Li-ion battery types' energy density, robustness, and safety. Just 1% of the world's raw ingredients for batteries are produced in the EU. Particular materials also merit examination in further detail: The Democratic Republic of the Congo produced 54% of the world's cobalt, with China coming in second with 8%, Canada with 6%, New Caledonia with 5%, and Australia with 4%. China produces 46% of the world's refined cobalt, followed by Finland (13%), Canada (6%), and Belgium (6%). 90% of the lithium mined worldwide is generated, primarily from brine and spodumene sources, in Chile (40%), Australia (29%), and Argentina (16%) (EC 2019). The availability of lithium is anticipated to pose little to no short- or medium-term problems for the battery supply chain, despite the current concerns about shortages and price surges. Nonetheless, Rosskill (Lithium-Ion Batteries Market Development & Raw Materials 2018) argues that to sustain the long-term development of new production capacity, a price increase from the existing low levels is necessary. In the global supply chain, not all nickel is suitable for the manufacturing of Li-ion batteries. The production of nickel sulfate, a key component of NMC (Nickel Manganese Cobalt oxide) and NCA (Nickel Cobalt Aluminium oxide) batteries, is necessary for the creation of high-grade nickel products. The desired supply of nickel class I (with purity over 99.8%) in particular is in jeopardy because of the low investments made in nickel refining capacity due to previous price crashes (EC, 2019).

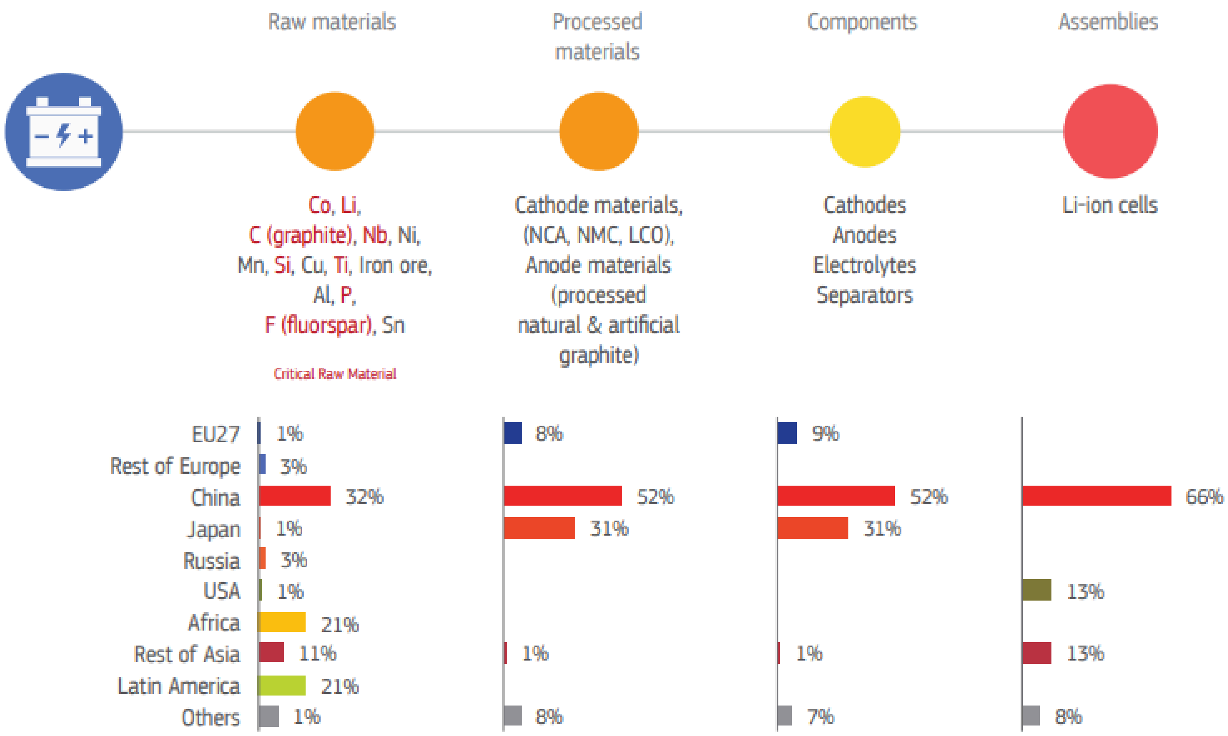


Figure 29 - Supply chain bottlenecks for batteries (European Commission 2020)

There are regulations about the carbon content and flake size distributions for natural graphite. These are usually attained by further refining processes, of which China is the primary producer of spherical graphite (Roskill, 2018). More research is needed to determine the percentage of the global supply that is appropriate for producing spherical graphite. Japan is the main source of NCA cathode material, whereas China is the main provider of anode materials, NMC (Nickel Manganese Cobalt Oxide) and LCO (Lithium Cobalt Oxide) processed materials. About 18% of NMC and 15% of LCO materials are supplied by the EU, which is entirely dependent on the supply of anode and NCA cathode materials.

The fact that these amounts are insufficient to meet the demand for Li-ion batteries in Europe is an important consideration for the EU. Asia, represented by China, Japan, and South Korea, provides 86% of the world's processed materials and Li-ion battery components. With 8% of the supply, the EU27 has a negligibly small share. Only 8% are supplied by other countries, leaving very little room for supply diversification. Because battery cells are entirely imported into the EU, there is a risk to supply. China accounts for 66% of the world's output of Li-ion cells, making it a prominent player in the market. The EU produces only 0.2% of Li-ion cells. About 8% of the world's supply comes from other suppliers, so there is little room for supply diversification. Nonetheless, the EU is making large investments throughout the battery value chain. The EU capacity of 3 GWh is expected to grow. These production facilities include investments from Asia on several occasions. These capacities in Europe are compared to the 150 GWh current worldwide capacity that has been identified (Joint Research Center 2018). Meanwhile, Chinese enterprises will achieve a significant increase in Li-ion cell production capacity, ensuring China's supremacy in the battery market. Original equipment manufacturers, cell manufacturers, and suppliers will probably engage in global competition to safeguard their battery supply chains and gain entry to the five critical raw materials for batteries: lithium, cobalt, nickel, graphite, and manganese (EC 2020).

2. Supply Chain Bottlenecks for Emerging Technologies in the Military Industry

The acquisition of final assemblies and raw materials is the weakest link in the supply chain of military technologies. This is especially true for Li-ion batteries and FCs; however, drones are also somewhat affected. The EU is heavily dependent on the supply of raw materials for these advanced technologies. Without taking into account digital technologies, the EU generates, on average, 3% of the total raw materials used in these technologies. With almost half of the world's raw materials supplied by China, it leads the world in production. Several small suppliers with minor shares of the world market produce the other half of the raw materials. At the component level, solar photovoltaics and robotics appear to be the most vulnerable technologies, despite minor supply issues being identified for Li-ion batteries and drones. It has been demonstrated that the availability of processed materials is very important for Li-ion batteries.

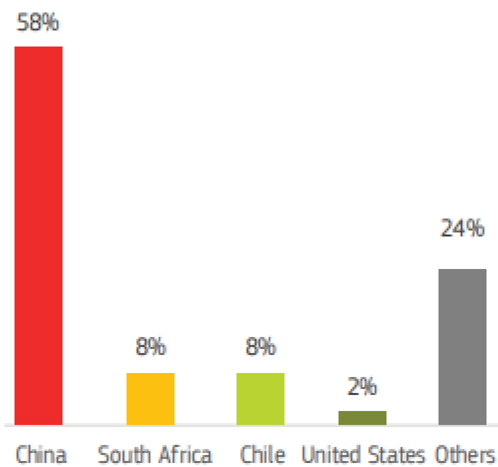


Figure 30 - Key players in the supply of raw materials for the defense sector (European Commission 2020)

Figure 31 - Potential supply risks in the value chains of key military technologies (batteries, fuel cells, PV modules, robotics, drones, 3D printing, semiconductors) (European Commission 2020)

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3. The Issue of Joint European Defense Procurement

The idea of European strategic autonomy has been closely linked to EU defense integration initiatives (like CDP, CARD, PESCO, and EDF) over the past five years, at least when this term is used to refer to defense and a more limited definition of "security" as opposed to, say, economic self-reliance. The speed of collaboration and the creation of new institutions, however, conceals a broad variety of official viewpoints taken by various EU members, as well as divergent opinions and perspectives even inside the political arena of any particular country. Most significantly, there are differences in opinion among European officials and professionals regarding leadership, autonomy, the ideal level of EU ambition, and the best way to strike a balance between the development of national and joint capabilities. Together and individually, these disparities threaten the overall goal of achieving European strategic autonomy by undermining its coherence, sustainability, and legitimacy.

The nature and purposes of European strategic autonomy are a highly debated topic. According to a 2018 study that examined various interpretations of "autonomy" among EU members, decision-making autonomy was defined as the capacity to make decisions and exercise political will in the majority of the countries (Belgium, France, Germany, Luxembourg, Poland, Portugal, Slovakia, and the UK before Brexit). The ability to mobilize military and civilian capabilities is commonly interpreted as European strategic autonomy in certain regions of Central and Eastern Europe, such as Bulgaria, the Czech Republic, Latvia, Romania, and Finland. A third set of states (Croatia, Estonia, Malta, and Austria) also have autonomy over information gathering, intelligence gathering, and data collection (Frank & Varma 2018). The term "Atlanticist" vs "Europeanist" divide refers to the further differences in how EU member states understand and value European strategic autonomy. These differences stem from some states' historical orientation toward the United States and NATO (such as many Eastern European and some Nordic countries), in contrast to a more Europe-centric leaning adopted by others (such as France, Germany, and the Benelux countries). While other countries, like Sweden, Finland, and Austria, are neutral or militarily non-aligned, they nonetheless collaborate with the EU and may interact with NATO as Enhanced Opportunity Partners. The way European strategic autonomy interacts with NATO and the degree to which the idea has been implemented in a way that complements NATO rather than contradicts it or presents an open challenge, while also taking into account national limitations, are crucial elements influencing the desire for European strategic autonomy in the first place.

The ability of individual and collective EU member states to build the capacities required to meet their desired degree of power is one of the other fundamental tenets of European strategic autonomy. The fundamental idea is that the EU as a whole—that is, the combined abilities and efforts of its many member states—is greater than the sum of its parts. Achieving European strategic autonomy in terms of combined capabilities would also require EU member states to rely less on defense technology, equipment, support systems, spares, and R&D from the US or other external sources (such as Israel or Turkey).

The determination of the European Defense Agency (EDA) participating member states to strengthen European defense is demonstrated by the deployment of Permanent Structured Cooperation (PESCO) and the European Defense Fund (EDF) to create joint capabilities through the pooling and sharing of mechanisms at the EU level. The purpose of these programs is to close the defense capability gaps that would prevent European governments from carrying out independent operations and missions. The establishment of the Directorate-General for Defense Industry and Space (DG DEFIS) also makes a clear statement about Brussels' intention to elevate defense and procurement concerns to the top of the EU agenda for the first time.

Opponents of European strategic autonomy, including those in the US and some generally skeptical European states like Poland and the Baltic states, have cautioned against the concept's extension to the military-industrial complex and argue that PESCO projects funded by the EDF may cause issues with NATO interoperability and spur transatlantic competition. However, proponents of the idea in Europe contend that a more robust European defense would be advantageous to both NATO and the United States, as it would increase the Alliance's overall preparedness and more fairly distribute burden sharing among its members. Without US (and to a much lesser extent Canadian) backing, European NATO countries are now unable to cover the area of operations that would allow them to defend themselves in the event of a major conflict. This deficit worsens when non-EU countries—most notably Turkey and the UK—are excluded from the equation. The projected time required for European NATO members to develop the needed defense structures and capabilities is probably a couple of decades.

3.1 History of European Defense Integration

In the aftermath of World War II, France and West Germany sought to extend European integration into the realm of defense, alongside the establishment of the North Atlantic Treaty Organisation (NATO) in 1949. Between 1950 and 1954, significant strides were taken in this direction. Notably, the European Coal and Steel Community (ECSC) was formed in 1952 under the leadership of Jean Monnet, a proponent of European integration. Concurrently, efforts were made to create a European Defence Community (EDC), envisioned as a supranational entity responsible for forming a European army. The EDC would have been overseen by a European Defence Minister and funded by member states, with a dedicated procurement program.

However, despite initial progress, the EDC faced opposition, particularly in France, where concerns over encroachment on national sovereignty and memories of World War II occupation ran deep. Consequently, the French Parliament refused to ratify the EDC treaty in 1954, dealing a significant blow to European defense integration. In response, the Western European Union (WEU) was established as a platform for security and defense cooperation among member states. Nonetheless, NATO's dominance during the Cold War relegated the WEU to a peripheral role in European security affairs.

Following the failure of the European Defence Community (EDC), European integration primarily focused on economic matters. However, the eruption of the Balkan crisis in 1991 thrust European defense back into the spotlight, exposing divisions among European capitals and highlighting Europe's dependency on the U.S. and NATO for defense and crisis management. The disjointed response to the Balkan crisis underscored the need for a common defense and foreign policy among European states. In 1992, the Western European Union (WEU) outlined the 'Petersberg tasks,' defining scenarios for which military force under a European banner could be utilized, including humanitarian missions and crisis management. The implementation of the Common Foreign and Security Policy (CFSP) as part of the Maastricht Treaty in 1992 marked a significant step towards a common defense policy within the European

Union (EU). The 1998 Saint-Malo declaration, endorsed by the UK, called for deepening military cooperation among European states and developing autonomous decision-making structures for EU defense actions.

At the 1999 Cologne European Council, consensus was reaffirmed for the EU to act autonomously in military affairs alongside NATO. The Helsinki Council that same year set a target for the EU to develop the capability to deploy an independent military force by 2003. To operationalize the Common Security and Defence Policy (CSDP), new permanent structures were established within the EU, including the Political and Security Committee (PSC) and the EU Military Committee (EUMC). In 2009, the Lisbon Treaty strengthened the CSDP and established the EU External Action Service (EEAS) and the position of High Representative for Foreign Affairs and Security Policy. This treaty also introduced a mutual defense clause binding member states to provide aid and assistance in case of armed aggression. However, despite these reforms, the EU still lacks the command structures and capabilities of a traditional military alliance like NATO (RAND 2021).

The annexation of Crimea by Russia and the ensuing conflict in eastern Ukraine in 2014 prompted a reevaluation of defense priorities in Europe, shifting focus from out-of-area operations to territorial defense. Concurrently, the European Union (EU) continued its expansion eastward and deepened integration across various policy domains. In June 2016, the European External Action Service (EEAS) introduced the European Union Global Strategy (EUGS), outlining five priority areas to bolster EU defense and security policy. These included enhancing the security of the Union, promoting resilience in states and societies, adopting an integrated approach to conflicts and crises, fostering cooperative regional orders, and advancing global governance in the 21st century.

The unveiling of the EUGS marked a significant turning point, with security and defense becoming top priorities for the EU. Events such as the UK's decision to leave the EU and the election of Donald Trump as US president further underscored the need for the EU to assert its autonomy and vitality in the face of geopolitical shifts. In response, an implementation plan for the EUGS was developed by the EU High Representative for Foreign Affairs and Security Policy and adopted by EU leaders in December 2016. Additionally, the European Commission adopted a European Defence Action Plan aimed at strengthening defense and security sectors, fostering deeper cooperation, resource pooling, joint capabilities, and a more robust defense industry. As part of this comprehensive approach, NATO and the EU signed a joint declaration in 2016, signaling a commitment to revitalizing their strategic partnership and addressing shared security challenges.

Over the past two decades, significant strides have been made in establishing principles and mechanisms to enhance military capabilities among European Union (EU) member states. The creation of the European Defence Agency (EDA) in 2004 marked a milestone, driven by advocacy from key EU members and defense industry lobbying. The Capability Development Plan (CDP), initiated in 2008 and refined in 2018, serves as a decision-making tool to identify member states' capabilities and needs in the short, medium, and long term. The EU Capability Development Priorities, established in 2018, further guide joint military capability development efforts, with input from the EUMC, EUMS, and EDA (RAND 2021).

Additionally, the Coordinated Annual Review on Defence (CARD), launched in 2018, aims to enhance cooperation among participating member states by overseeing defense spending, research, and investments. Although conducted voluntarily, the CARD fosters coherence and coordination across Europe's defense landscape. The development of Permanent Structured Cooperation (PESCO), activated in 2017 and implemented in 2018, has emerged as a cornerstone of European defense consolidation. PESCO, initially included in the Lisbon Treaty, facilitates coordinated military capabilities development among ambitious EU member states. With 25 participating member states, PESCO projects cover various military domains, albeit with some criticism focusing on their emphasis on lower-end capabilities.

Another significant initiative is the European Defence Fund (EDF), established in 2017 to address collective defense procurement and research shortages (European Commission 2019). Representing the first time EU budget funds defense activities explicitly, the EDF aims to increase investment efficiency and foster cooperation among member states. Despite an initial proposed budget reduction from €13 billion to €8 billion for the period 2021-2027, the EDF faces challenges, including the impact of the COVID-19 pandemic and debates surrounding third-country involvement.

In addition to EU-wide initiatives, several bi- and multi-lateral frameworks have emerged in recent years, reflecting a recognition among member states and partners that individual defense capabilities are insufficient to meet contemporary security challenges independently. One notable example is the European Intervention Initiative (EI2), launched in 2018 under the leadership of French President Macron. The EI2 serves as a flexible, non-binding forum for capable European governments to collaborate on military interventions, complementing both EU efforts, including PESCO, and NATO. Its focus areas include intelligence sharing, strategic foresight, planning, operational support, and lessons learned.

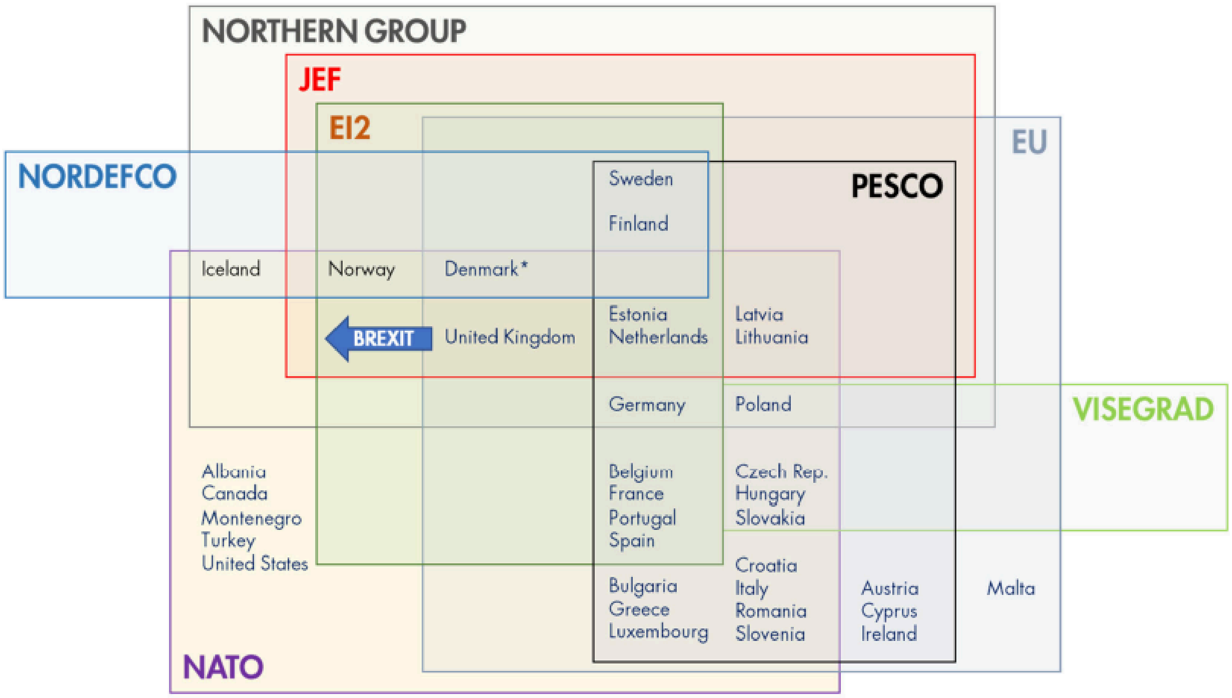

Figure 32 - The plurality of European defense frameworks and their participating countries (Source: Rand 2021)

In Northern Europe, the Nordic Defence Cooperation (NORDEFCO) involves Denmark, Finland, Iceland, Norway, and Sweden, aiming to enhance interoperability, develop common understandings, and optimize resource utilization across capabilities, armament, human resources, education, training, and exercises, as well as operations. Additionally, the Northern Group, comprising 12 countries bordering the Baltic or North Sea, fosters regional defense and security cooperation, focusing on information sharing, joint exercises, and military mobility initiatives.

3.2 Impact of the War in Ukraine on Joint EU Defense Procurement

Suffice it to say that the Russian invasion of Ukraine in 2022 was a wake-up call for the EU. Everyone could see that the European Defence Technological and Industrial Basis (EDITB) was unprepared to deal with the fallout from a prolonged, highly intense conflict on the Old Continent, two years after Russia attacked Ukraine. Thirty years of production, procurement, and technological trends that had previously influenced Europe's approach to defense hardware were impacted by the war. The EDITB was impacted in two ways starting in the 1990s by the inclination towards fewer, more sophisticated weapon systems that were precise, rather than using a lot of low- to medium-tech options. Initially, it caused a partial consolidation of the European markets and a drive for greater efficiency among individual companies. This meant avoiding investing in or maintaining outdated production facilities, leaving low-profit, low-demand industries like the production of artillery rounds, and focusing on high-end product research and development (R&D). The European Union's efforts to accelerate defense cooperation and integration among its member states were also influenced by the emphasis on technological superiority. This was primarily the case with the European Defence Fund (EDF) and Permanent Structured Cooperation (PESCO).

The conflict and Ukraine's insatiable need for ammunition, cutting-edge machinery, and NATO-standard armaments have altered the situation. By financing equipment transfers from member states through the European Peace Facility (EPF), an off-budget fund that was quickly repurposed to become the primary means by which Brussels supports Ukraine's war effort, the European Union has given more than 5.6 billion euros in military aid to Ukraine. However, Europe's limited defense reserves have not been able to meet Ukraine's demands, especially when it comes to land power. First and foremost, the transatlantic and European industrial capacities have been severely strained by Ukraine's widespread employment of artillery (including both 155mm rounds and missile systems).

The European Union's initial proposal was the European Defence Industrial Reinforcement via the Common Procurement Act (EDIRPA), which was intended to assist member states in setting up cooperative procurement processes for defense supplies. The 500 million euros that were set aside ought to have gone toward covering the extra technical and administrative expenses associated with participating in international procurement procedures. The budget of EDIRPA was reduced to a measly 300 million euros by the subsequent political agreement. Following nearly a year of deliberations, the concerned parties at last arrived at a consensus about the possible eligibility of non-EU actors and companies, thereby permitting some restricted exceptions for allies like the US.

The European Union's actions following the war have several consequences for the process of integrating the European defense industry. Naturally, the emergency actions carried out after February 2022 are directed toward a single goal: increasing the production of artillery shells and missiles to restore depleted supplies and give Ukraine long-term, sustainable aid. However, it is important to keep in mind that, as previously indicated, these measures primarily target the supply side of the market and do not support the long-term consolidation of demand. Furthermore, producing ammo is much simpler than producing sophisticated weaponry. Therefore, when it comes to more sophisticated technologies, EU defense integration would not necessarily proceed with a reimbursement and targeted financing mechanism. Demand-side analysis suggests that policies aimed at supporting Ukraine and boosting ammunition output may actually hinder the integration of European defense. Structural optimization of available production capacities can only result from organized institutional measures that bundle and rationalize European demand for defense goods. Examples of these measures include the establishment of European Defence Capability Consortia (EDCC) and full implementation of the Coordinated Annual Review of Defence (CARD) recommendations.

From a supply-side standpoint, the EDIRPA negotiations' delays also reveal differences between member states over whether or not to maintain the European defense markets' reasonable accessibility to foreign companies. In fact, because of the difficulty of maintaining several logistical chains and support systems, the current acquisition of weapons systems frequently discourages the procurement of alternative goods, given that these systems typically have extended service lifespans. While member states in the North and East downplay this issue because of the urgency of fast rearmament, as the European Sky Shield controversy has shown, France and Italy support a long-term strategy to increase the EDTIB's competitiveness and the degree of (shared) technological sovereignty over sophisticated systems. When it comes to long-term and permanent solutions, there should be a different strategy applied to short-term objectives that address immediate demands. It makes sense that the EDTIB would gain from EU financial incentives when the latter need to be handled.

Ultimately, to realize economies of scale, a thorough reassessment of the 2009 defense market guidelines is necessary, as they fail to adequately tackle the inefficiencies present in the European market structure. Directive 2009/81/EC subjects European collaborations to the same competition laws as domestic or foreign products. Since the EU decided that defense cooperation—including procurement and research and development—should be prioritized on its own, this rule is no longer applicable. In procurement procedures, hardware created as part of EU collaborative projects ought to be given preference, reflecting this political decision. However, because of the various and burdensome regulations that currently govern intra-European transfers, notably those on intellectual property and immaterial commodities, directive 2009/43/EC prevents European defense products from becoming genuinely competitive. Components, spare parts, and subsystems are still subject to national certification processes and customs clearances, which prevents the development of a truly European market and keeps supply chains and productive capacities divided along national borders. In the near future, lowering these non-tariff barriers ought to be a top goal.

Ultimately, Ukraine might be what sparks the political will within the EU to hasten defense procurement. As of now, the European Council has been calling to increase defense procurement, investment in the defense industry, as well as to increase its defense readiness and capabilities.

Full timeline of EU cooperation on security and defense: Timeline: EU cooperation on security and defence - Consilium

3.3 Where the EU is at Now vs Where it Should Be

Currently, the European Union (EU) has made significant progress in advancing joint defense procurement initiatives. Various programs and mechanisms, such as the European Defence Fund (EDF), Permanent Structured Cooperation (PESCO), and the Capability Development Plan (CDP), have been established to foster collaboration and resource sharing among member states. These efforts signify a commitment to strengthening Europe's defense capabilities and enhancing its strategic autonomy in the realm of defense procurement. The EU has taken concrete steps to address longstanding challenges and gaps in defense procurement, including disparities in capabilities among member states and inefficiencies in procurement processes. By promoting cooperation and standardization, the EU aims to streamline defense acquisition procedures, improve interoperability, and optimize resource allocation across the bloc. Furthermore, the EU has sought to bolster its defense industrial base and stimulate innovation in the defense sector through initiatives like the European Defence Industrial Development Programme (EDIDP) and the European Defence Technological and Industrial Base (EDTIB).

With the renewed war tension in Europe, as well as the eventual expected defeat of Ukraine in the war, there should be enough initiative amongst EU members to collaborate more seriously in the defense sector. Firstly, there is a lack of stronger mechanisms for coordinating defense procurement. There should exist a centralized platform for things like sharing information and best practices. While the EU is struggling to find resources for the manufacture of modern military equipment, it should look towards research and development initiatives to boost its own technological capabilities in the defense sector. Another blockage to smooth collaboration between member states are the cross-border barriers which unnecessarily hinder economic and logistical cooperation. In addition to that is the importance of promoting fair and open competition in defense procurement to maximize efficiency and value for money. Contracts should be awarded based on merit, capability, and cost-effectiveness - for the good of the whole European Union. Ultimately, the current level of collaboration should mature throughout the years, developing into a concrete framework and a smooth system. As decisiveness and fast actions are key in defense, the EU should have the capability to foster that throughout the Union, i.e. between all member states. The level of geopolitical tensions and threats, along with the EU leadership initiative and engagement will determine the level of progress for the upcoming years.

Analytical Summary

While supply chain dependencies have been an issue for decades, the real catalyst in the current EU defense 'crisis' is the 2022 war in Ukraine. While it has not started the issue, it was a rude awakening for Europe and it has deeply affected the urgency in material dependencies, collective defense, improvements in the EU military industry, and joint defense procurement.

Mainly, the degree to which ammunition reserves have struggled to keep pace with the demands of the conflict emphasized the region's reliance on external suppliers. The United

States remains the largest supplier of final-stage military equipment to the EU. Material-wise, the modern military landscape is defined by increasingly complex materials and processes, underscoring the significance and challenge of having a robust and independent military-industrial base. However, the EU is highly dependent on external sources for critical raw materials at all stages of the supply chain, with China dominating the processing of these materials. This dependency poses the main challenge to the EU's (relatively newly-founded) goal of achieving military self-sufficiency.

An economic analysis reveals a stark underinvestment in defense budgets by EU member states. In fact, the EU is so dependent on non-EU suppliers that over 60% of European Defense procurement budgets are spent on military imports. Workforce skills and manufacturing capabilities are also significant challenges, which is something the EU is attempting to address with the European Defense Skills Partnership. Despite increased defense expenditure, the investments remain lower than the target, and a significant portion of defense industrial investments occurs outside the EU framework. Amongst the EU member states, France stands out as a major advocate for investing in European defense infrastructure rather than relying on imports from the US.

Specific to the war context, the EU's inability to meet the demand for weapon and ammunition production for a major conflict is a major concern. War-gaming scenarios have shown that countries like the UK and Germany would deplete their ammunition stocks quickly in the event of a high-intensity conflict. However, the military-industry 'crisis' in Europe is more complicated due to the fact that the EU's approach to defense for the past three decades has favored sophisticated weapon systems over low- to medium-tech options, a strategy the gaps of which were only exposed by the 2022 war in Ukraine. The EU's post-war efforts focused on increasing the production of missiles and artillery shells, but these measures do not support long-term defense integration. A sub-issue is the fact that there is a lack of consensus within Europe, with the debate ongoing between short-term and long-term defense objectives. Ultimately, a reassessment of the 2009 defense market guidelines is needed to address the inefficiencies in the European defense market structure.

As was emphasized, one of the most critical aspects of the challenge of self-sufficiency is the dependency on semiconductors, which are integral to virtually all modern military equipment; from advanced propulsion systems to everyday military electronics. The EU is behind in the production of semiconductors significantly, relying on East Asian countries, especially China, which dominates the global supply chain. Apart from that, China has control over the supply and processing of many critical raw materials, which can heavily impact Europe's military capabilities through sanctions or other restrictive measures. These dependencies are intensified through the importation of manufactured products, such as lithium batteries and permanent magnets, where the EU's import value far exceeds the raw material imports due to the high added value of the processed goods. Perhaps the most concerning fact is that the EU's recognition of these dependency issues has been slow, which poses severe risks. To counter this, efforts like the European Chips Act seek to increase Europe's share of global semiconductor production capacity, with goals to increase it from below 10% to 20% by 2030. This might be an even lengthier process though, given the time it takes to establish manufacturing facilities and other infrastructure.

CRMs are especially important for the proper functioning of modern military equipment, including technologies like ferroelectric RAM and hypersonic weapons. The EU's current production capacity for special composite materials and their precursors is limited, making it highly dependent on imports for a significant portion of them. shockingly, the EU generates only 3% of the total raw materials used in advanced military technologies. The weakest links right now are in the military technology supply chain, an issue that forms a critical aspect of the EU's defense strategy. The EU produces only a tiny fraction of the raw materials necessary for advanced military technologies. The lack of political will for effective collaboration among EU member states exacerbates the issue greatly. Despite initiatives like the Permanent Structured Cooperation (PESCO) and the European Defense Fund (EDF) which aim to strengthen collective European defense, the reality is that without US backing, European NATO countries cannot fully cover the area of operations required for their defense. Even if concrete efforts begin right now, developing solid defense structures and capabilities is projected to take several decades.

For the correct operation of certain equipment, raw materials are as important as the technology itself. For instance, helium is essential for achieving the low temperatures required for semiconductors and quantum computing technologies. Similarly, advanced data storage technologies, such as ferroelectric RAM, require up to 40 kilotonnes of platinum, a significant amount more than the EU's current annual consumption. Even though the EU is a major producer of alloys and special steel, it is still behind on composite materials. The region's reliance on imports for a majority of CRMs is illustrated by the fact that 13 out of the 39 raw materials essential for defense-related manufacturing - such as boron, dysprosium, gold, magnesium, neodymium, and titanium - are entirely imported. These imports account for more than two-thirds of the total raw materials used in European defense applications, making sectors like aeronautics and electronics at a high risk for supply disruptions. The EU's dependency on the processing capabilities of other countries (particularly China) is especially apparent when one considers that the EU's imports of permanent magnets in 2021 were worth 12 times more than the total amount of rare earth imports, and imported lithium batteries were worth 75 times more than imported lithium.

The EU's production of metamaterials (advanced materials crucial for modern military applications like antennas and infrared sensors) is also lagging. Despite accounting for around 15% of total metamaterial publications and citations, the EU is not a leading manufacturer or patent holder in this field. While initiatives such as METRAMAT and CoMetaS are steps towards addressing these issues, the long-term challenges related to design, integration, and reliability persist.

The EU's reliance is exacerbated by a lack of political will for effective joint collaboration among EU member states, driven by factors such as Atlanticism versus Europeanism, state autonomy, and military non-alignment. Despite the challenges, the EU has made efforts to strengthen collective defense. There are visible attempts of centralization with the making of the European Defense Technological and Industrial Base and the Directorate-General for Defense Industry and Space, reflecting Brussels' intention to prioritize defense and procurement concerns. As mentioned, the 2009 defense market guidelines need revamping. Directive 2009/81/EC, for example, subjects European collaborations to the same competition laws as domestic or foreign products. Since the EU has prioritized fense cooperation, including procurement and research and develpment, this rule is no longer applicable. Additionally, directive 2009/43/EC prevents European defense products from becoming genuinely competitive due to various and burdensome regulations governing intra-European transfers. Components, spare parts, and subsystems still require national certification processes and customs clearances, which fragment supply chains and productive capacities along national borders.

Conclusion

The European Union (EU) faces significant challenges in achieving military independence due to heavy reliance on external sources for critical raw materials (CRMs) and advanced military technologies. The drive for strategic autonomy is compounded by geopolitical tensions, particularly with Russia's invasion of Ukraine and the complex relationship with China, which dominates the supply of many essential materials. The geopolitical landscape, marked by increasing tensions and conflicts, necessitates the EU's push for a self-sufficient defense industry. The EU's defense capabilities are hampered by dependency on external suppliers, notably the United States for military hardware and China for CRMs. The EU's vulnerability to supply chain disruptions and potential sanctions underscores the urgency to bolster domestic production and reduce reliance on these nations.

China's near-monopoly on rare earth elements, crucial for advanced weaponry, poses a substantial risk to the EU's defense sector. The EU's reliance extends beyond rare earths to include semiconductors, batteries, and other components vital for modern military technologies. The semiconductor shortage has highlighted the fragility of global supply chains, prompting initiatives like the European Chips Act aimed at enhancing domestic production capabilities. The recently proposed EDIP seeks to address these challenges by fostering collaboration among member states and increasing domestic weapons production. However, achieving true autonomy involves overcoming significant hurdles, including securing a stable supply of CRMs and advancing technological capabilities in sectors like artificial intelligence (AI), advanced information and communication technologies (ICT), and energy weapons.

The integration of AI and ICT is transforming modern warfare, offering enhanced efficiency and precision. However, the semiconductor industry's dependence on specific CRMs makes it vulnerable to global supply chain disruptions. The European Chips Act and national investment plans aim to boost local production, but the path to self-sufficiency is long and complex. Directed energy weapons (DEWs) and other advanced military technologies require specialized materials like rare earth elements. While chemical and free-electron lasers offer alternatives, the production of solid-state lasers still heavily depends on materials like yttrium aluminum garnet (YAG). The EU's capacity to produce these materials domestically is limited, necessitating strategic investments in research and manufacturing. Material dependencies also constrain the EU's capabilities in 3D printing and robotics. Critical raw materials for 3D printing are predominantly sourced from China, posing a risk to the production of advanced military components.

The concept of European strategic autonomy is closely tied to defense integration initiatives like PESCO, the European Defence Fund (EDF), and the Capability Development Plan (CDP). These efforts aim to streamline defense procurement, enhance interoperability, and optimize resource allocation across the EU. However, the pace of collaboration varies among member states, with differing views on the extent of autonomy and the relationship with NATO. The Russian invasion of Ukraine has exposed the EU's unpreparedness for high-intensity conflicts, highlighting the need for increased defense production and integration. Emergency measures, such as the European Peace Facility (EPF), have provided substantial military aid to Ukraine, but the focus on immediate supply needs may hinder long-term defense integration. The conflict underscores the necessity for the EU to strengthen its defense industrial base and enhance strategic autonomy.

The EU must seek alternatives to dependencies on major global powers, including exploring new sources of CRMs and investing in local production capabilities. Emphasizing research and development in advanced materials, AI, and other critical technologies is crucial to reducing reliance on external suppliers. Promoting seamless collaboration among member states to create a unified and efficient defense procurement system is essential. Implementing policies to reduce dependence on imports, particularly from adversarial nations, and focusing on developing a robust domestic defense industry can significantly enhance resilience. While the EU faces significant challenges in achieving strategic autonomy in its defense sector, concerted efforts in diversifying supply chains, investing in innovation, and fostering collaboration can enhance resilience and ensure security in an increasingly uncertain global landscape.

This paper was produced by the conceptual research team of the Global Arena Research Institute (GARI) as part of the preparatory work for utilizing GARI's signature digital twin of the globalized environment. Supported by the International Visegrad Fund and the Konrad Adenauer Stiftung, GARI is at the forefront of integrating leading-edge computing technologies with socio-economic and political analysis. These internal conceptual working

papers lay the foundation for our digital twin's application, offering critical insights and frameworks that enhance our understanding and foresight into global and local processes across various domains, including economy, trade, politics, defense, society, energy, and the environment.