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COMMISSION STAFF WORKING DOCUMENT

EU strategic dependencies and capacities: second stage of in-depth reviews

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EU strategic dependencies and capacities: second stage of in-depth reviews

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Executive Summary

The 2021 Industry Strategy update[1] highlighted the importance of better understanding the EU's strategic dependencies, how they may evolve in the future and the extent to which they lead to vulnerabilities for the EU. Accompanying the updated Strategy, the Commission carried out a comprehensive assessment[2] of the EU's strategic dependencies and capacities including a first round of in-depth reviews in six strategic areas (raw materials, active pharmaceutical ingredients, li-ion batteries, clean hydrogen, semiconductors and cloud and edge computing). The updated Strategy also announced that the Commission will launch a second stage of in-depth reviews of potential dependencies in key areas, including products, services or technologies key to the twin transition (such as renewables, energy storage and cybersecurity).

This staff working document (1) reports on progress made in addressing the strategic dependencies identified in the first round; and (2) presents a second round of in-depth reviews covering new areas and in some cases building on the first round of reviews. It complements the 2022 Annual Single Market Report[3] (issued at the same time), providing an update on the state of the Single Market.

Significant progress has been made to address the strategic dependencies identified in the first round of in-depth reviews. Recently launched international partnerships will enable more diversified and resilient supply chains, notably in the area of critical raw materials. Ongoing Industrial Alliances on batteries, hydrogen and raw materials are instrumental in strengthening European open strategic autonomy including by identifying investment needs and building project pipelines. New Industrial Alliances in the areas of semiconductors and cloud services have been kick started. Important private and public investments have materialised, facilitated also by ongoing Important Projects of Common European Interest (IPCEI) supporting breakthrough innovations on batteries and semiconductors. Possible new IPCEIs on cloud, hydrogen and an additional one on semiconductors are being prepared by Member States. EU funding (e.g. Recovery and Resilience Facility, Horizon Europe) is supporting investments and promoting innovation. Significant steps have also been taken in collaboration with stakeholders to identify supply chain vulnerabilities in the area of active pharmaceutical ingredients and how to address them. In parallel, the Commission has put forward proposals to provide fit-for-purpose regulatory frameworks on semiconductors, hydrogen and batteries.

[1] COM(2021)350

[2] SWD(2021)352, in the context of the updated Industry Strategy

[3] SWD(2022)40

The second stage of in-depth reviews presented in this staff working document complements the first stage by deepening the assessments related to raw and processed materials (focusing on rare earths and magnesium as well as the impact of raw material dependencies in the area of chemicals) and cloud and edge services (focusing on software capacities). In addition, the staff working document presents reviews for additional areas of strategic importance, namely photovoltaic panels and cybersecurity. Several of the identified strategic dependencies that might result into vulnerabilities (rare earths, magnesium and PV panels) are driven by a strong concentration of global production in China, with limited options for supply diversification including from within the EU. Dependencies are also identified for a number of chemicals of particularly critical importance. In addition, strategic dependencies also exist in the areas of services and technologies. Some in-depth reviews (cybersecurity, IT software) highlight risks for the EU to become (increasingly) dependent on providers from a limited number of economies for access to critical technologies in these areas.

Contents

1. Context and approach

The Industry Strategy update[4] highlighted the importance of better understanding the EU's strategic dependencies, as a basis to address them through tailored, facts-based and proportionate policy measures. This is a key element in increasing the EU's resilience and supporting the twin transition. Underpinning the updated Strategy, the Commission services carried out a comprehensive review[5] of the EU's strategic dependencies and capacities. This included both a bottom-up mapping of product dependencies, as well as a first round of in-depth reviews analysing strategic dependencies and related risks in six specific strategic areas (raw materials, active pharmaceutical ingredients, li-ion batteries, clean hydrogen, semiconductors and cloud and edge services).

Different actions are currently ongoing in the context of implementing the updated Industry Strategy to address the strategic dependencies identified in the first round of in-depth reviews. These include both strengthening and diversifying trade with international partners as well as increasing the EU's ability to act autonomously where necessary. Chapter 2 outlines the main (ongoing) actions as regards the six areas covered in the first round of in-depth reviews.

This staff working document provides also a second stage of in-depth reviews. The COVID-19 crisis has shown the relevance of a continued effort to monitor Europe's current and possible future strategic dependencies, consider the impact and risks they bring as well as take relevant corporate decisions to manage risks and also consider policy measures where necessary. In this context, the updated Industry Strategy announced that the Commission would carry out a second stage of in-depth reviews. The second stage of in-depth reviews presented in this staff working document complements the first stage by deepening the assessments related to raw and processed materials (focusing on rare earths and magnesium as well as chemicals) and cloud and edge services (focusing on software capacities). In addition, the staff working document presents reviews for additional areas of strategic importance, namely photovoltaic panels and cybersecurity. Chapter 3 outlines the main conclusions.

This selection of areas for in-depth reviews follows a similar logic as in the first round. Similarly to the first round, all in-depth reviews have a link with strategic areas, such as security, safety, health and the green and digital transformation.[6] Most in-depth reviews have a link to more than one of these strategic areas. For example, solar panels and technologies impact the EU's green transition, but also have important applications in the area of space. The in-depth reviews covering specific (groups of) products (rare earths, magnesium, solar panels, chemicals) are all related to goods for which dependency was demonstrated based on the bottom-up screening methodology laid out in the May 2021 SWD. In-depth reviews related to services and technologies (cybersecurity, IT software) focus on strategic areas where quantitative[7] and/or qualitative information point to possible EU dependencies. Further details on the selection of in-depth reviews are provided in annex.

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[4] COM(2021)350
[5] SWD(2021)352
[6] See SWD(2021)352, chapter 1.1
[7] As for example included in Technopolis Group, IDC, Fraunhofer ISI, Idea Consult: Advanced Technologies for Industry – Final report, 2021

These additional in-depth reviews complement other efforts aimed at generating a better understanding of the EU's strategic dependencies.[8] This includes the rollout of the Observatory of Critical Technologies across civil, defence and space industries[9] as well as specific exercises in the areas of the agri-food and energy[10]. In addition, relevant work is also ongoing in the context of the task force on strategic dependencies under the Industrial Forum. In its work so far[11], the task force underlined the pertinence of the Commission analysis of May 2021, while pointing to the importance of continuing to deepen the work. Furthermore, the task force identified specific products to be further examined and provided suggestions on assessing the strategic nature of dependencies. The task force will now discuss recommendations on policy measures.

2. Follow-up to first round of in-depth reviews

Different actions are currently ongoing in the context of the updated Industry Strategy to address the strategic dependencies and vulnerabilities identified in the first round of in-depth reviews. The May 2021 SWD on strategic dependencies and capacities highlighted different types of dependencies and risks across the six areas covered (raw materials, active pharmaceutical ingredients, li-ion batteries, clean hydrogen, semiconductors and cloud and edge services).

Industry is well placed to identify strategic dependencies but also to take measures to address them. As set out in the 2021 update of the Industrial Strategy, in most cases industry itself is well placed, through its corporate decisions, to improve resilience and reduce unwarranted dependencies and associated risks in its supply chains. In the context of the COVID-19 crisis, many EU businesses across industrial ecosystems have indeed started to take action to better understand potential vulnerabilities in their supply chains and consider measures to address them including by diversifying their sources of supply. At the same time, in areas of strategic importance, public policy measures might support industry's efforts to address these dependencies and overcome market failures, if needed.

Ongoing policy measures to address the identified dependencies build on strengthening and diversifying trade with international partners as well as increasing the EU's capacity to stockpile or act autonomously where necessary. On the one hand, policy measures are being taken that reinforce the EU's position in global value chains by strengthening and diversifying external trade and promoting sustainable value chains. For example, the EU/US Trade and Technology Council includes cooperation with the aim to strenghten resilience across several of the areas included in the first round of in-depth reviews (e.g. raw materials, active pharmaceutical ingredients and semiconductors). In addition, the Commission's enforcement strategy continues to address any distortions to international trade and investments, and bilateral trade negotiations are advancing. Moreover, actions are being

[8] Relevant in this regard are also European Commission: Foresight report on Shaping and securing the EU's Open strategic autonomy by 2040 and beyond, 2021 and the Resilience dashboards (https://ec.europa.eu/info/strategy/strategic-planning/strategic-foresight/2020-strategic-foresight-report/resilience-dashboards)
[9] See COM(2021)70
[10] Regarding agri-food see SWD(2021)317; regarding energy see Trinomics, Artelys: Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis, 2021
[11] https://ec.europa.eu/docsroom/documents/48596

developed that aim to strenghthen the EU's own capacity in areas where strategic dependencies lead to a vulnerability of the EU economy, through targeted tools and investments. A number of important and more recent initiatives taken in relation to the different areas covered in the first round of in-depth reviews are summarised in this chapter.

Raw materials

In the area of critical raw materials, important efforts to address the EU's strategic dependencies are ongoing. The first round of in-depth reviews highlighted the highly concentrated supply of several (critical) raw materials, some overwhelmingly relying on single countries or companies. The Commission is pursuing multiple actions including diversification and strengthening of international supply chains as well as increasing EU domestic capacity. Several concrete achievements have been made across the priorities of the Raw Materials Action Plan[12] (including promoting research and innovation through Horizon Europe, the mapping of potential secondary sources in the EU, the promotion of relevant expertise and skills, the use of earth observation programmes and the development of EU principles on sustainable raw materials).

The Commission is pursuing international cooperation to diversify and pool risks as regards critical raw materials. For example, strategic partnerships were established with Canada and Ukraine (in June and July 2021 respectively). The partnership with Canada focuses on the integration of the EU-Canada raw material value chains while specifically enhancing collaboration on science, technology and innovation; as well as environmental, social, and governance criteria and standards. The partnership with Ukraine includes activities along the entire value chain of both primary and secondary critical raw materials and batteries. Other international partnerships are being explored, including with six African pilot countries (through cooperation across the raw materials value chain, research, innovation and infrastructure development, capacity building and skills exchanges as well as alignment on environmental, social and governance criteria).

In addition, actions are underway – also in the framework of the European Raw Materials Alliance – to build up resilient raw material value chains in the EU.[13] To do so, the Alliance has identified the need for investments of 1.7 billion euros for the rare earth magnets value chains and 9 billion euros for other raw materials value chain projects. In addition, a Clean Technology Materials Task Force was established (October 2021) to create a joint platform and structured dialogue between the Commission, industrial alliances and investors (i.e. EIB, EBRD, NPBIs) as well as to set up a mechanism aimed at mobilizing funding and financing for investments. Furthermore, there are also ongoing efforts to increase awareness, acceptance and trust when it comes to EU sourcing and issues such as sustainability. For example, EU principles for sustainable raw materials were published in September 2021 aimed at aligning Member States' understanding of sustainable EU extraction and processing. Finally, EU research and innovation is another important avenue to reduce dependencies through better waste processing (recycling), innovative materials and increased substitution. With regard to raw materials, the EU is supporting research on raw

[12] COM(2020)474

[13] The in-depth review developed in this SWD provides further details of ongoing actions to build EU capacities on raw materials, focusing specifically on two high risks areas (rare earths and magnesium)

materials through Horizon Europe and in particular its cluster 4 (Digital, Industry and Space), with 300 EUR million available for 2021-2022.

Active pharmaceutical ingredients

In the health ecosystem, the structured dialogue on the security of medicines supply has allowed for a better understanding of vulnerabilities in the pharmaceuticals supply chains. The in-depth review concluded that while there is increased regional concentration (China, India) in the production of generic active pharmaceutical ingredients (APIs), there is insufficient clarity on precise supply chain risks, EU production capacities and the criticality of specific APIs. The first phase of the structured dialogue (finalised in September 2021) allowed increasing clarity on (a) the key conditions to achieve a robust pharmaceuticals supply chain; (b) relevant possible criteria to identify medicinal products critical to public health; (c) causes of vulnerabilities at different stages of the supply chains; and (d) priority R&D and information areas to ensure supply chains are adequately robust and resilient to meet EU public health needs.

This dialogue with the actors of the health ecosystem will help identifying policy options. The second stage of the structured dialogue – in the process of being finalised – will allow presenting policy options to strengthen resilience of the EU's pharmaceutical supply chains.

Li-ion batteries

Ongoing efforts are enabling sigificant progress in addressing the EU's dependencies in the area of batteries. The in-depth review highlighted dependencies in battery cells as well relevant raw materials. Nevertheless, the EU's position in the area of batteries is significantly improving.

There has been significant investment in the EU's battery value chain, facilitated by the European Battery Alliance. In terms of battery cells, the EU is expected[14] to reach production capacity of up to 379 GWh by 2025 representing around 70% of the expected European demand for electric vehicle batteries in 2025 (around 550 GWh). This will be the result of substantial investment in the European battery ecosystem with 111 major projects, including approximately 20 giga-factories[15]. These investments are beginning to turn into concrete outcomes in part driven by FDI but also with the first European-owned giga-factory, owned by Northvolt in Skelleftea (Sweden), which produced the first battery cells in December 2021. This substantial increase in planned production capacity is the result of rapidly rising demand due to record levels of sales of electric vehicles in the EU in 2021 making up 18.0% of total car registrations, up from a 10.5% share in 2020.[16] Finally, Member States are also urged to take action when it comes to boosting domestic production of high value advanced battery materials (e.g. cathodes and anodes).

The batteries regulatory framework (Commission proposal December 2020[17]) aims for a robust and innovation-friendly legislative framework. It puts sustainability objectives first

[14] Estimates by InnoEnergy
[15] Northvolt, Europe's biggest battery company, alone aims to have 150 GWh capacity by 2030
[16] European Automobile Manufacturers' Association (ACEA) https://www.acea.auto/fuel-pc/fuel-types-of-new-cars-battery-electric-9-1-hybrid-19-6-and-petrol-40-0-market-share-full-year-2021/
[17] COM(2020)798

and provides legal certainty for industry to make long-term investments. Discussions with the European Parliament and Council are progressing, with the aim of adoption in 2022.

The two ongoing Important Projects of Common European Interest (IPCEI) concerning batteries are important drivers to accelerate the development of innovative battery activities in the EU. These two battery IPCEIs together will inject around €20 billion of public and private investments into innovative projects along the battery value chain and in many parts of the EU.

Ongoing actions also aim to boost EU research and innovation in the area of batteries and improve the availability of relevant skills. Under Horizon Europe, a Batteries Partnership was put in place with a total budget of €925 million. Under the first work programme (2021-2022), it will provide €293 million for research projects along the battery value chain. As regards skills, for example, the Commission's Blueprint for Sectoral Skills includes the "ALBATTS" initiative, aiming to establish a framework for the long-term identification of skills gaps in the area of batteries, emerging skill needs and a strategy to meet them.[18] To help meet urgent short-term training needs, InnoEnergy's has launched the EBA250 Battery Academy[19], which delivers training through local professional trainers with programmes established, so far, in Spain, France and Hungary.

Clean hydrogen

Different initiatives aim at addressing relevant dependencies and risks in the area of clean hydrogen. The in-depth review highlighted two important sources of dependencies in the area of clean hydrogen: the potential lack of renewable and low-carbon electricity required in large amounts to produce clean hydrogen and the critical raw materials required for hydrogen electrolysers and fuel cells. Industry is working – with EU support – notably through the Clean Hydrogen Partnership and Horizon Europe – to reduce the critical raw materials required for the production of electrolysers and fuel cells. However, this is a medium-term process and strategic dependencies on platinum group metals critical raw materials remain an issue as the industry is moving to the significant scale-up of electrolyser and fuel cell manufacturing capacities. Ongoing actions in the area of raw materials continue therefore to be of high relevance.

EU industry is preparing the large-scale deployment of hydrogen technologies and applications to decarbonise industry and transport sectors. The European Clean Hydrogen Alliance in November 2021 presented an investment pipeline of more than 750 projects that its members are planning to undertake by 2030. With its 1700 members, the Alliance provides a platform for stakeholders to meet and exchange on roundtables, match-making workshops or thematic working groups, facilitating the emergence of a European hydrogen industry and integrated value chains. The Alliance finalised (October 2021) an analysis of the most pressing market, regulatory and technological obstacles to the large-scale rollout of clean hydrogen. These are being addressed, including in the July 2021 Fit-for-55 package, the December 2021 Hydrogen & Decarbonised Gas Market Package[20] and the

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[18] The EU battery value chain having also large job creation potential
[19] https://www.eba250.com/eba-academy/
[20] With the overarching objective to foster the use of renewable and low-carbon gases in pursuit of environmental objectives https://ec.europa.eu/commission/presscorner/detail/en/IP_21_6682

February 2022 EU Strategy on Standardisation[21], with further initiatives forthcoming to address remaining regulatory gaps. The Commission is moreover making available significant EU funds to support the deployment of hydrogen projects (e.g. Innovation Fund, Connecting Europe facility, Horizon Europe) and offers a hydrogen public funding compass in this regard.[22]

Finally, Member States make progress towards a possible number of IPCEIs in the area of clean hydrogen. This follows from the manifesto signed by 22 Member States in December 2020 committing to launch IPCEIs in the hydrogen sector.[23] The Commission is working with Member States to facilitate their preparation of these IPCEIs as well as state aid falling under other instruments such as the new Guidelines on state aid for Climate, Environmental Protection and Energy (CEEAG). Together with EU funding, these projects aim to leverage the important investments that are needed to achieve the ambitious targets for the production of clean hydrogen set out in the 2020 Hydrogen Strategy[24] (including 40 GW of renewable hydrogen electrolysers by 2030). Finally, a European strategy on international energy engagement is being prepared to reshape energy diplomacy for global access to sustainable, affordable and secure energy supplies under changing circumstances.

Cloud and edge computing

The recently launched European Alliance for Industrial Data, Edge and Cloud, the procurement of Smart middleware for a European cloud federation and for the European data spaces as part of Digital Europe[25] and a multi-country project on common data infrastructures and services will be instrumental in addressing EU dependencies. All together, these actions will be triggering major investments in next generation cloud technologies that meet EU rules and standards. The in-depth review highlighted that the EU cloud market is led by a few large cloud providers headquartered outside the EU.[26] The Alliance, launched in July 2021, will bring together relevant stakeholders from the private and public sector to define strategic investments aimed at facilitating the emergence of a European offering that would contribute to broadening the supply of trustworthy, energy efficient and competitive cloud and edge services. In addition, it will serve as a platform for exchange on issues of cloud governance, for example related to the public procurement of cloud services. In addition, Digital Europe Smart Middleware procurement has the ambition to increase Europe's open strategic autonomy in the cloud-to-edge supply chain facilitated by the development of innovative, secure, energy efficient and multi-provider cloud to edge technology that responds to European demand for secure and interoperable solutions.

In addition, Member States' preparation of an IPCEI on next generation cloud and edge technologies – responding to emerging industrial and public sector's expectations in

[21] COM(2022)31
[22] https://ec.europa.eu/growth/industry/strategy/hydrogen/funding-guide_en
[23] https://ec.europa.eu/growth/industry/strategy/hydrogen/ipceis-hydrogen_en
[24] COM(2020)301
[25] https://ec.europa.eu/newsroom/repository/document/2021-46/C_2021_7914_1_EN_annexe_acte_autonome_cp_part1_v3_x3qnsqH6g4B4JabSGBy9UatCRc8_81099.pdf
[26] The in-depth review on IT software developed in this SWD further extends this analysis, by assessing EU software capacities in the cloud and edge market (including as regards cloud and edge computing management software as well as certain segments of the enterprise software market offered in a Software-as-a-Service model)

terms of data processing – is also well advanced and solidly progressing towards its notification in 2022.[27] Several Member States are working towards this IPCEI on Next Generation Cloud and Edge Computing Services, as part of a Multi Country Project on European Common Data Infrastructure and Services.

Semiconductors

The Commission has adopted a proposal for a European Chips Act.[28] The in-depth review highlighted that Europe relies heavily on companies from Asia for advanced chip fabrication and from the US for general design tools. The Chips Act aims to introduce an overarching set of instruments to ensure the EU's security of supply and resilience in the sector, in close cooperation with Member States. It also puts in place measures to create an attractive investment environment and to reinforce Europe's technological leadership along the value chain. In order to achieve these ambitions, the EU is also engaging with partners such as the US (Trade and Technology Council), Japan, Singapore and Korea.

In addition, the Industrial Alliance on Processors and Semiconductor technologies is another important step to address strategic dependencies in the area of semiconductors. Launched in July 2021, the Industrial Alliance on Processors and Semiconductor technologies aims to identify current gaps in the production of microchips and the technology developments needed for actors of the electronics value chain, including academia, research and technology organizations and also users to thrive, regardless of their size. Work on a new IPCEI focusing on breakthrough innovation on microelectronics and connectivity is also ongoing among Member States, with a number of projects submitted at the end of December 2021. This IPCEI is proposed to cover also related value chains, such as automotive, industrial automation and communications.

Conclusions

Work is well underway to address the strategic dependencies identified in the first round of in-depth reviews. Recently launched international partnerships will enable more diversified and resilient supply chains, notably in the area of raw materials. Ongoing Industrial Alliances on raw materials, batteries and hydrogen are facilitating the identification of investment needs and concrete investment projects. New Industrial Alliances for semiconductors and cloud services have been kick started. Important public and private investments are taking place, in particular in the area of batteries. Ongoing IPCEIs on batteries and semiconductors as well as EU funding are accelerating innovation allowing for substitution of dependent products and increased capacities in the EU. Although industry is expected to take the necessary actions to increase the diversification of its critical supply resulting into overall increased resilience for the EU economy, in exceptional cases, policy interventions might be considered. In this context, for example, possible new IPCEIs on cloud, hydrogen and a second one microelectronics and connectivity are being prepared by Member States. Significant steps have also been taken in collaboration with stakeholders to

[27] In December 2020 several Member States launched an open and inclusive process to jointly prepare with other interested Member States a possible IPCEI focusing on next generation cloud and edge infrastructure and services. Since then Member State have launched and completed their calls for expression of interest at national level. The kick-off for the match-making process took place in October 2021.

[28] A corresponding staff working document is being prepared

further increase clarity on supply chain vulnerabilities in the area of active pharmaceutical ingredients and ways to address them. Finally, the Commission has adopted proposals to provide fit-for-purpose regulatory frameworks on semiconductors, hydrogen and earlier also on batteries.

3. Second round of in-depth reviews

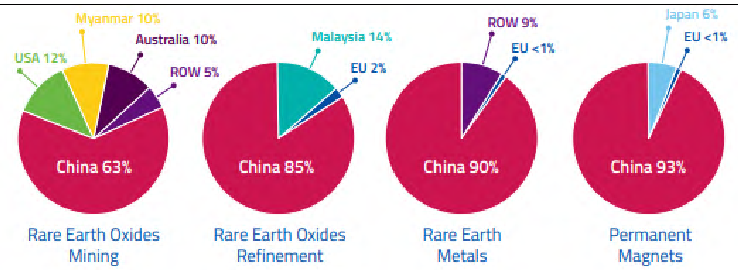
This second round of in-depth reviews assesses different areas of strategic importance. The second stage of in-depth reviews presented in this staff working document complements the first stage by deepening the assessments related to raw and processed materials (focusing on rare earths and magnesium as well as the impact of raw material dependencies in the area of chemicals) and cloud and edge services (focusing on software capacities). In addition, the staff working document presents reviews for additional areas of strategic importance, namely photovoltaic panels and cybersecurity. Each in-depth review outlines the strategic importance of the area concerned, EU dependencies and their impact, as well as relevant (ongoing) policy measures. This chapter outlines the main findings. The detailed assessments are provided in Annex.

Raw and processed materials

- *Rare earths and magnesium*

The technological advancements that will determine the EU's ability to reduce carbon emissions are dependent on access to critical raw materials. The need to address the EU's strategic dependencies in the area of raw materials has been highlighted already for some time.[29] Rare earths and magnesium are two prominent examples of increasing importance also in view of supply challenges and price hikes that have materialised during the COVID-19 crisis, large expected demand increases as well as examples of trade distortions. Rare earths are important inputs for key products and technologies across a wide range of areas from electronics to power generation, healthcare, space and defence. EU demand for rare earth permanent magnets – a key component for e.g. electric vehicles and certain wind turbines – may double by 2030 to up to 40.000 tonnes per year. Demand for magnesium – a key alloying material for e.g. aluminium production with an important role in reducing fuel consumption and CO2 emissions in the mobility ecosystem – is also expected to increase significantly in parallel with aluminium consumption.

Figure 1: Chinese dominance over the rare earth permanent magnets value chain



Source: ERMA (2021)

[29] See e.g. COM(2020)474

The EU has been monitoring the market development of critical materials. China holds 89% of magnesium global production. It also dominates the whole rare earth permanent magnets value chain, from access to rare earths to the production of rare earth permanent magnets (for which it holds 93% of global production). In addition, there is no EU production of magnesium[30], the EU does not mine rare earths and it produces only a very limited amount of permanent magnets. As a result, the EU faces important strategic dependencies and security of supply risks (e.g. due to potential export restrictions imposed by third countries). European companies have been facing magnesium price hikes as well as risks of shortages starting in Q4 2021. The potential to reduce dependencies via supply diversification for magnesium, rare earths and permanent magnets is currently limited.[31]

Structural and long-term policies are needed to overcome the identified possible strategic dependencies. On the global stage, the EU has been establishing partnerships on raw materials, with countries where there is a strong legal framework in place that avoids distortions to trade and investment. These help to diversify and strengthen supply chains. At the same time, structurally improving resilience in these areas would benefit from the EU strengthening its domestic capacities. The European Raw Material Alliance has identified investment needs[32] across the rare earths and permanent magnets value chain as well as relevant industrial projects to increase EU sourcing. The EU is also coordinating efforts to increase magnesium production in Europe, in the wake of the 2021 supply constraints. Further progress in recycling as well as increased material substitution via technology innovation will also facilitate reducing the EU's reliance on these imported raw materials.

- *Chemicals*

Safe and sustainable chemical products are key for the well-functioning of numerous supply chains. They are of major importance for economic development and resilience, enabling solutions across many industrial ecosystems as necessary inputs for products and technologies ranging from wind turbines to batteries, building insulation and medicines.

The in-depth review identifies six specific chemicals for which the EU has strategic dependencies. The in-depth review focuses on 61 chemical products in the area of chemicals that were identified in the bottom-up analysis of product dependencies accompanying the Industry Strategy update[33]. A criticality assessment[34] allows pinpointing those chemicals that are of particularly strategic importance, taking into account elements such as their importance in end-use, the EU's green and digital objectives, as well as risks of trade disruptions and the availability of EU production capacities. On this basis, six chemicals are identified as requiring particular attention (iodine, fluorine, red phosphorus, lithium oxide and hydroxide,

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[30] The last production site for magnesium in the EEA was located in Norway and closed in 2001 in large part due to price pressure from China. A French magnesium factory also closed in 2001. As a result, in 2018, 93% of the EU's 184kt magnesium consumption originated from China, in addition to smaller imports from Russia, Israel, Serbia, the UK and Turkey.

[31] See annex for further details

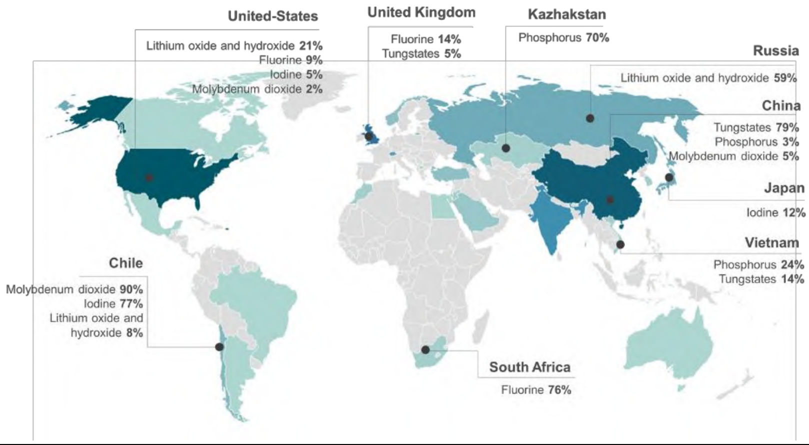
[32] Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance: Rare Earth Magnets and Motors: A European Call for Action, 2021

[33] This bottom-up mapping identifies products for which the EU is dependent based on a granular analysis of trade data (SWD(2021)352, chapter 2)

[34] Based on detailed information provided by the ECHA as well as interactions with stakeholders

molybdenum dioxide and tungstates).[35] The majority of these inorganic compounds are usually specific (processed) forms of (critical) raw materials. As a consequence of the dependence in some (critical) raw materials, the downstream chemical industry also faces strategic dependencies. Eurasian countries (China, Russia, Vietnam, Kazakhstan) are important exporters to the EU for these six chemicals.

Figure 2: Largest suppliers to the EU of the six identified chemicals



Source: Commission analysis based on Baci and Eurostat. Note: graph highlights the largest non-EU suppliers for the 61 dependent chemicals and specifies the percentage shares of imports for the 6 critical chemicals identified.

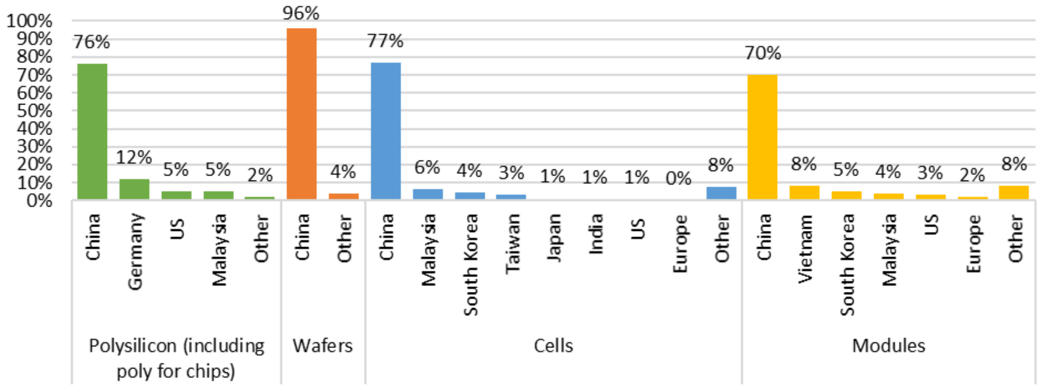
This highlights the importance of actions to increase access to critical raw materials but also foresight and resilience in the context of the Chemicals Strategy for Sustainability in particular for those chemicals that are EU strategic dependencies with high supply risks. The identification of consequences of specific strategic dependencies in raw materials on the chemicals sector provides a first step in increasing foresight. Different measures could be considered in reducing such strategic dependencies. Stockpiling of strategic reserves may ensure that supply chains can continue to operate unaffected in case of a crisis. New international partnerships and the production of sustainable alternatives in the EU can also provide opportunities to diversify supply sources.

Solar photovoltaic panels and technologies

Solar photovoltaic (solar PV) technologies have become the world's fastest-growing energy technology and play an important role in securing sufficient amounts of decarbonised electricity. Commission modelling suggests that meeting the goals of the European Green Deal will imply a threefold increase in solar energy generation by 2030 and an almost tenfold rise by 2050. Specific PV technologies are also critical in light of the EU's space and defence interests (e.g. as satellite power supply).

[35] To note is that this assessment does not specifically cover end-uses in the pharmaceutical and health downstream markets, as this is part of the structured dialogue on the security of medicines supply

Figure 3: China's strength along the PV value chain



Source: IEA PVPS and Trends Report 2021. Note: figures are rounded.

While the EU has strengths in downstream segments, it faces important strategic dependencies in the upstream manufacturing segments.[36] EU companies are global leaders in a number of downstream segments of the solar PV value chain (e.g. monitoring and control, balance of system). At the same time, they only have a minor role in several important areas of the upstream manufacturing segments, holding 1% of global production for solar wafers, 0.4% for solar cells and 2-3% for modules. China is leading in all steps of the PV manufacturing value chain. In view of such significant market concentration, the solar industry can be faced with a situation where it is no longer able to mitigate these risks by diversifying or flexibly responding to them. This creates a situation of strategic dependence that could in turn hamper the EU's future deployment of solar technologies. In addition to the dependencies on PV panels and their components, the EU also faces important strategic dependencies when it comes to the (critical) raw materials that are inputs to the PV supply chain (e.g. silicon).

An appropriate framework is necessary to ensure industry can mitigate the risks they face, in particular on those segments where dependency on imports is highest and most concentrated (i.e. ingots, solar wafers, cells). Europe's advanced R&I ecosystem is delivering technological leadership in segments of the PV value chain (e.g. solar wafers and cells), which enables EU companies to deliver cutting edge technology addressing key challenges as regards recyclability and carbon footprint. The European Solar Initiative[37] already aims to scale up annual EU PV production to 20 GW by 2025. Tools and funding are in place (e.g. Horizon Europe, Invest EU, state aid) to assist advanced and emerging technologies become market ready. In addition, the EU cooperates with international partners on ensuring the resilience of supply chains, including with the US under the Trade and Technology Council, as any efforts to diversify international supply chains will reduce the EU's strategic dependence.

Cybersecurity technologies and capabilities

The importance of cybersecurity spans across many industrial ecosystems including digital and electronics, mobility, energy, health and in particular also defence and space.

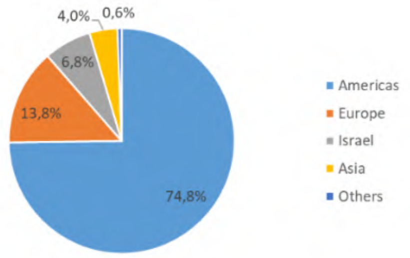
[36] See also COM(2021) 952

[37] A consortium of European solar companies together with EIT InnoEnergy and SolarPower Europe (the EU industry association of the solar sector)

The updated Industry Strategy highlighted the importance of strengthening the EU's capabilities in technologies that are important for the industrial future of the EU. The rapid evolution of the threat landscape, including an increased number of cyber-attacks, requires the EU to ensure cybersecurity and defend its interests.

Different elements point to weaknesses for the EU in comparison with other jurisdictions. While the EU is leading in cybersecurity research together with the US, this does not translate in a similar equally relevant industrial position. The EU lags mainly behind the US and also China in cybersecurity innovation as well as private investments in cybersecurity start-ups and scale-ups. Only 14% of the world's largest 500 cybersecurity companies are EU headquartered (compared to 75% in the US). Europe is partially relying on international providers of products and services to protect its infrastructures. While this in itself does not necessarily lead to a vulnerability, it could be a concern for specific sectors of strategic importance. This includes the area of defence, where the vast majority of hardware and software currently in use in the EU for cyber defence is developed in the US and manufactured in China. The large majority of EU companies are also micro or small sized entities, which are not able to cover the full cybersecurity range and instead need to rely on products purchased by third parties. These weaknesses and strategic dependencies create important concerns, for example in key areas such as next generation telecommunication networks infrastructure, quantum communication, personal data management, advanced manufacturing and defence technologies.

Figure 4: Top 500 global cybersecurity companies: US dominates the global cybersecurity market



Source: PwC, LSEC (Cybersecurity Industry Market Analysis, 2019). Note: top 500 by sales volume.

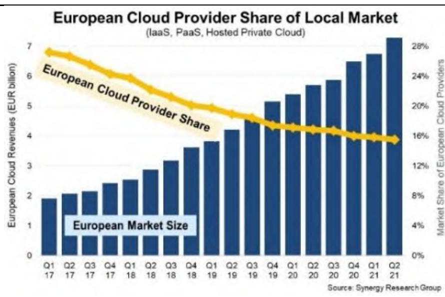
Different ongoing actions can strengthen the EU's capabilities in cybersecurity. The EU Cybersecurity Strategy for the Digital Decade aims to bolster Europe's resilience against cyber threats. Its priorities include the proposed European Cyber Resilience Act to ensure that products placed on the EU market are secure as well as the development of secure quantum communication infrastructure. In addition, the European Cybersecurity Competence Centre will reinforce EU capacities in cybersecurity, investing in areas such as cybersecurity in SMEs and in the health sector, 5G security and skills. Furthermore, the proposed revision of the cybersecurity directive (NIS 2) will set tighter cybersecurity obligations in terms of risk management, reporting obligations and information sharing. Cybersecurity is also a cornerstone area in EU funding programmes, such as Digital Europe and Horizon Europe. Cyber defence R&D is being supported by the European Defence Fund. Finally, cybersecurity has become an important consideration taken into account in EU legislative activity concerning a number of specific technologies and products. Together, these measures aimed at improving EU cybersecurity capacities strengthen resilience, increase the uptake of cybersecurity products and services and support the development of an ecosystem of EU cybersecurity providers.

IT software (with a focus on edge and cloud)

Cloud and edge software is a key enabler of the EU's digital transformation, encompassing all information technology applications and services used by businesses. It provides major potential to develop significant benefits to EU businesses including increased productivity, innovation and reduced risk. The European cloud market is worth 5.9 billion EUR, its value having tripled over the period 2017-2020. The in-depth review focuses specifically on software capacities in the cloud and edge market, building on the first round of in-depth reviews, which covered the overall market development. It provides a more in-depth assessment on the EU's position and software capacities in the cloud and edge market, including as regards cloud and edge computing management software as well as certain segments of the enterprise software market.

The EU faces strategic dependencies in the area of cloud and edge computing management software as well as regarding enterprise software. The EU market is led by a limited number of large global cloud providers ("hyperscalers"). In Q4 2021 cloud market leaders controlled 71% of the global public cloud market[38]. As regards cloud and edge computing management software, EU reliance on third country suppliers is found particularly in the cloud layers Infrastructure-as-a-Service and Platform-as-a-Service. There are furthermore risks of growing dependencies in emerging areas such as hybrid and multi-cloud models and the increasingly important edge computing, with cloud hyperscalers successfully proposing new services there as well. Strong presence of non-EU hyperscalers is seen also in the area of enterprise software, including cloud based collaboration as well as analytics and business intelligence platforms. Hyperscalers are ahead of EU providers, mainly because of much stronger innovation levels and integration of software offering complete end-to-end solutions. As a result, the EU faces important strategic dependencies in these different areas. The lack of state-of-the-art equivalent European solutions entails significant risks to the digital transformation of EU industrial ecosystems, linked for example to potential foreign cloud service disruption, locking-in effects faced by European users, or unlawful access to data, in particular in case of implementation of conflicting obligations stemming from third country legislations.

Figure 5: The EU cloud market is led by a limited number of large non-EU providers



Source: Synergy Research Group

[38] Synergy research, As Quarterly Cloud Spending Jumps to Over $50B, Microsoft Looms Larger in Amazon's Rear Mirror, https://www.srgresearch.com/articles/as-quarterly-cloud-spending-jumps-to-over-50b-microsoft-looms-larger-in-amazons-rear-mirror

There are opportunities for the European cloud sector to strengthen its capacities. Recent developments such as the increasing importance of edge computing and the wide availability of Cloud Native Software Architectures present an opportunity for the European cloud sector to overcome current cloud hyperscaler leadership, namely by relying on open source community efforts. The proposed Digital Markets Act (DMA) focuses on the gatekeeper role of hyperscalers in cloud computing services. The upcoming Data Act plans to address obstacles to switching between different cloud, edge and other data processing services, requiring also that such services are compatible with open standards or interfaces where these exist. Funding through Digital Europe specifically aims at reinforcing the EU's core AI, data and cloud capacities. Horizon Europe is supporting forward-looking cloud and edge computing research. The Alliance for Industrial Data, Edge and Cloud aims to strengthen Europe's position and serve the specific needs of EU businesses and the public sector. In addition, Connecting Europe Facility 2 supports cloud interconnection across Europe and 5G deployment, including Edge. Complementarily, several Member States are exploring an Important Project of Common European Interest on next generation Cloud Infrastructure and Services.

Conclusions

For the product areas analysed, the in-depth reviews highlight important possible strategic dependencies that could lead to vulnerabilities of the EU economy. Several of the identified possible strategic dependencies (rare earths, magnesium and PV panels) are driven by a strong concentration of global production in one country (China), with limited options for supply diversification (from within or outside the EU). Strategic dependencies are also identified for a number of chemical products of particularly critical importance. Some of these dependencies have been illustrated during the COVID-19 crisis, with certain products experiencing supply challenges.

As already highlighted in the updated Industry Strategy, strategic dependencies also exist in the areas of services and technologies. Some of the in-depth reviews (cybersecurity, IT software) highlight risks for the EU of becoming (increasingly) reliant on providers from other economies for access to state-of-the-art technologies in these areas. While the impact of such technological dependencies has been less visible during the COVID-19 crisis, they may risk undermining the EU's long-term strategic interests in specific cases.

4. Conclusion

The analysis carried out in this staff working document complements the May 2021 review of the EU's strategic dependencies and capacities accompanying the Industry Strategy update. The 2021 Industry Strategy update highlighted the importance of better understanding the EU's strategic dependencies, how they may develop in the future and the extent to which they would lead to vulnerabilities for the EU. This provides the basis to address these strategic dependencies based on a balanced mix of tailored, facts-based and proportionate measures. This staff working document contributes to ongoing efforts aimed at developing a better understanding and a more structural monitoring of the EU's strategic dependencies, highlighted in the updated Industry Strategy as one of the key pillars to improving the EU's open strategic autonomy. The Commission will continue efforts to identify and assess strategic dependencies, in close collaboration with industry and Member States (e.g. in the context of the Industrial Forum).

The COVID-19 crisis highlighted in some specific sectors the importance of tailored and proportionate policy measures to address strategic dependencies. As set out in the 2021 update of the Industrial Strategy, in most cases industry itself is best placed, through its corporate decisions, to improve resilience and reduce unwarranted dependencies and associated risks. At the same time, in areas of strategic importance, public policy measures can support industry's efforts to address these dependencies and overcome market failures in a sustainable way. The EU is pursuing international partnerships to increase supply chain security and the availability of diversified sourcing options. At the same time, increasing resilience may also require developing a certain level of EU strategic capacities in particular where strategic dependencies lead to important vulnerabilities for the EU. Different measures can facilitate such build-up of European capacities, with relevant actions tailored to the specific challenges of the concerned area. These range from EU (e.g. RRF[39]) and national funding in line with State aid rules where applicable (e.g. IPCEIs), to targeted support for R&I, industrial alliances in strategic areas (namely, where such alliances are the best tool to accelerate activities that would not develop otherwise), enhanced circularity as well as relevant legislative actions to ensure that regulatory frameworks do not end up deterring and eventually stimulate innovation and investment in the EU. A significant number of measures have already been undertaken to address strategic dependencies identified in the first round of in-depth reviews. This staff working document highlights strategic dependencies and relevant ongoing measures in the areas covered in the second round of in-depth reviews.

[39] In addition, tailor-made technical expertise is provided to Member States through the Technical Support Instrument (Regulation (EU) 2021/240)

Annex – Second round of in-depth reviews

The second round of in-depth reviews build on the approach and concepts developed in the context of the updated Industry Strategy. The SWD on strategic dependencies and capacities accompanying the updated Industry Strategy introduced a number of concepts that are the basis also of this second round of in-depth reviews. This notably includes definitions for concepts such as "dependencies"[40], "strategic dependencies"[41] and "strategic capacities"[42].

The reviews use quantitative evidence as well as more qualitative market information and intelligence provided by stakeholders. The in-depth reviews covering specific products (or product groups) assess EU dependencies based on a combination of elements (e.g. trade flows, global production concentration, EU production capacities, etc.). In the area of technologies, as highlighted in the SWD on strategic dependencies and capacities[43], an analysis of EU dependencies and weaknesses requires taking into account a range of indicators (e.g. on research, innovation, investments, entrepreneurial activities, market concentration and other trends). Together, these may point to risks of (future) dependencies in the area of such technologies emerging or further increasing.

Selection of second stage of in-depth reviews

The areas covered in this second stage of in-depth reviews are linked to strategic interests of the EU and its Member States. Similarly to the first stage of reviews, the in-depth reviews in this second stage are related to areas of strategic importance such as security, safety, health and the green and digital transformation.

Furthermore, in the area of products, the in-depth reviews follow on the results of the bottom-up mapping presented in the May 2021 SWD on strategic dependencies and capacities. This bottom-up mapping relies on a data-driven assessment, allowing to identify products for which the EU is dependent on third countries based on trade data.[44] The mapping qualifies products as dependent, based on three economic indicators: concentration of imports, importance of imports in total EU demand and domestic EU production capacities.[45] Similarly to the first stage of in-depth reviews, the reviews presented in this second stage provide a

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[40] Reliance on a limited number of actors for the supply of goods, services, data, infrastructures, skills and technologies combined with a limited capacity for internal production to substitute imports

[41] Dependencies that are considered of critical importance to the EU and its Member States' strategic interests such as security, safety, health and the green and digital transformation

[42] A certain level of capabilities held within the EU allowing to produce, provide or rely on strategic goods, services, data, infrastructures, skills, industrial know-how and technologies

[43] SWD(2021)352, chapter 3

[44] It should nevertheless be noted that this bottom-up mapping cannot be considered an exhaustive screening of all possible product dependencies, given its limitations (e.g. in some cases the granularity of available data is not sufficient to capture dependencies on specific products or inputs). See SWD(2021)352, chapter 1.2.

[45] For further details see SWD(2021)352, chapter 2. As a follow-up, European Commission (2022) has complemented the bottom-up mapping by including a specific treatment for re-exports using the newly created Eurostat's FIGARO merchandise trade database. This uses the information provided by Member States about the country of origin and country of consignment (entering the EU) in EU merchandise trade (Comext). Such a treatment of re-exports is important as they can potentially affect the intensity and origin of the identified foreign dependencies. Taking re-exports into consideration broadly confirms the dependent products identified in the bottom-up mapping (e.g. accounting for re-exports, identified dependencies on products such as permanent magnets, magnesium and PV panels are even reinforced in view of higher levels of supply concentration and lower capacity of substitution with internal production) and complements some of the existing findings. See https://publications.jrc.ec.europa.eu/repository/handle/JRC128381 for further details.

more in-depth assessment of one or more products identified as dependencies based on this bottom-up mapping methodology (see table 1). This follows also from the May 2021 SWD and the updated Industry Strategy, which highlighted that the Commission would further assess the dependencies identified through this bottom-up methodology, including their impact and the possible risks they entail to the EU's strategic interest.[46]

In-depth reviews concerning services and technologies focus on areas where quantitative[47] and/or qualitative information point to possible EU strategic dependencies. Also similarly to the May 2021 SWD[48], these in-depth reviews are related to services and technologies with possible technological strategic dependencies for the EU.

Table 1: Selection of second stage in-depth reviews

In-depth review	Short rationale for selection
Rare earths and magnesium	The bottom-up mapping[49] identifies rare earths, permanent magnets and magnesium as EU dependencies. They are of strategic importance, notably in relation to the EU's green transition. Strong demand increases for these products are expected in the coming years.
Chemicals	The bottom-up mapping identifies dependencies notably on (critical) raw materials to products in the chemicals sector. Several of these chemicals are important inputs for a wide range of products and technologies. The in-depth review also fits with the Chemicals Strategy for Sustainability, calling for increased foresight and understanding of strategic dependencies in the area of chemicals.
PV panels	The bottom-up mapping identifies PV panels as an EU dependency.[50] Solar energy is a crucial energy source in the context of the green transition objectives. Strong demand increases are expected towards 2030 and 2050.
Cybersecurity	A strategic technology for the EU's digital transition but also in the area of defence and space. Its strategic importance and market size is expected to continue growing significantly. Several indicators point to EU technological weaknesses in the area of cybersecurity compared to its global competitors.
IT software	A key enabler of the EU's digital transition. The EU has certain weaknesses compared to its global competitors (in both cloud computing management software as well as enterprise software). The in-depth review extends the analysis conducted in the first stage, which covered the overall market development for cloud and edge.

Source: European Commission

[46] See SWD(2021)352, chapter 2.2. This includes also interactions with stakeholders on the results of this bottom-up assessment, as for example in the context of the Industrial Forum's task force on strategic dependencies
[47] As for example included in Technopolis Group, IDC, Fraunhofer ISI, Idea Consult: Advanced Technologies for Industry – Final report, 2021
[48] See SWD(2021)352, chapter 5
[49] SWD(2021)352, chapter 2
[50] The BACI database corresponding to the 2019 trade flows has been used to update the analysis (the initial analysis was based on 2018 data). The methodology underlying this bottom-up mapping has remained unchanged. The 2018 data did not show an EU dependency for PV panels, which is related to the anti-dumping and anti-subsidy measures with China imposed by the EU over the period 2014-2018.

1. Raw and processed materials

Ensuring a reliable supply of raw, processed and advanced materials is of critical importance for the EU, including when it comes to delivering on the green transition. The broad deployment of green technologies and renewable sources of energy in the years to come, from wind turbines to solar photovoltaic and batteries for electric vehicles, will lead to a rising demand for raw materials. In addition, improving the energy efficiency of public and private buildings will also require undisturbed access to raw materials used in the area of construction. Furthermore, as highlighted in the first stage of in-depth reviews, critical raw materials are also key inputs to other strategic areas such as health, digital, space and defence.

The EU's access to many of these raw materials is subject to important risks. This is notably due to high concentration of global production in specific third countries (which also often have lower environmental and social standards) and the use of export restrictions by third countries. As outlined in the EP report on a European strategy for critical raw materials[51], addressing these strategic dependencies will be key to enabling the green transition while building resilient and sustainable industrial value chains. Building on the first round of in-depth reviews (which covered the area of raw materials from a horizontal perspective) and existing raw materials assessments[52], this second round deepens the assessment by focusing on rare earths and magnesium. In addition, it provides a first criticality assessment of the chemicals identified as dependencies through the bottom-up mapping presented in the SWD on strategic dependencies and capacities of May 2021.

1.1 Rare earths and magnesium

This in-depth review focuses on rare earths and magnesium, identified as critical raw materials at the processing stage of the value chain[53]. The EU is dependent on third countries to meet its demand of rare earth elements (REE) needed for rare earth permanent magnets, which provide key inputs across many of the EU's industrial ecosystems (including e.g. mobility, renewable energy, defence and space). In this context, increasing EU resilience in the rare earths and magnets value chain was identified as the first objective of the European Raw Materials Alliance (ERMA, initiated in September 2020). In its September 2021 report[54], ERMA presented its assessment and recommendations, which the Commission is implementing with actions related to investment and market creation, the regulatory framework, research and innovation and global competitiveness. The EP's report on critical raw materials agrees on the importance of developing a resilient European value chain for rare earths and permanent magnets. Finally, Member States are also taking action. For example, in response to the report prepared for it by Philippe Varin, Chairman of SUEZ, the French government announced this January its intention to develop a rare earths and permanent magnets cluster in South West France and to dedicate France Relance funding for this purpose.

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[51] 2021/2011(INI)
[52] See for example European Commission: Study on the EU's list of Critical Raw Materials, 2020
[53] European Commission: Study on the EU's list of Critical Raw Materials –Factsheets, 2020
[54] Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance: Rare Earth Magnets and Motors: A European Call for Action, 2021

Likewise, magnesium has many industrial applications and its recent shortage in supply linked to production disruptions in China (notably in Q4 2021) risks affecting different EU industrial ecosystems (such as the mobility ecosystem or aluminium and steel industries). It illustrates the need for industry to make best use of the Commission's assessment of Critical Raw Materials[55] in its efforts to improve resilience through corporate policy, given that magnesium has been consistently flagged as one of the critical raw materials with the highest supply risk but with no improvement over time.

a) Context and strategic importance of the in-depth review

Access to raw materials is essential to enable the green transition. Raw materials are the primary products on which a variety of industrial ecosystem rely as inputs to their value chains. The technological advancements that will determine the EU's ability to reduce carbon emissions, paving the way for the green transition, are dependent on access to many raw materials, some of them critical.

Rare earths importance for the green transition

Rare earths are used to make permanent magnets, which are key components in electric motors (used notably for electric vehicles (EV)) and wind turbines, two crucial technologies to deliver on the EU's green transitions. Such rare earth (RE) permanent magnets are made from alloys composed by rare earth elements, and have a stronger magnetic field than ceramic or ferrite magnets. They are also essential components of computer hard drives, audio equipment and magnetic resonance imaging devices. In addition, they have applications in household items, such as washing machines and energy efficient refrigerators, as well as in the mobile telephone industry (e.g. microphones and speakers). European final demand for these magnets (often already integrated in assembled products before placed on the EU market) may reach between 35.000 and 40.000 tonnes per year by 2030, from 18.000 tonnes in 2019. At the same time, the EU's production capacity covers only a limited share of EU demand and use (500 tonnes produced in 2019).[56] If no action is taken, the EU's strategic dependencies on rare earths and RE permanent magnets value chain will only deepen.

The expected mass deployment of e-mobility will significantly increase demand for RE permanent magnets. 95% of EV traction motors contain RE magnets. The EV and hybrid fleet in the EU is projected to grow by over 200-250 million vehicles and could reach up to almost 300 million vehicles by 2050. The EU automotive and mobility sector is expected to grow to about 400 billion EUR by 2030.[57] This will nevertheless require the sector to sustain its level of competitiveness, which is largely conditional upon the EU's access to relevant inputs necessary to manufacture electric motors and EVs.

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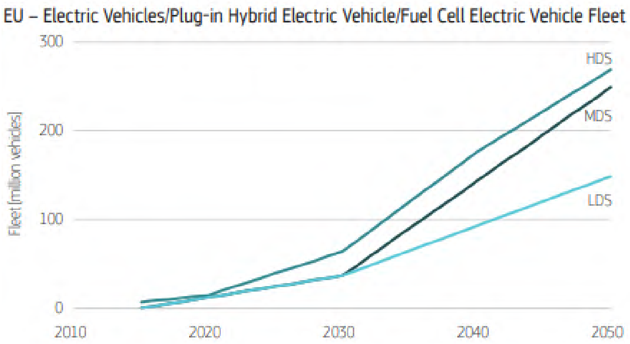
[55] The EU screens more than 80 raw materials as part of its three-yearly criticality assessment. While the focus of the exercise is to assess the raw materials where the security of supply risks are the highest, such as silicon metal for semi-conductors and photovoltaics, it is clear that the EU economy will also need growing amounts of base metals such as copper, aluminium and nickel. To reduce the pressure on primary resources, the EU economy has to become more resource-efficient and circular.

[56] Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance: Rare Earth Magnets and Motors: A European Call for Action, 2021 (pg. 28)

[57] Value added, idem (pg. 8)

Figure 6: Expected deployment of e-mobility until 2050 (million of vehicles)



Source: CRM Foresight Study 2020. Note: HDS: high demand scenario; MDS: medium demand scenario; LDS: low demand scenario

Most electric vehicles and hybrid mobility devices use synchronous motors with neodymium-iron-boron (NdFeB) magnets, the strongest magnets with the largest market share. Such permanent magnet synchronous motors are up to 15% more efficient than induction motors and they are the most power-dense type of traction motor commercially available.[58] The magnets use a variety of rare earths, such as neodymium and praseodymium. These two elements represent 75% of the total REE global market value and 20% of its volume.[59] NdFeB magnets will dominate the market, with over 90% of EVs and hybrid vehicles using motors that contain them. Some industries use alternatives to permanent magnets in order to avoid exposure to supply risk, but this strategy comes with a trade-off in terms of performance.

Annual neodymium consumption for EV motors could increase 15 times by 2050.[60] An average electric traction motor contains between 1-2 kg of permanent magnets (i.e., around 0.25 kg of Neodymium and 0.1 kg of Dysprosium[61]). With the strong expected growth of EVs and hybrid vehicles, forecasts show major spikes in consumption for borates and rare earths (and by extension for permanent magnets) used in the production of these traction motors.

In addition, EU demand for RE permanent magnets will also increase in light of a growing wind turbine fleet. Permanent magnets are essential components of a type of wind turbine generator[62], which converts kinetic energy to electricity. Their high-power density coupled with low mass offers high efficiency, with optimal weight, dimensions and maintenance. The permanent magnets used for wind turbines are similar to the ones used for EVs, made of rare earth elements such as neodymium, praseodymium and dysprosium. Wind turbines contain up to 600 kg of permanent magnets per MW, of which about one third are REE (2% of Dysprosium, 27% of Neodymium, 4% of Praseodymium and 1% of Terbium[63]). The EU represents 58% of the world market share of wind turbines, and its growing onshore

[58] In kW/kg and kW/cm3. Source: European Commission: Study on the EU's list of Critical Raw Materials – Critical Raw Materials Factsheets, 2020
[59] Idem, pg. 549
[60] European Commission: Critical raw materials for strategic technologies and sectors in the EU – A foresight study, 2020
[61] European Commission: Material composition trends in vehicles: critical raw materials and other relevant metals. Preparing a dataset on secondary raw materials for the Raw Materials Information System, 2021
[62] Direct Drive PMSG
[63] European Commission (JRC): The role of rare earth elements in wind energy and electric mobility, 2020

wind turbine fleet will heavily contribute to the increase in EU demand for permanent magnets.

Magnesium's relevance for decarbonisation

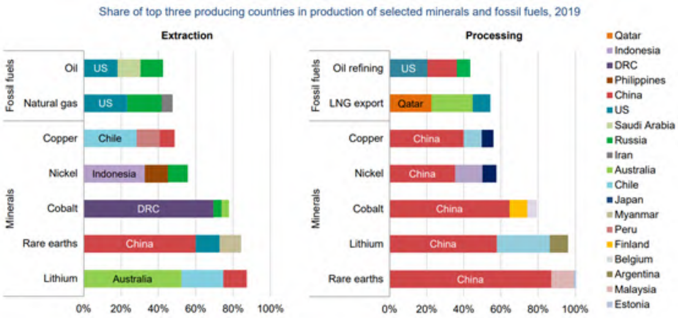
Magnesium metal is primarily used in aluminium alloys, with aluminium's particularly light proprieties making it a material of choice for application in the packaging, transport (automotive) and construction industries. Magnesium is also used in the desulphurisation process for the production of steel. Its alloys can reduce vehicles' weight if used instead of steel components, lowering fuel consumption and CO2 emissions. The mass of embedded magnesium is estimated at around 1 kg per battery electric vehicle. The European consumption of magnesium is of around 228,000 tonnes per year, 19% of the global market.[64] Its demand is expected to rise in parallel with aluminium consumption, which is expected to double from 2010 to 2050.[65] The magnesium production by China (the world's largest producer), using a thermal-reduction method, is energy-intensive and generates significant greenhouse gas emissions compared to the production method that was used in Europe.

b) *Identified dependencies, impact and related risks*

The EU faces strategic dependencies for both rare earths and magnesium. These are due to global market concentration in production, combined with limited possibilities for supply diversification, including due to limited EU capacities. As a result, the EU faces important supply risks.

The Commission has identified both rare earths and magnesium as critical raw materials and as dependent products in the bottom-up mapping accompanying the updated Industry Strategy. Critical raw materials are characterised by both a high supply risk and a high economic importance. Indeed, the concentration of the supply of critical raw materials in specific countries outside of the EU leads to vulnerabilities for several of the EU's industrial value chains. In fact, the production of many raw materials that are key for the energy transition are today more geographically concentrated than oil or natural gas (for both extraction and processing, see Figure 7).

Figure 7: Concentration production of raw materials vs fossil fuels



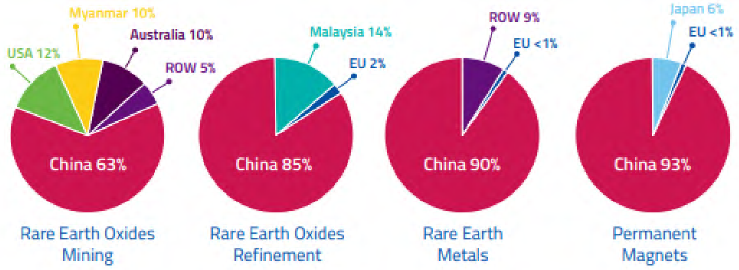
Source: IAE report: The Role of Critical Minerals in Clean Energy Transitions, 2021

[64] European Aluminium: Position paper, 27 September 2021
[65] European Aluminium Association: An aluminium 2050 roadmap to a low-carbon Europe

Dependencies and related risks across the rare earth permanent magnet value chain

The EU (as well as other economies) is strongly dependent on China for the whole rare earth permanent magnets value chain, from access to rare earths to the production of RE permanent magnets. When RE permanent magnets were developed in the 1980s, most magnet manufacturers were located in Japan. However, the lower-cost Chinese production triggered the relocation of manufacturers from Japan to China, thereby leading to a transfer of key technologies and skills.[66] China acquired the knowledge and skills to refine magnets and develop manufacturing capacity for this critical product.[67] Today, China holds a dominant position across the whole value chain: the country represents 63% of Rare Earth Oxides mining and 85% of its refinement, while it produces 93% of the world's magnets. In 2018, there were six Chinese rare earth producers and their total production capacity amounts to 227,000 tonnes, while the whole industry, including recycling of REE, amounts to 300,000 tonnes.[68] In December 2021, three of the six Chinese state entities producing rare earth merged to create of a SOE (State-owner enterprise) named China Rare Earth Group Co, which holds nearly 40% of China's rare earth production.

Figure 8: Chinese dominance over the rare earth magnet market value chain



Source: ERMA (2021)

China considers the rare earth permanent magnet market as strategically important and it has taken steps to secure its value chain and major downstream markets. In addition to government ownership of all the major actors in the value chain in China, certain WTO compatible import charges and VAT refund mechanisms created an industrial environment where rare earth magnet production became significantly less viable outside of China, causing substantial competitive disadvantage to Europe. There is a price difference of about 20-30% for a magnet produced in Europe compared to one produced in China. Even countries with mining capacity, such as the US, which mined 38,000 tonnes of rare earths in 2020, rely on China for refining activities.

Limited exploited resources and few refining and production capacities are hindering the EU's ability to rely on domestic production to reduce supply chain risks. Europe does not mine rare earths. So far, only LKAB in Sweden is developing a process to start a small-scale REE production from iron ore mining waste.[69] The EU substantially decreased its REE

[66] French companies also initiated joint ventures with China at the time.
[67] Pitron, Guillaume: The Rare Metals War (chapter V), 2020
[68] European Commission: Study on the EU's list of Critical Raw Materials, 2020
[69] Idem

processing and refining capacities, although some European companies still produce different REE products.[70]

At the level of the permanent magnet's production, the dependency persists. The EU's magnet producers are small and also under economic pressure.[71] The EU produces only 500 out of the 18,000 tonnes of permanent magnets it uses each year, mainly for specialised parts of the automotive and aerospace markets. This production is mostly done by the US-owned Vacuumschmelze, located in Germany. Additionally, there is marginal production of refined rare earths for magnets in Estonia's Silmet, which is owned by the Canadian-American NEO Performance Materials. The remaining production comes predominantly from Asia, with China accounting for 78% of the extra-EU imports of permanent magnets in 2019, followed by the Philippines and Switzerland (representing each 6% of the extra-EU import value of such magnets)[72].

Rare earth permanent magnets are at high risk of supply chain disruptions. The EU's strong reliance on a single country (China) for the whole value chain entails important risks of disruptions in case of demand and/or supply shocks. The market concentration across the REE magnets value chain enhances China's ability to set prices. Permanent magnets saw their average import price increase by almost 28% over the first eight months of 2021 compared to their pre-crisis levels (i.e., the first eight months of 2019). In addition, the security of the European supply chain can be impacted by rising global tensions. With Lynas, an Australian-Malaysian company being the only major non-Chinese producer in the market of rare earths and Japan being the second largest magnet producer with a market share below 10%, Europe is not in a position to rely on temporary supply from alternative countries in case of disruptions.

China also has tools such as production controls, export restriction (quotas or tariffs), or company consolidation at its disposal. It has already used its position strategically in the past: in 2010, it reduced its export quota to 40%, sending prices for rare earths soaring. In the wake of this, the US reactivated its Mountain Pass Mine and Japan invested heavily in the Australian rare earth production (Lynas) to diversify their supply.[73] The EU's only recourse was to join the dispute settlement at the WTO which resolved the issue. Since then, China has, for instance, considered limiting the export of rare earths used for the production of military equipment of its systemic rivals (e.g. the magnets used for US F-35 fighter jets). Linked to this, the US has launched a section 232 investigation into permanent magnets. In parallel, the US engaged actively, alongside Japan, to secure other sources of rare earth supply in Africa or Latin America. Since January 2022, all rare earth elements are covered by Chinese export control measures, although at present not resulting in restrictions.

Dependencies and related risks in the area of magnesium

Magnesium experiences a similar level of dependency. In the early 21st century, the low cost of labour and energy in China made the use of its thermal reduction process economically

[70] Including NPM-Silmet in Estonia and Solvay in La Rochelle, France. See European Commission: Study on the EU's list of Critical Raw Materials, 2020 (pg. 233)
[71] European Commission: Study on the EU's list of Critical Raw Materials, 2020
[72] SWD(2021)352
[73] European Commission: Study on the EU's list of Critical Raw Materials, 2020

viable, enabling China to become the leading magnesium producer. Currently, the supply of magnesium to EU industry is heavily dependent on imports from China, which controls 89% of total world production.

The last production site in the EEA was located in Norway and closed in 2001 in large part due to price pressure from China. A French Magnesium factory also closed in 2001. As a result, in 2018, 93% of the EU's 184kt magnesium consumption originated from China, in addition to smaller imports from Russia, Israel, Serbia, the UK and Turkey.

European companies have been at risk of experiencing magnesium shortages as from Q4 2021. The EU's high degree of dependency on imports from one country increases the risk of supply challenges significantly. As a result, shortages for critical raw materials such as magnesium may arise for any number of reasons, many of which are beyond EU control. In 2021, geopolitical tensions in the Pacific lead to coal shortages in China, creating an energy crisis that saw Chinese authorities ordering the closure of some factories to reduce energy consumption. 25 magnesium plants were temporarily shut down, creating a major disruption of the global supply chain. The Chinese producers cancelled orders from European companies. This led to a substantial hike in magnesium prices globally, increasing with over 400% in September-October 2021.[74] As a result, the sustained ability of European industry to produce and source magnesium or products containing magnesium is at risk, affecting downstream industries (as aluminium alloyed with magnesium is used e.g. for the production of car bodies, packaging, etc.) and the production of steel (as magnesium is used for desulphurisation). The lack of diversification of global sources of supply limits the availability of short-term actions to compensate for reduced volumes of magnesium produced in China. In this context, the Commission services convened a meeting with Member States in January 2022 to explore possibilities to develop an EU magnesium value chain and to identify reliable alternative sources of third country supply.

c) Relevant (ongoing) policy measures

Structural and long-term policies are needed to overcome the identified strategic dependencies. As underlined in the update of the Industry Strategy, in most cases industry itself is best placed, through its corporate decisions, to improve resilience and security of supply. In specific cases public policy is needed to support industry's efforts to address strategic dependencies. This can involve a mix of policy measures including international partnerships and enforcement of bilateral and/or plurilateral commitments, building domestic capacity in the EU through funding and investments, sustainability and recycling as well as research and innovation. Strengthening resilience is also one of the key elements of the transition pathway for the energy intensive industries that the Commission is co-creating with relevant stakeholders.[75]

International partnerships

Currently, the possibilities to diversify EU supply chains of critical raw materials such as RE permanent magnets and magnesium are constrained by their strong global

[74] TradingEconomics. This price increase has only partially lowered by January 2022 with prices still significantly above early 2021 levels.
[75] See SWD(2021)277

market concentration. Still, as the EU shares these strategic dependencies with other partners, such as the US, ongoing international cooperation can facilitate increasing supply chain resilience. As of September 2021, the EU-US Trade and Technology Council (TTC) identified the resilience and security of supply chains as a priority and established a Working Group on Secure Supply Chains. The parties announced cooperation including to increase transparency of both supply and demand in the area of raw materials, particularly in the field of permanent magnets.

On the global stage, the EU has been establishing partnerships to diversify sourcing and to secure further access to raw materials with resource-rich countries such as Ukraine or Canada. These strategic partnerships envisage cooperation on the integration of raw material value chains and research and innovation, as well as alignment on Environmental Social and Governance criteria. Deliverables include the development of critical raw material projects in the EU or in partner countries (including on magnesium or rare earths), aligning financial support or encouraging innovative mining from extractive waste. The Commission is engaging through ERMA with interesting projects in partner countries across the value chain of both rare earth and magnesium. Further partnerships are developed with countries in the EU neighbourhood and in Africa[76] pursuing the implementation of the 2020 Action Plan on critical raw materials.

Building domestic capacity in the EU

Building domestic capacities can contribute to structurally improving EU resilience in these areas. For both RE permanent magnets and magnesium, the envisaged increases in EU production capacities do not aim at reaching complete self-reliance in the supply of these critical raw materials. Instead, the purpose of EU capacity building is to further diversify and enhance security of supply, alongside other policy measures that aim to tackle the identified strategic dependencies in a structural manner.

Figure 9: EU rare earths investment opportunities

Source: ERMA (2021)

A resilient and viable RE permanent magnet supply chain in Europe would contribute to lower supply chain risks and increase resilience as regards permanent magnets in a

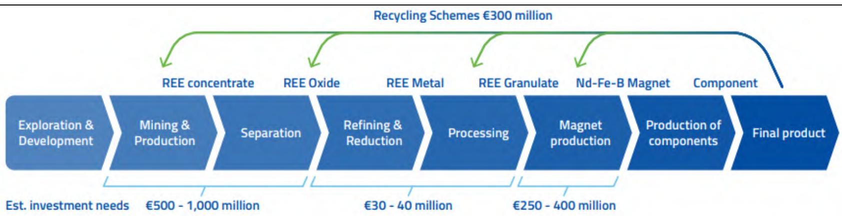
[76] EU/Africa cooperation also takes place under the Global Gateway initiative, including in the area of sustainable mineral raw materials value chains

structural manner. In 2021, ERMA identified 14 industrial projects to secure rare earth mining and urban mining with projects from all over Europe. These projects could potentially cover 20% of Europe's rare earth magnet needs by 2030. There is potential for additional investments cases beyond this, providing further possibilities to increase EU sourcing.

The Commission services are also engaging to explore possibilities for increasing magnesium production in Europe, particularly in the wake of the 2021 shortages. The Commission services have launched a work stream directly with interested Member States to identify solutions for the magnesium and rare earth value chains, as well as for battery raw materials. The Commission services have established contacts with key industrial stakeholders (e.g. aluminium, steel and non-ferrous industries) to assess the need for a renewed EU production capacity.

Materialising these pipelines to increase EU capacities will require important investments. ERMA identified the need for investments of 1.7 billion euros for the rare earth magnets value chains and 9 billion euros for other raw materials projects, mainly critical. Restoring production capacity of magnesium metal in the EU will need an estimated investment of 1-2 billion euros to restart smelting activity in Europe by 2025 with the potential of covering at least 15% of EU needs of magnesium metal by 2030.[77]

Figure 10: Investment needs for an EU permanent magnets value chain capable of matching up to 20% of EU demand by 2030



Source: ERMA (2021)

This will require the mobilisation of all potential resources. In response to the Varin report, the Commission is exploring options for the blending of private and public funding to build more resilient value chains. The Commission is identifying investments relevant for the value chain as well as the different instruments that could be used to channel them. For instance, in October 2021, the Clean Technology Materials Task Force was established to create a joint platform and to implement a structured dialogue between the European Commission, industrial alliances and investors (i.e. EIB, EBRD, NPBIs) whilst creating a mechanism to mobilize funding and financing for investments in the critical raw materials value chain.

Finally, measures proposed by the Commission seek to create a level-playing field on international markets. Critical raw materials sourced in China tend to be cheaper than when sourced or processed in Europe. The estimated price difference is about 20-30% for a magnet produced in Europe compared to an equivalent one produced in China, depending on the application[78], reflecting lower production costs in part linked to lower social and

[77] Industry estimates

[78] Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance: Rare Earth Magnets and Motors: A European Call for Action, 2021

environmental standards. An involvement of European industry (through investment, off-take agreements) is key for building domestic capacity. Upstream industrial sectors agree that potential voluntary commitments are needed from European Original Equipment Manufacturers (OEMs) to buy part of their rare earth materials from European producers for EU capacity to emerge. This is the most effective way for the downstream industry to diversify their supply chains and to maintain access to a knowledge hub for future magnet and motor designs.

Sustainability and recycling

Further progress in recycling can increase the EU's resilience and security of supply of raw materials by increasing the availability of secondary raw materials. So far, only 12% of raw materials used in European industry originate from recycling.[79] For rare earths, the recycling input rate is below 1%.[80] The lack of efficient collection and dismantling systems, energy-intensive processes and high costs hamper the development of a viable rare earth recycling industry. European industrial actors need end-of-life products, including waste materials, so that they can facilitate effective recycling and re-processing of products. EV motor shows a good potential not only for recycling but also for remanufacturing and this would increase resource efficiency of RE permanent magnets.[81] Regulation and standard-setting can help to ensure sustainable use of raw materials. With its new proposals on Waste Shipment, the Commission seeks to encourage the uptake of recycled materials. Further actions can be taken to enable the extraction and processing of rare earths from the wastes arising from former mining activities (iron ore, bauxite, coal), particularly in coal regions in transition.[82] Finally, relevant investments also take place under the Recovery and Resilience Facility, with several Member States' plans covering measures aimed at boosting innovation and improving circularity including in the area of raw materials. Member States are bound by the milestones and targets agreed in the plans, which they should now implement.

Research and innovation

Reducing material intensity and encouraging material substitution via technology innovation can help reduce the EU's dependencies in the area of rare earth permanent magnets. For this purpose, research is currently underway on component substitution, to reduce the dependency on rare earths in the making of such magnets. Research also focuses on increasing material efficiency in magnet production and optimising the motor design, enabling high technical performance while using less NdFeB magnet.

The EU is also running EU R&I projects on magnesium. This includes projects (2020) on the environmentally friendly extraction of magnesium from seawater.[83] Further projects could focus on increasing the shelf life of magnesium, which now is of around 3 months before its oxidation. Such technological developments may potentially foster a strategic stockpiling of magnesium coordinated by the EU.

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[79] European Commission: Factsheet on Waste shipments, 2021. See also Eurostat, circular material use rate https://ec.europa.eu/eurostat/databrowser/bookmark/c6638243-2f7f-4256-b2fd-6a5159b4b68a?lang=en

[80] https://rmis.jrc.ec.europa.eu/?page=scoreboard2021#/ind/15

[81] European Commission: Sustainable use of Materials through Automotive Remanufacturing to boost resource efficiency in the road Transport system (SMART), 2021

[82] Rare Earth Magnets and Motors: A European Call for Action. Op. Cit.

[83] This method, used by the US and Israel bears a lesser environmental impact than processing from rock.

Sustainable Finance

The EU taxonomy provides companies, investors and policymakers with appropriate definitions for which economic activities can be considered environmentally sustainable. Taxonomy can play an important role in attracting investments into raw materials related activities, including critical raw materials such as permanent magnets and magnesium, promoting the most sustainable investments in these value chains.

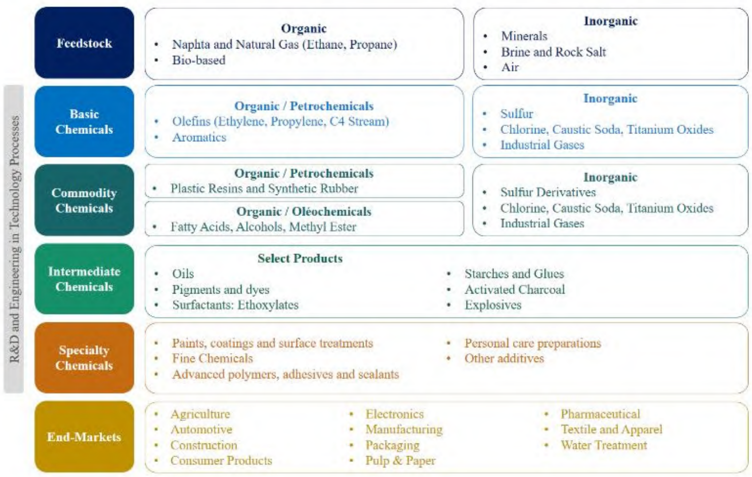
1.2 Chemicals

Chemicals are key for the well-functioning of various strategic supply chains. The 2020 Chemicals Strategy[84] highlighted the importance of increasing foresight in the area of chemicals and identifying critical chemicals in strategic value chains for the green and digital transition, as a basis to promote the EU's security of supply for chemicals. This in-depth review provides first insights into the EU's possible dependencies and vulnerabilities in the area of chemicals. It takes a targeted approach, focusing specifically on further assessing the possible strategic nature of the 61 chemical product (groupings) identified with the bottom-up mapping methodology laid out in the updated Industry Strategy of May 2021.

a) Context and strategic importance of the in-depth review

The European chemical industry is of major importance for economic development and resilience, providing inputs for production of modern products and materials and enabling solutions in virtually all sectors. Whether it is chemistry for solar panels, wind turbines, batteries, building insulation or medicines, the chemicals sector is a major enabler for the EU's green, digital and resilient transitions.

Figure 11: Overview of the Chemical Industry and Supply Chain



Source: Based on Manufacturing Chemical Global Value Chains: Opportunities for Upgrading, Duke University (2016)

The European chemical industry is mainly composed of specialty chemicals (39.6%), commodity chemicals such as synthetic materials (21.3%), as well as petrochemicals and basic inorganic chemicals (13.7%).[85] All of these are present in diverse upstream, mid-

[84] COM(2020)667
[85] Deloitte: Future of the chemicals value chain in Europe, 2020

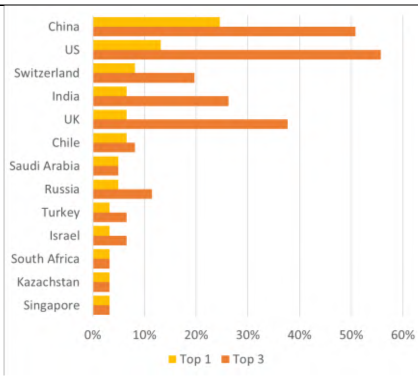
stream and downstream processes, such as mining, chemical refining and end-product realisation:

- **Specialty chemicals** include personal care products, plastic and coating additives, construction chemicals and adhesives, amongst others. As specialty chemicals are closely intertwined with the consumer market, health and environmental factors as well as standards are often of public concern. The production of such chemicals requires advanced technical and application knowledge and an awareness of end-product properties. The actors in the specialty chemical market include virtually all forms and sizes of companies, ranging from local to global entities, whilst production is often carried out in smaller scale processes;
- **Commodity chemicals** include various forms of synthetic materials, such as plastics, polymers and synthetic rubbers. As opposed to specialty chemicals, there are a comparatively smaller number of players, and a significantly diverse number of market applications;
- **The petrochemicals and basic inorganic chemicals sector** is highly competitive and defined by large multinational players. These chemical companies operate on the premise of specificity and scale of production. Global feedstock and energy prices often influence this sector, impacting attempts to switch to sustainable and/or renewable energy sources.

b) Identified dependencies, impact and related risks

Of the 137 dependent products identified by the Commission in its bottom-up mapping of products trade dependencies[86], 61 incorporate elements used in the chemicals sector and related ecosystems. An analysis looking at the main and top-three non-EU sources of imports for each of these chemicals highlights the important role in EU imports of China, US and Switzerland followed by India and the UK.

Figure 12: Origin of third country imports across the identified 61 dependent chemical groupings (proportion of top-1 and top-3 provider per country)



Source: Commission analysis based on Baci. Note: across the 61 identified dependent products, the figure shows the relative importance of third countries as the main (top 1) or the 3 main (top 3) import sources for the EU. For example, China is the main supplier for about 25% of the identified products and among the main three suppliers for about 50% of the products. Countries are ranked according to their importance as top 1 supplier.

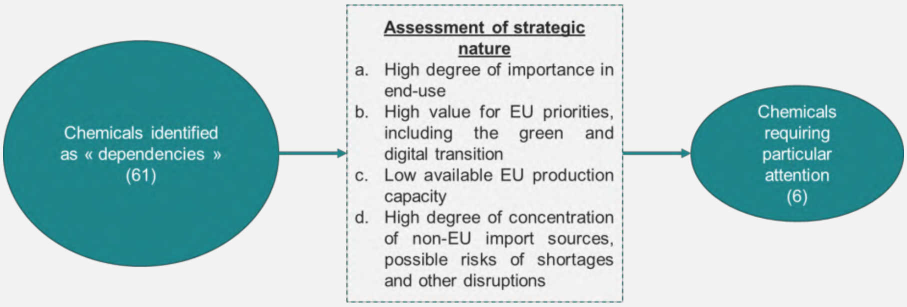
[86] SWD(2021)352

The updated Industry Strategy highlighted the importance of assessing the possible strategic nature of identified dependencies. The strategic nature of the identified dependencies was assessed on a case-by-case basis, relying on discussions with industry stakeholders[87] and the European Chemicals Agency (ECHA). The impact and the risks that they entail on the functioning of the more sensitive ecosystems were assessed based on a number of relevant criteria (see box 2).

Box 2 – Criticality assessment of the identified dependent chemicals

The purpose of the criticality assessment is to identify a first selection of specific chemicals out of the identified 61 chemical products groups that exhibit a particularly strategic or critical character. Such particularly critical chemical groupings were identified by reviewing the identified dependent chemical groups taking into account the following criteria:

a. High degree of importance in end-use, particularly in sensitive or critical ecosystems;[88]
b. High value for EU priorities, including the green and digital transition;
c. Low available EU production capacity;
d. High degree of concentration of EU import sources and possible risks of supply challenges.



Relevant information was gathered (based on data provided by ECHA) to evaluate each of the identified dependent substances on the basis of these four criteria. This includes information on:

- End-uses and role in different supply chains, to assess the importance of the substance for sensitive or critical ecosystems;
- Estimated (maximum) production capacity in the EU, based on tonnage registered per company in the EU;
- Extra-EU import flows (based on tonnages imported).

The analysis first identifies those substance having a strategic nature (i.e. meeting criteria a) or b)). Further detailed information on these substances is then gathered on the relative

[87] Beyond the six chemicals identified in this in-depth review, an additional chemical grouping mentioned by the International Association for Soaps, Detergents and Maintenance Products (AISE) in a stakeholders' meeting is worth noting: 1-chloro-2-nitrobenzene is a crucial feedstock for benzisothiazolinone (BIT), a key preservative in industrial settings, including textile and leather processing. The EU relies heavily on China for its import and use. However, as the chemical grouping identified by AISE is not directly related to e.g. the green and digital transition objectives, it is not included in the results of the criticality assessment.

[88] To note is that this does not specifically cover end-uses in the pharmaceutical and health downstream markets, as such an assessment is part of the ongoing structured dialogue on the security of medicines supply

importance of extra-EU imports compared to the EU's production capacity, their import concentration as well as possible information on possible risks of shortages and other disruptions.

This screening identifies a first selection of 6 specific chemical groupings requiring particular attention. Most of the remaining 55 chemicals include chemicals either of a non-strategic nature, or of non-strategic sector end-use (e.g. photographic films, plates and print film). Chemicals specifically or exclusively related to the health ecosystem (e.g. vitamins, insulin, amino-acids, medicaments and antibiotics) were also excluded as they are part of the ongoing structured dialogue on the security of medicines supply.

After a thorough analysis of the criticality of the 61 chemicals and chemical groupings that were identified as EU dependencies, six are identified that may require particular attention. The bottom-up mapping identified 61 chemicals, several of which linked also to dependencies identified in other Commission assessments in the area of (critical) raw materials. The May 2021 SWD highlighted that the Commission would further assess the dependencies identified through this bottom-up methodology, including their impact and the possible risks they entail to the EU's strategic interest. Out of the 61 identified chemicals, six chemicals are assessed as strategic as they meet several or all of the assessment criteria (see box 2):

- Iodine;
- Fluorine;
- Red phosphorus;
- Lithium oxide and hydroxide;
- Molybdenum dioxide;
- Tungstates (wolframates).

The above-noted six chemicals are used in a wide range of sectors and key industrial ecosystems, including health, energy intensive industries, renewable energy and agri-food. Their end-uses as part of supply and value chains most critical for the green, digital and resilient transition include energy storage, food production and feedstuff additives, production of nuclear material for nuclear power plants, production of semi-conductors used in solar panels, production of electric vehicle batteries and production of space missiles and rocket nozzles.

Figure 13: Overview of identified chemicals and chemical groupings[89]

Chemical(s) and/or chemical groupings	End-use in industry or sector (non-exhaustive list)	Role in 'green' or other critical supply/value chains	EU production capacity vis-à-vis imports (low/medium/ high)	Top 3 foreign (non-EU) import sources
Iodine	Pharmaceutical and medical industry; printing inks and dyes; disinfecting agents	Food production, feedstuff additives	low	1. Chile (77.1%) 2. Japan (11.5%) 3. USA (5.3%)
Fluorine	Cleaning, disinfecting and etching agents; surface treatment and modification	Production of nuclear material for nuclear power plants; insulation of electric towers	high[90]	1. South Africa (76.3%) 2. UK (13.5%) 3. US (9.0%)
Red phosphorus	Pyrotechnics; fertilisers; flame retardants; ignition (match sticks)	Production of semi-conductors used in solar panels	low	1. Kazakhstan (70.0%) 2. Vietnam (23.8%) 3. China (3.4%) *Country totals include red and white phosphorus
Lithium oxide and hydroxide	Absorbent, lubricating, pH regulating and heat transfer agents; pharmaceuticals	Production of electric vehicle batteries	low	1. Russia (58.9%) 2. USA (20.9%) 3. Chile (8.1%)
Molybdenum dioxide	Coatings, nanowires, nanofibers and textiles; chemical catalysts; surface treatment and corrosion reduction agents	Energy storage and production of electrochemical capacitors	medium	1. Chile (89.6%) 2. China (5.3%) 3. USA (1.7%)
Tungstates (wolframates)	Heat and erosion resistant uses (coatings, seals, metalworking, mining); electric lamps; magnets; x-ray targets	Space missiles and rocket nozzle production; high-temperature industrial applications	N/A	1. China (79.1%) 2. Vietnam (14.2%) 3. United Kingdom (4.8%)

Source: ECHA and Commission analysis

EU production capacity is relatively limited for most of the identified six chemicals, mainly as a direct consequence of the strategic dependencies on (critical) raw materials. Production capacity vis-à-vis imports is estimated based on data collected from ECHA. Within the EU, Germany is the country with the largest production capacity of the identified six chemicals (Figure 14). Most companies producing iodine, fluorine, red phosphorus, lithium oxide and hydroxide and molybdenum dioxide are registered in Germany, Ireland and Belgium. The production capacity is measured in tonnage bands that outline production levels at which individual companies operate. These tonnage bands range from 1 to 10, 10 to 100,

[89] The identification of the top 3 foreign (non-EU) import sources relies on the BACI dataset developed by the CEPII based on Comtrade. For the purpose of this assessment, the 2018 import flows have been considered. The HS6 codes used in the analysis are as follows: HS6 280120 for Iodine; HS6 280470 for Phosphorus; HS6 282520 for Lithium oxide and hydroxide; HS6 282570 for Molybdenum oxides and hydroxides; HS6 284180 for Tungstates (wolframates). In the specific case of Fluorine, Eurostat data at a more granular level (CN8 28013010) was used.

[90] Fluorine is still included in the list of chemicals requiring particular attention given the very limited number of companies from which the EU imports this substance

100 to 1000 and over 1000 tons. The overall tonnage band registered for EU companies (in other words the maximum production capacity of EU companies) can be compared to the tonnage band of imports from non-EU countries. For instance, EU iodine production is considered "low" (Figure 13) as the quantity imported is significantly higher than the estimated quantity manufactured in the EU.

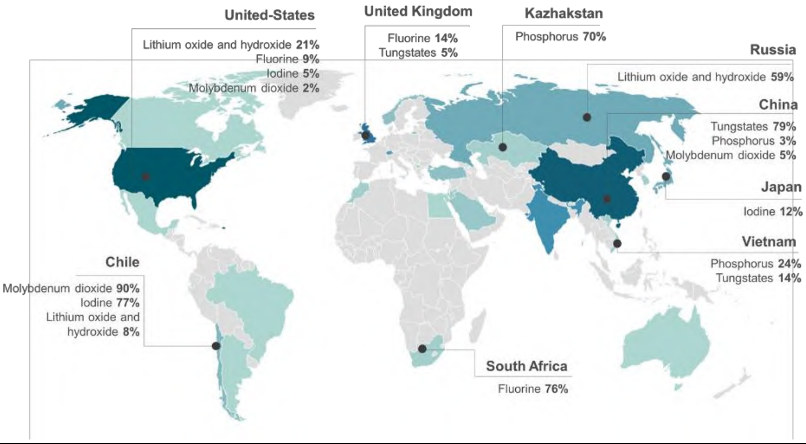
Figure 14: Number of companies registered producing one of the six identified chemicals per EEA country

EU locations of registrants	Number of companies	Number of Companies per Tonnage band / Production Capacity (in tons)			
		Over 1000	100 to 1000	10 to 100	1 to 10
Germany	22	6	8	2	6
Belgium	9	3	4	1	1
Ireland	10	2	5	3	-
Italy	4	3	-	-	1
The Netherlands	3	2	-	-	1
France	4	-	2	2	-
Norway	1	1	-	-	-
Austria	1	1	-	-	-
Latvia	1	-	1	-	-
Slovenia	2	-	-	1	1
Sweden	1	-	-	1	-
Hungary	1	-	-	1	-
Poland	1	-	-	1	-
Romania	1	-	-	-	1
Finland	1	-	-	-	1

Source: Information provided by ECHA. Note: data on tungstates: wolframates excluded as unavailable

Highly concentrated extra-EU imports are observed for these identified chemicals, the majority of them relying on one or two importing countries. Figure 15 highlights the largest non-EU suppliers for the entire list of 61 chemicals and specifies the percentage shares of imports for the 6 critical chemicals identified. Eurasian countries (Kazakhstan, Russia, China, Vietnam) are important exporters to the EU for the identified six chemicals. In addition, South Africa constitutes 76% of EU fluorine imports. In the Americas, Chile is an important market partner for iodine and molybdenum dioxide, while the US is the second source of EU imports of lithium oxide and hydroxide.

Figure 15: Largest non-EU suppliers of identified chemicals imports to the EU



Source: Commission analysis based on Baci and Eurostat

The EU faces strategic dependencies also a number of raw materials that are at the basis of these identified chemicals. Most of these inorganic compounds are some specific (processed) forms of (critical) raw materials.[91] For example, phosphorus is a limited resource with significant reserves in just a few countries, none of which are in the EU. It has already been identified as one of the EU's critical raw materials.[92] Phosphate rock reserves are mainly located in Russia, China, Morocco, and the United States. While finite reserves are present in the EU (such as in Finland and Estonia), they are not mined due to environmental concerns. Only five countries control around 85% of the world's remaining phosphate rock reserves. Furthermore, protection policies and regulations in Europe are and will continue to be stricter than anywhere else. This divergence of policies worldwide benefits some countries due to cost competitiveness, especially as social and environmental costs are increasingly included in the pricing of products.

Finally, the identified six chemicals generally face important risks for (future) disruptions. Overall market demand for most of these chemicals is expected to see (important) increases in the coming years in view of their extensive use in several (growing) industries (Figure 16). For some of them, shortages and/or price increases have already been experienced on the ground. High concentration in the feedstock for some of these chemicals provide additional risks.

Figure 16: Global market outlook and risks of disruptions

Chemical(s)	**Projected global market growth (EUR)**		**Possible shortages, disruptions or price-increases**
	From	to	
Iodine	818 million (2019) of which 322.32 million (2019) is EU	1.16 billion (by 2027)[93, 94]	Most recently in September 2021, shortages due to reduced supply and shipping delays.[95]
Fluorine	282.5 million (2020)	376.76 million (by 2027)[96, 97]	There is a continuous rise in price and demand due to fluorine's extensive use in several industries and parallel production reduction due to domestic policy in China.[98]
Red phosphorus	426.82 billion (2020) Of which 153.65 billion is Europe as a whole (2020)	602.3 billion (by 2028)[99, 100]	Risk of depletion in 30 to 40 years' time due to overuse, particularly in fertilisers sector.[101]
Lithium oxide	991.34 million	1.09 billion (2026)[103,	Demand for lithium expected to significantly

[91] See also SWD(2021)352, chapter 5.1
[92] COM(2020)474
[93] Iodine Market Size, Share & Growth | Forecast [2020-2027] (fortunebusinessinsights.com)
[94] Converted from USD to EUR using the average exchange rate in 2019: US Dollar to Euro Spot Exchange Rates for 2019
[95] Industrial Minerals (indmin.com)
[96] Global Fluorine Market Analysis till 2027 | Share, Size, Growth - WBOC TV
[97] Converted from USD to EUR using the average exchange rate in 2020: US Dollar to Euro Spot Exchange Rates for 2020
[98] POWER RESTRICTION, PRODUCTION SHUTDOWN, SHORT SUPPLY AND PRICE SPIKES – FLUORO CHEMICAL MARKET – HCA Consulting China Ltd. (hcacchina.com); Fluorine Market Size and Share | Industry Outlook – 2028 (datamintelligence.com)
[99] Red Phosphor Market Size USD 686.77 Billion by 2028 | Industry Growth 4.3% CAGR (emergenresearch.com);
[100] Converted from USD to EUR using the average exchange rate in 2020: US Dollar to Euro Spot Exchange Rates for 2020
[101] The Depleting Elements You Didn't Know We Were Using (interestingengineering.com); Red Phosphorus - Materials - Materials Library - Institute of Making
[103] Lithium Hydroxide Market | 2021 - 26 | Industry Share, Size, Growth - Mordor Intelligence

and hydroxide	(2019)[102]	[104]	increase by 2030. Prices hit record high in 2021.[105]
Molybdenum dioxide	3.74 billion (2018)	4.3 billion (by 2024)[106, 107]	China supplies over 40% of the world's mined molybdenum. The market could be prone to supply shocks.[108]
Tungstates (wolframates)	216.13 million (2019)[109, 110]	N/A	China exports 67% of the world's wolframates. The market could be prone to supply shocks.[111]

Source: Different sources (see footnotes)

c) Relevant (ongoing) policy measures

While this in-depth review has allowed the identification of criteria, datasets and a methodology to define the strategic character of a chemical dependency, these dependencies are not set in stone and will evolve with time. The Commission will intensify its ongoing efforts to identify and address strategic dependencies, including as novel products or technologies are developed. Appropriate contingency analyses will have to continue to be conducted as trends change, the global markets recover from the COVID-19 pandemic, and further data becomes available. In this regard, a foresight study for chemicals (initiated in January 2022) aims to provide a deeper mapping and understanding of the already identified six chemicals.

New international partnerships as well as stockpiling can provide opportunities to reduce dependencies. For example, the Commission is exploring potential new partnerships through the Global Gateway framework in order to ensure continuous supply and bolster international value chains. While diversification can reduce supply chain risks, its potential may be limited for those chemicals where global production is highly concentrated.

Actions to ensure the availability of feedstock for the identified chemical dependencies may also reduce risks. For several of the identified dependent chemicals requiring particular attention, the EU is also highly dependent for access to the raw materials that are at the basis of their production. Ongoing work to secure resilient raw material supply chains (e.g. in the context of the 2020 critical raw materials action plan) is therefore also of high relevance.

Also innovation towards more sustainable alternatives can help address dependencies in the area of chemicals. Horizon Europe provides a platform and funding to support the development of sustainable alternatives in the chemical industry. This represents an opportunity to respond to the objective of the Green Deal whilst at the same time enhancing the EU's strategic capacities in chemicals production. Changes in the REACH Regulation are expected to also further incentivise innovation and substitution through the greening of the industry towards more safe and sustainable products and increased consumer confidence.

[102] Lithium oxide and hydroxide (HS: 282520) Product Trade, Exporters and Importers | OEC - The Observatory of Economic Complexity
[104] Converted from USD to EUR using the average exchange rate in 2019: US Dollar to Euro Spot Exchange Rates for 2019
[105] https://www.reuters.com/business/energy/shortages-flagged-ev-materials-lithium-cobalt-2021-07-01/
[106] Molybdenum Market Growth: Industry Analysis & Report, 2019 - 2024 (knowledge-sourcing.com)
[107] Converted from USD to EUR using the average exchange rate in 2018: US Dollar to Euro Spot Exchange Rates for 2018
[108] Molybdenum: 5 Factors Driving Price In 2021 - Commodity.com
[109] Metallic tungstates (wolframates) (HS: 284180) Product Trade, Exporters and Importers | OEC - The Observatory of Economic Complexity
[110] Converted from USD to EUR using the average exchange rate in 2019: US Dollar to Euro Spot Exchange Rates for 2019
[111] Metallic tungstates (wolframates) (HS: 284180) Product Trade, Exporters and Importers | OEC - The Observatory of Economic Complexity

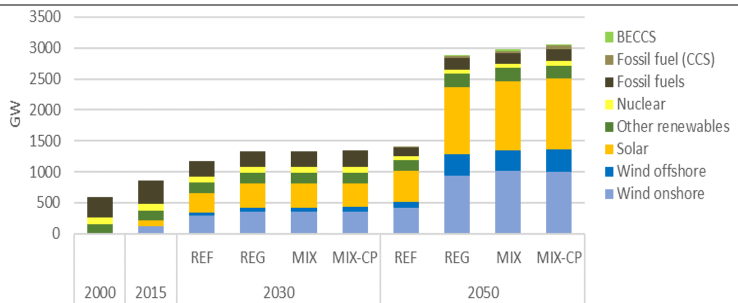
2. Photovoltaic panels and technologies

Solar photovoltaic (solar PV) technologies have become the world's fastest-growing energy technology and play an important role in securing sufficient amounts of decarbonised electricity to meet the goals of the European Green Deal. Contrary to the wind sector where the EU industry has a strong position (with solid manufacturing capabilities, robust production shares and a positive trade balance), the EU PV industry is more reliant on international supply and value chains. While the EU ranks high in terms of deployment of solar PV installations[112], EU companies only represent a very small part of global production. Solar cells and panels are an example of a "common dependency", where the EU and other global actors strongly depend on China's (upstream) manufacturing capacities.

a) Context and strategic importance of the in-depth review

Solar energy represents an important and increasing share of the EU's electricity generation. In 2020, for the first time, renewables overtook fossil fuels as the EU's main electric power source, generating 38% of EU electricity[113], compared to 34.5% for fossil fuel-based electricity generation (solid fossil fuels, natural gas, oil and petroleum products). Solar energy, together with wind, are the main contributors to the EU's rise in renewables and together supplied 19.3% of the total EU electricity generation in 2020.[114] Solar generated around 5% of the total EU electricity in 2020, having increased by 17.9% relative to the previous year.[115] Importantly, the EU has a binding target to increase the share of energy consumed from renewable sources to 32% by 2030, up from around 21-22% as estimated for 2020. Furthermore, in its July 2021 package of legislative proposals delivering on the European Green Deal, this target is set to become more stringent (40% share of renewables in gross final energy consumption) in order to meet the EU's climate goals for 2030 of reducing GHG emissions by 55% compared to 1990 levels.

Figure 17: Installed power production capacities in the EU (GW)



Source: Eurostat and PRIMES modelling as presented in the Impact Assessment of the revision of RED II, July 2021

The share of solar in the power mix[116] would need to increase to 14% in 2030 to be in line with EU's climate goals (as proposed in July 2021). More specifically, for solar PV,

[112] At the end of 2020 the EU was the second largest market in terms of cumulative PV capacity installed (23 GW), after China, accounting for about 15% of global PV market installations. Source: European Solar Manufacturing Council (ESMC), based also on IEA PVPS.
[113] Eurostat (Share of energy from renewable sources [nrg_ind_ren])
[114] COM (2021)950
[115] Eurostat (Production of electricity and derived heat by type of fuel [nrg_bal_peh])
[116] Gross electricity generation

the installed capacity would need to increase threefold in the next decade (from the current capacity level of 136 GW[117] up to 420 GW by 2030), also in a context of increased electricity demand required to decarbonise the economy. Or put differently, the share of solar in the energy sector will have to increase from a current 2% to around 8% in 2030 and further to approximately 12% in 2050, which means a threefold increase in solar energy generation by 2030 (from 147 TWh in 2019 to 447 TWh) and an almost tenfold rise (to 1286 TWh) by 2050.[118]

It is important that the EU addresses its strategic dependencies in the area of solar PV. All projections point to a significant role for solar PV in the future EU energy system. The EU therefore needs to increase its resilience to external factors affecting the EU's structural dependency on PV imports. For this, the EU will need to address its dependencies notably in the manufacturing segments of the PV value chain, while building on its strengths by continuing to invest in next-generation PV technologies.

b) Identified dependencies, impact and related risks

The global solar PV market, previously dominated by Europe, has in the last decade rapidly changed into one dominated by companies from Asia, notably China. The SWD on strategic dependencies and capacities accompanying the update to the EU Industrial Strategy included a bottom-up mapping of product trade dependencies. A recent update of this analysis shows that the EU faces important import dependencies for solar photovoltaics.[119] The bulk of EU imports comes from less than three non-EU countries, with China accounting for 63% of the EU imports in 2019.[120] It is followed by Malaysia and South Korea, which represent 9% and 6% of EU imports, respectively. As around 68% of the total (intra and extra) EU import value comes from non-EU countries, it is apparent that the EU heavily relies on foreign sources to satisfy its demand. As shown in Figure 18, China is the main global exporter and the EU one of the biggest importers. There may be some limited potential for trade diversification towards for example Malaysia, Vietnam and Korea, as current EU imports from these countries are relatively low for this product.

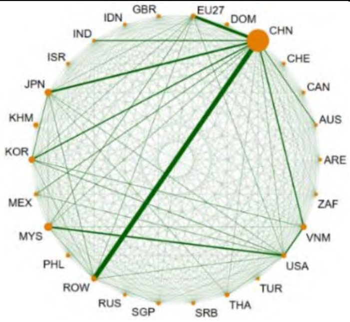
[117] Eurostat (Electricity production capacities for renewables and wastes [nrg_inf_epcrw])

[118] Based on energy scenario projections linked to the Fit-for-55 July 2021 package (https://visitors-centre.jrc.ec.europa.eu/en/media/tools/energy-scenarios-explore-future-european-energy)

[119] The BACI database corresponding to the 2019 trade flows has been used to update the analysis (the initial analysis was based on 2018 data). The methodology underlying this bottom-up mapping has remained unchanged. The 2018 data did not show an EU dependency for PV panels, which is related to the anti-dumping and anti-subsidy measures with China imposed by the EU over the period 2014-2018.

[120] To note is that this data as well as figure 18 provide an approximation of trade in solar photovoltaics based on HS6 trade code 854140, which covers photosensitive semi-conductor devices (including photovoltaic cells whether or not assembled in modules or made up into panels) as well as light emitting diodes. In 2019, the share of LEDs in EU imports for this trade code was around 18%.

Figure 18: Global trade network of solar photovoltaics



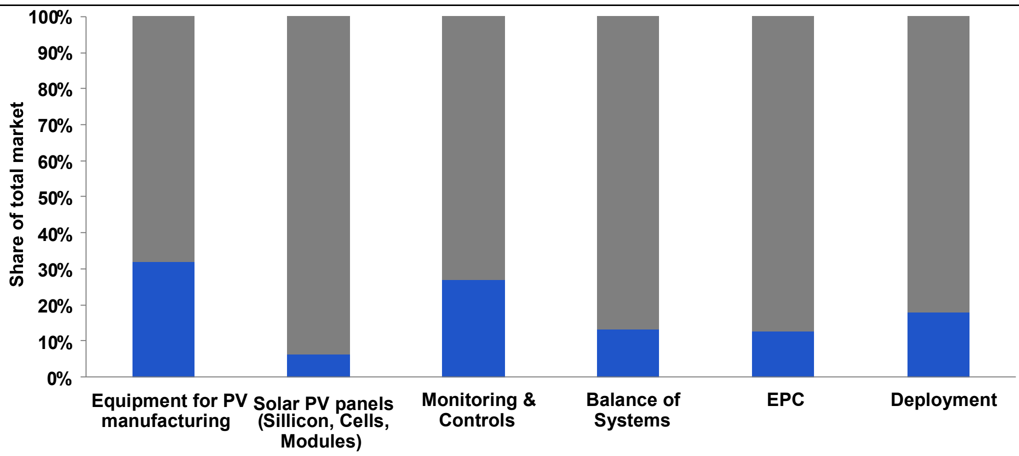
Source: Commission based on BACI database. The figure shows the global network for the products covered by HS6 code 854140, where the size of bubbles shows importance of exporters and the width of edges indicates intensity of bilateral trade

The EU is experiencing an increasingly important negative trade balance in the solar PV sector[121], with a rapid decrease, as of 2007. While imports of PVs into the EU steadily increased, the share of EU-manufactured PV in world markets remained at around 2-3%, reflecting the lack of competitiveness of EU companies. This trend is most often explained by differences in unit labour cost, mass production facilities in China and access of Chinese manufacturers to very favourable state support, including access to land, finance and (relatively) cheap energy. The latter factors relate to the anti-dumping and anti-subsidy measures imposed by the EU over the period 2014-2018 on Chinese PV manufacturers. Although these measures decreased Chinese-made PV imports, this did not translate into an uptick of EU PV production but rather with increased imports from other Asian markets. Currently, EU imports are again highly concentrated in China.

Solar PV value-chain and current market structure

The solar PV industry is characterized by a long and complex value chain, with comprehensive upstream and downstream industrial sectors. The manufacturers of solar cells and modules depend on polysilicon production, ingot production, wafer production and equipment manufacturing, glass, laminate and contact material manufacturers.

Figure 19: EU market shares across solar PV manufacturing value chain



Source: Guidehouse Insights, 2020 (SWD(2020)953 PART 2/5)

[121] In 2019, EU exports were less than 25% of EU imports for HS code 854140

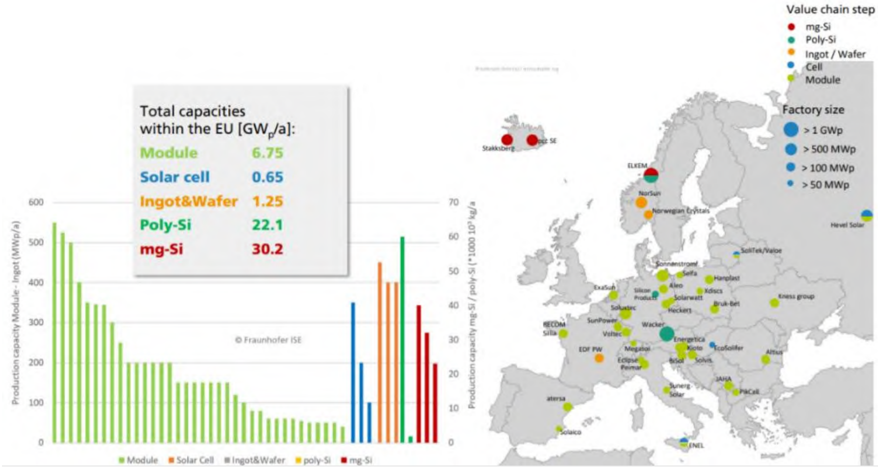
The downstream part of the value chain encompasses inverters, balance of system components, system development, project development, financing, installations and integration into existing or future electricity infrastructure, plant operators, operation and maintenance.[122]

EU companies are global leaders in several segments of the solar PV value chain. They are more competitive in the downstream part of the value chain with key roles in the monitoring and control (with companies like GreenPower Monitoring, Meteo&Control and Solar-log) and balance of system segments, especially inverter and solar trackers manufacturing (e.g. SMA, FIMER, Siemens, Gamesa Electric, Solartec, Ingeteam and Power Electronics). European companies have also maintained a leading position in the manufacturing of equipment and machinery used in PV manufacturing (Meyer Burger), as well as in the deployment segment, where companies such as Enerparc, Engie, Enel Green Power or BayWa.re have been able to move into new solar markets and gain global market share.[123]

On the other hand, EU manufacturers do not play a significant role in several important areas of the upstream segment of the value chain. This notably includes the manufacturing of the solar PV panel, which has become a very competitive business with low margins. In 2021, from the top 10 end product solar PV manufacturers 7 are from China, 1 from South Korea, 1 from Canada and 1 from the United States.

Generally, five key components exist in the manufacturing process of the predominant photovoltaic technology that makes up 95% of the PV global market share: polysilicon, ingots, wafers, cells and modules. Each of these components requires different specialized materials, production processes and equipment.[124] As can be seen in Figure 20, one EU company has a sizeable manufacturing capacity for polysilicon and a number of (smaller) module producers are also present in the EU.

Figure 20: Current European c-Si PV Manufacturing Landscape (Q4 2020)

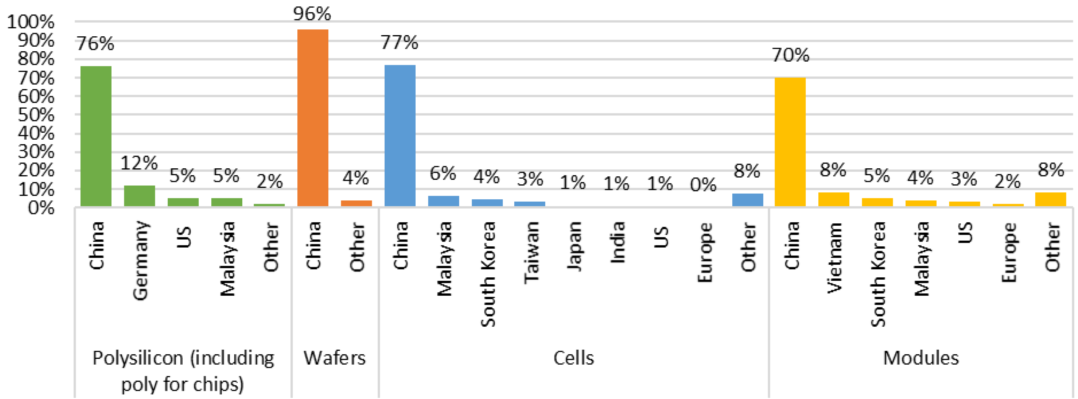


Source: Fraunhofer Institute for Solar Energy Systems, supported by PSE Projects GmbH, Photovoltaics Report, July 2021

[122] SWD(2020)94 part 2/5, pg. 84.
[123] SWD(2021)307, pg. 118.
[124] SWD(2021)307, pg.110.

Still, the EU generally only plays a minor role in the global production of the different manufacturing components. The EU's strategic dependencies in the manufacturing segment of the PV value chain are linked mainly to the absence of significant production capacities for ingots, modules and in particular solar cells based on silicon wafer. The latter are the central building block of a solar PV panel (wafers are electrified to become solar cells, which in turn connect to become solar panels).[125] In 2020, the global EU manufacturing share in PV was 11% for polysilicon, 2-3% for modules, 1% for solar wafers and 0.4% for solar cells.[126] As regards polysilicon, the EU still hosts one of the leading polysilicon manufacturers (Wacker Polysilicon AG). However, for solar cells and modules manufacturing, EU companies significantly fell behind its Asian competitors due to limited amounts of fresh capital in Europe following the 2008 financial crisis while China injected substantial liquidity during the same period. Chinese dominance in the production stages of polysilicon and PV cells has grown significantly over only a few years.[127] In general, the EU manufacturing capacity for these components can be considered as very low, whilst China dominates in all of them (Figure 21).

Figure 21: Global production shares along the PV value chain (2020)



Source: IEA PVPS and Trends Report 2021. Note: figures are rounded.

Risks linked to the EU's import dependencies

The very high import dependence, in particular on a single country, creates supply risks of disruptions in the deployment of PVs in the EU. China's global leadership in the PV manufacturing capacity, together with the low manufacturing output currently in place in the EU are creating a strong EU dependency on solar PV imports. This situation is volatile and entails important risks as country-specific events can severely hamper, delay or worst case altogether stop the import and subsequent necessary deployment of solar technologies in the EU. The leading role of China is also problematic to the extent that, in case of scarcity, Chinese authorities have tools at their disposal to establish a preference for supply of the domestic market, even in the absence of formal export restrictions.

Recent events worldwide have had a serious impact on the EU's import and deployment of solar PV panels. Recent spikes in global energy and raw material prices as well as increased transport and logistical costs, coupled with country specific events in China (such as

[125] SWD(2020)953, part 2
[126] European Solar Manufacturing Council
[127] BloombergNEF: Solar PV trade and manufacturing, 2021

factory closures due to accidents and other supply chain disruptions), have had a serious impact on the EU's import and deployment of solar PV panels. Stakeholders representing the EU PV manufacturing industry have reported that 20-25 % of planned EU solar projects were either postponed or cancelled entirely for these reasons in 2021. The strategic dependency on Chinese imports and exposure to international and country-specific events can pose a serious risk to the EU's climate and energy transition. Moreover, a high concentration of manufacturing capacities reduces the negotiating power of the EU's downstream industry.

In addition to the dependencies on PV panels and their components, the EU also faces important dependencies when it comes to the (critical) raw materials that are inputs to the PV supply chain. The EU is very import-dependent for these raw materials as well (Figure 22). Several of these raw materials (e.g. silicon) have high supply risks. Efforts to deploy more PV panels would likely aggravate supply risks through increased demand for these materials.

Figure 22: Raw materials - vulnerabilities in the solar PV chain

		Vulnerable element	Vulnerability criteria			
	Supply chain stage	Vulnerable element	Import dependency	Market concentration	Easy of substitutability	Price stability
			Import reliance	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
Solar PV	Raw / processed materials	Aluminium	59%	43% (RU, DE, MZ, FR)	Medium, by copper	22%
		Boron	100%	99% (TR, AR, NO, BO)	Low	Downward trend since mid-2000s
		Cadmium	6%	94% (NL, DE, PL, BG)	Medium	Downward trend
		Copper	42%	58% (PL, CL, PE, ES)	Medium, by aluminium	42%
		Gallium	31%	94% (DE, UK, CN, US)	Low	18-20% (4 years)
		Germanium	31%	89% (FI, CN, UK, RU)	Medium	14-17% (4 years)
		Indium	~43%	72% (FR, BE, UK, DE)	Low	~23% (4 years)
		Lead	18%	58% (DE, IT, ES, PL)	Medium	Lost ~ 25% of its value through 2018
		Molybdenum	100%	73% (US, CL, CA, PE)	Low - alternatives are associated to and/or loss in performance and higher cost	NA
		Nickel	59%	59% (CN, RU, JP, CA)	Medium	50%
		Phosphrous (elemental)	100%	98% (KZ, VN, CN)	Low	NA
		Silver	80%	82% (MX, PE, PL, AR)	Varies per application	Higher volaitility than gold
		Silicon metal	63%	68% (NO, FR, CN, BR)	Low	NA
		Selenium	17%	67 % (DE, BE, RU, FI)	High	Show high fluctuation
		Tellurium	100%	49% (UA, SE, CN, RU)	High but with loss of efficiency	NA
		Tin	78%	92% (US, PT, ES, TH)	High	All time high in 2011 and drop after
		Zinc	60%	64% (CN, AU, PE, US)	For corrosion protection Zi coating is substituted by Al alloys (less effective), Cd, paint and plastic coatings (less durable)	40%
		Steel	21%	44% (Extra-EU) (RU, TR, CN, UK)	Medium	21%
	Components / Equipment / Assembly	PV Cells	>90%	93%	High	NA
		PV Modules	65-80%	87%	High	NA
		PV Inverters	0%	78%	High	NA

Source: Eurostat PRODCOM/COMEXT; JRC (2020). Study on the EU's list of Critical Raw Materials; European Commission. (2020). Report on progress of clean energy competitiveness. COM(2020) 953

Industry is working towards decreasing its strategic dependency in the area of raw materials, including also for cost reasons. R&D efforts concentrate on finding substitutes for many raw materials like copper[128] or minimising the use of silver. This is important as certain raw materials represent an important share of the cost of an end module (e.g. silver – 10%) and thus its availability and price heavily influence the price of the end product. PV allows for a broad range of material substitutes offering possibilities to mitigate risks linked to the dependency on raw materials for certain technologies. On the other hand, while innovation can reduce certain dependencies it can also aggravate others. For instance, innovative higher-efficiency solar panels based on heterojunction cells make an increased use of critical raw materials Indium and Bismuth. In addition, demand for materials like concrete, steel, plastic, glass, aluminium and copper used in structural and electric components of PV power plants

[128] Copper is furthermore important for electrification and smart elements in the energy transition and thus also for increased energy efficiency

may double by 2050 in a low demand scenario and increase by up to 21 times in the high demand one.[129] Therefore, in general, the increase in PV deployment in the EU will continue to require a cost-effective availability of a large range of relevant raw materials.

Recovery of materials in end-of-life products and reuse of materials during the manufacturing process are equally important to increase access to raw materials, while at the same time increasing the circularity of the solar PV industry. It is estimated that 90% of a solar panel can be recycled and that by 2050, there will be between 60 and 78 million tons of PV waste in circulation.[130] An effective circular and recycling framework requires investing in the industry's recycling capacity and establishing an ecosystem with a functioning business case. At the same time, secondary materials from today's end-of-life panels will not yet be available for a number of years. Hence, the raw materials supply in the rapidly growing PV sector will still need to be covered from the primary sources.

Finally, EU dependencies in the area of PV also raise concerns in relation to space, security and defence applications. Satellite on-board systems require continuous power supply for the whole lifetime of the satellite, which is typically provided by solar cells. Ultra-high efficient solar cells for space application are produced by a few leading companies worldwide, with different production capacities, outside the EU. Alternative(s) do exist in the EU but they will have to be adapted to meet the needs and requirements of EU space programmes in terms of technology maturity level and capacity. In fact, challenges or disruptions in the supply of critical high-performance triple/quadruple junction solar cells could lead to an increase of EU dependency for Galileo and Copernicus satellites as well as for other new EU space assets (e.g. on secure communication) and/or a reduction of performance of future satellites and the services they provide. Therefore, it is key to diversify the EU supply chain, making efforts to also support EU solar cells developments that are not based only on silicon but alternative substrates such as Germanium and Gallium Arsenide allowing for the fabrication of multi-junction solar cells with higher efficiency than terrestrial applications. This would reduce the risk of strategic dependencies and challenges also in the space domain.

c) Relevant (ongoing) policy measures

While the deployment of solar in the EU will face specific challenges throughout the PV value chain (which will be notably addressed in the Solar Strategy due in 2022), the focus of this section is on (ongoing) policy support measures on the upstream parts where the strategic dependencies lie.

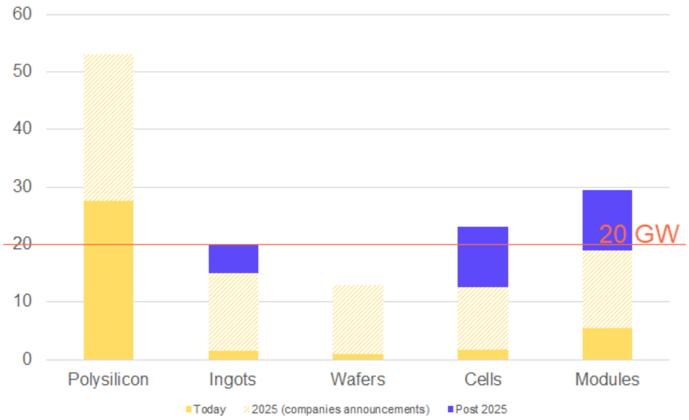
In 2021, a consortium of European solar companies together with EIT InnoEnergy and SolarPower Europe (the EU industry association of the solar sector) created the European Solar Initiative, which aims to scale up annual solar production to 20 GW by 2025. This target applies separately to each segment of PV manufacturing (polysilicon, ingots,

[129] Trinomics, Artelys: Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis, 2021 (pg. 156)

[130] IEA-PVPS: Life Cycle Inventory of Current Photovoltaic Module Recycling Processes in Europe, 2017; IEA-PVPS-IRENA: End-of-Life Management Solar Photovoltaic Panels, 2016; SolarPower Europe: Solar Sustainability. Best Practices Benchmark, 2021

wafers, cells, modules). Nevertheless, according to current trends (based on industry data) the target is expected to be achieved only for the case of polysilicon.

Figure 23: Projections of EU PV production capacity (today, 2025 and post 2025[131])



Source: Solar Power Europe

Facilitating access to finance (Horizon, InvestEU, state support)

Ensuring access to finance plays two distinct but interlinked roles in upscaling PV production in the EU, including for space solar cells. It can facilitate emerging technologies to become market ready as well as more established ones to scale up.

First, early stage financing (including EU and Member States' support) could help emerging technologies and practices (notably linked to PV recycling) become market ready. Under Horizon 2020, close to EUR 260 million were invested between 2014 and 2020 on activities related to photovoltaics. Silicon cells, as the leading commercial PV technology, received the largest share with just over EUR 60 million of funding, while perovskite PV cells, a major emerging research area, profited from around EUR 35 million in funding between 2014 and 2017. Substantive funding also went into recycling projects, also considering that high-efficient recycling of PV panels has potential to significantly recover critical and precious metals.[132] Historically, the EU's research and innovation framework programs have funded innovative PV components and applications.[133]

Investing in R&D could improve performance of multi-junction space solar cells of the alternative EU suppliers to meet the requirements of the EU space programme notably Galileo, Copernicus and future space programme such a secure connectivity. The current Horizon Europe space call 2021-2022 for Critical Space Technology (CST) includes a line dedicated to the development of advanced solar cells.

Second, de-risked financing may be necessary to scale up production of technologies that are already available on the market. The InvestEU programme could help scaling up the production of viable technologies (including space solar cells), including through equity support channeled via the European Investment Fund to SMEs and Midcaps active in that market. The Innovation Fund (IF), which primary aim is providing support for the

[131] 2025 projections are based on company announcements; not approved projects
[132] https://www.sciencedirect.com/science/article/pii/S0956053X19302909?via%3Dihub
[133] For example, a Horizon Europe project was also at the origin of the ENEL PV manufacturing plant in Sicily

demonstration of innovative low-carbon technologies, is already playing a role in scaling-up PV manufacturing: out of the seven proposals preselected during the IF first call for large scale projects, one is dedicated to the development of an industrial-scale pilot line for bifacial heterojunction PV cells in Italy.[134]

National policies also play a role in supporting emerging PV technologies and upscaling viable production. For example, permitting delays have a serious impact on investors, which are deterred from developing projects due to increased costs and risks. Additional efforts by Member States to streamline and simplify permitting procedures for the deployment of new renewable energy installations such as solar farms would provide manufacturers further certainty when upscaling production capacities.

Public funding for research projects on solar panels could be available under the State Aid Guidelines on Research and Development and Innovation. These guidelines and the 2014 Environmental Protection and Energy State aid guidelines are being or have been recently reviewed to ensure their alignment with the objectives of the European Green Deal and the updated Industrial Strategy. In this respect, the new Guidelines on State Aid for climate, environmental protection and energy (CEEAG) will continue to enable Member States to support projects on renewable energy and to scale up ambition and facilitate public support, where needed, in the transition towards a low-carbon economy.

Providing a level playing field

It will be vital to ensure fair competition between EU PV manufacturers and their foreign competitors. A number of the EU's main trading partners are also conducting comprehensive reviews of the resilience of their strategic supply chains, with solar PV being a key sector. Any subsidisation would have to respect the applicable WTO rules so as to ensure fair trade and investment. The EU is cooperating with the US on secure supply chains for PV panels in the context of the Trade and Technology Council.

Ensuring a secure and sustainable access to raw materials

Given their increasing demand, securing and diversifying access to relevant raw materials is an important condition to increasing EU capacities in solar PV. This includes making use of mineral reserves in the EU through technological solutions for developing primary sourcing that are fully compliant with existing environmental and other requirements.

Increased reuse and recyclability of recovered materials can further help to ensure security of supply in the area of solar PV. Increased coordination across actors of the value chain (collection, logistics, transportation, processing and purification) may facilitate an increased material recovery-rate. Other facilitating actions may include for example setting specific objectives for recycling specific raw materials from solar PV waste as well as considering standardising the quality of traded secondary materials to enhance recycling.

[134] https://ec.europa.eu/clima/eu-action/funding-climate-action/innovation-fund/focus_en; https://ec.europa.eu/clima/system/files/2021-11/policy_funding_innovation-fund_large-scale_successful_projects_en.pdf

3. Cybersecurity technologies and capabilities

The rapid evolution of the threat landscape, including an increased number of cyber-attacks, has raised the need for the EU to enhance its resilience and defend its interests in a critical area such as cyber. This is high on the agenda of the EU, where recent policy initiatives such as the Cybersecurity Strategy for the Digital Decade[135] highlight that cybersecurity will be the main cornerstone of a more trustworthy digital ecosystem. The focus is on building collective capabilities to respond to major cyberattacks and working with likeminded partners around the world to ensure international security and stability in cyberspace.

a) Context and strategic importance of the in-depth review

Cybersecurity is today a fundamental societal need. Cybersecurity touches upon every aspect of the digitalisation of society. The ongoing digital revolution will also bring an increase in cybersecurity threats, which could ultimately impact the safety of citizens and businesses. Indeed, as more and more connected devices come into use, the number of people impacted simultaneously by a single cyber incident strongly increases as well: in October 2021 alone, 6 major security incidents were recorded.[136]

Situational awareness, application security and infrastructure have been the segments experiencing the highest growth in the cybersecurity industry.[137] Another important segment is industrial automation and the growing Internet of Things, where the connectivity of cyber-physical systems is becoming more pervasive. Cybersecurity is crucial for smart grids, smart buildings and smart appliances, which are the next step for energy efficiency and energy system integration. Strong cybersecurity capabilities are essential for maintaining Europe's position where it is strong in the global market, for example in the machinery sector. A third set of segments comprise all sectors enabled by communication networks in general and 5G more in particular. Finally, important segments relate also to e-Health, where data and privacy breaches are increasing. Similar considerations apply to e-Mobility, including autonomous vehicles and drones, which are prone to cyberattacks for systems disruption through remote control.

b) Identified dependencies, impact and related risks

The EU should be able to rely on strong technological capabilities in the area of cybersecurity. Given the strategic importance of cybersecurity and its relevance for several of the EU's strategic interests, there is a need for strong generation and uptake of state-of-the-art cybersecurity technologies in Europe. This is necessary in particular to minimise technological dependencies on third countries in this critical area from emerging or increasing further.

EU technological capacities, weaknesses and dependencies

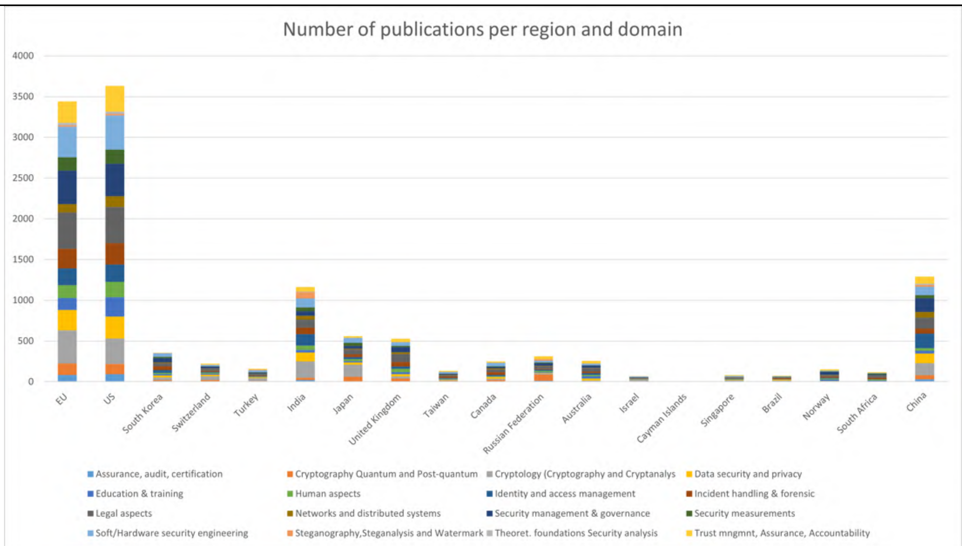
A range of different indicators can give a picture of the EU's technological capabilities in the area of cybersecurity. The May 2021 SWD on strategic dependencies and capacities

[135] JOIN(2020)18
[136] https://www.csis.org/programs/strategic-technologies-program/significant-cyber-incidents
[137] PwC, LSEC: Cybersecurity Industry Market Analysis, 2019

highlighted that in the area of technologies, the EU's possible dependencies and weaknesses cannot be captured by an analysis of trade statistics only.[138] Instead, the combination of different indicators (e.g. on research, innovation, investment, market concentration) together are better at providing indications (or early warnings) as to possible weaknesses or risks of dependencies in the area of such technologies emerging or further increasing. For example, comparatively low levels of research, innovation, investments and entrepreneurial activities are key drivers of Europe becoming potentially more dependent on other countries for access to state-of-the-art technologies.

First, as regards scientific research, while the US is in the lead the EU is not far behind. An analysis of the cybersecurity scientific literature shows that the US leads scientific research in cybersecurity, generating the largest number of worldwide publications with the EU in close second place. The remaining scientific production is done mostly in China and India. Most publications are concentrated in the domains of security management, network security, data security and privacy and cryptology.[139]

Figure 24: Cybersecurity scientific publications since 2016



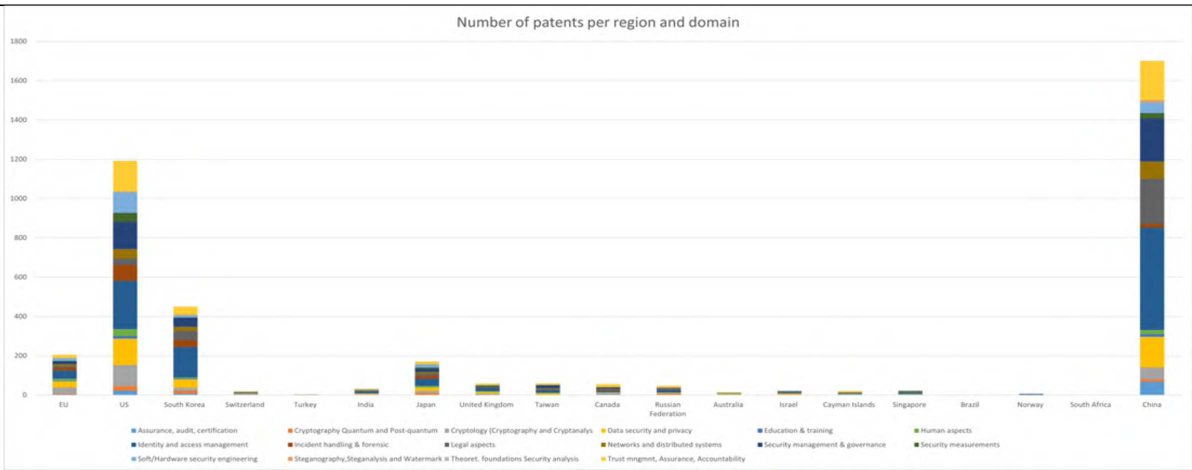
Source: European Commission, based on TIM Analytics

Second, the EU lags significantly behind both the US and China when it comes to the development of new cybersecurity products and technologies. While the analysis of scientific publications shows Europe as one of the leading actors on the international scene, the analysis of cybersecurity related patents (i.e. the natural following step in the product development value chain) shows a significantly different picture, with Europe generally lagging significantly behind both the US and China.

[138] SWD(2021)352, chapter 3

[139] European Commission (Joint Research Centre): Cybersecurity – our digital anchor, 2020

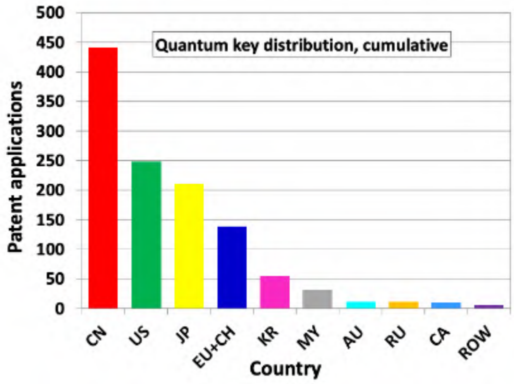
Figure 25: Cybersecurity patenting activity between 2016-2021



Source: European Commission, based on TIM Analytics

The case of quantum key distribution[140], which is already offered as a cybersecurity solution[141], provides a good example of how the EU is lagging behind the innovation levels seen for other big international actors. China leads in patent applications in this field, significantly ahead of the US and Japan with the EU only in fourth place. Considering the broader context of quantum computing (which has indeed huge cybersecurity implications) gives a similar picture with only 8% of the first 100 leading companies filing quantum computing patents being European.[142]

Figure 26: Quantum key distribution: cumulative patent applications (1992-2017)



Source: European Commission

Third, it is clear that only larger Member States are investing in cybersecurity research for those sectors and applications that require costly facilities and applications. A mapping of cybersecurity research competences in Europe[143] (considering all the countries associated to the H2020 program) shows that, in general, sectors where costly facilities are needed to perform cybersecurity research (e.g. energy, space and defence) are only well

[140] Quantum key distribution (QKD) uses the principles of quantum mechanics to share a secret key in a highly secure manner, overcoming the disadvantages of current public key encryption systems

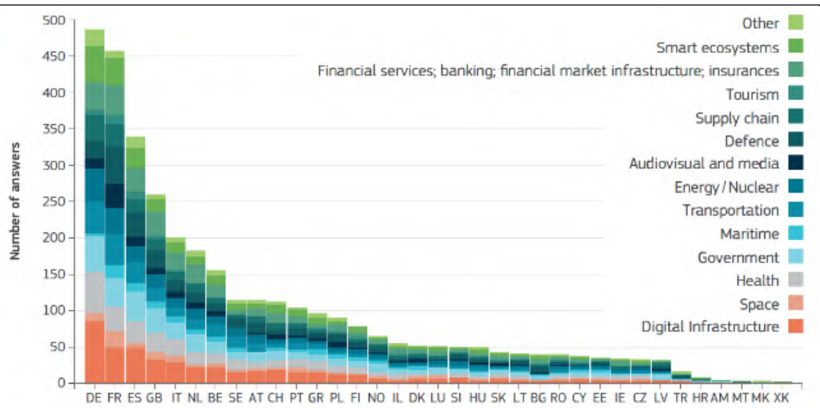
[141] European Commission (Joint Research Centre): Patent analysis of selected quantum technologies, 2019

[142] European Commission (Joint Research Centre): Shaping and securing the EU's Open Strategic Autonomy by 2040 and beyond, 2021

[143] Based on a pan-european survey involving more than 700 European research centres conducted in 2018 by the European Commission aimed at mapping European Cybersecurity Competences

covered in those countries with more resources to invest in such large facilities or having strong industrial player(s) in the specific sector. Also in the field of applications, those that require more investment (such as high-performance computing, AI and quantum) are well covered only in those countries that traditionally can afford to invest in such areas. This underlines the need for coordination in term of investments across Member States, to pull together enough resources to compete in the global cybersecurity industry.

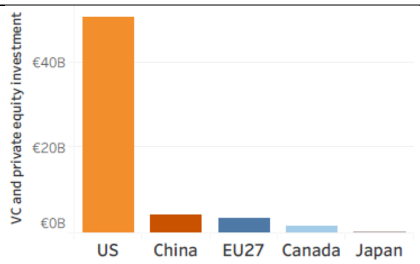
Figure 27: Number of Competence Centres declaring to have competencies in cybersecurity for a given sector (2018)



Source: European Commission

Fourth, the EU lags significantly behind the US in private investments directed to innovative start-ups and scale-ups. EU private equity and venture capital investments over the last decade in the area of cybersecurity are of a much smaller scale than in the US and of a similar size as China (see Figure 28 for cumulative investments over the period 2010-2019). More recent 2020 data[144] shows that this large gap compared to the US is persisting.

Figure 28: Cybersecurity private equity and venture capital investments (cumulative 2010-2019)



Source: Technopolis Group (2020)[145]

Finally, the structure of the global cybersecurity market confirms the EU's weaknesses. While the EU has some strengths in specific areas[146], only 14% of the world's top-500 cybersecurity companies are EU based. While many of the high growth companies have

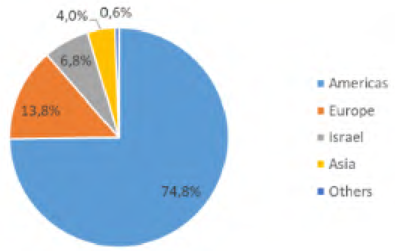
[144] Technopolis Group, IDC, Fraunhofer ISI, Idea Consult: Advanced Technologies for Industry – Final report, 2021

[145] Technopolis Group: Advanced Technologies for Industry Policy brief Cybersecurity, 2020

[146] Including in the antivirus market, where European companies are well placed in term of market shares, with two companies in the first three places globally https://www.statista.com/statistics/271048/market-share-held-by-antivirus-vendors-for-windows-systems/

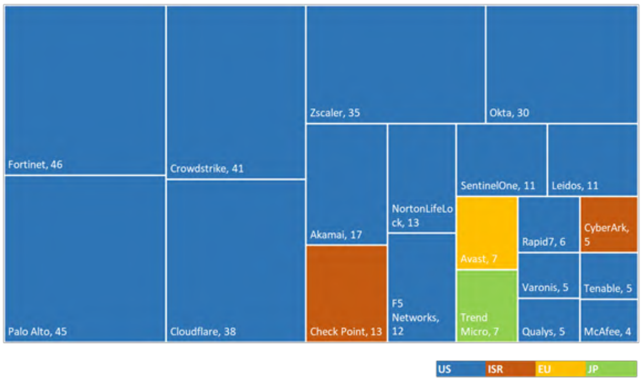
offices in EU, the large majority of them are headquartered in the US. A significant majority of the largest cybersecurity companies by market capitalisation are also US-based (Figure 30).

Figure 29: Top 500 global cybersecurity companies by sales volume



Source: PwC, LSEC (Cybersecurity Industry Market Analysis, 2019)

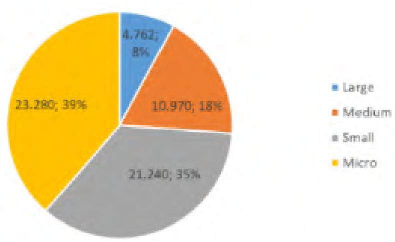
Figure 30: TOP-20 global cybersecurity companies by market cap (billion EUR)



Source: https://companiesmarketcap.com/it-security/largest-companies-by-market-cap/ (consulted in December 2021)

The large majority of EU cybersecurity companies are also micro and small sized enterprises. In the EU, the large majority of cybersecurity companies are micro and small sized enterprises (approximately 74%), which nevertheless only represent a small size of the overall market. This testifies to the vibrant liveness of European entrepreneurship in the cybersecurity field. At the same time, it is clear that the majority of these companies are not able to cover the full surface of the cybersecurity industry value-chain. Instead, they are often covering the last mile, as system integrators who put together products purchased by third parties (often non-EU).

Figure 31: Number (and proportion) of EU cybersecurity companies by size



Source: PwC, LSEC (Cybersecurity Industry Market Analysis, 2019)

Furthermore, the smaller scale of EU industry also implies lower influence in the standardisation setting-process at international level in the area of cybersecurity.

Overall, these indicators show that while research in the EU stands up among the big cybersecurity players, this does not translate in an equally relevant industrial

prominence. The comparatively lower EU levels of innovation, public and private investments and market presence among the largest players all highlight potential dependencies in the area of cybersecurity emerging or further increasing. This conclusion is confirmed when looking at EU imports of products that have a link with cybersecurity technologies. An assessment of EU trade for a range of technological products shows that the EU faces a particularly strong negative trade balance in the area of cybersecurity. This is in line with other estimates, which highlighted that about 70% of imports by Member States of goods and services in the area of cybersecurity are from outside the EU (30% being intra-EU imports).[147]

Figure 32: Trade balance for selection of high tech products (expressed as % of trade volume, 2018)

Source: Technopolis Group, IDC, Fraunhofer ISI, IDEA Consult

Finally, the EU's capacity in the area of cybersecurity also depends on its access to certain essential inputs for which it currently depends on third countries. Shortages in semiconductors have brought these external dependencies to the public attention during the COVID-19 crisis. They are an essential input in the area of cybersecurity, with many of the security/authentication features on critical but also day-to-day activities being implemented through security chips (where the EU is a leader) requiring silicon to produce (e.g., SIMs, smart-cards, secure elements, hardware security modules). Without these chips, EU citizens would not be able to perform in a secure way many of their daily activities.[148]

Impact of the identified weaknesses and dependencies

The EU's strategic dependencies in the area of cybersecurity raise important risks. As cybersecurity becomes more encompassing and transversal for the digital transformation of all sectors in the EU Single Market, the identified weaknesses and dependencies create risks. Failure to address these challenges could negatively affect Europe's capabilities in the area. In addition, at a technological level, cybercriminals are able to exploit an increasingly greater vulnerabilities surface.

[147] PwC, LSEC: Cybersecurity Industry Market Analysis, 2019
[148] https://www.eurosmart.com/digital-security-industry-affected-by-global-chip-shortage/

There are specific concerns, including in relation to next generation telecommunication networks infrastructure and protocols. A clear example is the issue of high-risk vendors for hardware and software to build and deploy the European 5G network, which will penetrate the European economy and society at an unprecedented level of pervasiveness, and the importance of having EU capacities in this area.[149] The EU currently has strengths in this area with companies such as Ericsson and Nokia having been identified as being worldwide 5G leaders in terms of vendors' abilities to execute and completeness of vision in 5G solutions.[150]

Quantum communication is another example of possible concerns linked to the EU's cybersecurity capacities. Quantum communication networks use the latest developments in quantum communication technologies to safely transmit sensitive data. Although the EU's quantum communication industry is developing fast, it is not yet sufficiently advanced to meet the needs of governmental and private users that wish to make use of EU solutions alone. The EU faces important dependencies in the field of quantum key distribution used in space and on ground.

Specific considerations for the area of cyber-defence

Finally, cybersecurity has a clear strategic importance and a significant impact on the specific area of defence. This in-depth review has outlined weaknesses, dependencies and their impact regarding the general or civilian cybersecurity. In addition, rapid, mainly civilian-driven technological evolution in the cyber domain also has a direct impact on the EU defence sector, with its specificities. It is therefore crucial for the defence sector to profit from the technological evolution of the sector, identify synergies with the civilian sector, adapt technologies to military needs and safeguard the freedom to act of EU (Member States) defence forces. However, the defence industry in Europe has suffered from fragmentation and underinvestment, notably in research, development and innovation. There is an urgency to fill strategic gaps and reduce technological and industrial dependencies in defence, including in the area of cyber defence applications.

Having autonomous industrial capacity is the cornerstone of Member States defence forces' capacity to act, and therefore of critical importance for the EU. Cyber-industry and cyberspace are different from more traditional military domains, as ownership typically lies with commercial entities. The fact that cybersecurity and cyber defence technology development is mainly done by extra-EU global digital enterprises poses clear risks.

The EU depends on solutions developed by companies established in third countries when it comes to cybersecurity and cyber-defence. The European Defence Agency has already highlighted that the European cybersecurity and defence industrial and technological base, despite of existing capacities and ongoing programmes, is highly dependent on external markets to provide state-of-the-art solutions both for the commercial and the military sector.

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[149] The EU Toolbox on 5G cybersecurity recommends assessing the risk profile of suppliers and applying relevant restrictions – including necessary exclusions – to effectively mitigate the risks (https://digital-strategy.ec.europa.eu/en/library/cybersecurity-5g-networks-eu-toolbox-risk-mitigating-measures)

[150] Gartner Research (2021)

This situation is exacerbated by the fact that the European internal cyber defence market is highly fragmented. The vast majority of hardware and software currently in use in the EU for cyber defence is developed in the US and manufactured in China. The EU lacks a strong presence in the global cyber-defence industry, which leaves room for industrial and technological dependencies from the outside world, mainly from the US. This is limiting the European Union's freedom of action.[151]

These dependencies lead to important risks in the defence area. The result of these dependencies are potential supply shortages, risks in terms of security of information, potential blockages linked with defence items export regulations and risks of unknown vulnerabilities. Digitalisation overall, but specifically a more digitalised and connected defence sector requires better preparedness and defence infrastructures that are equipped with well-developed cybersecurity.

c) Relevant (ongoing) policy measures

First, the EU Cybersecurity Strategy for the Digital Decade was presented in December 2020 as a key component of the Communication on Shaping Europe's Digital Future, the Recovery Plan for Europe, and the EU Security Union Strategy.[152] It aims to bolster Europe's collective resilience against cyber threats and ensure that citizens and businesses can fully benefit from trustworthy and reliable services and digital tools. The Strategy is also intended to step up leadership on international norms and standards in cyberspace, and to strengthen cooperation with partners around the world to promote a global, open, stable and secure cyberspace.

The development of a secure quantum communication infrastructure (EuroQCI) spanning the entire EU is a key element in the Cybersecurity Strategy. The Cybersecurity Strategy includes a plan for the Commission together with Member States and the European Space Agency, to develop and deploy in the period 2021-2027 a secure quantum communication infrastructure spanning the entire EU (including its overseas territories) to meet the needs of national governments and public services. The EuroQCI (based on a terrestrial segment relying on fibre communication networks and a space segment based on satellites) will provide an unprecedented way of securing communications and data, integrating innovative and secure quantum products and systems into conventional communication infrastructures. The first service that it will provide will be quantum key distribution.[153] As quantum space technologies related to EuroQCI would mature, the multi-orbital secure connectivity system under consideration by the Commission would incrementally integrate the EuroQCI space component.

The upcoming European Cyber Resilience Act would aim to ensure that products placed on the EU market are secure and support trust in the digital transformation, and that consumers are protected from insecure products and services. In addition, the initiative

[151] See previous work for the European Defence Agency such as Key Strategic Activities at EU Level. Cyber Defence R&T (Annex 2), 2019
[152] JOIN/2020/18
[153] Relevant actions under the work programme for 2021-2022 of the Digital Europe and Horizon Europe programme as well as under the ESA programme will support the further development of Europe's quantum communication industry

would also aim to prevent further fragmentation of cybersecurity product requirements on the internal market. The Cyber Resilience Act would build on and complement the relevant existing tools and instruments, such as the recently adopted Delegated Regulation on the basis of the Radio Equipment Directive, which establishes requirements on cybersecurity safeguards for wireless devices. It would aim to cover more products, including non-embedded software, looking at their whole life cycle, ensuring that all the relevant EU frameworks concerning cybersecurity aspects would be coherent and complementary. The Commission Work Programme for 2022 envisages the adoption of the Cyber Resilience Act in the third quarter of 2022.

Second, the Cybersecurity Strategy is complemented by the recent Regulation establishing the European Cybersecurity Industrial, Technology and Research Competence Centre and the Network of National Coordination Centres.[154] Its purpose is to reinforce EU industrial and technological capacities in cybersecurity and ensure a safe online environment. It will invest in topics such as Security Operations Centres, cybersecurity upgrades in SMEs and in the health sector, 5G security, or training and skills. Possible synergies will be exploited, but in light of the sensitivity of cyber defence and Member States responsibilities of defence, the Centre will focus mainly on civil matters.

Third, in December 2020, the Commission proposed a revised version of the cybersecurity directive (*NIS 2*)[155]. It aims at setting tighter cybersecurity obligations in terms of risk management, reporting obligations and information sharing, addressing the resilience of critical entities, to enhance cyber resilience of key entities. Moreover, the Cybersecurity Act[156] is intended to strengthen the trust of our citizens in the digital transition under an EU cybersecurity certification framework. Such a framework will provide industry and digital service providers with tools to demonstrate to the global market that their products and services provide state of the art cybersecurity features.

Fourth, cybersecurity is also a cornerstone area in EU funding programmes such as Digital Europe and Horizon Europe. The Commission has adopted a work programme on cybersecurity under Digital Europe, with a EUR 269 million budget until 2022. It is intended to build up advanced cybersecurity solutions to be leveraged by the European economy.[157] Furthermore, different cybersecurity-related topics (e.g. cybercrime, security of network, information systems and certification) are considered by the Horizon Europe programme under Cluster 3 *Civil security for society* with a budget of EUR 1.6 billion.

Additionally, the Recovery and Resilience Facility supports the public sector investment in cybersecurity projects. Together with other EU programmes, the RRF contributes to achieving the goal set out in the cybersecurity strategy of EUR 4.5 billion of investments in cybersecurity between 2021 and 2027. The RRF supports investments aimed at enhancing detection and incident response capabilities, which now need to be implemented in line with the agreed milestones and targets of the Member States' recovery plans. Among others, it funds actions for securing public administrations' network and information systems,

[154] Regulation (EU) 2021/887
[155] https://digital-strategy.ec.europa.eu/en/library/proposal-directive-measures-high-common-level-cybersecurity-across-union
[156] Regulation (EU) 2019/881
[157] https://ec.europa.eu/commission/presscorner/detail/en/ip_21_5863

supporting the development of cybersecurity companies, establishing cybersecurity certification and testing facilities, boosting research and innovation as well as developing training and skills.

Among the many initiatives taken by the EU, the European Defence Fund (EDF) plays a fundamental role in improving cybersecurity and strengthening cyber capabilities. The EDF supports and co-finances defence R&D and technological innovation and will support Member States in developing jointly interoperable cutting-edge military capabilities. The objective of the EDF is to support innovation and competitiveness of the defence industry so the latter can develop the capabilities needed for the military end-user. Although it already supports support R&D in the area of cybersecurity and cyber defence, there is a need to further increase investments in this area, and to support digital and cyber skills. Such efforts will enable the European defence technological and industrial base to harness technological advances and remain innovative and competitive. The EDF is supporting R&D projects related to requirements that are specific for military applications.[158] Cyber is also covered under other thematic categories as most military systems and weapon systems have electronic devices. The EDF would also support the adaptation of the civil state of the art technology to military needs, which will create synergies with activities of the civil research programme in order to prevent unnecessary duplication.

Fifth, cybersecurity has become an important consideration in legislative activity. Legislative frameworks of existing technologies need to be revised in order to address cybersecurity challenges:

- Under the Radio Equipment Directive[159], a recent delegated regulation[160] sets out requirements for radio equipment not to harm the network, to ensure safeguards for the protection of personal data and privacy and to ensure protection from fraud. It covers devices such as smartphones, tablets, laptops, Internet of Things, radio controlled toys, smart meters in the field of energy, equipment for 5G communication networks, smartwatches and fitness trackers. A relevant part of these products is used in the industry field. Standards to this effect will be developed by the European Standardisation Organisations;
- The proposed Machinery Regulation replacing the Machinery Directive[161] clarifies its existing safety and health provisions, requiring that machinery must be robust, be resilient and must remain always safe despite external influences, which would include actions from malicious third parties. Furthermore, manufacturers, when performing the machine risk assessment, must take into account all the risks that may appear during the life cycle of the machine, including those stemming from software updates or uploads.

[158] Such as cyber defence for military communication networks and information security for defence systems, IT security of critical infrastructure, improving cyber capabilities and responsive operations, cyber situational awareness and joint training and exercises through R&D actions (such as R&D for technical environments where to conduct cyber-trainings)
[159] 2014/53/EU
[160] C(2021)7672
[161] COM(2021) 202

Finally, there are other complementary ongoing initiatives regarding cybersecurity and defence. These include:

- 5G is widely recognised as a key component for the security and supply-chain aspects of industrial infrastructures. At European level, the EU toolbox[162] follows a risk-based approach to set out a common set of measures, aimed at mitigating the main cybersecurity risks of 5G networks;
- The Strategic Compass (foreseen to be adopted in March 2022) will set a new level of ambition for the Common Security and Defence Policy. In line with this ambition, the European Commission has announced[163] ambitious policy initiatives in this area ("*Europe must become a leader in cybersecurity, through a genuine European Cyber Defence Policy, in order to protect, detect, defend and deter*"), notably also in the Commission contribution to European defence in the context of the Strategic Compass adopted on 16 February 2022;
- The Commission explores all the possibilities to exploit the potential synergies in cybersecurity and cyber defence through the Action Plan on Synergies between civil, defence and space industries[164] and the complementary Roadmap on critical technologies for security and defence adopted on 16 February 2022. In addition, an EU strategy for space and defence currently under consideration by Member States in the context of the Strategic Compass and planned to be published in 2023, could further strengthen synergies between space and defence to fully exploit the potential of both areas by allowing space to act as an enabler for more secure, resilient and reliable defence applications;
- The recent *Artificial Intelligence Act* considers a risk-based approach to ensure safety and fundamental rights protection;
- The *Product Liability Directive*[165]*,* which establishes a harmonised system for compensating consumers who suffer damage from defective products, i.e. products that fail to provide the safety a person is entitled to expect. Its upcoming proposed revision[166] considers including product-related software and software manufactures in the definition of "product" and "producer" respectively, to better account for cybersecurity aspects;
- Any legal framework on cybersecurity will need to be underpinned by implementing measures (i.e. technical solutions) that operationalise policy objectives and guarantee its efficiency and effectiveness in a timely manner. In this view, the *standardisation* of cybersecurity will be a key effort to ensure a correct rollout and to guarantee a fair Internal Market (responding to EU policy needs, usability across industrial ecosystems etc.).

[162] https://digital-strategy.ec.europa.eu/en/library/cybersecurity-5g-networks-eu-toolbox-risk-mitigating-measures
[163] Namely President von der Leyen in the State of the Union speech in September 2021
[164] COM(2021)70
[165] 85/374/EEC
[166] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12979-Civil-liability-adapting-liability-rules-to-the-digital-age-and-artificial-intelligence_en

4. IT software (with a focus on cloud and edge software)

Cloud and edge software encompasses all information technology applications and services for an organisation. Cloud and edge software is a vast area that comprises all information technology applications and services for an organisation, including those required for managing the underlying computing infrastructure. Increasingly, private and public organisations opt for cloud computing models in order to obtain application on-demand and software 'as-a-service' in a pay-per-use model.

a) Context and strategic importance of the in-depth review

Cloud and edge computing technologies are recognised as key enablers of the European Digital Transformation. At business level, cloud computing constitutes a crucial element to achieve increased productivity, faster time-to-market, simplified innovation, easier scalability, and reduced risk. The value of cloud and edge computing has been highlighted in many industrial sectors such as the manufacturing sector as being a key technology transforming industrial production.[167] Cloud computing supports data analytics in ways that were uneconomical and even unfeasible with traditional IT platforms, while acting as a key enabler for new digital customer experiences. Progressively, in order to cope with the necessity of rapid data processing and to reduce latency in the provision of services, cloud-computing technologies are being complemented with edge computing. Edge computing allows the delivery of data processing services from decentralised locations at the edge of the network, avoiding non-essential data transmission over the network and enhancing the overall performance of cloud computing. Cloud and edge computing technologies – working cohesively with diverse heterogeneous technologies such as algorithms, sensors, data, artificial intelligence, machine learning, virtual reality, robotics, advanced materials and energy storage – have the potential to develop significant business benefits and fundamental changes in the way we live and work.

The use of cloud and edge computing technologies is expected to gain momentum in the future. Gartner predicts that by 2025, "*85% of organizations will embrace a cloud-first principle and will not be able to fully execute on their digital strategies without the use of cloud-native architectures and technologies*".[168] International Data Cooperation (IDC) foresees that by 2026,*"70% of CIOs will require cloud and Telco Partners to deliver secure cloud to edge connectivity solutions that guarantee performance and consistency in data collection*".[169] Still, cloud computing has yet to become mainstream in the EU. In 2020, 26% of European companies consumed cloud services considered to be of medium to high sophistication (such as hosting of the enterprise's database, accounting software applications and Customer Relationship Management) and incorporated cloud technologies to improve their operations.[170]

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[167] JRC Technical Report (A. Kontogeorgos, A. Kona, T. Barbas): Cloud and Edge Computing in Manufacturing

[168] Gartner Says Cloud Will Be the Centerpiece of New Digital Experiences, https://www.gartner.com/en/newsroom/press-releases/2021-11-10-gartner-says-cloud-will-be-the-centerpiece-of-new-digital-experiences

[169] IDC FutureScape: Worldwide Cloud 2022 Predictions, https://www.idc.com/research/viewtoc.jsp?containerId=US47241821

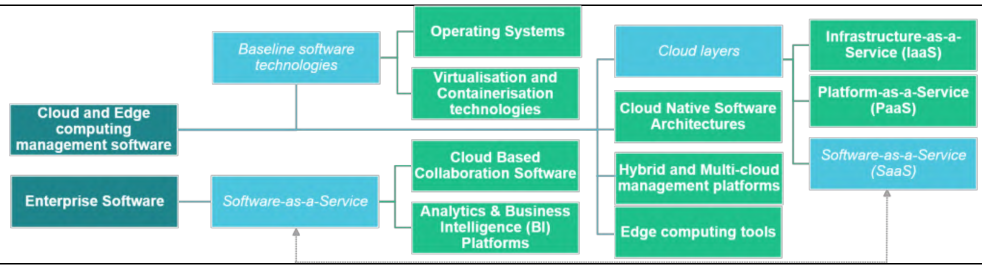
[170] Digital Economy and Society Index 2021, Thematic chapters

While the absolute value of the European cloud market has increased, the European cloud providers' market share has decreased over the last years, due to the quality and breadth of services provided as well as the fragmentation of offers. The European cloud market in 2020 was estimated to be worth 5.9 billion EUR, multiplying by three the value of the market in 2017.[171] Even in this context of significant growth, European cloud providers' market share has decreased from 26% in 2017 to 16% in 2020. The grouping formed by the three global cloud providers Amazon Web Services, Microsoft Azure and Google Cloud (often referred as cloud "hyperscalers") accounted for the 66% of the European cloud market share in 2020. The European industrial technology roadmap for the next generation cloud-edge prepared by a group of CEOs of European companies explains that "*While taken as a whole, European cloud offerings cover a wide spectrum of services, in practice, customers must work with many providers to achieve the quality and breadth of services provided by leading global cloud providers. End-users seek simplicity and efficiency, and have become accustomed to 'one-stop-shop' offers that provide access to a suite of best-in-class cloud functionalities and tools they require and on a global scale*".[172]

b) Identified dependencies, impact and related risks

This section provides an in-depth analysis of strategic dependencies in the European cloud and edge software market, focusing on cloud and edge computing management software and enterprise software. This in-depth review builds on the analysis conducted in the May 2021 SWD on strategic dependencies and capacities[173], which covered the overall market development for cloud and edge computing in Europe.

Figure 33: Areas covered in the in-depth review



Source: European Commission

It focuses specifically on software capacities in the cloud and edge market, including as regards cloud and edge computing management software as well as certain segments of the enterprise software market offered in a Software-as-a-Service model (see Figure 33):

- Cloud and edge management software constitute the essential building blocks that enable European IT industry to develop cloud and edge computing service offerings. Generally, it offers to all kind of industries tools to develop software applications that can take advantage of cloud computing flexibility. In this area, the analysis covers cloud computing baseline technologies including operating systems and virtualisation and containerisation technologies. In addition, the analysis covers the cloud stack layers of Infrastructure as a Service (IaaS) and Platform-as-a-Service (PaaS).

[171] https://www.srgresearch.com/articles/european-cloud-providers-struggle-reverse-market-share-losses.
[172] European industrial technology roadmap for the next generation cloud-edge offering, 2021
[173] SWD(2021)352

Furthermore, the in-depth review reports on the status of cloud native architectures and advanced management solutions for hybrid and multi-cloud management and edge management software;

- At the level of Enterprise software, the focus of the in-depth review is on Software as-a-Service products, cloud-based collaboration and analytics and business intelligence software, as fundamental tools that enable European enterprises digitalisation and data processing capacities.

b.1) Cloud and edge computing management software

Operating Systems in the cloud

When it comes to operating systems, risks of EU dependencies appear limited. Operating systems are the low-level software that manage the hardware resources of a server. Linux is today the de-facto standard operating system to empower cloud computing. As regards edge computing, the choice of operating system strongly depends on the nature of the edge devices involved. For Embedded Systems and Internet of Things, Linux is the leading operating system for general computing purposes. Real-time operating systems (RTOS) is an area where proprietary operating systems still fight Linux prevalence.[174] Still, cloud hyperscalers increasingly support RTOS open source developments. European contributions to the Linux Foundation are recognised as significant.[175] In addition, the Linux Foundation is considered an Open Source foundation with safeguards against being controlled by specific entities.[176] Overall therefore, risks of EU technological dependencies at the level of operating systems appear limited, but cannot be completely excluded. Such operating systems fall within the scope of core platform services within the Digital Markets Act.

Virtualisation and Containerisation technologies

The risks of EU dependencies in the area of virtualisation and containerization appear limited as well. Virtualisation technologies allow the abstraction of the hardware resources of a server into multiple Virtual Machines (VMs) or Containers. Virtualisation is a key technological foundation for cloud service provisioning and the enabler to achieve economies of scale in cloud data processing. In the past, hypervisor-based virtualization was the only possibility to share the capacity of a server into multiple VMs. Thanks to the underlying improvements in the Linux kernel this feature can now also be achieved by Container technology (although not yet offering the same isolation levels). At the level of hypervisor-based virtual machine provisioning in Infrastructure as a Service, Cloud hyperscaler providers trust in a combination of adapted open source hypervisors (Xen, KVM) as well as their own technologies. User reports from open source private cloud toolsets identify KVM as the most widely adopted hypervisor.[177] Remarkably, both for private and public clouds, open source hypervisor technologies rely on the Linux Foundation endeavours.

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[174] Fraunhofer ISI, Open Forum Europe: Open source software and hardware on technological independence, competitiveness and innovation in the EU economy, 2021

[175] Germany and France are the second and third geography to support to Linux Foundation development. Overall, EMEA is estimated to make 53% of the contributions to the Linux Foundation repositories.

[176] Fraunhofer ISI, Open Forum Europe: Open source software and hardware on technological independence, competitiveness and innovation in the EU economy, 2021

[177] https://docs.openstack.org/arch-design/design-compute/design-compute-hypervisor.html.

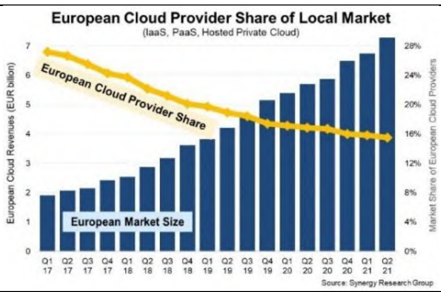
Containerization is a new reality in the enterprise software and in the cloud. It can act as an alternative or as a complement to traditional hypervisor-based virtualization. Use of container technologies is today mainstream. Risks of technological dependencies in this context are reduced by the widespread adoption and popularity of the related Open source technologies, Linux Containers (LXC) and Docker.[178] LXC acts as a de-facto standard for containerisation.[179] The outstanding uptake of Docker can be explained by its early open source release, the fact that it relies on LXC technologies together with its widespread availability in all kinds of execution environments, including public clouds.[180]

Overall therefore, the widespread adoption of Open source together with the European contributions to the relevant communities in the areas of Virtualisation and Containerisation develop a solid European position and limited risks of EU dependencies.

Cloud Layers: Infrastructure-as-a-Service (IaaS)

Infrastructure as a Service (IaaS) provides the most basic services for data processing infrastructures, covering the provision of Virtual machines based on virtualisation technologies. IaaS services can be obtained from public cloud providers, in which the Cloud infrastructure is shared among all users; or from private Clouds, implemented by Private cloud management platforms on top of a set of servers dedicated to an organisation.

Figure 34: European cloud Provider Share of Local Market



Source:

Despite the significant growth of the European cloud market, there is a decline in the market share of European public cloud providers (Figure 34). Following behind the cloud hyperscalers, the most important EU public cloud providers on the European market are Deutsche Telekom, OVHcloud and Orange. [181]

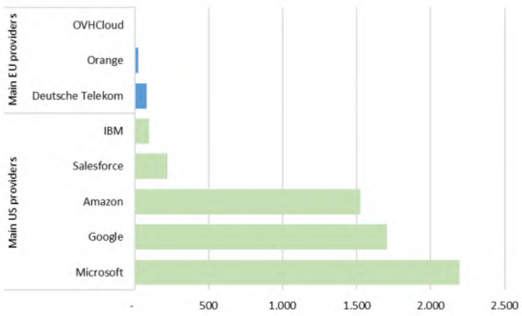
[178] Flexera: State of Cloud report, 2021

[179] Pahl, Claus & Brogi, Antonio & Soldani, Jacopo & Jamshidi, Pooyan: Cloud Container Technologies: A State-of-the-Art Review (IEEE Transactions on Cloud computing), 2017

[180] D. Bernstein: Containers and Cloud: From LXC to Docker to Kubernetes (IEEE Cloud computing, vol.1, no. 3), 2014

[181] Synergy Research Group, Amazon & Microsoft Lead the Cloud Market in all Major European Countries, https://www.srgresearch.com/articles/amazon-microsoft-lead-cloud-market-all-major-european-countries

Figure 35: Market cap main US/EU providers on European cloud market (EUR billion)



Source: Synergy Research Group and https://companiesmarketcap.com/

Non-EU hyperscalers hold a very strong position in the market, with the largest European cloud provider only capturing 2% of the European market. The differences in market capitalisation between these EU and non-EU providers are also clear (Figure 35).

Cloud services offered by the three major European cloud providers cover only mainly basic compute, storage, networking and security services at the IaaS layer. These offerings do not significantly differ from first generation services of cloud hyperscalers that were available already almost 10 years ago, except for the use of containerisation. Even the more advanced offered feature, the provision of GPU-based computing services linked to the execution of AI workloads, does not really represent a technical novelty. Back in 2010, AWS[182] was the first cloud provider to offer GPU capabilities and was soon followed by Microsoft Azure and Google Cloud. Cloud hyperscalers today do not solely supply the IaaS feature and basic programming tools, instead they offer a complete end-to-end ecosystem encompassing data management and as-a-service AI software toolsets that significantly facilitate the users' development and deployment of AI solutions. While this serves to illustrate the degree of innovation that cloud hyperscalers demonstrate, it could point towards specific concerns related to lock-in of users of cloud services by means of unfair practices that limit their contestability and thereby negatively impact the innovation by other providers of such services, including European ones.

As for private cloud management platforms, similar risks as in the case of public cloud providers are emerging. Private clouds are used, for example in relation to data security and data protection requirements. Traditionally, commercial offerings have focused on the IaaS layer (with VMware leading adoption). OpenStack is also widely used, with Europe accounting for 61% of its total deployment base.[183] At the same time, cloud hyperscalers are also capturing a very significant position in private cloud developments with their targeted products Microsoft Azure Stack, AWS Outpost and Google Anthos. This can potentially bring similar risks to the private cloud environment as regards technology dependence, which may already exist in the area of public cloud, in particular if combined with an unfair behaviour that may lead to customer lock-in and thereby limiting the ability of innovative market entrants to gain sufficient user base to provide for a viable alternative to existing hyperscalers.

[182] http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/accelerated-computing-instances.html.
[183] https://www.openstack.org/analytics/

Cloud layers: Platform-as-a-Service (PaaS)

While there are important European cloud Platform-as-a-Service providers, the EU is still subject to important risks of dependencies, given the fast innovation pace in this area. The PaaS layer commonly encompasses programming toolsets and data management services, which facilitate the development of applications. PaaS services frequently supply structured and unstructured databases, object storage, as well as access to data processing toolsets, as-a-service. Europe, and specifically France, have important cloud PaaS providers (i.e. Plaform.sh and Scalingo). However, the continuous pace of innovation that cloud hyperscalers exhibit in the PaaS field is yet to be achieved by European cloud providers. Cloud hyperscalers already have in place sound services and product platforms for serverless and data analytics, artificial intelligence, and IoT – including edge computing. Their degree of innovation and investment in cutting-edge technology makes them capable of offering nowadays pioneering PaaS services, such as robotics-as-a-service empowered with edge data processing features. However, this does not come without risks, in particular where service offering is accompanied by restrictive elements (e.g. customer lock-in) that can undermine innovation potential of other market operators who face difficulties in entering or growing in these markets.

Cloud Native Software Architectures

Cloud native technologies provide a key approach for software applications that generate data or extract value of data, supporting their execution in both private and public clouds. Cloud native technologies are defined by the Cloud Native Computing Foundation (CNCF)[184] as the set of technologies that "*empower organizations to build and run scalable applications in modern, dynamic environments such as public, private, and hybrid clouds. Containers, service meshes, micro-services, immutable infrastructure, and declarative APIs exemplify this approach.*"[185] Cloud native technologies are today the trendiest architectural and development approach for software applications that generate data or that extract value of data. They support the execution of applications in private and public clouds, and increasingly at the edge. Gartner in its 2022 predictions anticipates that "*cloud-native platforms will serve as the foundation for more than 95% of new digital initiatives by 2025 — up from less than 40% in 2021.*"[186]

The recent developments towards edge computing together with wide availability of Cloud Native Software Architectures present a crucial opportunity for the European cloud market. Today, all cloud hyperscalers offer the necessary toolset and services to enable the development and deployment of cloud native architectures. Beyond these, the CNCF, which is part of the Linux Foundation, advocates for an open source and vendor neutral approach. CNCF currently hosts over a hundred projects (including crucial technologies such as Kubernetes). The overall CNCF landscape entails a complete ecosystem of widely adopted cloud solutions. These offer a strong potential to enable real technical interoperability among public cloud offerings, in particular considering their existing and foreseen important market uptake. Additionally, CNCF developments towards Edge computing, presented under the

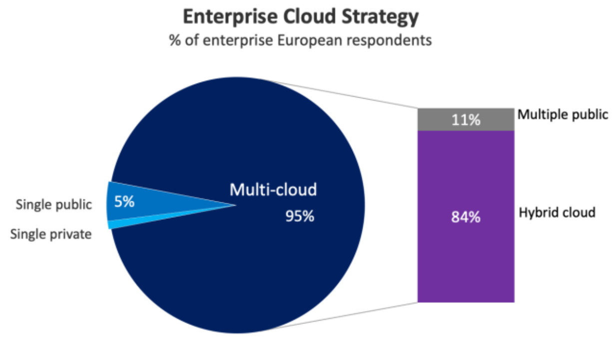
[184] https://www.cncf.io/
[185] https://github.com/cncf/toc/blob/main/DEFINITION.md.
[186] https://www.gartner.com/en/newsroom/press-releases/2021-10-18-gartner-identifies-the-top-strategic-technology-trends-for-2022

umbrella of Linux Foundation Edge, show the most technically solid developments after the public cloud providers' offerings. As such, developments at the CNCF are a crucial opportunity for the European cloud market to overcome current strong market position of cloud hyperscalers by relying on open source community efforts providing ground-breaking developments that answer to the need of European cloud users to avoid vendor lock-in.

Hybrid and Multi-cloud management, marketplaces and brokerage platforms

There is increasing European demand for secure, truly interoperable and open Hybrid Multi-cloud platforms. Hybrid and Multi-Cloud models consider the coordinated use of services from multiple cloud providers. User concerns in relation to vendor lock-in, data security and privacy, protection of personal data and legal compliance are increasing demand for multi-cloud and hybrid cloud models. This is specifically the case for European cloud customers. Findings of the State of cloud report reflect that 95% of European cloud users plan to have a multi-cloud strategy and that 84% would consider a hybrid cloud approach that combines the coordinated use of public and private cloud services (see Figure 36).[187] In order to respond to this trend, cloud hyperscalers are proposing new offerings to the market that entail the provision of software toolsets to be installed by cloud users on-premises, and that offer full compatibility with public cloud offerings of the same provider. As already highlighted, such approaches continue to bind the user to a single ecosystem provider and present equivalent concerns in terms of European technological dependence on public cloud offerings by hyperscalers. The existing European demand for multi-cloud underlined the need of developing policies and investments towards a secure, truly interoperable and open cloud market in which freedom of choice prevails for European users.

Figure 36: Enterprise cloud Strategy (% of enterprise European respondents)



Source: Flexera 2021 State of cloud Report

Edge computing tools

IoT edge software solutions and Telco edge developments are two more advanced tools in the area of edge computing. Edge computing locates data processing services in distributed locations close to data generation sources, allowing for near real time processing of data close to data sources and avoiding unnecessary data transmissions over the network. Edge computing is not yet a mature market. At the current stage of development, two main types of software tools can be identified: IoT edge software solutions, which focus on the

[187] Flexera: State of Cloud report, 2021

provision of computing and data management services to IoT installations; and Telco edge developments, which aim at supporting Telco operators 5G deployments.

IoT edge software solutions: For Cloud hyperscalers, edge computing represents an additional entry point for the consumption of their Cloud services. Cloud hyperscalers started to present these solutions back in 2017 in products such as AWS Greengrass and Azure IoT edge. Cloud hyperscaler IoT edge solutions, available as Open Source, offer management platforms that cater for end-to-end integration among edge and cloud workload and data management, as well as off-line operation modes. In addition, these offerings include advanced features such as over-the-air device updates as well as machine learning inference capabilities, for AI models developed and trained in the cloud. By relying on the same exact toolset common for cloud development, usage of these solutions avoids any learning curve for cloud developers. By means of such advanced edge services, cloud hyperscalers bring to the users the opportunity to benefit from a complete and unified edge to cloud ecosystem, with the drawback of being fully locked-in to the ecosystem of that vendor and the significant cost of migration across solutions.

Telco edge developments: The need for high performance services – specifically with regards to low latency – creates the need for the 5G network to support novel features for the deployment of distributed edge cloud infrastructure. The resulting network infrastructures constitute a combination of network and computing technologies. Initial approaches for this convergence are being developed by hyperscaler cloud providers with their mobile edge computing services. These offerings are often conceptualised in two different levels of offerings for near and far edge. Near edge is intended to make use of telecom operator infrastructure, and this results frequently in joint go-to-market between cloud and telecom. Additionally, far edge considers the deployment of a complete data centre in-house in a certain telco user location. Notably, existing examples such as AWS Outposts do not only consist in a software platform but includes the hardware platform for the telco. Mobile edge computing and telecom cloud are recent market developments, where concerns related to technology dependence, interoperability and vendor lock-in have not yet materialised. However, lessons learned from public cloud adoption can anticipate these concerns, as Telco infrastructures are today critical infrastructures that sustain processes of major importance for European industries and have been already recognized by the European Commission as a key pillar for shaping Europe’s Digitization Strategy.[188]

Hence, existing developments at IoT and Telco Edge levels highlight additional risks of technological dependencies for the EU even in this incipient market. This underlines the urgent need for cloud-to-edge interoperability services, allowing the European Cloud industry to capture the significant market opportunity that edge computing bring.

b.2) Enterprise software

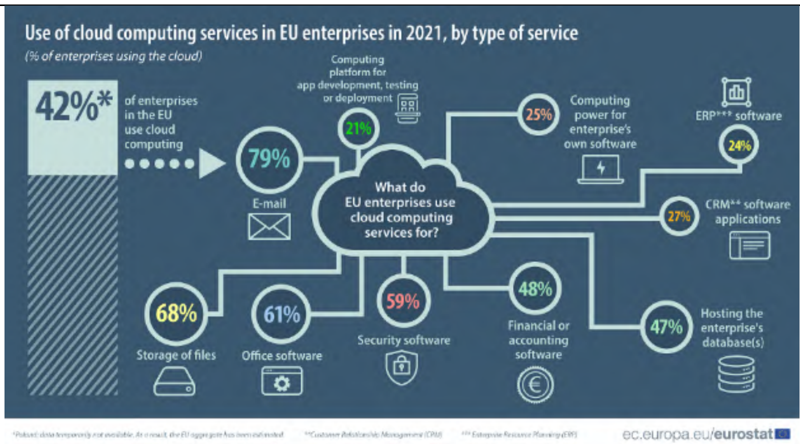
Cloud Based Collaboration Software

Given the wide adoption of collaboration software, the EU’s dependencies in this area are of high importance. Collaboration software embraces a wide area of tools that enable

[188] Shaping Europe's digital future, https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/shaping-europe-digital-future_en

Digital workplace platforms (including Unified Communication and Collaboration, Document management system, Project and team management, Enterprise social collaboration and even, email solutions). These are also often denominated as Productivity and Office suites. While such tools had been available for years both for in-house deployment at organisations and as SaaS solutions, the recent COVID-19 crises has acted as a catalyst for its wide adoption and global market growth.[189] Cloud adoption data[190] highlights that cloud based collaboration software is included among the most popular solutions used by European enterprises in the cloud (see Figure 37): "*a vast majority (79%) opted for a cloud solution to host their e-mail systems. About two-thirds (68%) used the cloud for storing files, 61% used it for office software (such as word processors and spreadsheets)*". Increasingly these solutions are offered in the form of business suites that enable end-to-end integration for both users and IT administrators. The most popular tools of this category in EMEA are: Microsoft 365, AWS, Atlassian Product Suite and Google Workspace, showing a clear trend towards the adoption of cloud hyperscaler solutions.[191]

Figure 37: Use of cloud computing services in EU enterprises 2020, by type of service



Source: Eurostat. Note: CRM stands for Customer Relationship Management.

Specifically for productivity suites, Microsoft maintained its strong market position in 2020 accounting for a 90% market share, with Google being its nearest rival, gaining 1% to 2% per year.[192] Even before the remarkable growth in adoption stemming from telework due to the COVID-19 pandemic, public authorities had already explored the necessity of open standards[193] and questioned certain practices of cloud hyperscalers in relation to data protection.[194,195] Recently, at commercial level, initiatives such as "Bleu"[196] aim at addressing sovereignty aspects associated to these concerns. In addition, cloud hyperscalers such as

[189] Forbes: The History And The Future Of Cloud Office Suites, 2020
[190] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210121-1.
[191] Okta: Businesses at Work, 2021
[192] Gartner Blog: Should Microsoft Office 365 be Afraid of Google Workspace?, 2021
[193] Danish Competition and Consumer Authority, The market for office software - competition and the importance of open standards, 2009
[194] https://www.privacycompany.eu/blogpost-en/impact-assessment-shows-privacy-risks-microsoft-office-proplus-enterprise
[195] https://petri.com/dutch-report-slams-microsoft-gdpr-violations
[196] https://www.orange.com/en/newsroom/press-releases/2021/capgemini-and-orange-announce-plan-create-bleu-company-provide-cloud

Microsoft, have started to react to these concerns with specific actions to support the storage and processing of data in the EU.[197] Further developments to address the abovementioned concerns could support to overcome risks of dependencies and concerns for this widely adopted area.

Analytics & Business Intelligence (BI) Platforms

Analytics & Business Intelligence (BI) Platforms are yet another area where risks of EU dependencies exist. IDC estimates that the European market for big data and business analytics solutions were to reach $50 billion in 2021, with a growth of 7% over 2020.[198] These services allow the execution of data processing services that demand high computational capacity. According to user reports, analytics and BI platforms are mostly employed to achieve better decision-making, improved operational efficiency and cost saving, growth in revenues, increased competitive advantage and enhanced customer service. North America and EMEA report the highest levels of BI technologies penetration (41% or greater).[199] Gartner[200] highlights that the integration of these solutions with productivity tools and cloud vendor ecosystems as well as the possibility to integrate both in house and cloud data with AI processes are important user selection criteria. Both point to market preference towards cloud hyperscaler offerings. In this context, Microsoft has gained market leadership by means of the joint offering of its SaaS solutions part of the Azure cloud and on premises Power BI Report Server. Its integration with its office and productivity suite (Office 365) appears successful on the market, although such vertical integration is raising multiple concerns with user communities (e.g. unfair contractual practices, vendor lock-in).[201] This example once more reflects the EU's dependence on cloud hyperscaler offerings and the resulting user lock-in, based on their competitive advantage developed thanks to a high degree of innovation and integration of solutions, as well as the end-to-end solutions ecosystems they offer.

b.3) Conclusions

The EU market is characterised by a strong position held by a limited number of non-EU global cloud providers ("hyperscalers"), creating important strategic dependencies. As regards cloud and edge computing management software, EU dependencies are found particularly in the cloud layers Infrastructure-as-a-Service and Platform-as-a-Service. There are furthermore risks of growing dependencies in emerging areas such as hybrid and multi-cloud models and the increasingly important edge computing, with cloud hyperscalers successfully proposing new services there as well. At the same time, recent developments such as the wide availability of cloud native software architectures present an opportunity for the European cloud sector to overcome the current strong market position of cloud hyperscalers by relying on open source community efforts. The strong market position of non-

[197] https://blogs.microsoft.com/eupolicy/2021/05/06/eu-data-boundary/
[198] Centre for the Promotion of Imports from developing countries (CBI), The European market potential for big data services, https://www.cbi.eu/market-information/outsourcing-itobpo/exporting-big-data-services-europe/market-potential
[199] https://www.sisense.com/reports/dresner-wisdom-crowds-business-intelligence-market-study/?v=embedded-wp&fof=whitepaper
[200] https://www.gartner.com/doc/reprints?id=1-26QIXY7E&ct=210707&st=sb
[201] https://www.fairsoftware.cloud/

EU hyperscalers is seen also in the area of enterprise software, including cloud based collaboration as well as analytics and business intelligence platforms. Hyperscalers are ahead of EU providers, mainly because of much stronger innovation levels and integration of software offering complete end-to-end solutions. As a result, the EU faces important strategic dependencies in these different areas with several risks for European users including in relation to lock-in effects and data protection.

c) Relevant (ongoing) policy measures

The priorities established in the EU's Communication on the recovery plan[202] highlight the importance of increasing European industrial data cloud capacities. In this context, it is vital that European user industries have the choice to store and process their data in Europe with adequate reassurance that the service provider is in compliance with European rules and standards. The aim is to ensure a thriving data economy and to contribute to Europe's digital sovereignty by building the next generation cloud offering in Europe. Europe has an unprecedented market opportunity to meet the demand for the next generation of cloud infrastructure, made of more distributed forms of computing and intelligence, including edge computing.

The Digital Markets Act (DMA) aims at ensuring that markets in the digital sector remain fair and contestable. Cloud computing services provide infrastructure to support and enable functionality in services offered by others and at the same time offer a range of products and services across multiple sectors, and mediate many areas of society. They benefit from strong economies of scale (associated to a high fixed cost and minimal marginal costs) and high switching costs (associated to the integration of business users in the cloud). The vertical integration of the large cloud services providers and the business model they deploy has contributed to further concentration on the market, where it is very difficult for other less-integrated players, or market actors operating in just one market segment to compete. To address these concerns the DMA identifies cloud computing services as one of the core platform services and envisages that if an undertaking providing these services would be designated as a gatekeeper, it would need to comply with a number of obligations in order to tackle concerns associated with lack of switching or leveraging of economic power. Furthermore, the upcoming Data Act plans to facilitate switching between different cloud, edge and other data processing services as well as requires that such services are compatible with open standards or interfaces where these exist.

The Digital Europe Programme (DIGITAL) aims at reinforcing Europe's digital transformation for the benefit of citizens and businesses. DIGITAL will invest EUR 409 million for actions dedicated to reinforce the EU's core AI, data and cloud capacities, as a fundamental enabler for Europe's public and private sectors' digital transformation. These actions aim at empowering private and public actors to unleash the full potential of data, in line with the European Data Strategy. A key pillar to achieve these objectives is the establishment of cloud-to-edge interoperability services responding to the European user demands for multi-cloud solutions. It will also build on innovative secure and energy efficient cloud to edge technology, by means of the procurement of Smart middleware for a European cloud federation and for the European data spaces. This Smart Middleware has the ambition

[202] COM(2020) 456

to allow the EU to develop its own cloud-to-edge supply chain, increasing its open strategic autonomy. In addition, Connecting Europe Facility 2 will support the deployment across Europe of cloud infrastructure interconnections and 5G installations, including Edge set-ups. Moreover, as part of Horizon Europe the Commission will continue to fund ground-breaking and forward-looking cloud and edge computing research developments.

Strengthening the EU's own capacities in the area of cloud and edge computing is a central element when it comes to addressing strategic dependencies in the area. The recently kick started Alliance for Industrial Data, Edge and Cloud is intended to strengthen Europe's position on cloud and edge technologies and serve the specific needs of EU businesses and the public sector. By bringing together relevant industrial players from across Europe, it will play a key role in delivering on Europe's industrial ambition to develop the next generation of highly secure, distributed, interoperable and resource-efficient computing technologies.

Twelve Member States are exploring an Important Project of Common European Interest on Next Generation Cloud Infrastructure and Services[203], as part of a Multi Country Project on European Common Data Infrastructure and Services. Seven of these Member States have committed to employ part of their funds coming from the Recovery and Resilience Facility in order to support the implementation of this Important Project of Common European Interest.

Finally, energy efficiency of cloud and edge computing services, offered by means of computing infrastructures in data centres, is targeted by new legislation such as the proposal for the Energy Efficiency Directive recast.[204] This proposal introduces reporting obligation for data centres with significant energy consumption with the view of establishing sustainability indicators for these computing infrastructures.

[203] IPCEI on Next Generation Cloud Infrastructure and Services, https://www.bmwi.de/Redaktion/EN/Artikel/Industry/ipcei-cis.html
[204] COM/2021/558 final