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COMMISSION STAFF WORKING DOCUMENT

Strategic dependencies and capacities

Accompanying the

**Communication from the Commission to the European Parliament, the Council, the
European Economic and Social Committee and the Committee of the Regions**

**Updating the 2020 New Industrial Strategy: Building a stronger Single Market for
Europe's recovery**

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Executive Summary

The COVID-19 pandemic has tested the resilience of economies worldwide. Despite severe disruptions in production, transport and people's mobility, most value and supply chains have shown remarkable resilience. Still, the crisis has also highlighted that while the EU gains resilience from world markets being open and integrated in global value chains, disruptions in these global value chains can affect specific essential products and inputs that are particularly critical for society and the EU economy. One of the key lessons of the crisis is that there is a need to get a better grip and understanding of where Europe's current and possible future strategic dependencies lie. This can provide the basis for the development of facts-based and proportionate policy measures informed by anticipation to address such strategic dependencies while safeguarding the open and trade-based EU economy. In this context, the European Council invited the Commission to “*identify strategic dependencies, particularly in the most sensitive industrial ecosystems such as for health, and to propose measures to reduce these dependencies, including by diversifying production and supply chains, ensuring strategic stockpiling, as well as fostering production and investment in Europe*”.

Strategic dependencies affect the EU's core interests. They notably relate to areas as regards security and safety, the health of Europeans as well as the ability to access goods, services and technologies that are key for the green and digital transitions at the core of the EU's priorities. Such strategic dependencies are more likely to be found in the most sensitive ecosystems, which are the focus of this staff working document. This staff working document provides a further step towards a more structural, systematic and cross-sector monitoring of the EU's possible strategic dependencies and an additional basis to consider when taking measures to address them.

Bottom-up mapping of strategic dependencies in the area of products (chapter 2)

A bottom-up (quantitative) mapping using external trade flows for more than 5,000 products as its starting point identifies 137 products in the most sensitive ecosystems where the EU can be considered highly dependent on imports from third countries (representing about 6% of the extra-EU import value of goods). The three main foreign sources of EU import value for these dependent products are China (representing about half of import value), Vietnam and Brazil. The identified dependent products are situated mainly in the energy intensive industries ecosystem

(with 99 dependent products identified, including raw/processed materials and chemicals), as well as in the health ecosystem (including active pharmaceutical ingredients and other health-related products) and other inputs and products that are relevant to support the green and digital transformation. Out of the 137 products identified as dependencies in the most sensitive ecosystems, 34 (representing 0.6% of extra-EU import value of goods) could be considered as potentially more vulnerable given their possibly low potential for further diversification as well as substitution with EU production. At the same time, the EU can also be a source of dependency vis-à-vis important trading partners. The analysis provides examples of products where the US is highly dependent on the EU (“reverse dependencies”) and vice-versa. Furthermore, “common dependencies” that the EU and the US share vis-à-vis China and the world can also be identified.

Reliance on international trade is not a vulnerability but rather helps to sustain diversified supply and demand. Still, some of the identified dependencies could be considered of potential strategic importance. Discussing the results of this bottom-up mapping with Member States and industry (e.g. in the context of the Industrial Forum) will allow assessing the exact nature of identified dependencies in more detail, including the risks they entail to the resilience and functioning of the EU’s industrial ecosystems as well as possible prospects for reducing these dependencies in the future including through the development of alternatives.

Also internal dependencies may exist within the Single Market whereby the EU relies on a limited number of sources within the Single Market, linked to a concentration of supply or activities at the level of individual firms. This underlines the importance of a well-functioning Single Market – especially during times of crisis – that also remains open to the global economy.

Strategic dependencies in the area of key technologies (chapter 3)

The Industry Strategy of March 2020 highlighted that the EU should build competitiveness for technologies that are strategically important for Europe’s industrial future. Complementary to the analysis of trade flows done in chapter 2, an assessment of the EU’s performance as regards the generation and uptake of certain key technologies shows both strengths and weaknesses. The EU faces particular challenges in comparison with its global competitors for technologies in the digital ecosystem such as cloud and micro-electronics. This provides important indications of risks concerning future dependencies with regard to these technologies, while not precluding possible technological dependencies in other ecosystems. If left unaddressed, dependencies in the area of these technologies could further materialise and possibly new ones might emerge. Finally, when it comes to the renewables ecosystem, the EU has a strong competitive position in several technologies that are of key importance to achieve Europe’s climate ambitions (e.g. in the area of hydrogen). Still, there are indications of risks concerning possible (future) dependencies in this area as well and continued efforts are needed to facilitate scaling up and deployment of these technologies.

Possible policy measures to address strategic dependencies (chapter 4)

For several of the dependencies identified in the bottom-up analysis of this staff working document, work has already been initiated since the March 2020 Industry Strategy to address these dependencies or assess them in more detail together with relevant stakeholders. Such

actions notably include the Action Plan on Critical Raw Materials and the European Raw Materials Alliance, the structured dialogue taking place in the context of the Pharmaceuticals Strategy, strengthened foresight in the context of the Chemicals Strategy as well as other specific actions with regard to essential products or inputs necessary for the green and digital transition (e.g. batteries, semi-conductors).

Any possible additional measures to address strategic dependencies need to be tailored to the specific nature of the dependency and ecosystem concerned. They would need to build on in-depth discussion and dialogue with Member States and industry, be proportionate and consider all available options and tools. Policy measures can, on the one hand, reinforce the EU's position in global value chains by strengthening and diversifying external trade. Actions under the EU's Trade Policy Review will promote a level playing field and enable international trade and investments to ensure more diversified sources of supply and demand to cushion future shocks and enhance competitiveness. On the other hand, the EU can strengthen its own capacity in strategic areas where necessary with targeted tools and investments in key strategic areas, building on the strengths of a fully functioning Single Market and competition policy facilitating open and dynamic markets that promote innovation.

When it comes to possible internal dependencies on a limited number of firms within the Single Market, the COVID-19 pandemic has shown that the Single Market and its unhindered Treaty freedoms should be at the core the Union's readiness for potential crises. Competition policy, as an enabler of strong business dynamics within the Single Market, as well as the EU's integration into diversified global value chains and undistorted access to export markets are also important in mitigating possible risks related to such internal dependencies.

As regard possible strategic dependencies identified in the area of key technologies, the Recovery and Resilience Facility provides an important step-up in investments in digital technologies, together with other programmes such as Digital Europe. Relevant actions to identify and address strategic dependencies are being taken also in the context of the Communication on the Digital Decade and the Action Plan on synergies between civil, defence and space industries (through an observatory on critical technologies and technology roadmaps). Tools such as Important Projects of Common European Interest where proved well targeted, justified and efficient as well as industrial alliances can continue to play an important role in specific sectors. Targeted research and innovation efforts (such as through Horizon Europe and the European Defence Fund) are also key in addressing the EU's R&I gap in comparison with its global competitors and thereby reducing strategic dependencies. Existing capacities (including those under the EU space programmes) contribute strongly to the EU's open strategic autonomy and act as a positive lever for multilateral cooperation.

In-depth reviews of strategic dependencies (chapter 5)

The in-depth reviews presented in this staff working document provide a selected number of analyses across a number of key areas that can be considered strategic, notably raw materials, batteries, active pharmaceutical ingredients, hydrogen, semiconductors and cloud and edge technologies. These assessments provide further insights on the origin of strategic dependencies and their impact as well as relevant (ongoing) policy measures. They provide a first set of

analyses for a limited number of specific areas. As a follow-up to this staff working document, further such detailed reviews of possible dependencies can be carried out covering other strategically important areas, including products, services or technologies key to the twin transition, such as renewables or energy storage.

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1. Context and approach

The EU economy is both a major importer and exporter on the international stage. Ensuring an open and fair trading system is of key importance for the prosperity and future growth of EU industry and to the benefit of European consumers and citizens. The EU plays a central role in developing a more resilient and open global economy with undistorted trade, investments and mutually beneficial bilateral relations. The COVID-19 crisis demonstrates how the Single Market's integration into global value chains not only maximises economic efficiency but is also essential in times of crisis to absorb shocks, offer options to adjust and speed up recovery.¹

At the same time, the Industrial Strategy of March 2020² already underlined the importance for the EU of “*reducing dependence on others for things we need the most: critical materials and technologies, food, infrastructure, security and other strategic areas*”. The COVID-19 crisis further emphasised the relevance of this issue in turbulent and challenging times, as it exposed further some strategic dependencies and specific disruptions caught Europe by surprise.

One of the key lessons of the crisis is that there is a need to get a better grip and understanding of where Europe's current and possible future strategic dependencies lie. The European Council, highlighting that “*Achieving strategic autonomy while preserving an open economy is a key objective of the Union*”, invited the Commission to “*identify strategic dependencies, particularly in the most sensitive industrial ecosystems such as for health, and to propose measures to reduce these dependencies, including by diversifying production and supply chains, ensuring strategic stockpiling, as well as fostering production and investment in Europe*”.³

The Commission's 2020 Strategic Foresight Report⁴ provided a broad assessment of the EU's and Member States' resilience. It also introduced resilience dashboards as a possible tool allowing to monitor for the social and economic, geopolitical, green, and digital dimensions of resilience. The Commission's Communication on the Trade Policy Review⁵ makes the case for an open, sustainable and assertive trade policy that contributes to more resilient and sustainable value chains by providing a stable rules-based trading framework, opening up new markets to diversify sources of supply, and developing cooperative frameworks for fair and equitable access to critical supplies. Identifying and addressing the EU's strategic dependencies is an essential step to increasing resilience. In addition, it is equally important to ensure competitiveness and stimulate investments in technologies that are of key importance for the EU's future. The Communication on the Digital Decade⁶ presents a vision, targets and avenues for a successful digital transformation of Europe by 2030. Finally, this staff working document should also be seen in relation with the upcoming 2021 Strategic Foresight Report on Europe's open strategic autonomy.

¹ See also OECD: Shocks, risks and global value chains: insights from the OECD METRO model, 2020 and Trade Policy Review (COM(2021)66)

² COM(2020)102

³ EUCO 13/20

⁴ COM(2020)493

⁵ COM(2021)66

⁶ COM(2021)118

The assessment of strategic dependencies involves not only the identification of dependencies, but also an assessment of whether they are of a strategic nature that leads to a vulnerability for the EU, taking into account the risks such dependencies may represent to the EU's core strategic interests.⁷ This assessment can contribute to the development of facts-based and proportionate measures while at the same time safeguarding the open and trade-based EU economy.

The staff working document takes both a bottom-up and a top-down perspective. A bottom-up (quantitative) analysis taking trade statistics in products as its starting point, while characterised by data limitations and caveats, can provide first and indicative insights into areas where the EU's dependence on a limited number of suppliers is most prominent in particular for a number of more sensitive ecosystems⁸. A top-down assessment needs to complement this bottom-up approach, taking into account (at a more detailed level) other risks and possible dependencies of strategic nature (e.g. related to services, infrastructures, technologies, skills, etc.) that cannot be captured by relying on quantitative trade statistics and data. A first qualitative assessment for selected areas is presented.

The analysis presented provides a contribution and a first step to a more systematic monitoring of strategic dependencies in the EU's most sensitive ecosystems. It complements actions that have already been initiated on the analysis and identification of the EU's strategic dependencies in specific policy fields.⁹ It is also worthwhile highlighting that other countries (including notably the US¹⁰) are in the process of carrying out similar types of analyses to identify possible risks and vulnerabilities in global supply chains as well as ways to address them.

1.1 Terminology and the concepts of “dependencies” and “strategic”

Key concepts used for the purposes of this staff working document are set out in box 1.

Box 1 – Terminology and definitions

The following concepts and definitions are used for the purposes of this staff working document:

- **Resilience:** the ability not only to withstand and cope with challenges but also to undergo transitions in a sustainable, fair, and democratic manner.¹¹ Resilience is necessary in all policy areas, also to undergo the green and digital transitions, while maintaining the EU's core purpose and integrity in a dynamic and at times turbulent environment;
- **Open strategic autonomy:** the ability to shape the new system of global economic governance and develop mutually beneficial bilateral relations, while protecting the EU from unfair and abusive practices, including to diversify and solidify global supply chains

⁷ The concept of “strategic dependency” is further explained in chapter 1.1

⁸ The concept of “sensitive ecosystems” is further explained in chapter 1.1

⁹ For example in the context of the critical raw materials action plan (COM(2020)474) and the Pharmaceutical Strategy for Europe (COM(2020)761)

¹⁰ See Executive Order on America's Supply Chains (<https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains/>)

¹¹ COM(2020)493

to enhance resilience to future crises;

- **Strategic capacity:** 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 technologies¹²;
- **Dependencies:** 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 imports¹³;
- **Strategic dependencies:** 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.

External and internal dependencies

Both external and internal dependencies co-exist. External dependencies concern the EU's reliance on external partners (third countries or firms). Internal dependencies are dependencies within the EU Single Market, notably related to the possible concentration of activity at firm level. The risks related to external dependencies are different from the risks related to internal dependencies. This is the case, for example, in relation to political tensions and geo-political uncertainty, which can be important risks for the EU at an international level. At the same time, dependence on a very limited set of companies for supplies in a specific sector can result in vulnerabilities even if these companies are based in the EU.¹⁴ Such internal dependencies linked to a concentration of supplies can have a potentially important impact on the functioning of EU value chains within the Single Market (e.g. in the case of natural disasters or closing down of production).

There are different types of shocks that play a role when assessing the impact of dependencies. Such shocks can be supply-related (e.g. a given supplier within a value chain no longer producing or delivering certain goods and services, or in reduced quantities; or the country where the supplier is based imposing certain export restrictions) as well as demand-related (e.g. a sudden important drop in EU or global demand for goods and services, or a sudden global rise in market demand for certain goods or services) and they can have multiple origins (man-made, natural, etc.). Scarcity of resources (e.g. related to critical raw materials) is also an important element to be taken into account when considering the impact of dependencies and shocks. Companies, through their own corporate decisions and corporate policies, play a key role in mitigating and adapting to possible shocks, as they have the ability to diversify supply and demand sources to become more resilient. At the same time, they cannot always accommodate all types and magnitudes of unanticipated demand or supply shocks.

¹² This may include the availability of scalable manufacturing capacities that can be relied on during a crisis situation and increase of demand

¹³ Dependencies can also be extended to exports and the possibility to rely on internal consumption to substitute exports

¹⁴ Furthermore, the ownership of companies by EU entities or foreign investors may also be relevant

Box 2 – Demand and supply shocks during COVID-19

The EU experienced the impact of different types of shocks to global value chains during the COVID-19 crisis. These shocks were both demand and supply related.

On the one hand, the pandemic has caused significant effects on the demand side. The most important impact from the crisis across many ecosystems has been the sudden and very significant reduction of demand within the EU and on export markets. At the same time, other ecosystems saw large peaks in demand. Most notably, the crisis led to a global surge in the demand for medical supplies and devices. This led to shortages in this sector, including for example with regard to personal protective equipment and ventilators. Another example of a positive demand shock has been the global surge in demand for semi-conductors that resulted in shortages during the first months of 2021¹⁵, entailing risks of a slowed down recovery in sectors that are dependent on the supply of these semi-conductors (e.g. the automotive industry).

The crisis has also seen important supply related shocks, notably in the health sector. For example, for some key medical supplies, several foreign countries introduced measures restricting or banning exports. This worsened the situation of acute under-capacity due to an exploding global demand in these products in addition to the aggravating factor of reduced production capacity due to the fact that many businesses active across global value chains were forced to reduce or halt production due to the spread of the virus and health precautions such as lockdowns, quarantines and social distancing. Restrictions concerning the movement of people and their impact on international transport networks represented another important supply shock.

Disruptions were also experienced within the EU Single Market. Several Member States introduced exports bans in particular during the early stages of the pandemic. In addition, border restrictions, quarantine requirements and other measures limiting free movement of persons, goods, services also hampered the functioning of supply chains within Single Market.

Strategic nature of dependencies

Determining the specific areas and dependencies that are “strategic” for the EU requires a careful assessment of the current and future interests at stake and potential risks, building on a collective understanding of what matters most and what is critical for Europe. Dependencies that are strategic can be identified by taking into account the extent to which they affect these core interests. This can only be done on a case-by-case basis, taking into account not only quantitative data but also qualitative, ecosystem-specific elements and expert knowledge.

Firstly, dependencies are likely strategic when they impact the security and safety of Europeans or limit the possibility for the EU to exercise a foreign and security policy in line with its values and strategic interests.¹⁶ The EU framework for screening of foreign direct

¹⁵ Pandemic-related spikes in demand contributed to a shortage of chips, while also being linked to structural problems such as distortive government subsidies and export restrictions. Further details are provided in chapter 5.5

¹⁶ It should be noted that the European Council has also requested the Commission in the context of security and defence to prepare “a technology roadmap by October 2021 for boosting research, technology development and innovation and reducing our strategic dependencies in critical technologies and value chains” (SN 2/21)

investment provides a reference in this regard, outlining specific infrastructure, technologies and inputs that are considered to be critical. Dependencies with an impact on security and safety are of particular relevance for the aerospace and defence ecosystem and may also exist in various other ecosystems (such as for example digital and electronics). Examples of actions which already address strategic dependencies in this area include the Space Strategy for Europe¹⁷ aimed at reinforcing Europe's autonomy in accessing space in a safe and secure environment, the European Defence Action Plan¹⁸ towards a strong, competitive and innovative defence industrial base, the European Defence Fund¹⁹ as well as strengthening the competitiveness of EU security industry through investment in civil security research and innovation in the Horizon Europe Programme²⁰ and most recently the Action Plan on synergies between civil, defence and space industries²¹.

Secondly, the impact on the health of EU citizens is another important driver to define dependencies as strategic. For example, the COVID-19 crisis exposed a number of strategic dependencies in the area of health (e.g. access to medical supplies such as personnel protective equipment). The European Council has also asked the Commission to “*identify strategic dependencies, particularly in the most sensitive industrial ecosystems such as for health*”. The Commission has already initiated work in the context of the Pharmaceuticals Strategy for Europe²² with concrete actions to ensure accessibility, availability and affordability of medicines, including an assessment of security of supply chains.

Thirdly, in certain cases dependencies can also be considered strategic when they significantly impact the EU’s access to inputs, technologies and services that are key for the green and digital transitions at the core of the EU’s priorities.²³ The Commission has recently reconfirmed the importance of these green and digital ambitions in the context of the Recovery and Resilience Facility, requiring that each national recovery and resilience plan includes a minimum of 37% of expenditure related to climate and 20% related to digital. Dependencies that have a significant negative impact on the ability of the EU to remain at the edge of innovation and transformation towards an increasingly green and digital economy and society will ultimately be detrimental to the functioning of the EU economy and the welfare of its citizens. The Commission has already recognised the strategic nature of third country dependencies in relation to its green and digital ambitions in several recent initiatives. Such dependencies are mainly related to critical inputs needed to support the digital and green transition²⁴ as well as the ability of the EU to access key enabling technologies.²⁵

¹⁷ COM(2016)705

¹⁸ COM(2016)950

¹⁹ https://ec.europa.eu/growth/sectors/defence/european-defence-fund_en

²⁰ Horizon Europe Cluster 3 – Civil security for society

²¹ COM(2021)70

²² COM(2020)761

²³ Political Guidelines for the Next European Commission 2019-2024

²⁴ See for example the Action plan on critical raw materials (COM(2020)474), the Hydrogen strategy for a climate-neutral Europe (COM(2020)301), the Commission proposal for a new regulatory framework on batteries (COM(2020)798/3)

Within these areas, the individual nature of the dependency and the degree of risks involved need to be assessed. It is important to underline that a certain reliance on international trade and commercial relations and partnerships with companies in third countries do not necessarily give rise to an external dependency that would result in a vulnerability for the EU economy. To the contrary, such relations and partnerships help to strengthen the EU's resilience to supply and demand shocks, in addition to the substantial efficiency gains that help to sustain the competitiveness of the EU economy over time. Only those dependencies that significantly affect the EU's core interests and limit the EU's freedom to analyse, make decisions and act according to its own priorities can be considered strategic.

Box 3 – FDI screening Regulation, critical raw materials list and Action Plan on synergies between civil, defence and space industries

The strategic nature of certain areas and dependencies has already been established in the EU framework for screening of foreign direct investment, the EU's critical raw materials list as well as the recent Action Plan on synergies between civil, defence and space industries.

Regulation (EU) 2019/452 establishing a framework for the screening of foreign direct investments into the Union created a cooperation mechanism for Member States and the Commission to screen foreign investment. The mechanism (operational as of 11 October 2020) establishes cooperation and the exchange of information between EU Member States and the Commission and provides the possibility to raise concerns related to specific foreign investments, where warranted. The Commission may issue opinions when an investment poses a threat to the security or public order of more than one Member State or when an investment could pose a risk to a project or programme of Union interest. The screening framework also establishes core requirements for Member States who maintain or adopt a national screening mechanism. In Article 4, the Regulation outlines certain factors that may be taken into consideration by Member States or the Commission in determining whether a foreign direct investment is likely to affect security or public order. These include potential effects on critical infrastructure, critical technologies and dual use items and supply of critical inputs. Several of the criticalities defined in this Regulation are of particular relevance for the analysis in this staff working document including critical technologies (e.g. artificial intelligence, robotics, semiconductors, cybersecurity, aerospace, defence, energy storage, quantum and nuclear technologies as well as nanotechnologies and biotechnologies) as well as critical inputs (e.g. raw materials).

The EU's critical raw materials list provides an overview of the raw materials that are considered to be most important economically and having a high supply risk. The list²⁶ is

²⁵ See for example, the White Paper on Artificial Intelligence (COM(2020)65), the joint declaration by Member States on processors and semiconductor welcomed by the Commission (<https://ec.europa.eu/digital-single-market/en/news/joint-declaration-processors-and-semiconductor-technologies>)

²⁶ Available in COM(2020)474

reviewed every three years by the Commission, based on a comprehensive screening and assessment methodology²⁷. The Commission takes it into consideration when developing and implementing policies relating to raw materials, including when negotiating trade agreements and seeking to eliminate trade distortions. It also helps to identify investment needs and guide research and innovation.

The Commission’s Action plan on synergies between civil, defence and space industries identifies a list of examples of critical technologies relevant across the civil (including security), defence and space industry domains. Using this list as a basis, a new EU Observatory of Critical Technologies will start, in 2021, regular monitoring and analysis of critical technologies, their potential applications, value chains, needed research and testing infrastructure, desired level of EU control over them, and existing gaps and dependencies. Every second year, the Observatory, in consultation with key stakeholders, will produce a classified report on critical technologies, dependencies, value chains and testing infrastructure for the defence, space and related civil industries. On the basis of these reports, the Commission will develop technology roadmaps to boost innovation on these critical technologies. These technology roadmaps may lead to the launch of new flagship projects taking into account their likely impact on the technological sovereignty and leadership of the EU, their sources of financing and their governance.

In general, the existence or risks of strategic dependencies are more probable in a few “sensitive ecosystems”. Ecosystems such as tourism, textiles and proximity and social economy might be unlikely to hold important risks for strategic dependencies as a whole. On the other hand, dependencies within the aerospace and defence as well as the health ecosystem are more likely to be of a strategic nature. In addition, certain dependencies within ecosystems such as digital, electronics, renewable energy and energy intensive industries can also be strategic when they impact health or security interests or significantly affect the EU’s ability to achieve the green and digital transformation. Furthermore, some ecosystems are also more closely related to critical areas already listed in the FDI screening Regulation (e.g. aerospace and defence ecosystem), the EU’s critical raw materials list (e.g. energy intensive industries ecosystems) as well as the critical technologies outlined in the Action Plan on synergies between civil, defence and space industries (e.g. digital and electronics ecosystem). Therefore, the bottom-up mapping of dependencies developed in chapter 2 will focus on a number of these more sensitive ecosystems (see Graph 1) when considering the question of identifying possible strategic dependencies. This also follows the Council conclusions of 16 November 2020, which specifically highlighted health, defence, space, digital, energy and critical raw materials as examples of sensitive industrial ecosystems and areas.²⁸ Nevertheless, this does not exclude the

²⁷ European Commission: Study on the EU's list of Critical Raw Materials, 2020

²⁸ 13004/20 (paragraph 3)

existence of possible risks or dependencies in other ecosystems not covered by the analysis in this staff working document.²⁹

Graph 1: More sensitive ecosystems for the purposes of this staff working document



Source: European Commission

Note: Circles represent a selection of more sensitive ecosystems for the purpose of this staff working document

1.2 Approach of the staff working document

The staff working document combines a number of elements to address the objective of identifying and addressing strategic dependencies.

Firstly, Chapter 2 develops a *bottom-up* (quantitative) analysis of trade dependencies in goods, taking as its starting point a detailed assessment of the EU’s trade flows, following a step-by-step approach:

- In a first step, the analysis identifies goods where the EU is dependent on a limited number of sources, based on the concentration of suppliers, the relative importance of extra EU imports as well as their possible substitution with internal EU production;
- In a second step, the dependencies identified in step 1 are narrowed down to more sensitive ecosystems with a higher risk of dependencies being of a possible strategic nature (as outlined in chapter 1.1);

²⁹ For example in the agri-food ecosystem, the international dimension is important in the common agricultural policy (CAP), as maintaining a healthy balance of imports and exports is key to safeguarding internal market stability. There are already tools in place to monitor this ecosystem. Notably, in order to ensure the delivery of the CAP objectives, the Commission collects statistics and produces analyses of agricultural trade and international agri-food policy developments. The most up to date information is published monthly in “Monitoring EU agri-food trade”, while a more in-depth examination of how the EU agri-food trade flows have changed in the past year is provided in the annual “Monitoring agri-trade policy” report.

- In a third step, consisting of a qualitative assessment, specific dependencies are identified that might be strategic for the EU (in line with the different elements set out in chapter 1.1 concerning the concept of “strategic”) or that require further in-depth analysis to assess their impact and strategic nature.

For each of the identified product dependencies spotted in the more sensitive ecosystems the analysis also gives an indication of the potential to further diversify the EU’s import sources for these products as well as the potential for substitution with EU production (see chapter 2.4).

This bottom-up analysis faces a number of data limitations and caveats as to the conclusions that can be drawn. The first relates to the level of aggregation. While the analysis covers more than 5,000 traded products or product groups, in some cases the level of detail is not sufficient to capture dependencies on specific or specialised products or inputs.³⁰ Second, sufficiently detailed trade statistics are not available for services and trade statistics cannot (clearly) identify dependencies in the area of complex technologies including those that are of a more emerging nature. Third, the analysis only looks at trade dependencies at one point in time and cannot capture changing or emerging trends. In addition, the assessment whether dependencies are strategic (step 3) is a qualitative exercise and this staff working document can only provide a first indication, which needs to be complemented through further dialogue with industry on the exact nature and impact of identified dependencies.

As a consequence, the bottom-up mapping cannot be considered to be an exhaustive screening of all possible product dependencies. In addition, it needs to be complemented by discussions with industry and Member States on the strategic nature of the identified dependencies taking into account the specific ecosystems concerned. Despite these limitations, the analysis offers a methodical screening giving preliminary insights into individual products and inputs where the EU has a higher level of dependence on third countries including some with a possible strategic character. This analysis is dynamic by nature and requires regular updating and refinement, given the changing nature of dependencies. Further details on the approach and methodology of the bottom-up mapping are set out in chapter 2.

Secondly, the Industry Strategy of March 2020 highlighted the importance of developing key enabling technologies that are strategically important for Europe’s industrial future. In addition, the recent Communication on the Digital Decade underlined that digital technologies are currently mostly developed outside of Europe and highlighted the importance of reinforcing internal strengths and capacities for the EU to achieve digital leadership. The EU’s performance in comparison with its global competitors in the area of these key technologies cannot be clearly captured by an analysis of trade statistics as performed in chapter 2. **In this context, chapter 3 aims to complement the assessment done in chapter 2 by considering the EU’s position in comparison with its global competitors in the area of key technologies that will drive future competitiveness.** It does this on the basis of a range of indicators (considering e.g. research,

³⁰ In addition, the bottom-up product mapping faces a number of specific limitations when it comes to identifying dependencies within the defence and aerospace ecosystem, linked to the sensitivity of data associated to defence goods, as well as the classification level of most defence contracts. Further work is needed to assess this specific area in detail.

investments, innovation and business dynamics), looking into the EU's relative performance in comparison with its global competitors. These provide important indications, albeit not complete, as to possible risks of potential (future) dependencies in the area of such technologies. For example, comparatively low levels of innovation and investments may result in Europe becoming more dependent on other countries for access to state-of-the-art technologies. Chapter 3 relies on information obtained from different sources, including the *Advanced Technologies for Industry project* as well as other data and analyses on the EU's performance in research and innovation.

Thirdly, chapter 4 provides indications of relevant possible measures that might be able to mitigate strategic dependencies and related risks. Such measures would need to build on in-depth discussion and dialogue with and between Member States and industry. They should build on the opportunities of international trade to diversify and strengthen sources of supply as well as, where needed, the strengths of the Single Market to build up adequate EU capacity. Measures would need to be carefully examined with a view to maintain the competitiveness of the EU, choosing to address dependencies and increase resilience in the most cost-efficient manner.

Finally, for those specifically identified dependencies of strategic importance, possible policy intervention would need to build on a thorough understanding and detailed analysis of the functioning of relevant value chains as well as the underlying drivers of Europe's current and possible future strategic dependencies. **Chapter 5 presents a selected number of in-depth reviews of possible dependencies identified in chapters 2 and 3 that can be considered strategic across a number of key areas (including health, digital, green).** These reviews provide an overview of the origin of strategic dependencies, their impact on the EU economy as well as possible relevant (ongoing) measures. They provide a first stage of assessments in strategic areas and should not be considered to be an exhaustive analysis of all the EU's strategic dependencies. Further key areas, including products, services or technologies key to the twin transition such as renewables or energy storage, might be considered in the future.

2. Mapping of EU dependencies in the most sensitive ecosystems

The COVID-19 crisis showed the importance of obtaining a more comprehensive understanding of the EU's strategic dependencies as a first step to strengthening resilience. This chapter provides a bottom-up mapping of the EU's ecosystems and their reliance on international trade. It covers trade flows for some 5,000 products classifying goods as dependent based on various meaningful and objective economic criteria. While this assessment faces a number of data limitations and caveats, it provides a first indication of goods (final products and inputs) where the EU might have a higher level of dependence on a limited number of suppliers, including those with a possible strategic character in more sensitive ecosystems.

2.1 Context

Over the last decades, production processes and supply chains have become increasingly interlinked across countries and continents. The drivers explaining the continuous integration of Global Value Chains (GVCs) include, among others, cost reduction, greater market openness (lower tariff and non-tariff barriers), changes in the political environment, as well as multiple technological innovations. GVCs enable firms to improve their market position through delocalisation strategies and generate benefits from a more efficient production process (including in some cases lower prices for final consumers) and help firms to reduce risks. In addition, when firms become geographically closer to their final customers, they may also gain from a better consumer knowledge.

While global value chains are highly efficient from a cost, growth, and a diversification perspective,³¹ they could also entail vulnerabilities to external demand and supply shocks. Reliance of EU firms on international trade is a strength for the resilience of the EU economy and it is fundamental to safeguard the wealth and competitiveness of the EU through efficiency and productivity gains, as well as to sustain demand for EU output. In that regard, private firms have the ability, the incentive and the information to diversify supply and demand sources sufficiently to absorb normal discontinuities in trade flows. However, not all of them might be able to accommodate unanticipated demand and/or supply shocks exceeding by far what normal business operations would dictate. In such instances, the collective cost of a potential demand and supply shock to the general EU public may exceed the lost profits to the market operator importing specific goods or services. Given the result, akin to a market failure, policy action addressing strategic dependencies may be justified.

While the majority of value chains have shown resilience during the pandemic, the crisis has shown that disruptions in GVCs might affect specific products, some of which are particularly critical for society. For instance, the greatest disruptions have been felt in medical (e.g. personal protective equipment) and medical-pharmaceutical supplies. These products have been under severe strain due to the enormous surge in demand compared to supply.³² Export

³¹ OECD: Shocks, risks and global value chains: insights from the OECD METRO model, 2020

³² See OECD: Global Value Chains: Efficiency and Risks in the Context of COVID-19, 2020; S. Evenett: Chinese whispers: COVID-19, global supply chains in essential goods, and public policy, 2020 (Journal of International

restrictions imposed by some countries on these specific products or their components have worsened the situation. At the same time, other measures adopted by governments cut import duties, facilitated customs-clearance and streamlined approval requirements for medical supplies³³.

While observing significant differences across sectors, overall, the EU is an important supplier and customer for extra EU countries. Using GVC data, national and international links between sectors along value chains can be tracked, by looking for each sector at both upstream links (which shape supply chains) and downstream links (which contribute to final demand). Graph 2 shows the exposure of EU industry to extra EU markets both in terms of demand and supply, which are then used in the production process of each sector. It shows that the sectors with the highest upstream and downstream foreign links are *Computer & electronics*, *Chemicals and Pharmaceuticals*, *Basic Metals* and *Electrical equipment*. Sectors above the 45 degree line rely more on extra EU demand than on the supply from extra EU countries.

With few exceptions, extra EU demand is relatively more important for the EU aggregate than extra EU supply. However, foreign supply from certain sectors still plays a significant role for EU production. Graph 3 ranks sectors according to the extent to which EU production depends on foreign supply. The EU relies on extra EU countries particularly in raw materials and electronics, but also textiles, financial activities, as well as chemicals and active pharmaceutical ingredients. Consequently, this highlights the need for the EU to continue being integrated in the global economy.

EU trade diversification is high and stable over time. At a macro level, extra-EU trade is diversified. Both extra-EU exports and extra-EU imports concentration have not varied much in the last decade (see Graph 4). Compared to other countries, while extra-EU import concentration has remained broadly constant over the last two decades, concentration decreased significantly in China and increased in the US. For example, US imports at an aggregate level are currently around twice as concentrated as EU imports.

Macro and sectoral trade give an overview of dependencies, but a more granular detail is required to identify specific products where the EU has strong external dependencies.³⁴ Ideally, the identification of dependent products would use product information at a 8-10 digit level on the Harmonised Standardisation (HS) system or firm level data. However, comparable data sources across all countries in the world are not available. This would jeopardise the calculation of the dependency indicators proposed in this chapter and their comparison across countries. Thus, a 6-digit level of disaggregation is used, which already provides informative results of the level of dependency across products.

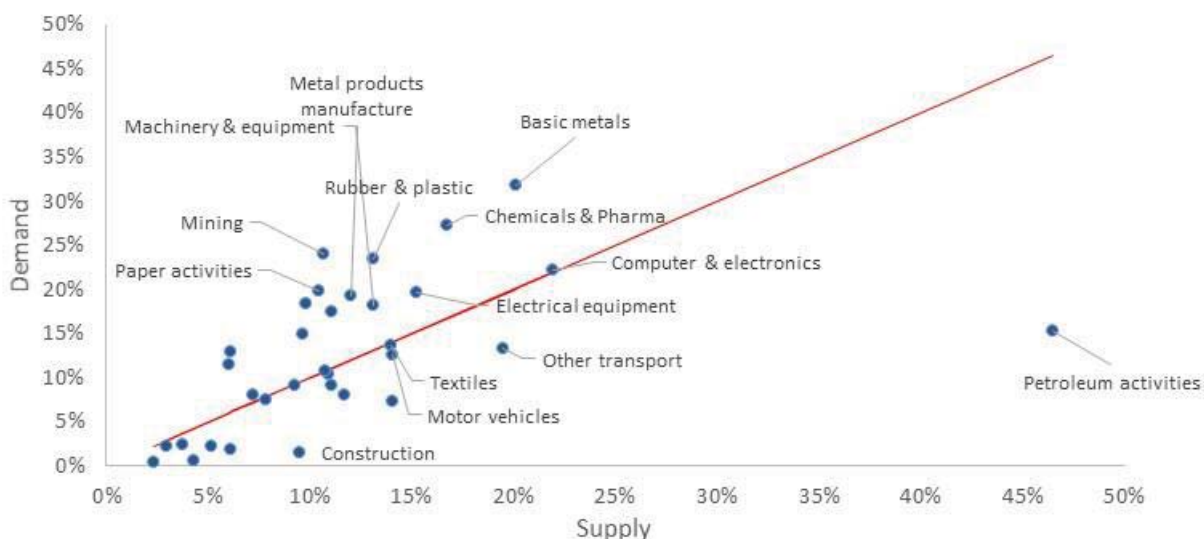
Business Policy); OECD: COVID-19 and global value chains: Policy options to build more resilient production networks, 2020

³³ In this respect see, for example, European Commission Decision [2020/491](#) and European Commission Notice [2020/C 96/I/01](#).

³⁴ To be noted is that trade in services is not captured in the database used for this analysis.

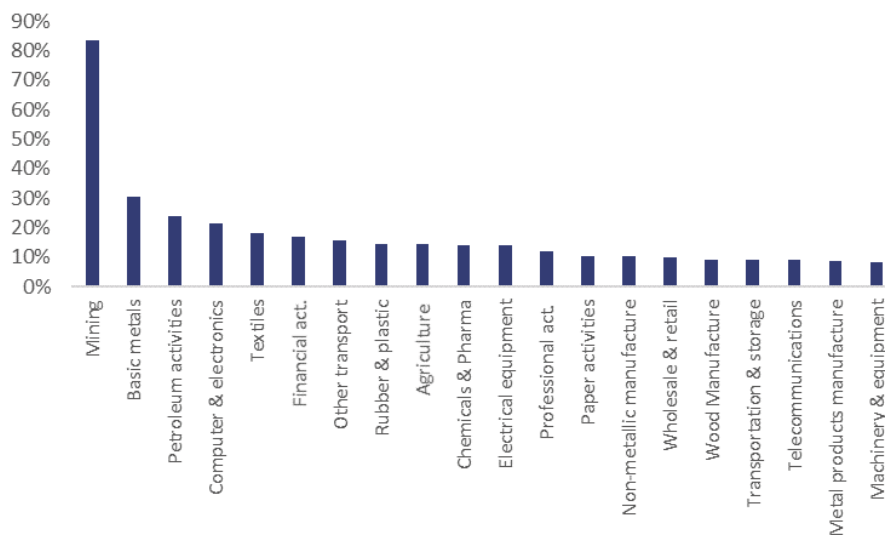
The following section outlines a methodology to identify existing dependencies of the EU, including dependencies of a possible strategic nature in more sensitive ecosystems. This exercise has certain limits dictated by the information sources available as already outlined in Chapter 1.2.

Graph 2: Downstream and upstream exposure to extra EU markets



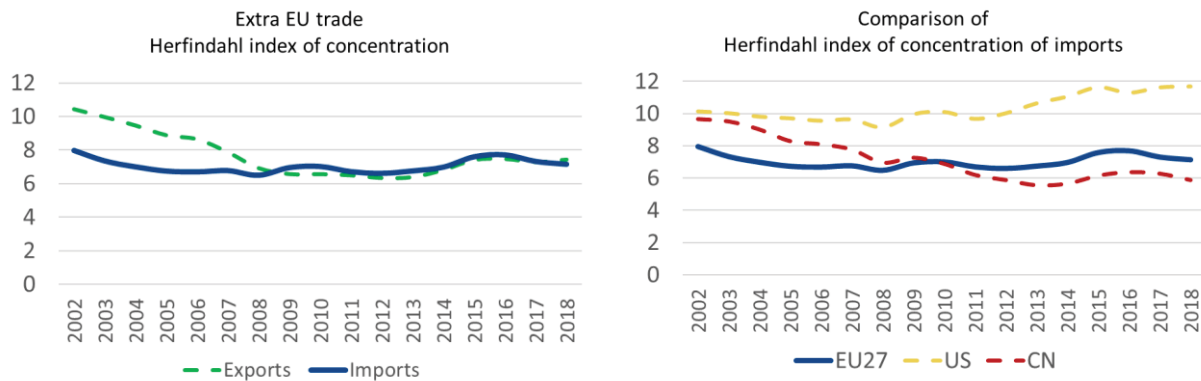
Source: Commission elaborations based on OECD 2016-AMNE data. Note: on the horizontal axis, the indicator measures for each EU sector the share of value added that depends on intermediate inputs generated by extra EU supply chains; on the vertical axis the indicator measures for each EU sector the share of final demand absorbed by exports to extra EU countries. These figures are based on the most recent available data (2016). As the share of value added has stayed rather stable over time, more recent figures are not expected to substantially depart from this illustration.

Graph 3: Foreign (extra EU) dependency for EU production



Source: Commission elaborations based on OECD-AMNE 2016 data. This graph shows the share of value added embedded in the production process that comes from non-EU countries for 20 sectors in decreasing order. Note that this level of aggregation is not suited to identify dependencies in some sectors/ecosystems such as defence and aerospace.

Graph 4: Foreign (extra EU) trade is very diversified and has remained stable over time



Source: Felbermayr presentation to Informal Meeting of Trade Ministers Berlin, Sept. 21, 2020 “Fostering the Resilience of EU Trade Links”.

Data source: BACI (CEPII). The Herfindahl index takes a value of 100 if trade is fully concentrated on 1 foreign country,

2.2 Methodology to identify foreign dependencies

The *bottom-up* mapping of foreign dependencies relies on an agnostic, data-driven perspective with the objective of identifying products with extra EU dependency. The bottom-up mapping follows a step-by-step approach. In a first step, the analysis identifies traded products where the EU is more dependent on third countries based on three economic indicators. Then, the identified dependencies are narrowed down to the most sensitive ecosystems. On this basis, a further qualitative assessment consists in spotting dependencies in the most sensitive ecosystems, with a *possible* strategic nature (in line with definition of “strategic” outlined in Chapter 1.1).

Graph 5: Approach *bottom-up* analysis



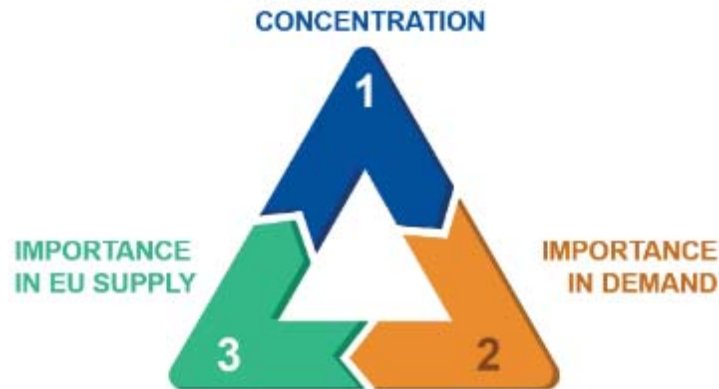
Source: European Commission

2.2.1 Core Dependency Indicators

The *bottom-up* approach classifies products as highly foreign dependent if the levels of import diversification and potential substitutability with EU supply are low. This mapping of dependencies builds on the approach used by Bonneau and Nakaa (2020), but it extends their

analysis by considering potential substitutability with EU production.³⁵ Data covering the universe of country trade in goods is used, including more than 5,000 products defined at the six-digit level using the international nomenclature of the Harmonized System (HS6),³⁶ across all industrial ecosystems.³⁷ Given that the level of dependency cannot be characterised by a single metric, the *bottom-up* approach combines three complementary economic indicators that are referred to as the *core dependency indicators* (CDIs) as presented in Graph 6.

Graph 6: Core Dependency Indicators



Source: European Commission

1. **Concentration of EU imports from extra EU sources:** The first indicator aims at quantifying the concentration of EU imports with respect to the rest of the world, in order to capture the risk of disruptions faced by the EU due to low diversification of extra EU sources. In particular, this indicator identifies products for which EU imports (in values) are highly concentrated in a few extra EU countries. To this end, the Herfindahl-Hirschman Index (HHI) index is used, computed as detailed below:

$$CDI_1 = \sum_{i=1}^n (s_i^2)$$

where s_i is the market share of the extra EU supplying country i in EU's imports, and n is the total number of extra EU supplying countries.

³⁵ See Bonneau and Nakaa: *Vulnérabilité des approvisionnements français et européens*, 2020 and other recent studies that have analysed the foreign dependencies by looking at the diversification of EU imports from non-EU sources (e.g. G. Felbermayr: *Fostering the Resilience of EU Trade Links*, 2020 and Cernat and Guinea: *On ants, dinosaurs, and how to survive a trade apocalypse*, 2020)

³⁶ The first two digits (HS-2) identify the chapter the goods are classified in, the next two digits (HS-4) identify groupings within that chapter. The next two digits (HS-6) are even more specific. Up to the HS-6 digit level, all countries classify products in the same way. While HS-6 classification is already highly disaggregated and suitable for analysing dependencies across ecosystems, for some specific products, an analysis at a higher level of disaggregation would be necessary to complement this assessment.

³⁷ The notion of ecosystems captures the complex set of interlinkages and interdependencies among sectors and firms spreading across countries in the Single Market. This concept takes into account specificities of business models, presence of vulnerable players (SMEs and micro) and interdependencies.

2. **Importance of extra EU imports in total demand:** The second indicator measures the importance of extra EU imports in total EU imports (i.e. extra and intra EU imports), so as to identify the products for which the EU mainly relies on foreign sources. It is computed as the share of extra EU imports in total EU imports (in values):

$$CDI_2 = \frac{\text{extra EU import value}}{\text{total EU import value}}$$

3. **Substitutability of extra EU imports with EU production:** The third indicator aims at capturing whether the EU production can cover the extra EU import needs in the event of trade disruptions. For this purpose, EU total exports, including intra and extra EU exports, are used as a proxy for the EU internal production capacity.³⁸ For each product, the ratio between the extra EU import value and the total EU export value (i.e. extra and intra EU exports) is computed as detailed below:

$$CDI_3 = \frac{\text{extra EU import value}^{EU}}{\text{total export value}^{EU}}$$

2.2.2 Identifying foreign dependencies

The narrowing down of foreign dependencies is based on the application of thresholds on the three indicators. As depicted in Graph 5, the whole sample of around 5000 products is considered, with the objective of narrowing the number of products down to most dependent goods, satisfying the following thresholds for each indicator:

i. $CDI_1 = \sum_{i=1}^n (s_i^2) > 0.4$

The indicator suggests that the higher the concentration, the lower the diversification of EU imports from extra EU sources. Consequently, this threshold implies that the EU import value originates mainly from 2.5 foreign countries.³⁹ It is important to acknowledge that the diversification of imports could be complemented with additional information on the trading partner in question, so as to assess the overall level of risk.

ii. $CDI_2 = \frac{\text{extra EU import value}}{\text{total EU import value}} > 0.5$

³⁸ Ideally, production data should be used for the purpose of this indicator but European production data do not allow to analyse dependencies at 6-digit level. Databases like PRODCOM contains many missing values at this level of product disaggregation.

³⁹ This threshold is more conservative than 0.25, which is considered by the economic literature as an indication of a high concentration.

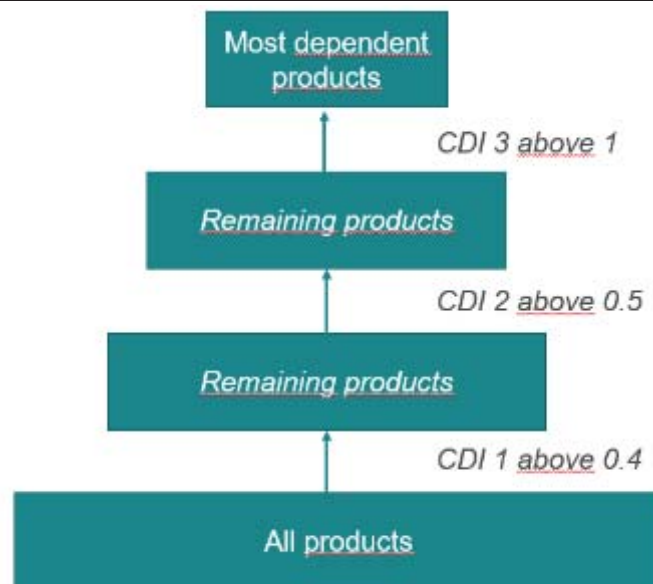
The indicator suggests that the higher the share, the higher the importance of extra EU imports in total EU imports. Hence, this threshold implies that the value of extra EU imports accounts for the majority (> 50%) of the value of total EU imports.

$$\text{iii. } CDI_3 = \frac{\text{extra EU import value}^{EU}}{\text{total export value}^{EU}} > 1$$

The indicator suggests that the higher the ratio, the less able the EU is to substitute extra EU imports with EU production in case of a trade disruption. Therefore, this threshold implies that the value of extra EU imports is higher than the value of total EU exports.

A sensitivity analysis is conducted, based on the whole distribution of the three indicators. More precisely, all 5000 products are ranked based on each indicator. The ranks of these three indicators are combined in a composite indicator measuring the overall foreign dependency of each product. Broadly, the results of the approach based on thresholds corresponds to the most dependent products based on a composite indicator.

Graph 7: Identification of dependencies on extra EU supplies



Source: European Commission

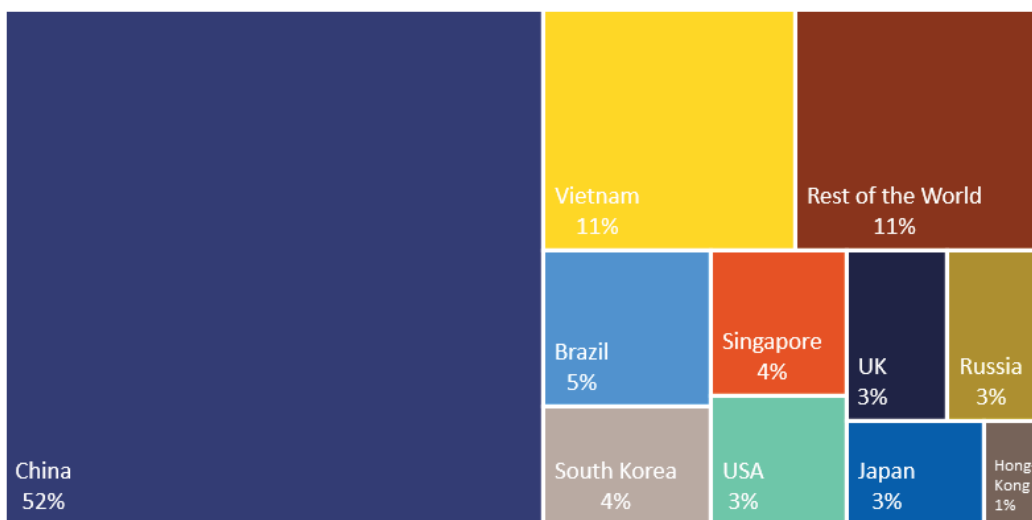
2.3 Results

As highlighted in chapter 2.2, the bottom-up mapping consists in the application of three economic indicators and their respective thresholds to the whole sample of about 5,000 products to identify foreign dependencies (Graph 7). The mapping exercise first identifies around 390 dependent products across all ecosystems. In a second step, the list of products identified as dependent is narrowed down to the most sensitive ecosystems. Finally, in the third step, only the most dependent products in the most sensitive ecosystems are considered.

The bottom-up mapping identifies 137 products in the most sensitive ecosystems where the EU can be considered highly dependent on imports from third countries. These pre-identified products represent about 6% of the EU’s total import value of goods.

The three main foreign sources of EU import value for the 137 products identified as highly dependent are China, Vietnam and Brazil (Graph 8). China represents around 52% of the total value of imports of the most foreign dependent products and it is among the top three suppliers for around 54% of these goods. In terms of stages of processing, around 16% of the most foreign dependent products are raw materials, around 57% are intermediate goods and around 27% final goods. At the same time, the EU can also be a source of dependency for other countries (see Box 4 for an example of reverse dependencies of the EU and US and their common dependencies vis-à-vis important trading partners).

Graph 8: Share of EU imports value of dependent products



Source: European Commission based on BACI database

The strategic nature of these identified dependencies needs to be assessed on a case-by-case basis, relying on in-depth discussions with Member States and relevant industries. Further discussions with Member States and relevant industries would be needed to assess the possible strategic character of these dependencies, as well as their impact and the risks that they entail on the functioning of the more sensitive ecosystems (including e.g. taking into account risks linked to the specific trading partners in question). In what follows, a preliminary description of the dependencies identified in the more sensitive ecosystems as well as a number of considerations on the possible strategic nature of the identified dependencies is provided.

A large group of identified dependencies are raw and processed materials and chemicals that can be classified in the *energy intensive ecosystem* but that have also wider importance and implications across several other ecosystems. The bottom-up mapping exercise highlights foreign dependencies for 99 products related to raw/processed materials and chemicals (e.g. beryllium, cobalt, antimony, lithium, aluminium, tungstates, chromium, nickel, molybdenum,

manganese, ferro-alloys, steel,⁴⁰ various chemical products). Several of these identified raw materials have already been assessed as critical in the context of the EU's regular monitoring of critical raw materials.⁴¹ The mapping also highlights dependencies regarding imported energy products (e.g. petroleum products and fossil fuels), which are important to consider in the context of the decarbonisation of EU industry. Chapter 5 of this staff working document provides more in-depth reviews of the EU's dependencies and possible vulnerabilities in the areas of raw materials as well as hydrogen as a key contributor to the EU's future decarbonised economy.⁴²

A second important group of dependencies belongs to the *health ecosystem*, including active pharmaceutical ingredients (APIs), other medicines and COVID-19 related goods in the health ecosystem. Access to medical products and pharmaceuticals is crucial for the health of Europeans and the EU's open strategic autonomy, as evidenced by the COVID-19 crisis. The bottom-up mapping identifies 14 products as foreign dependent, some of which have been of high relevance during the COVID-19 crisis (e.g. part of protective garments). Others include chemical substances known as APIs (i.e. antibiotics, vitamins, hormones, heterocyclic compounds), which are particularly important in the manufacturing of medicines. The mapping indicates for a range of APIs that they are concentrated in a few sourcing countries, with little potential for substitution with domestic production as the EU produces different products compared to the ones imported. In this regard, given that APIs are potentially essential inputs for producing a wide range of medicines, Chapter 5 of this staff working document provides a more in-depth review of the EU's potential strategic dependencies in the area of APIs.

An important number of dependent products are also identified in the *renewables, digital and electronics ecosystems* as they are directly related to the green and digital transition. The bottom-up analysis notably reveals that the EU has a high level of foreign dependency with respect to 17 products related to renewable energy production, green mobility and digital/electronics (e.g. permanent magnets, electric accumulators, electric motors, radio broadcast receivers, laptops, mobile phones).

The production of many green and digital products relies on various (critical) raw materials. As highlighted above, several of these raw materials are identified by the bottom-up mapping as dependent (e.g. lithium, cobalt, nickel, copper, chromium, molybdenum). For example, the production of permanent magnets, which are used in different types of wind turbines, is reliant on various raw materials. The bottom-up mapping indicates that not only the relevant raw materials but also the permanent magnets themselves are foreign dependent goods. As for green mobility, the dependent electric accumulators might use raw materials on which the EU is foreign dependent as well. More broadly, in the renewable ecosystem, several

⁴⁰ Steel is a vital component in most of the EU's industrial ecosystems. For this reason, the Staff Working Document "Towards competitive and clean European steel" shows different policies that the EU already has at its disposal to help the steel industry in its transformation – from research funding, through regulatory measures to trade instruments.

⁴¹ See European Commission: Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study, 2020

⁴² This is in line with the objectives of the European energy union, which aims at creating a reliable, affordable and sustainable energy system.

dependencies may have an impact on the decarbonisation and continued proper functioning of the EU electricity system.⁴³ For example, several hydrogen related technologies depend on imports of raw materials for key components such as electrolyzers and fuel cells. In the area of digital, for example, some of the identified dependent raw materials are used in the production of semi-conductors, the basic building blocks of all digital products and services. Chapter 5 of this staff working document provides more in-depth reviews concerning Li-ion batteries and hydrogen technologies.

The bottom-up product mapping faces a number of limitations when it comes to identifying dependencies within the defence and aerospace ecosystem and can only provide tentative insights. Identifying foreign dependent products within this ecosystem through a bottom-up mapping faces a number of challenges given the lack of complete data (notably for confidentiality reasons) and the required level of detail. For these reasons, in this ecosystem in particular, the bottom-up methodology relying on trade data should be complemented with other more qualitative, ecosystem-specific assessments (at a more granular level). This specific assessment will be tackled through the EU Observatory on Critical Technologies for civil, defence and space industries.

Box 4 – Reverse and common dependencies in products

The main trading partners of the EU (notably the US and China) are also conducting comprehensive reviews of the resilience of their own strategic supply chains. The US issued an Executive Order on America’s Supply Chains⁴⁴ with the goal of strengthening supply chain resilience and security, building capacity and diversifying sources. Concerning China, a review of strategic supply chains is part of the Chinese 5-year plan (5YP) which, among other objectives, aims at minimising external dependencies.











Given the current global environment, this box intends to shed light on the foreign dependencies in goods that the EU and the US have with each other, as well as their common dependencies vis-à-vis the rest of the world and China specifically (being the main source of dependencies for both the EU and the US). As a starting point, the analysis identifies the general foreign dependencies in goods of the EU and the US based on two out of the three the economic indicators detailed in Section 2.2.1. More precisely, in this context, a high level of foreign dependency is associated with a low diversification of import sources (i.e. high concentration) and a limited domestic capacity (i.e. low substitutability of imports with domestic

⁴³ A dedicated study for the Commission (forthcoming, May 2021) assesses the resilience of the critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis. It assesses dependencies and criticalities related to different key areas such as the cables, conductors and equipment needed to transport and distribute electricity, the production of renewable energy sources (especially wind and solar energy), the storage of electricity and smart grid technologies required for operating the electricity system.

⁴⁴ President Biden signed on 24 February an [Executive Order on America’s Supply Chains](#) launching a comprehensive review of US supply chains for semiconductors, high-capacity batteries, pharmaceuticals and medical supplies and strategic and critical minerals that will identify ways to secure supply chains against risks and vulnerabilities. This review should be completed in 100 days (i.e. by early June). There will also be an in-depth one-year review of six industrial bases covering defence, public health and biological preparedness, ICT, transportation, energy, and agricultural commodities and food production.

production) as defined above.⁴⁵ Then, relying on the identified general foreign dependencies, the analysis identifies those products where the US is highly dependent on the EU (“reverse dependencies”) and vice-versa. Furthermore, “common dependencies” that the EU and the US share vis-à-vis China and the world can also be identified. These identified reverse and common dependencies are then further assessed by evaluating their potential for diversification using the existing global trade networks as a proxy.⁴⁶

Overview of EU & US dependencies in sensitive ecosystems

Dependent Country	Source of dependency	Number of dependent products	Potential for diversification (% of dependent products)	Share in total import value								
		~ 260 products	<table border="0"> <tr> <td>18%</td> <td>34%</td> <td>28%</td> <td>20%</td> </tr> <tr> <td>Low</td> <td>Medium Low</td> <td>Medium High</td> <td>High</td> </tr> </table>	18%	34%	28%	20%	Low	Medium Low	Medium High	High	3.1%
18%	34%	28%	20%									
Low	Medium Low	Medium High	High									
		~ 15 products	<table border="0"> <tr> <td>0%</td> <td>7%</td> <td>13%</td> <td>80%</td> </tr> <tr> <td>Low</td> <td>Medium Low</td> <td>Medium High</td> <td>High</td> </tr> </table>	0%	7%	13%	80%	Low	Medium Low	Medium High	High	0.1%
0%	7%	13%	80%									
Low	Medium Low	Medium High	High									
 		~ 20 products	<table border="0"> <tr> <td>61%</td> <td>9%</td> <td>9%</td> <td>21%</td> </tr> <tr> <td>Low</td> <td>Medium Low</td> <td>Medium High</td> <td>High</td> </tr> </table>	61%	9%	9%	21%	Low	Medium Low	Medium High	High	EU: 2.8% US: 4.1%
61%	9%	9%	21%									
Low	Medium Low	Medium High	High									
 		~ 70 products	<table border="0"> <tr> <td>25%</td> <td>8%</td> <td>22%</td> <td>45%</td> </tr> <tr> <td>Low</td> <td>Medium Low</td> <td>Medium High</td> <td>High</td> </tr> </table>	25%	8%	22%	45%	Low	Medium Low	Medium High	High	EU: 4.6% US: 5.1%
25%	8%	22%	45%									
Low	Medium Low	Medium High	High									

Note: This table focuses on potentially sensitive ecosystems; The chart shows products where the US can be considered dependent on the EU (first row); the EU dependent on the US (second row); common dependencies for the EU and the US on China (third row); and common dependencies for the EU and the US on the world (fourth row)

Source: Commission analysis based on BACI database

The EU is less dependent on the US than vice-versa and both countries have important dependencies vis-à-vis China. The US appears more dependent on imported products from the EU than vice-versa. This is in line with the aggregate finding that the US has more concentrated sources of imports compared to the EU (see Graph 4). In addition, the EU and the US have an important amount of common dependencies vis-à-vis China. Furthermore, for many of these common EU/US dependencies vis-à-vis China, the potential for trade diversification to other countries (beyond China) appears limited given the current structure of world trade where China takes up a very central position for these dependent products.











These common dependencies of the EU and the US on China include various goods in sensitive ecosystems. Notable examples include products in the *Health* ecosystem (e.g. various Covid-related goods and APIs including vitamins, antibiotics, hormones) and goods

⁴⁵ The indicator corresponding to the importance of extra EU imports in total demand is not used in this analysis, as it is specific to the EU context and cannot be mirrored within the US.

⁴⁶ To measure the potential of diversification of different products, an indicator measuring the risk of centrality is used (IMF Working Paper No. 17/30), which identifies situations where an exporter is central to a large number of countries in a trade network. The classification of the potential for diversification across four categories is done based on the quartiles of the distribution of the indicator taking into account more than 5000 products.

belonging to the ecosystems relevant for the EU's twin transition (e.g. permanent magnets, electric accumulators, cell phones, radio broadcast receivers). Similarly as for the bottom-up mapping carried out in chapter 2 of this staff working document, these analytical findings would need to be further corroborated with qualitative analysis and discussion with Member States and industry.

Common and reverse dependencies (EU & US) in sensitive ecosystems: examples at product level

Dependent Country	Source of dependency	Health	EII	Renewables	Digital/Electronics
		Active Pharmaceutical Ingredients (APIs) (e.g. types of antibiotics) Medical apparatus (e.g. pacemakers)	(Critical) Raw materials (e.g. types of steel / phosphates)	Wind-powered electric generating sets	
		APIs (e.g. hormones, vitamins)	(Critical) Raw materials (e.g. lithium oxide, beryllium)	Types of electric motors and generators	Optical devices
 		Covid-19 related goods (face masks and gloves) APIs (e.g. types antibiotics)	(Critical) Raw materials (e.g. tungstates, ferro-alloys)	Permanent magnets	Laptops, cellphones, radio-broadcast receivers
 		Covid-19 related goods (face masks and gloves) APIs (e.g. antibiotics, vitamins, alkaloids)	Various (Critical) Raw Materials	Permanent magnets Type electric accumulators	Laptops, cellphones, radio-broadcast receivers

Note: chart shows examples of products in sensitive ecosystems where the US can be considered dependent on the EU (first row); the EU dependent on the US (second row); common dependencies for the EU and the US on China (third row); and common dependencies for the EU and the US on the world (fourth row). These examples might not be representative of the overall level of dependency.

Source: European Commission based on BACI database.

2.4 Assessing the further vulnerability of dependent products: potential for diversification and substitution

Out of the 137 products identified as dependencies in the sensitive ecosystems, a lower number could be considered as possibly more vulnerable given that their potential for diversification is low. To evaluate the diversification potential, a measure for concentration of world exports is used.⁴⁷ Thus, the HHI index computed at the world level for each product (based on the total export flows of each third country) captures the concentration of production in the world outside the EU.⁴⁸ A high level of concentration of world exports of a given product could indicate that the EU has limited potential for further diversification of imports (e.g. in case of an unexpected trade disruption).

⁴⁷ Alternatively, a network centrality indicator could be used to identify products where there are a few central players in the world, which takes into account the whole structure of the trade network.

⁴⁸ The indicator used to measure the potential for further diversification is again the HHI index considering the exports of every country in the world excluding the EU countries.

For about half of the identified dependent products world export values outside the EU are concentrated in 2-3 countries. To identify products with low potential of diversification, a threshold of 0.4 for the HHI index is used (i.e. world export value outside the EU being concentrated in 2-3 countries). It is important to acknowledge that the diversification capacity could be complemented with a risk analysis of the trading partner in question so as to assess the overall level of vulnerability. About 50% of the 137 products previously identified as dependent, have an index higher than 0.4, representing around 4.5% of total imports. These products could be considered possibly more vulnerable as the potential for diversification is low.

To evaluate the potential for substitution of imports with domestic production across the dependent products, the average price of exports is compared with the average price of imports. The underlying idea is that the higher the price differences, either positive or negative, the more difficult it is to substitute foreign goods with domestic goods even if internal capacity is available.

Another layer of possible vulnerability is a price difference between extra-EU imports and total EU exports of at least 30%. The distribution of price differences between extra-EU imports and total EU exports shows that the median price difference is 30%. This suggests that for half of all identified dependent products, the goods produced within the EU are significantly different compared to the ones imported from third countries, representing around 1.2% of total import value. While the analysis cannot point to specific reasons behind these price differences (e.g. quality differentiation, efficiency or other), the fact that the goods produced are different from the ones imported reveals another layer of possible vulnerability for this half of the identified dependent products.

Together, a low potential of diversification and high price differences between extra-EU imports and total EU exports might point to a subset of 34 particularly vulnerable products. This subset of 34 goods has an HHI higher than 0.4 (i.e. possibly low potential for diversification) and a price difference of at least 30% (i.e. possibly low potential for substitution). This final subset represents 0.6% of total import value. Among the 34 products identified, 22 products are classified as raw materials and intermediates goods (e.g. some APIs including alkaloids or heterocyclic compounds and some ferro-alloys including ferro-tungsten and ferro-niobium) and 12 as final goods (e.g. Turbo-propellers, COVID-19 related products such as part of protective garments, types of radio-broadcast receivers and some types of medicines).

2.5 Single Market dependencies linked to concentration of economy activity

The Single Market per definition relies on an open exchange of goods and services between Member States. The Single Market is key for the economic resilience of the EU as a whole, since Member States can rely on the capabilities and strengths of each other. One of the main advantages of the Single Market is the possibility of enabling economies of scale, through specialisation, with notable benefits for the overall economy, i.e. contributing to the overall economy growth, creating jobs and adding value to consumers.

Still, it is important to consider that activity concentration in firms within the Single Market brings about various risks. As highlighted in Chapter 1.1, risks related to internal dependencies, arising from an important concentration of activity, are of a different nature compared to external dependencies. Possible internal dependencies might emerge when the EU relies on the provision of key products and inputs originating from a relatively limited number of sources within the Single Market. For instance, a natural disaster affecting activities concentrated in one or a few firms could affect the well-functioning of EU value chains within the Single Market. Relying on very few firms within the Single Market for supply of specific goods can also lead to reduced capacity to respond to demand surges.

Identifying risks across firms originating from production concentration within the Single Market requires detailed and comprehensive information. Such analysis should be based on data including the location of production facilities at a very granular product level. This data would allow to explore whether there are important levels of economic concentration at a product level, which can create risks for the EU as a whole in case of an unexpected shock. Currently, such granular data on production locations at a very detailed product level is not available across the EU. Further work would be needed (e.g. in the form of ad-hoc surveys, case studies, use of existing national firm level databases) to collect information on firm production facilities at a product level across Member States.

A smooth functioning of the Single Market is a key asset to ensure the resilience of the EU economy and mitigate risks of possible internal dependencies. The COVID-19 pandemic has shown that a well-functioning Single Market should be at the core of the Union's assets to tackle future potential crises. Structural solutions are needed to safeguard free movement during crisis times. This is particularly important where concentration of activities within the Single Market may exist. Furthermore, competition policy can also play a major role in addressing possible risks related to such internal dependencies, by diversifying sources of supply, promoting innovation and fostering an open competitive industrial fabric that prevents overreliance on a few players or products, be it within or outside the Single Market.

3. EU performance in key technologies and research & innovation

Strengthening the EU's capacity to develop and take up technologies that are important for the industrial future of the EU is of key importance to enhance future competitiveness and avoid possible (future) strategic dependencies. The Industry strategy of March 2020 specifically highlighted that the EU should support the development of key enabling technologies that are strategically important for Europe's industrial future. The Communication on the Digital Decade underlined the importance of reinforcing internal strengths and capacities in the area of digital technologies in order for the EU to be a stronger international partner.

This chapter aims to complement the assessment done in chapter 2 by considering the EU's position in comparison with its global competitors in the area of key technologies that will drive future competitiveness. The EU's performance in comparison with its global competitors in the area of these technologies cannot be clearly captured by an analysis of trade statistics as performed in chapter 2. In this context, this chapter assesses the EU's relative position in the area of key technologies on the basis of a range of indicators (considering e.g. research, investments, innovation and business dynamics). These provide important indications (or early warnings) as to possible risks of (future) dependencies in the area of such technologies. 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.

The analytical basis for this chapter consists of a number of different quantitative and qualitative sources. It first considers the EU's position in the development and uptake of certain key technologies, based on information developed through the *Advanced Technologies for Industry project*⁴⁹. This provides an indicative overview of the EU's performance in key technologies compared to its global competitors, using indicators and proxies of technology generation, entrepreneurial activities, investments and available skills. In addition, as regards green technologies, information is used from the Commission report on progress of clean energy competitiveness. Secondly, the EU's performance in research and innovation (R&I) is a key driver of technological performance. For this, the analysis mainly relies on available Eurostat statistics on R&I and the 2020 EU Industrial R&D Investment Scoreboard⁵⁰.

3.1 Key technologies for (future) competitiveness

Technologies that will drive the EU's future competitiveness include both those that are already at a more mature stage of development as well as emerging and breakthrough technologies that will gain importance in a more long-term perspective.

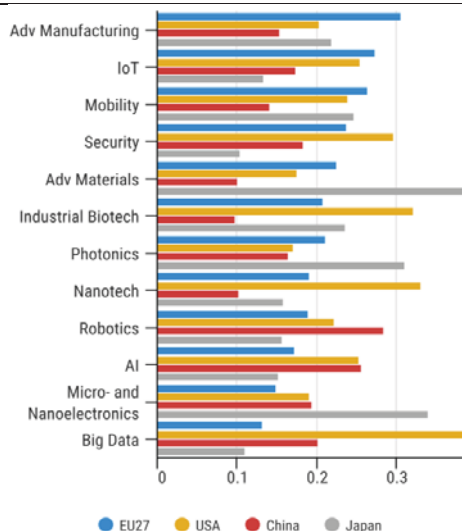
⁴⁹ <https://ati.ec.europa.eu/>

⁵⁰ European Commission (JRC/DG R&I): 2020 EU Industrial R&D Investment Scoreboard. The Scoreboard is based on companies' published annual reports and accounts.

Key technologies (based on Advanced Technologies for Industry project)

In the context of extensive monitoring of technological trends in the area of key enabling technologies for industry, a number of technologies have been identified as being of strategic importance for the EU's industrial future.⁵¹ These key technologies are expected to substantially alter the business and social environment. The focus of this section will be on technologies that are part of the *Advanced Technologies for Industry project*, including Advanced materials, Advanced manufacturing, Artificial Intelligence, Big data, Cloud, Industrial biotechnology, the Internet of Things, Micro- and nanoelectronics (including semi-conductors), IT for Mobility, Nanotechnology, Photonics, Robotics and Cybersecurity.⁵² These technologies are also part of the list of critical technologies highlighted in the Action plan on synergies between civil, defence and space industries. Several are also closely linked to the six key strategic value chains identified in the Strategic Forum on Important Projects of Common European Interest.⁵³

Graph 9: Indicator of overall EU performance in key technologies



Source: Advanced Technologies for Industry project

Note: The graphs provides a ranking of performance in key technologies in terms of technology generation, start-up creation and skills comparing EU with US, China and Japan⁵⁴

The EU has both strengths and possible weaknesses across these technologies. An overall assessment – based on a number of elements including technological generation and uptake,

⁵¹ Notably in the context of the Key Enabling Technologies Observatory and the Digital Transformation Monitor – now centralised in the ongoing Advanced Technologies for Industry (ATI) project. The list of identified technologies also takes into account the findings of the high-level strategy group on industrial technologies.

⁵² Definitions for these technologies are available at <https://ati.ec.europa.eu/reports/eu-reports/technology-definitions>

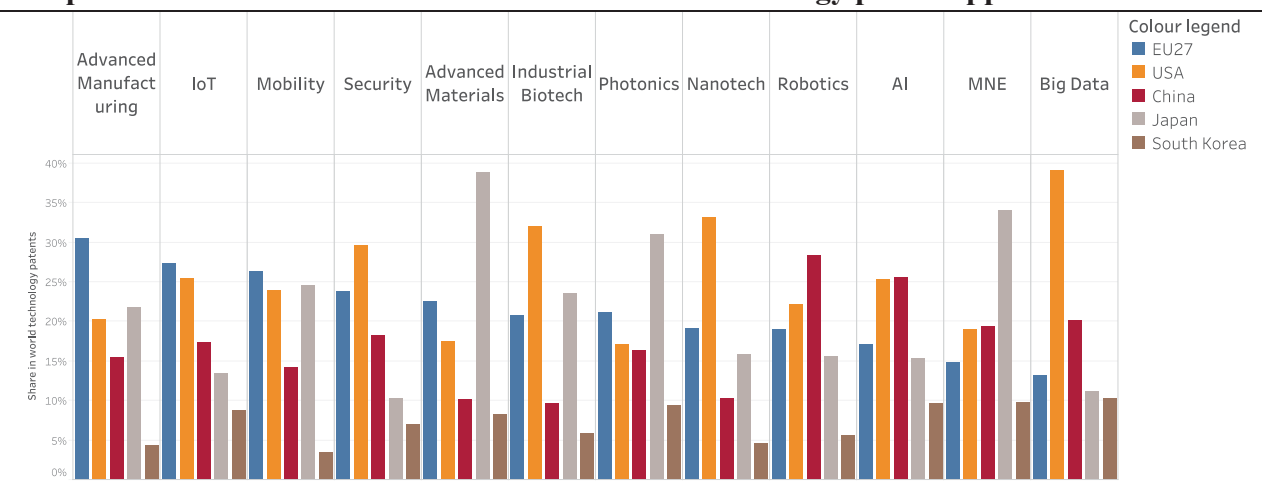
⁵³ The Strategic Forum on Important Projects of Common European Interest identified six key strategic value chains in Europe where further joint and coordinated efforts are needed. These six identified value chains are connected, clean and autonomous vehicles; smart health; low-CO2 emission industry; hydrogen technologies and systems; industrial internet of things; and cybersecurity.

⁵⁴ Detailed methodology available at <https://ati.ec.europa.eu/reports/eu-reports/advanced-technologies-industry-methodological-report>

entrepreneurial activities and available skills – shows that the EU has a relatively strong position for some technologies (Graph 9). For example, the EU currently maintains sound technological leadership in Advanced Manufacturing, with European firms delivering a wide range of advanced manufacturing equipment that are key enablers to production lines across the world. The EU also shows some strengths for related technologies such as in the area of Advanced materials. At the same time, some indicators appear to suggest that the EU faces certain challenges in comparison with its global competitors for several other technologies including AI, Big Data, cloud, cybersecurity, industrial biotech, robotics and micro-electronics (including semi-conductors).⁵⁵

Looking in more detail at technology generation confirms important differences in performance across technologies. In some areas, the EU holds the highest share of worldwide patent applications (e.g. advanced manufacturing technologies, Internet of Things and in the area of IT for mobility⁵⁶) showing strengths in technology generation (Graph 10). Such strong performance in technology generation has a positive impact on business performance. In fact, European firms that own intellectual property rights (IPRs) have on average 20% higher revenue per employee than firms that do not.⁵⁷ The impact is even higher for SMEs, among which the revenue per employee is 68% higher for SMEs that own IPRs.

Graph 10: Share in world transnational advanced technology patent applications



Source: Advanced Technologies for Industry project

Note: Based on EPO Worldwide Patent Statistical Database (PATSTAT, 2017)

At the other side of the spectrum, the EU has been gradually losing leadership in many technologies in terms of its share in worldwide patent applications. This is largely due to the rise in Chinese patents but also patent activity in Taiwan and South Korea. Currently, the EU is lagging behind both China and the US in a number of the areas. This is the case for AI and Big Data, although the EU is showing some increasing dynamics in AI-related patenting. The EU

⁵⁵ IDC, Technopolis Group, Capgemini, Fraunhofer, IDEA Consult and NESTA: Advanced Technologies for Industry – General Findings, 2020

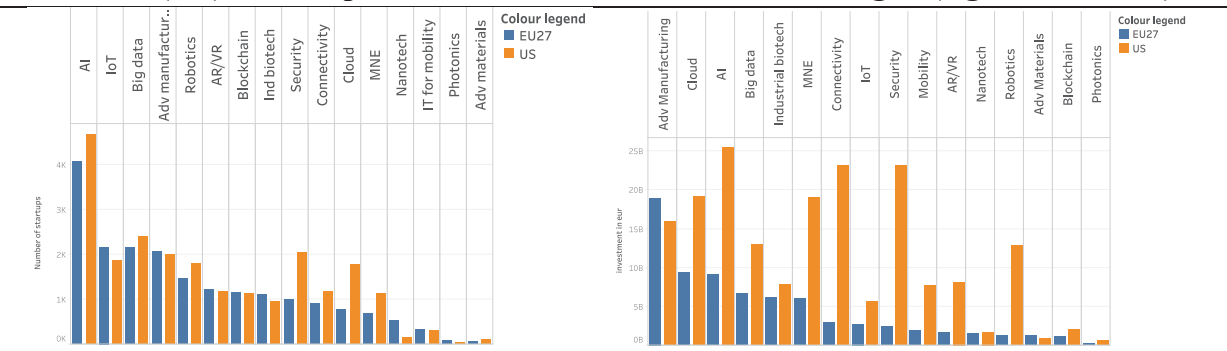
⁵⁶ IT for mobility covers e.g. satellite navigation and radiolocation, which are core technologies in the area of autonomous driving

⁵⁷ EUIPO, EPO: Intellectual property rights and firm performance in the European Union (firm-level analysis report), 2021

share in worldwide patenting has significantly dropped in Robotics, now showing a large gap compared to China. When it comes to semi-conductors, the EU's technology generation approximated by the number of patent applications is significantly below Japan and also lower than China and the US. Overall, this indicates that while the EU is positioning itself well when it comes to the 'factory of the future', it might be falling behind its main competitors in terms of scientific leadership and technology generation in other key areas that have important spill-over effects to many other ecosystems.

The growth of venture capital backed start-ups and scale-ups provides for another indication of the EU's comparative position across key technologies. It equally shows a divergent picture on performance across technologies (Graph 11). For example, in fields such as Internet of Things, Nanotechnology and Industrial biotechnology the EU appears to have a relative advantage compared to the US. At the same time, in other areas including AI, cloud, cybersecurity and micro-electronics the number of EU venture capital backed start-ups and scale-ups is lagging behind the levels seen in the US. Even larger differences are seen when considering total capital investments, with important gaps in investments compared to the US.⁵⁸

Graph 11: Number of active venture capital backed start-ups and scale-ups established since 2009 (left); total capital investments in advanced technologies (right, 2010-2019)

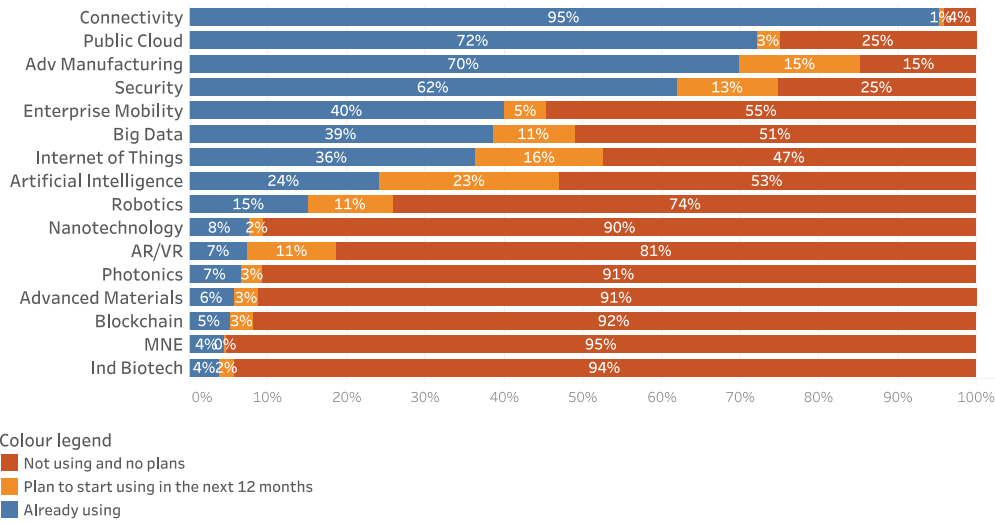


Source: Advanced Technologies for Industry project
 Note: Based on Crunchbase and Dealroom

An analysis of the uptake of key technologies by EU businesses shows that while some are becoming more established, others are still only relevant in very specific sectors. Relatively more established technologies such as cloud computing, cybersecurity and advanced manufacturing appear to play an important role supporting the EU's digital transformation. Other technologies are showing lower but still promising adoption levels. This is the case, for example, for technologies such as AI or Internet of Things. A relatively high share of companies appear willing to invest in such technologies in the near future, although the COVID-19 crisis might have a negative impact on these expectations. Technologies such as Industrial biotechnology show low adoption levels, as there are largely still used only by EU businesses in very specific sectors.

⁵⁸ Which on the one hand is due to the prevalence of the much stronger venture capital market in the US, on the other hand, the comparison of total investment figures has to be interpreted with caution given the somewhat different coverage of data

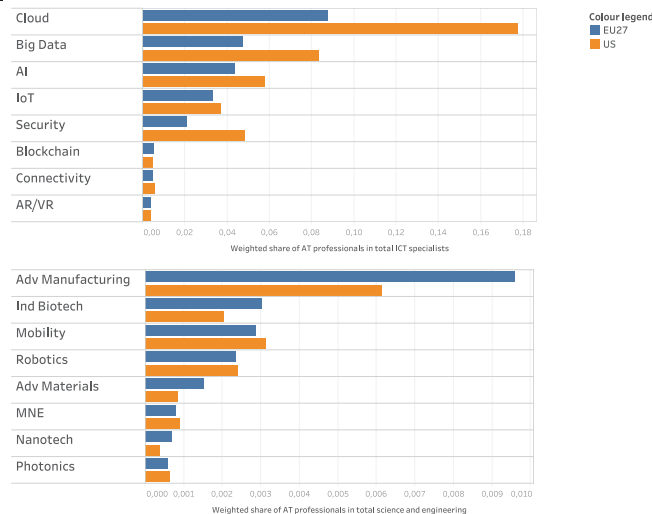
Graph 12: Advanced Technologies current uptake in the EU (2019)



Source: Advanced Technologies for Industry project

In addition to technology generation, entrepreneurial activity and uptake of technologies, it is also important to consider whether EU industry has access to the relevant technical and digital skills to fully capture the potential of technological advances. An approximation⁵⁹ of available skills in the EU across different fields of technologies provides for a rough indication of this. Compared to the US, the EU has a higher relative share of professionals with skills in advanced manufacturing technologies, advanced materials, industrial biotechnology and nanotechnology. Nevertheless, the EU appears to lag behind the US when it comes to available skills in areas such as cloud technologies, big data, AI, cybersecurity and micro-electronics.

Graph 13: Weighted share of professionals with advanced technology skills (proxy)



Source: Advanced Technologies for Industry project. Note: Analysis relying on (online) self-reported skills by professionals

⁵⁹ For more details on methodology: <https://ati.ec.europa.eu/reports/eu-reports/advanced-technologies-industry-methodological-report>

The EU's performance in green technologies

This Commission's annual progress report on clean energy competitiveness⁶⁰ has assessed the state and competitiveness of the EU as regards clean energy technologies. It includes a focus on six key technologies that are expected to play an increasing role in the EU's 2030 and 2050 energy mix: offshore renewables (wind and ocean), solar photovoltaics (PV), renewable hydrogen, batteries and grid technologies.

On the one hand, the report highlights the importance of regaining and strengthening EU's competitive edge in the solar photovoltaic industry and the battery sector. In the solar photovoltaic industry, the EU has lost market share in some of the upstream parts of the value chain (such as solar PV cell and module manufacturing). Considerable market opportunities exist in the segments of the value chain where specialisation or high value products are key. Building a sizeable EU PV manufacturing industry would also reduce the risk of supply disruptions and quality risks. Regarding batteries, there is an ongoing competitive recovery by the EU, which is further assessed in chapter 5 of this staff working document.

The EU holds a first mover advantage in the wind, renewable hydrogen and ocean energy industries. At the same time, large increases in the capacity size of these markets are expected. This will require scaling up and realising economies of scale. The EU offshore wind industry has strong innovative capacity, while needing the perspective of a growing home market as well as sustained R&I funding to benefit from growth in global markets. Also in renewable hydrogen, European companies are well-placed to benefit from market growth (including thanks to their leading position on the electrolysers market). Still, large efforts to scale up are needed to achieve a significant renewable hydrogen production capacity by 2030. Renewable hydrogen is further assessed in chapter 5. As regards ocean energy, technologies have yet to become commercially viable and further efforts are needed to maintain and expand the EU's current leading position. Finally, the EU smart grid industry is relatively small but also competitive. Given its regulated nature, governments and regulators in the EU play a key role in developing the benefits of this industry.

Emerging break-through technologies

A horizon scanning of potentially important, disruptive innovations over the coming 15 to 20 years reveals the expectation of high diffusion potential mainly in digital but also green innovation, making disruptive innovation key for the twin transition.⁶¹ The main expectation is that digital technologies, which have gained importance in the COVID-19 crisis, have the highest diffusion potential in the 2038 horizon by increasing efficiency, effectiveness and convenience everywhere.⁶² With a somewhat less ubiquitous role, innovations in biology, energy

⁶⁰ COM(2020) 953

⁶¹ In 2018, a horizon scanning exercise identified 100 important radical innovation breakthroughs by 2038 regarding their potential techno-economic and social impacts (European Commission, 100 Radical Innovation Breakthroughs for the future, 2019)

⁶² Varnai et al: The scientific, technological and socio-economic conditions of exit from the COVID 19 crisis (report to the EC), forthcoming

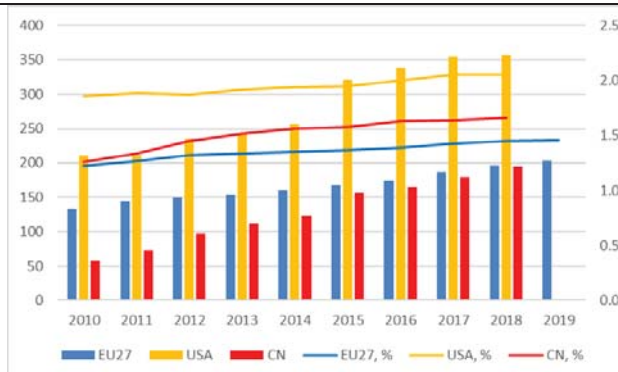
and materials are expected to diffuse into highly digitised and automated industrial ecosystems and to bring massive improvements in (competitive) sustainability.⁶³

Emerging break-through technologies with a high likelihood of maturity by 2038 exist across different ecosystems. In the digital ecosystem, for example, important emerging technologies include areas such as speech recognition and computational creativity. In the electronics ecosystem, examples of technologies with important potential include nano-leds, flexible electronics, 2D material based technologies⁶⁴ and bio-degradable sensors. Also in ecosystems such as health (e.g. gene editing and therapy) and renewables (e.g. bioplastics), there are several important break-through technologies with a high likelihood of maturity by 2038. While limited data is available to assess the EU's performance in many of such emerging technologies, it is clear that they deserve attention from industry and policymakers.

3.2 Europe's research and innovation performance

The EU's performance in R&I gives insights in possible future developments of the EU's competitive position in key technologies. R&I is a key driver that will define Europe's performance when it comes to key technologies to support competitiveness, match the EU's green and digital ambitions and safeguard the security and health of Europeans. The EU's R&I performance compared to its global competitors is creating concerns over (future) technological dependencies. While the EU is a global R&D powerhouse, accounting for almost 20 % of R&D worldwide⁶⁵, it is threatened by global competitors in a number of innovation key indicators.

Graph 14: BERD in EU and its main global competitors in bln EUR (left axis) and BERD intensity (% , right axis)



Source: JRC elaboration based on Eurostat data

Business expenditure on R&D is far below the US and has been caught up by China as well (Graph 14). EU business expenditure on R&D (BERD) was around 200 billion EUR in 2019, accounting for about 1.5% of GDP. Despite its 50% growth over the last decade EU BERD

⁶³ See Sachs, J.D, Schmidt-Traub, G., Mazzucato, M., Messner, D, Nakicenovic, and N., Rockström, J.: Six Transformations to Achieve the Sustainable Development Goals, 2019 (Nature Sustainability); and M. Porter: Developing the EU's 'competitive sustainability' for a resilient recovery and dynamic growth, 2018 (Cambridge Institute for Sustainability Leadership)

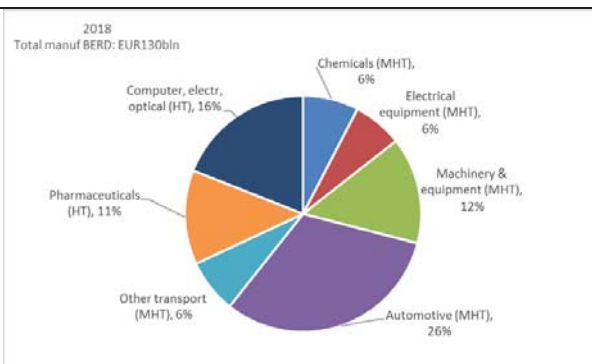
⁶⁴ <https://graphene-flagship.eu/>

⁶⁵ European Commission: Science, Research and Innovation Performance of the EU 2020, 2020

has been caught up by Chinese BERD also in monetary terms and it is significantly lower (by 45%) than the amounts that US businesses spend on R&D.

Manufacturing BERD in the EU is performed mostly in the high tech (HT) and medium high tech (MHT) sectors. In 2018, these sectors accounted for more than half of total BERD (56%) and for 83% of total manufacturing BERD. The main industrial sectors for BERD include the automotive industry, computer & electronic & optical and pharmaceuticals. The decade long changes in these shares have been minor.

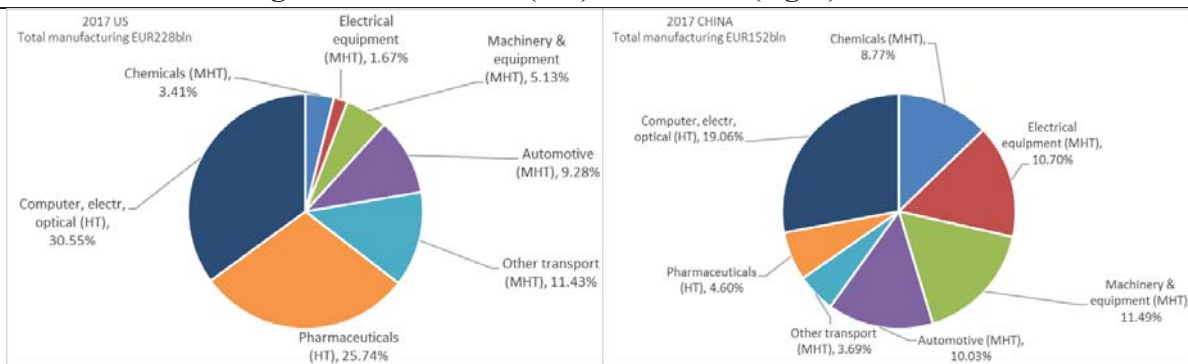
Graph 15: Medium high tech and high tech manufacturing BERD as a share of total manufacturing BERD in EU



Source: JRC elaboration based on Eurostat data

Still, the share of EU high tech BERD is only less than half of that of the US. The US invests significantly more in HT compared to the EU (57% vs 27%) and less in the automotive and other MHT manufacturing. China’s HT BERD has only a slightly lower share (24%) than that of the EU. The EU’s scaling-up performance also lags behind the US and China: for each EU private unicorn in 2018 there were eight in the US and four in China.⁶⁶

Graph 16: Medium high tech (MHT) and high tech (HT) manufacturing BERD as a share of total manufacturing BERD in the US (left) and China (right)



Source: JRC elaboration based on Eurostat data

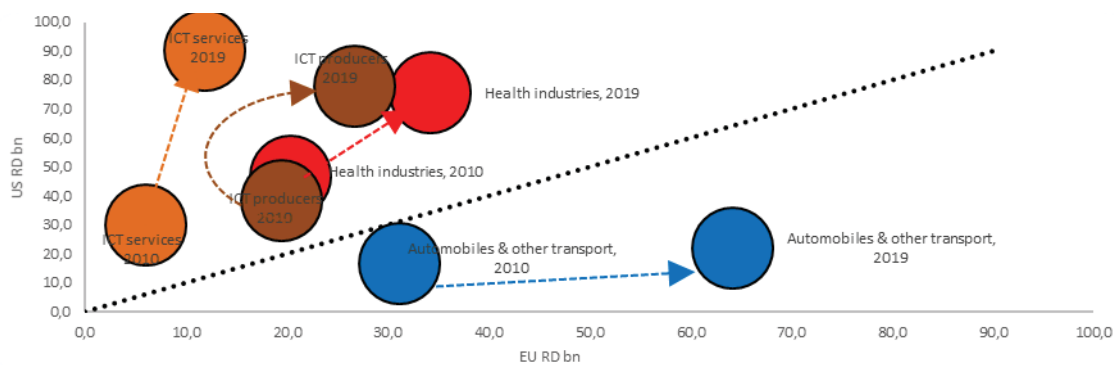
The EU (as well as the US) is also losing ground in favour of China with respect to scientific excellence and patenting. Regarding scientific output measured by the top 1% highly cited

⁶⁶ European Commission: Science, Research and Innovation Performance of the EU 2020, 2020

publications, the EU is behind the US and also overtaken by China in 2015.⁶⁷ Regarding world shares in transnational patent filings, the EU remains world leader, but the gaps between the EU, US, Japan and China are narrowing.⁶⁸

Technological specialisation has deepened given similar R&D trends observed for over 10 years, shaping specialisation patterns and increasing differences across regions, particularly between the EU and the US. Companies' R&D investments in the EU and the US have increased significantly over the past ten years in the top four R&D investing sectors.⁶⁹ In 2010, EU companies in the automotive industry were investing more in R&D than their US counterparts, whereas US companies in the health and the ICT industries (both services and producers) invested the most in R&D. These differences have increased further in 2019, particularly in both ICT sectors. The ratio of R&D investment between the EU and the US remained constant in the health sector, increased significantly in the automotive sector and substantially decreased in both ICT sectors.

Graph 17: R&D investment in 2010-2019, comparison of selected sectors in the EU and US⁷⁰



Source: The 2020 EU Industrial R&D Investment Scoreboard, European Commission

A closer look to the EU and US data at the sub-sector level shows even more striking differences in R&D investment, for example in biotechnology and software & internet. In 2019, the US had many more companies in both sub-sectors (8.6 times more in biotechnology and 8.8 times more in software & internet) as well as significantly higher R&D investments (EUR 34.3 billion vs EUR 2.6 billion in biotechnology and EUR 92.7 billion vs EUR 7.5 billion in software & internet).

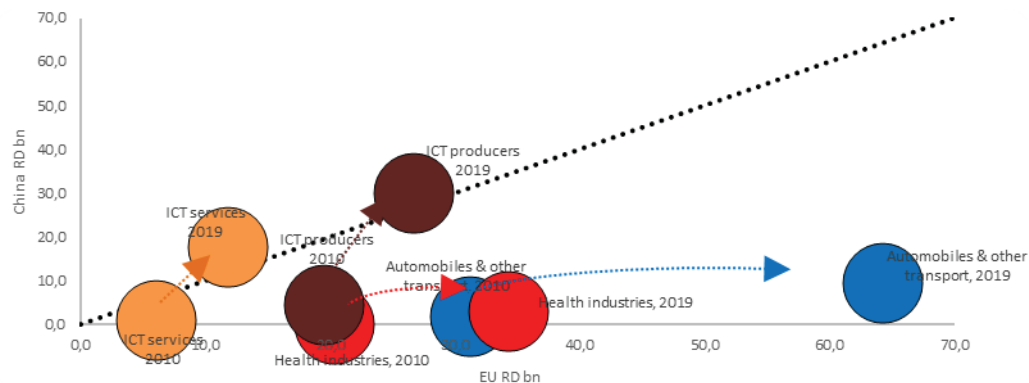
⁶⁷ Commission elaboration based on INCITES (Web of Science) data

⁶⁸ Commission elaboration PATSTAT

⁶⁹ Source: European Commission (JRC/DG R&I): 2020 EU Industrial R&D Investment Scoreboard. R&D in the Scoreboard is extremely concentrated, with the top four sectors contributing 77% of the total R&D: ICT producers (23.0%), health industries (20.5%), ICT services (16.9%), and the automotive industry (16.3%).

⁷⁰ Note: data refers to 514 (EU:164, US:350) of the 805 companies (EU:204, US:601) in the four sector groups in the two regions considered for which R&D data are available for the all period 2010-2019, accounting for 90.2% of the R&D in 2019.

Graph 18: R&D investment in 2010-2019, comparison of selected sectors in the EU and China⁷¹



Source: The 2020 EU Industrial R&D Investment Scoreboard, European Commission

In the past 10 years, the R&D investment of Chinese companies operating in the ICT sectors has overtaken that of EU companies. By contrast, the EU retained its lead in the health and automotive sectors. The average R&D investment per company in the EU Industrial R&D Investment Scoreboard has grown significantly in China in 2019.⁷² However, it has still remained little more than half of the average EU company (EUR 509.6 million). Thus, while overall EU firms' R&D investments remain well ahead of that of Chinese firms, the gap is continuously decreasing.

Finally, when it comes to green technologies, it is crucial that the EU maintains its strong position. R&I as well as the development and uptake of eco-innovations will be key to achieving the climate goals. Existing technology will not be able to deliver the full emissions reduction required to achieve EU climate objectives and new technologies should ideally become commercialised by 2030, to allow for timely scaling and deployment across the EU by 2050.⁷³ At the same time, in the case of more mature techniques, necessary investment into large-scale demonstration and deployment will require increased pooling of resources.

The EU makes too little use of its world-leading R&D in industry and must ensure a better transfer of that R&D into the economy,⁷⁴ especially when it comes to green innovations. The EU currently has a higher share in clean energy technologies in overall patenting activity than most other major economies.⁷⁵ The EU is also the global leader on high-value green patents (protected in at least two patent authorities), with Japan and the US following closely.

⁷¹ Note: Data refers to 347 (EU:164, CN:183) of the 497 companies (EU:204, CN:293) in the four sector groups in the two regions considered for which R&D data is available for the entire period, accounting for 91.1% of R&D in 2019.

⁷² From €47.2million in 2010 to €274.4 million in 2019

⁷³ In-depth analysis in support of COM(2018)773: A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy; European Commission: Science, Research and Innovation Performance of the EU 2020, 2020

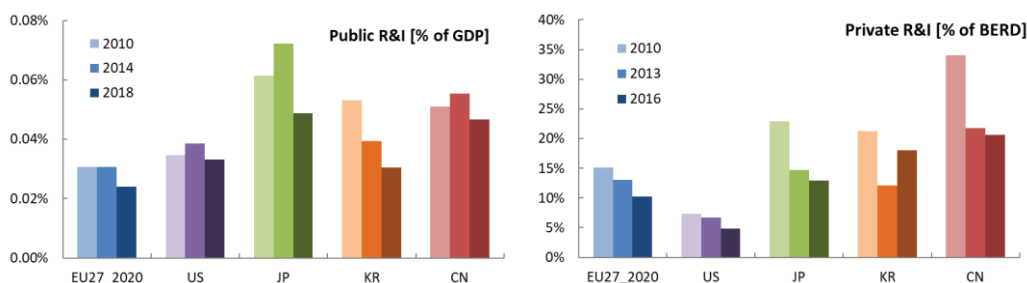
⁷⁴ New ERA, COM(2020)628, chapter 2.3.

⁷⁵ Over the period 2010-2016, the EU was second among major economies in terms of patenting activity in green technologies as a share of all inventions (at 9.5%), following South Korea at 10.3%, well above the global share of 7% (European Commission: 2020 EU Industrial R&D Investment Scoreboard)

Nevertheless, the green transition will depend on the degree to which the corresponding green innovations are created and deployed.

In addition, there is an overall decrease in national budgets devoted to R&I in clean energy technologies and a lack of national objectives and funding targets that show concrete pathways to 2030 and 2050.⁷⁶ Even though some Member States have been increasing efforts, overall, national budgets for clean energy research have been in slight decline in recent years⁷⁷. The R&I budget allocated to energy in the EU represents 4.7% of total spending on R&I. In 2018, the EU public R&I investment in clean energy technologies as a share of GDP was less than 0.03%, against around 0.05% in Japan or China. Estimates of private investment in the same areas have also been decreasing in recent years and amount to around 10% of the companies' total expenditure in R&I.⁷⁸ This is higher than the US, but lower than China.

Graph 19: Estimated public⁷⁹ and private⁸⁰ R&I financing in the Energy Union R&I priorities



Source: JRC⁸¹ based on IEA, Mission Innovation, Eurostat/OECD

3.3 Conclusions

This snapshot assessment of the EU's performance in key technologies and R&I shows that the EU has certain strengths but is also at risk of falling behind in other areas that will drive future competitiveness. While the EU still has a sufficient technological base, it is exposed to strong global competition. In some areas such as advanced manufacturing the EU seems to be performing well. Also in the area of certain green technologies (such as hydrogen, see chapter 5.4) the EU is highly competitive, while overall efforts are needed for the EU to maintain and further build its strong position. At the same time, the increased technological capacities of the EU's competitors highlight the risk of the EU not being able to create and grow

⁷⁶ COM(2020)564

⁷⁷ COM(2020)950; COM(2020)953

⁷⁸ Contrasted with BERD statistics: *Eurostat/OECD* Business expenditure on R&D by NACE Rev. 2 activity and source of funds

⁷⁹ This excludes EU funds (2018 value; for EU27 partly estimated)

⁸⁰ Private R&I estimates for China are challenging and uncertain, given the differences in Intellectual Property protection and the difficulty in mapping the company structure (e.g. state backed companies) and financial reporting

⁸¹ <https://setis.ec.europa.eu/publications/setis-research-innovation-data>; Pasimeni, F.; Fiorini, A.; Georgakaki, A.; Marmier, A.; Jimenez Navarro, J. P.; Asensio Bermejo, J. M.: SETIS R&I country dashboards, 2018

a sufficient number of firms in certain key technology sectors.⁸² Furthermore, the EU's R&D efforts in the digital ecosystem fall significantly behind those of the US and have been overtaken by China as well. Such lagging performance provides at least indications as regards possible (future) dependencies with regard to these technologies. If left unaddressed, strategic dependencies in the area of these technologies could further materialise and possibly new ones might emerge.

Particular technologies where the EU's competitive position appears to be weaker compared to its global commercial competitors include AI, High Performance Computing, Big Data, cloud, industrial biotech and micro-electronics (including semi-conductors). These key technologies in the digital ecosystem deserve particular attention, as key enablers and sources of transformation for many other ecosystems (such as the defence and aerospace, automotive, agri-food and health ecosystems). Chapter 5 of this staff working document provides in-depth reviews of the EU's position and potential strategic dependencies in the areas of semi-conductors and cloud technologies.

⁸² Moncada-Paternò-Castello P. and H. Hernandez (JRC Policy Insights, European Commission): Ten-year evolution of EU industrial R&D in the global context, 2018

4 Policy measures with a potential to address strategic dependencies

Any measures addressing strategic dependencies would need to be designed and applied on a case-by-case basis, taking into account the specific nature of the dependency, the global situation and the policy objectives pursued within the ecosystem concerned. They would need to build on in-depth discussion and dialogue with Member States and industry. Dialogue with industry (e.g. in the context of the Industrial Forum) is particularly important when it comes to better understanding the impact of certain dependencies and the drivers of current supply patterns.

A detailed understanding of the functioning of relevant value chains as well as the potential risks that specific strategic dependencies entail to the EU's core interests allows building policy measures that would aim at address dependencies in a targeted manner.⁸³ This would allow taking proportionate measures, without compromising the open and trade-based EU economy and ensuring competition is not distorted. Addressing strategic dependencies requires targeted measures depending on the dependency concerned and its potential risks. Different alternatives should be carefully examined with a view to maintaining the competitiveness of the EU and choosing to address dependencies in the most cost-efficient manner.

4.1 Relevant measures to address external and internal strategic trade dependencies

There are differences between external and internal (concentration of activity at a firm level within the Single Market) dependencies also when it comes to identifying relevant types of policy measures. Different types of measures may play a role when it comes to considering how to mitigate risks of external and internal dependencies.

Measures to address external trade dependencies considered strategic

Policy measures to address external strategic dependencies can be diverse. On the one hand, they should ensure that the EU reinforces its position in global value chains by strengthening and diversifying external trade. On the other hand, the EU should strengthen its own capacity in strategic areas where necessary, building on the strengths of a fully functioning Single Market with open and competitive markets.

On the external side, the diversification of import sources is a key element when it comes to increasing the EU's resilience in a context of global uncertainty and growing international tensions. A strong EU engagement in multilateral cooperation and coordination mechanisms is important for this, including when it comes to preparing for a future crisis. At the same time, companies themselves play the key role in this regard as they are able to assess risks and take action so that they are able to tap into a sufficiently diversified and environmentally sustainable set of suppliers.

⁸³ For example, in the area of raw materials in addition to a regular review of the EU's critical raw materials list, the Commission has recently also carried out specific foresight work to obtain a better understanding of the EU's future raw material needs in particular in light of the green and digital transitions (see European Commission: Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study, 2020)

Public policy can facilitate the process of diversification to alternative sources of supply and strengthening of existing supply chains. The recent Trade Policy Review provides the basis and direction for this. A reinforced use of the EU's trade policy tools can contribute to obtaining access to new and improve access to existing global markets as well as ensuring an undistorted functioning of existing supply chains, based on a stable, rules-based trading framework. This requires building partnerships with like-minded partners and further engaging with a range of markets and countries around the world. In addition, trade policy also plays an important role in allowing EU businesses to compete on an equal footing with third country businesses. Better enforcing existing trade agreements and ensuring effective defence against unfair trade practices are key in this regard, including in those areas where the EU currently faces possible strategic dependencies. Likewise, the Commission plans to adopt as a follow-up to the White Paper on foreign subsidies⁸⁴ a proposal for a new instrument to address possible distortive effects of foreign subsidies in the Single Market particularly in relation to concentrations and public procurement.

On the internal side, the EU can address strategic dependencies by increasing or diversifying domestic production and where necessary and possible also consider strategic stockpiling. In addition to diversifying sources of imports (or where the potential of such diversification is limited), the EU can also develop or improve its own capacity in strategic areas.⁸⁵ In addition, a crisis preparedness strategy (including e.g. the building of stocks or the development of alternatives, possibly together with international partners) can also be of relevance for certain strategic areas, including when it is not fully possible or efficient to substitute foreign goods with domestic production.

Achieving increased EU capacity in areas considered strategic requires a fully functioning and competitive Single Market. Actions taken to facilitate a better functioning Single Market are key when it comes to ensuring increased strategic capacity in specific areas. Fostering the growth of firms and increasing industrial dynamics both via the ecosystems and the Single Market is key to achieving the twin transition.⁸⁶ The EU would need to ensure that regulatory frameworks are fit for purpose and provide legal certainty to facilitate large-scale investments. Unnecessary or disproportionate barriers to the Single Market that hinder innovative businesses from exploiting opportunities of scale should be removed, particularly for areas of strategic importance.⁸⁷ The Single Market Programme can be a key facilitator in this regard. Furthermore, open and competitive markets support resilience. Competition policy is key in this regard as a tool to promote innovation and foster a competitive industrial fabric, including in areas of strategic importance. The use of existing tools such as Important Projects of Common European Interest have already shown to offer important potential benefits in specific areas where the

⁸⁴ See COM (2020)253 on levelling the playing field as regards foreign subsidies

⁸⁵ Demand-side substitution policies may also be relevant, diversifying or changing demand for specific products

⁸⁶ JRC policy brief: EU corporate R&D intensity gap: structural features call for a better understanding of industrial dynamics, 2016.

https://iri.jrc.ec.europa.eu/sites/default/files/contenttype/publication/policybriefs/1568801201/EU%20corporate%20R%26D%20intensity%20gap%20_PolicyBrief.pdf

⁸⁷ See also COM(2020)93 on identifying and addressing barriers to the Single Market and COM(2020)94 on the Long term action plan for better implementation and enforcement of single market rules

market alone cannot deliver breakthrough innovation, while ensuring that the benefits are shared across the EU economy. Industrial alliances can also serve as a platform to convene and rally a wide range of stakeholders in a given area to uncover opportunities and address bottlenecks in achieving the EU policy objectives. Finally, the COVID-19 crisis has also indicated that in exceptional cases, specific solutions (such as advance purchase agreements) allow investments to be made in a context of high cost and high failure rates.

Modern, well-managed and efficient procurement by public authorities can also play an important role in increasing resilience. Smart procurement already today takes up a central part in enabling the achievement of key priorities (e.g. related to the green transition, innovation and social objectives) across many ecosystems. The role of public procurement and specific criteria in reducing dependencies and thus strengthening the resilience of different ecosystems can be further explored and developed.

Targeted funding geared towards strategic priorities and investments in research can also provide a key contribution to building capacity and increasing resilience. The Recovery and Resilience Facility provides a major boost in this regard. In addition, support for research and innovation can help to extend the EU's strategic industrial capabilities including in new and emerging areas. For example, Horizon Europe is already providing support to research and innovation in different areas of strategic importance (e.g. raw materials, batteries, quantum technologies).⁸⁸

SMEs may require specific support to diversify supply chains and increase their resilience. Strategic dependencies have a particular impact on SMEs, as they are more vulnerable to lock-in effects and high switching costs. A recent SME survey⁸⁹ highlights that the COVID-19 crisis strongly or moderately affected seventy-two percent of respondents because of supply chain disruptions, employee absences and temporary shutdowns. In addition, SMEs were not well prepared: almost two thirds of respondents had no plan in place to handle supply chain disruptions. One third created such a plan during the pandemic.

Developing the skills of the EU workforce in identified areas of strategic importance can help the EU build capacity. This requires mapping-out the skills needed and supporting workers in acquiring them. Such efforts would help regain skills that might have been transferred to parts of the value chain located outside the EU, or learn new ones that emerge as the economy transforms. Developing skills can increase EU workers' productivity, ensuring that an increased EU production in certain areas is at the same time also economically efficient.

For several of the possible external strategic dependencies highlighted in chapter 2.3, actions have been initiated or further developed since the March 2020 Industry Strategy.

⁸⁸ It should also be noted that for actions related to Union strategic assets, interests, autonomy or security, the Horizon Europe work programme may provide that the participation can be limited to legal entities established only in Member States, or to legal entities established in specified associated or other third countries in addition to Member States. In addition, exceptionally and for duly justified reasons, entities established in the Union or in Associated Countries directly or indirectly controlled by non-associated third countries or by legal entities of non-associated third countries may also be excluded from individual calls for proposals.

⁸⁹ EU Survey carried out by European Commission July-December 2020

Chapter 2.3 identified possible strategic dependencies for a number of products, notably in the energy intensive industries ecosystem (including raw/processed materials and chemicals), the health ecosystem (including active pharmaceutical ingredients and other health related products) as well as other inputs and products that are relevant to support the green and digital transformation. Several recent initiatives aim to address these dependencies or assess them in more detail.

Firstly, in the area of raw materials, the action plan on *critical raw materials*⁹⁰ (September 2020) presents the challenges for a secure and sustainable supply of critical raw materials and actions to increase EU resilience and open strategic autonomy. In the context of this action plan, actions taken to address strategic dependencies consist of both internal EU capacity building as well as strengthening and diversifying external sources. Actions taken to build up EU production capacities include identifying and developing viable industrial projects on critical raw materials exploration, extraction, processing and refining; launching research and innovation; developing relevant expertise and skills; and deploying Earth-observation programmes and remote sensing. The action plan also aims to make better use of the potential of recycling and secondary critical raw materials. On the external side, the strategy sets out that EU will continue to diversify supply from third countries and strengthen rules-based open trade in raw materials and remove distortions to international trade. The EU will also engage in strategic partnerships with resource-rich third countries to secure a diversified, sustainable and responsible supply of critical raw materials. The Commission will implement parts of the critical raw materials action plan together with the European Raw Materials Alliance. The alliance will identify barriers, opportunities and investment cases to build capacity at all stages of the raw materials value chain, from mining to waste recovery. Chapter 5 will provide a more detailed analysis on the nature and impact of strategic dependencies as well as relevant measures in the area of raw materials.

Furthermore, the chemicals strategy for sustainability was adopted in October 2020.⁹¹ One of the key actions of the strategy is to promote the EU's resilience of supply and sustainability of critical chemicals. In this context, the Commission is stepping up strategic foresight in the field of chemicals together with relevant stakeholders including by gathering more in-depth evidence on chemicals that are critical for the Europe's societal and economic resilience and the green and digital transition of industrial ecosystems.

Secondly, in the area of health, the Commission Communication on building a European Health Union (November 2020)⁹² **proposes actions to reinforce the EU's resilience for cross-border health threats.** The COVID-19 crisis showed that the EU lacked effective mechanisms and structures to monitor demand and supply of critical medical countermeasures and support Member States in addressing shortages. Different measures were taken during the crisis to

⁹⁰ COM(2020)474

⁹¹ COM(2020)667

⁹² COM(2020)724

address these shortcomings (e.g. stockpiling of emergency medical equipment⁹³ and offering regulatory flexibility while maintaining safety standards). In addition, the Communication on a European Health Union proposes further actions aimed at increasing resilience to all cross-border health threats and providing European citizens with a high level of public health. It focuses on crisis preparedness and response measures such as strengthening coordination at EU-level when facing cross-border health threats; revising the mandates of the European Centre for Disease Prevention and Control and of the European Medicines Agency to provide stronger surveillance, scientific analysis and guidance before and during a crisis; and setting up a new EU agency for biomedical preparedness.

In addition, the Pharmaceuticals Strategy for Europe (November 2020) presents actions to ensure accessibility, availability and affordability of medicines, including through diversified and secure supply chains. Specifically on the issue of supply security of medicines, the Commission is steering a structured dialogue with relevant actors in the pharmaceuticals value chain, public authorities and other stakeholders. In a first phase, the structured dialogue aims at obtaining a more detailed understanding of the functioning of global pharmaceutical supply chains and identifying the precise causes and drivers of different potential vulnerabilities. In a second phase, the structured dialogue will allow putting forward a set of possible measures and policy options. These will aim to address possible vulnerabilities, including potential dependencies, and ensure the security of supply and the availability of critical medicines, active pharmaceutical ingredients and raw materials. Chapter 5 will provide a more detailed analysis on the nature and impact of strategic dependencies as well as relevant possible measures in the area active pharmaceutical ingredients.

Thirdly, a number of recent and forthcoming initiatives aim to address strategic dependencies in the area of green and digital. For example, the Commission's proposal for a new regulatory framework on *batteries*⁹⁴ aims to ensure that there are robust sustainability, safety and performance requirements for all batteries placed on the EU market. In addition, a second Important Project of European Interest in the area of batteries was authorised in January 2021. Similarly, the recent Digital Services Act and Digital Markets Act package⁹⁵ opens up new opportunities for businesses that depend on gatekeeper platforms to offer their services in the Single Market, as they will be able to innovate and compete in a fair and balanced market. In addition, the Commission will soon propose a Data Act⁹⁶ to provide the best conditions for the access to and control over data in B2B and B2G situations. Also, the proposed regulatory framework on Artificial Intelligence has the twin objective of creating ecosystems of excellence and trust to promote the development and uptake of AI while addressing the risks associated with certain uses of this technology. Such regulatory initiatives would allow providing legal certainty

⁹³ In the context of the COVID-19 crisis the Commission has set up a strategic rescEU stockpile of medical equipment. This common European stock of medical equipment is hosted by nine Member States (as of January 2021) and includes products such as medical masks, gloves, gowns and ventilators. It has already delivered essential medical supplies to a number of countries participating in the EU Civil Protection Mechanism that have requested assistance via that mechanism.

⁹⁴ COM(2020)798

⁹⁵ <https://ec.europa.eu/digital-single-market/en/digital-services-act-package>

⁹⁶ See COM(2020) 66, 'A European strategy for data'

for investments and place European players at the forefront of these technological developments. Chapter 5 will provide a more detailed analysis on the nature and impact of strategic dependencies as well as relevant possible measures in the areas of lithium-ion batteries, cloud and edge computing, and semi-conductors.

Policy measures in the context of internal Single Market dependencies linked to concentration of activities

In view of possible internal dependencies on a limited number of sources within the EU (notably linked to possible concentration of activities at a firm level), it is of key importance to safeguard a free flow of goods and services across the Single Market. The internal Single Market disruptions experienced particularly during the first wave of the pandemic have highlighted the importance of a functioning Single Market where all Europeans can rely fully on the capacities held by individual Member States. For example, national bans or other restrictions on intra-EU exports undermined the principle of European solidarity and created a domino effect across the Single Market. In addition, they were subject to frequent adjustments exacerbating legal uncertainty and triggered uncoordinated stockpiling responses. Businesses repeatedly underlined the negative impact on their supply chains of export restrictions within the Single Market established in the context of COVID-19. The Commission worked to lift around 30 of such restrictions during the first wave of the pandemic. This shows the need for structural solutions to safeguard and strengthen the functioning of the Single Market during times of emergency.

In addition, competition policy plays a key role by enabling lively entrepreneurial ecosystems in Europe. A well-functioning Single Market with strong business dynamics and competition is also key when it comes to mitigating the possible risks of internal dependencies linked to a potential concentration of critical supplies at firm level. Generally, market entry of new firms in a given sector has positive effects on competition, allocative efficiency and overall competitiveness of the sector. In sectors of strategic importance, a higher level of diversification (and lower concentration) of individual sources within the Single Market also increases the EU's resilience to unexpected shocks (e.g. natural disasters). This is important, for example, in situations where a very limited number of EU production facilities is producing certain critical products. Competition policy plays an essential role in this regard by ensuring access to diversified sources of supply within the EU and preventing too strong reliance on a few players or products.

Finally, the EU's integration into global value chains can also play an important role in mitigating possible risks related to internal dependencies. Together with a functioning Single Market, potential risks related to internal dependencies are further reduced by the EU's open economy being integrated in an effective and fair global trading system. Global trade can notably help to diversify supply sources and sustain demand for our industrial output. International trade helps not only to cushion possible shocks and disruptions having an impact on internal EU value chains, but also to ensure that the EU can meet its internal demand in case of rapidly increasing demand of certain goods.

4.2 Relevant measures in the area of key technologies

Chapter 3 highlighted a number of challenges the EU faces in comparison with other economies in the areas of key technologies. While the EU has certain strengths (e.g. in the area of advanced manufacturing), it is also at risk of falling behind in certain other areas (e.g. cloud) that will drive future competitiveness. Furthermore, the EU's efforts in research and development show important gaps in comparison with international competitors notably in the digital ecosystem, highlighting concerns over technological dependencies increasing or possible new ones emerging.

It is paramount to step up cooperation with industry on research and innovation providing increased certainty for private engagement based on a common agenda for technological development. The pandemic is leading to shrinking turnover and profits, often leaving even less room for company investment. There is a need for more favourable conditions supporting the emergence and growth of companies and investments in strategic and R&D intensive sectors of economic and social interest. In addition, the capacity of traditional (and mature) medium- and low-technology sectors – where Europe is comparatively strong – to absorb new technologies should be strengthened. It is essential to crowd in private investment to this end and to provide directionality and ambition to public support. The Commission will develop industrial technology roadmaps⁹⁷ for a number of priority ecosystems offering a common vision for technological development with industry and Member States. They will make concrete recommendations to speed up the transfer of research results into the real economy, linking relevant partnerships under Horizon Europe with industrial ecosystems.

The Recovery and Resilience Facility and the Digital Europe programme provide major opportunities to step up investments in advanced digital technologies and turn the immediate challenges presented by the COVID-19 into a long-term opportunity. On top of existing funding programmes, 20% of the Recovery and Resilience Facility has been reserved for digital investments and reforms. Several of the flagship initiatives identified by the Commission are targeted towards a stronger generation and uptake of digital technologies (including “connect”, “modernise”, “scale-up” and “reskill and upskill”).⁹⁸ In addition, the Digital Europe programme aims to build the strategic digital capacities of the EU and to facilitate the wide deployment of digital technologies in the EU.⁹⁹

Investment in Multi-Country Projects can target strategic dependencies in the area of technologies more effectively. The Digital Decade communication proposes investments in a set of multi-country projects around 4 pillars: digital infrastructure, digital skills and education, digitalisation of businesses and digital government. Such projects include deploying a common and multi-purpose pan-European interconnected data processing infrastructure; endowing the EU with capabilities in electronics design and deployment of the next generation of low power

⁹⁷ As announced in the European Research Area Communication (new ERA)

⁹⁸ SWD(2021)12

⁹⁹ For duly justified security reasons, participation of EU-based entities controlled from third countries may be excluded from specific actions under the programme (Article 12 (5) and (6) of the Digital Europe Regulation)

trusted processors; deploying 5G corridors along major pathways; connecting public administrations with interoperable services; supporting the digitisation of industry via European Digital Innovation Hubs; and developing specialised ICT education and training. The Digital Policy Programme foreseen under the Digital Decade Communication will set up a mechanism to enable the Commission to engage with Member States with the objective of taking joint commitments as well as possible measures at EU and national level. The variety of mechanisms that has been used for different projects and investments until now has revealed a gap in the Commission's toolbox to combine funding from Member States, the EU budget and private investment for the purposes of deploying and operating infrastructures and services of common interest, outside the research area. In this regard, the Council conclusions of 25 March 2021¹⁰⁰ also highlight the need for appropriate vehicles to support multi-country projects.

Cohesion policy co-funds research and innovation actions in areas where regions have particular strengths, while supporting the reinforcement of EU value chains in key technologies. The new Interregional Innovation Investment instrument (I3) will bring together partners from different Member States and regions to develop joint investment to accompany Europe and its regions in their efforts to strengthen the EU on the global stage and facilitate the recovery.

Skills are crucial to the development and uptake of new technologies, to address existing or potential future strategic dependencies in key technologies. Important ongoing initiatives in this regard include the European Skills Agenda as well as the Pact for Skills. In addition, pursuing gender equality could be crucial as closing the gender gap in science, technology, engineering and mathematics (STEM) careers would be key for the EU to meet its needs in terms of ICT professionals in years to come.

Important Projects of Common European Interest (IPCEIs) provide a State aid compatibility basis under Art. 107(3)(b) TFEU under which Member States can jointly design large cross-border projects to achieve EU strategic goals in areas where the market alone cannot deliver breakthrough innovations. Furthermore and as also announced in the Industry Strategy of March 2020, the Commission will revise in a targeted manner the applicable State aid rules in 2021 to facilitate further SMEs' participation in future IPCEIs and clarify further the applicable state aid criteria, while at the same time continue to respect the EU's international obligations.¹⁰¹

Industrial alliances can play a key role in building up EU capacity in specific strategic areas through joint action by all the interested partners. Industrial alliances are already used

¹⁰⁰ SN 18/21, para 4: 'We stress the need to strengthen the competitiveness and resilience of the European Union's industry, including SMEs, to accelerate its green and digital transitions, including through appropriate vehicles to support multi-country projects [...]'

¹⁰¹ The ongoing adaptation of relevant horizontal State aid Guidelines, including the Communication on Important projects of common European interest, the Regional aid Guidelines, the Framework on Research, Development and innovation, the Risk Finance Guidelines as well as the Environmental and Energy Guidelines, together with the review of the transport specific aviation and railway state aid guidelines, will ensure that they are fit for purpose for an economy that is changing fast, increasingly digital and must become greener and more circular. The adaptation process follows the Better Regulation principles (including public consultations of industry and Member States).

as one of the delivery vehicles for existing EU strategies including in the fields of hydrogen, raw materials and plastics. Possible new alliances can be considered including in the area of advanced technologies, where proved a well-targeted and efficient tool.

The EU Space Programmes are effectively strategic capacities, built up by sustained investment over decades by Member States and the EU in strategic infrastructure and technologies. Both Copernicus and Galileo contribute strongly to the EU's open strategic autonomy by providing global Earth Observation data and satellite navigation services, which are used in a wide range of applications, including critical security applications and monitoring of greenhouse gasses, crucial for the green deal. Simultaneously, those EU space capabilities act as a positive lever for multilateral cooperation, for example in climate action with Copernicus data, in satellite navigation for security applications with the US, and providing satellite navigation services in Africa. Thereby, those EU flagships represent open strategic autonomy in action.

Finally, the Commission's Action plan on synergies between civil, defence and space industries identifies a (non-exhaustive) number of critical technologies that are relevant across the civil (with a focus on security), defence and space industry domains. Several of these identified critical technologies include technologies highlighted in Chapter 3 for which the EU appears to be facing challenges compared to its global competitors (e.g. cloud, semi-conductors). In the context of this Action plan, the Commission will set up an EU Observatory of Critical Technologies that can provide a regular monitoring and analysis of these critical technologies, their potential applications, the value chains, the desired EU control over them and the existing gaps and dependencies. Every second year, this Observatory, in consultation with key stakeholders, will produce a classified report. On the basis of these reports, the Commission will develop technology roadmaps to stimulate cross-fertilisation between civil, defence and space industries for critical technologies.

5 Reviews of a selected number of strategic areas

This chapter provides more in-depth reviews for a number of strategic areas. As for any area of strategic importance, policy intervention would need to build on a thorough understanding and detailed analysis of the functioning of relevant value chains as well as the underlying drivers of Europe's current and possible future strategic dependencies and the risks they entail. This chapter provides in-depth reviews of a number of areas that can be considered strategic for Europe's interests. They look into the nature of possible strategic dependencies, their impact as well as relevant (ongoing) policy responses.

These assessments should not be considered as an exhaustive analysis of all the EU's possible strategic dependencies, but rather as a first stage of assessments concerning a number of important areas. Further key areas, including products, services or technologies key to the twin transition such as renewables or energy storage, can be considered and analysed in more detail in the future.

The chapter develops reviews of six specific areas. Four reviews (hydrogen, raw materials, batteries and active pharmaceutical ingredients) look further into possible strategic dependencies that were identified through the bottom-up mapping of dependencies developed in chapter 2. Another two reviews (semi-conductors and cloud and edge computing) look into examples of technological areas where the EU appears to be falling behind in relation to its global competitors as highlighted in chapter 3, creating concerns over possible technological strategic dependencies in the digital ecosystem.

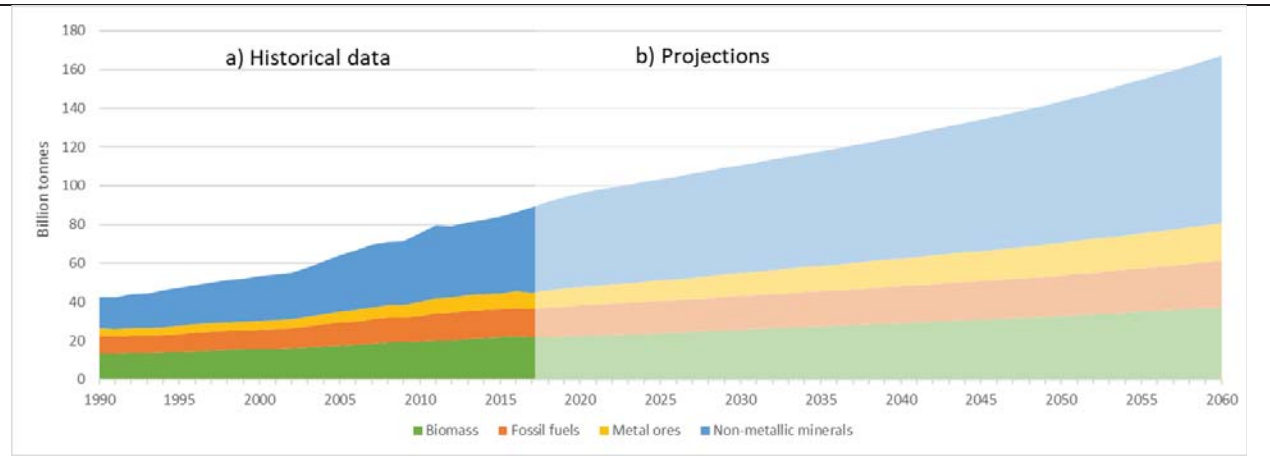
5.1 Raw materials

Access to resources is fundamental for the entire EU industry and central to Europe's ambition to deliver the Green Deal and ensure the digital transformation of the EU economy. These ambitions will need to continue to be anchored in diversified and undistorted access to global markets for raw materials.

a) Context and possible weaknesses in the EU

As the EU does not produce raw materials that can meet our demand, EU industry faces global competition in access to raw materials. The OECD¹⁰² estimates that material extraction doubled since 1990 and that global consumption of resources will grow up to 40% by 2040 and close to 90% by 2060 (both values as compared to 2017). This puts high pressure on the resilience of raw materials supply chains globally.

Graph 20: Global material use by resource type: a) historical data (world, 1990 - 2017) and b) projection (world, 2018 - 2060)



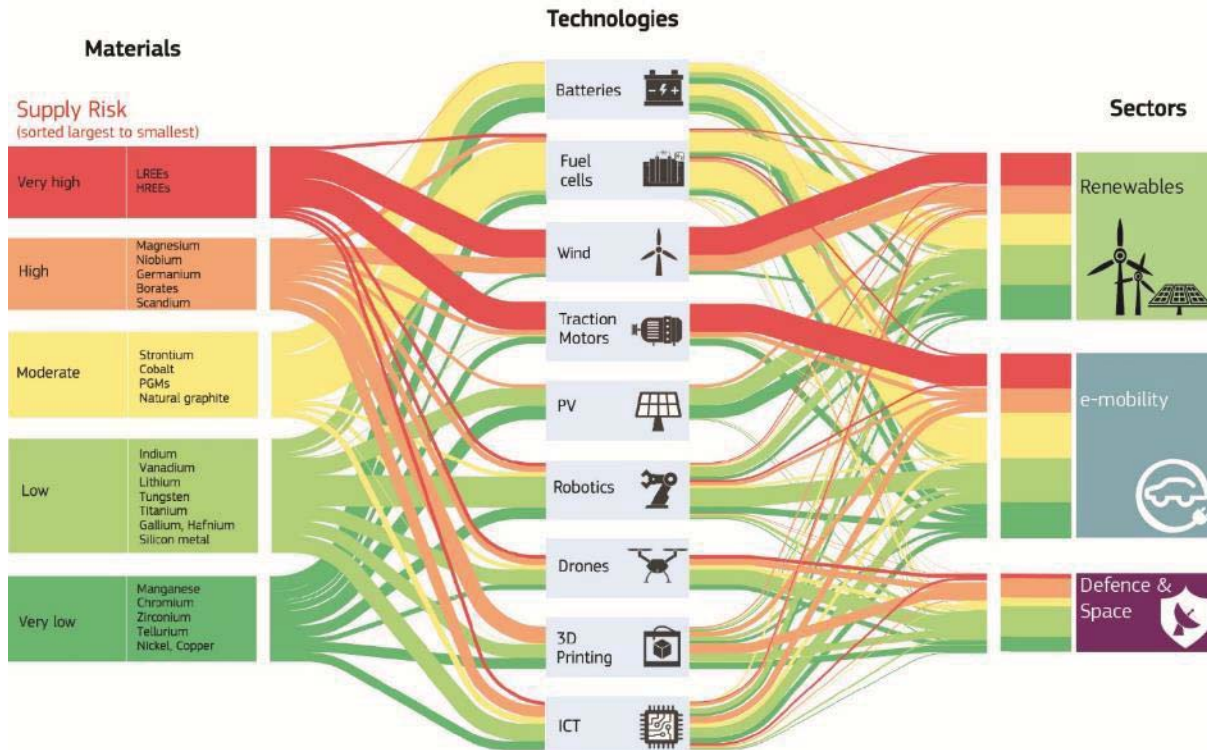
Source: European Commission, Raw materials Scoreboard in preparation. Adapted from OECD (2019), 'Global Material Resources Outlook to 2060'.

Metals and minerals are part of our daily lives. With the transition of Europe's industry to climate-neutrality, the reliance on available **fossil fuels will progressively be replaced with reliance on non-energy raw materials.** For many of them, the EU sources from abroad and global competition is fierce. **Those raw materials that are very important economically and have a high supply risk are called critical raw materials.** Critical raw materials are essential to the functioning and integrity of a wide range of industrial ecosystems. Rare earths based magnets move electric cars and make wind turbines work. Gallium and indium are part of light-emitting diode (LED) technology in lamps. Semiconductors need silicon metal. Hydrogen fuel cells and electrolyzers need platinum group metals.

¹⁰² OECD, Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences (OECD Publishing, Paris), 2019. <https://doi.org/10.1787/9789264307452-en>

Dependence on critical raw materials of nine strategic technologies and three sectors has been analysed¹⁰³ as a part of the EU raw materials criticality assessment in 2020. Graph 21 shows competition of technologies and sectors for the same materials. For example, wind energy and traction motors compete both for various rare earths, as well as for borates; robotics and drones also use motors; fuel cells and digital technologies require a large amount of platinum group metals (PGMs).

Graph 21: Flows of raw materials and their current supply risks to the selected technologies and sectors



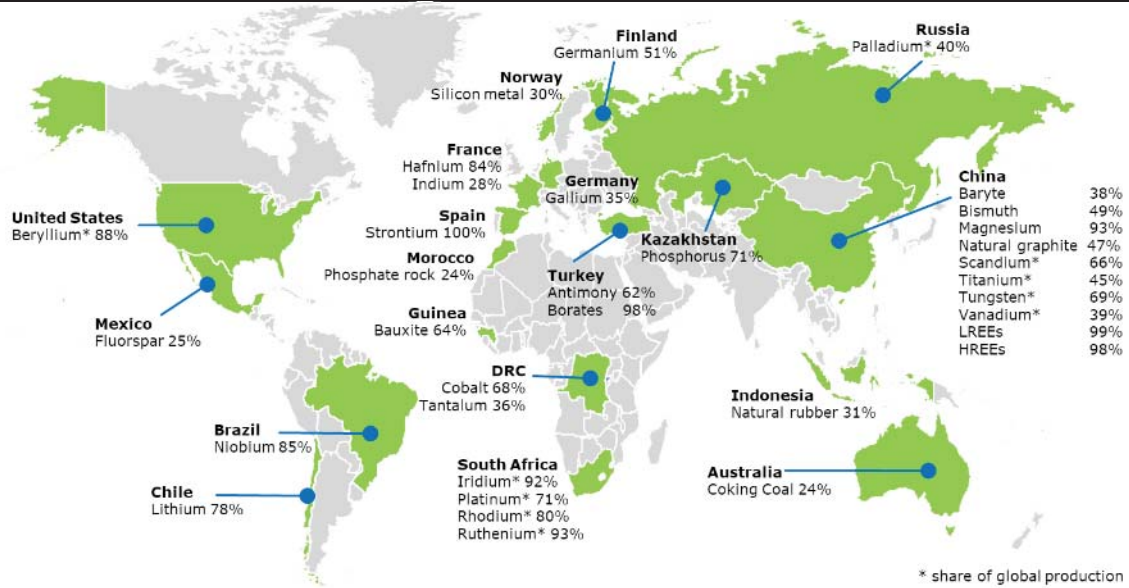
Source: European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020

b) Origin of vulnerabilities

The EU identified 30 critical raw materials in 2020. Their supply is highly concentrated. For example, in the period of 2012-2016, China provided 98 % of the EU’s supply of rare earth elements (REE), Turkey provided 98% of the EU’s supply of borate, and South Africa provided 71% of the EU’s needs for platinum and an even higher share of the platinum group metals iridium, rhodium, and ruthenium. The EU relies on single EU companies for its supply of hafnium and strontium.

¹⁰³ <https://ec.europa.eu/docsroom/documents/42881>

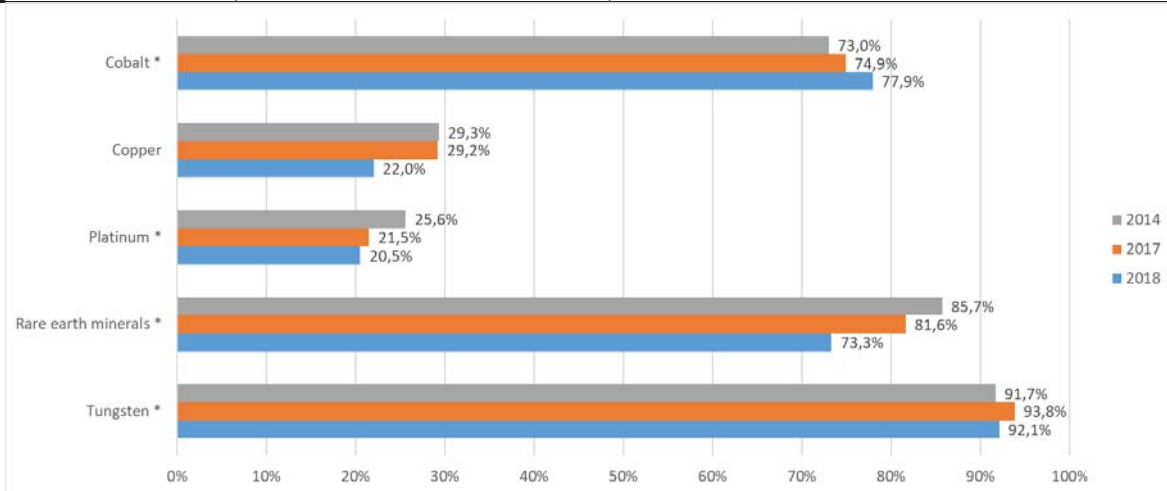
Graph 22: Biggest supplier countries of critical raw materials to the EU



Source: European Commission, Study on the EU's list of Critical Raw Materials (2020)

Many supplier countries of raw materials increasingly impose restrictions on exports of minerals and metals. The continuing growth of the global demand of metals and non-metallic minerals could lead to more restrictions to secure local supply or foster the domestic downstream industry. The share of global production of cobalt, rare earths and tungsten affected by export restrictions was higher than 70% (as of 2018, see Graph 23).

Graph 23: Share of global primary production of five selected raw materials subject to export restrictions (world, 2014, 2017 and 2018)

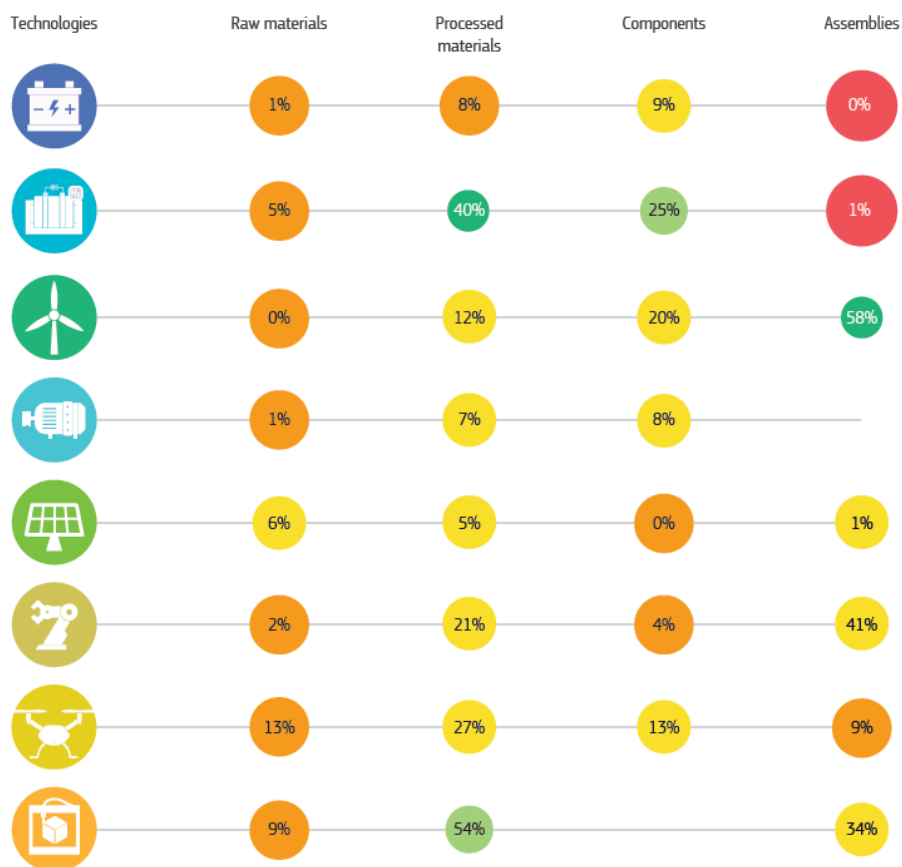


Source: European Commission, Raw materials Scoreboard in preparation. JRC, based on data on export restrictions provided by OECD, 'Inventory on Restrictions on Exports of Raw Materials' and data on global production data from C. Reichl and M. Schatz (2019).

The EU is very dependent on imports of the raw materials needed for key products and technologies. Graph 24 shows current supply risks across a number of key products and technologies in the subsequent stages of processed materials, components and assemblies. For

example, the EU only provides 1% or less of some specific raw materials for Li-on batteries, wind turbines and electric traction motors.

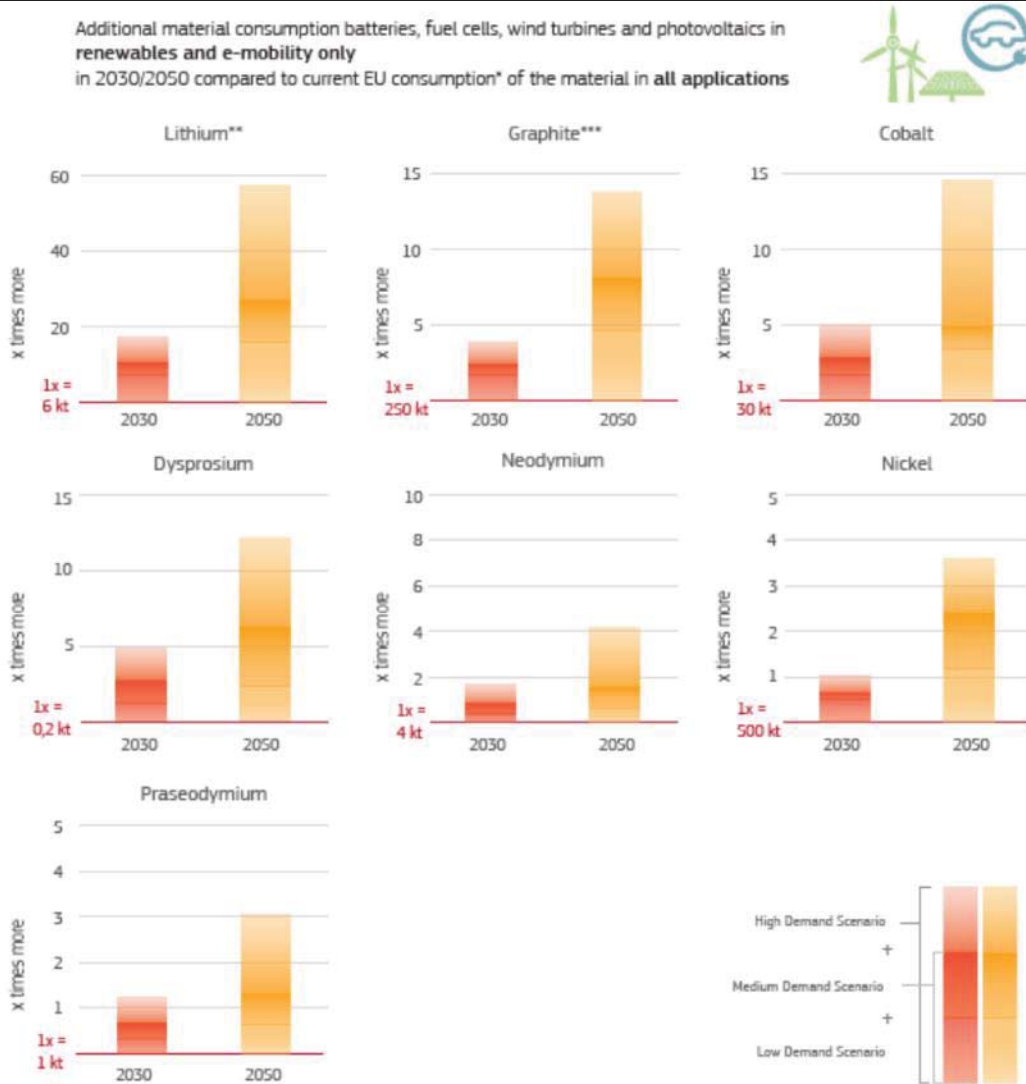
Graph 24: Identified supply risks for the EU and EU shares of production



Source: European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020
 Note: Percentage means proportion of EU on the global production. Products and technologies highlighted above (from top to bottom) are: Li-on batteries, fuel cells, wind energy, electric traction motors, photovoltaic technology, robotics, drones and 3D printing. Supply risks are highlighted from red (very high) to green (low).

In addition to current supply risks, demand for multiple raw materials is expected to strongly increase across different sectors and technologies. Graph 25 shows the expected increases in the use of a number of critical raw materials for the renewables and e-mobility sectors by 2030 and 2050 (according to low, medium and high demand scenarios). Furthermore, additional increases in use can be expected from other sectors, including defence and aerospace as well as digitalisation (e.g. handheld devices use batteries, sensors and motors; data is stored on drives containing permanent magnets; etc.).

Graph 25: Critical raw materials use in different technologies in the EU in 2030 and 2050



Source: European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020

The EU is well-endowed with aggregates and industrial minerals, as well as certain base metals such as copper and zinc. It is **less successful in developing projects to produce critical raw materials, even though there is significant potential** for some of these. As the timeframes for starting extractive operations are quite long, these tend to lag behind price peaks. Price drops during the start-up time can therefore reduce economic viability and result in freezing the activity before it has started.

The early phase from inception to permitting constitutes a high-risk phase of project development and is particularly vulnerable. This is partly due to the inherent risk and cost of new projects, lack of incentives and financing, the diversity and length of national permitting procedures, and the lack of public acceptance for mining in Europe.

Access to resources and sustainability is key for the resilience of the EU raw materials supply chains. Achieving resource security requires diversified supply from both primary and

secondary sources, reduced dependencies and improved resource efficiency and circularity, including sustainable product design. This is true for all raw materials, including base metals, industrial minerals, aggregates and biotic materials, but is even more necessary when it concerns those raw materials that are critical for the EU.

c) Way forward and relevant (ongoing) measures

In the fall of 2020, the Commission adopted the Critical Raw Materials action plan that outlines a set of concrete actions to tackle vulnerabilities in the raw materials supply chains.

Building resilient value chains in the EU

The first action under the action plan was the launch of the **European Raw Materials Alliance (ERMA)** in September 2020. ERMA has started its work towards developing a resilient European value chain for the rare earths and permanent magnets in eMotors (see also chapter 5.3). Its role is to facilitate investment in the raw materials value chain. Downstream manufacturers such as automotive OEMs, wind turbine manufacturers and the defence and aerospace industries need to provide strong support to developing a resilient European supply chain for eMotors. **Member States and industry can assess the situation and decide on the investments needed for the production of rare earths and their refining, magnetic alloys, magnets and their recycling, building on the investment pipeline prepared by ERMA.**

The pipeline as it currently stands would contribute to addressing important raw material dependencies. The EU currently imports all permanent magnets for wind turbines, mostly from China. Offshore wind turbines contain on average 600 kg of permanent magnets per MW, while onshore wind turbines contain 80-160 kg/MW, such that an average wind turbine in Europe contains 230kg/MW. Installed EU wind energy capacity today is 220 GW. According to estimates by WindEurope¹⁰⁴, 397 GW of wind energy capacity would be installed in the EU by 2030 in a High Scenario. On average, this implies an annual wind capacity addition of 18 GW, which would increase to around 25 GW when taking into account replacements of old turbines. ERMA identified investment projects with a potential to increase rare earths magnets production capacity. If these projects were fully implemented this would be sufficient to cover around 60% of the EU annually installed wind energy capacity by rare earths magnets made in the EU¹⁰⁵. Regarding battery raw materials, the EU foresight study on Critical Raw Materials estimates, for a high-demand scenario, an annual EU demand of 500,000 tonnes of nickel for e-mobility and renewable energy by 2030. ERMA has identified investment projects with a potential to increase production from 10,000 tonnes to 100,000 tonnes nickel capacity per year, representing 20% of projected EU annual demand in 2030.

Investments

Under Action 5 of the action plan, together with Member States and ERMA, the Commission identifies **mining and processing investment projects, as well as investment needs** and related financing opportunities for critical raw materials in the EU that can be operational by 2025,

¹⁰⁴ <https://windeurope.org/about-wind/reports/wind-energy-in-europe-scenarios-for-2030/>

¹⁰⁵ Source: ERMA estimates

prioritizing coal-mining regions. ERMA will also support the development of projects and facilitate contact with investors. Significant investments would be needed in order for Europe to compete with the current global raw materials market leaders. The two IPCEIs on the battery value chain already include raw material projects (R&I and First Industrial Deployment) on sustainable mining, refining and recycling. Such concerted action could also be of relevance in the area of eMotors, including electricity generators.

Recovery funds. The EU raw materials sector has been left in a vulnerable position due to lack of investment. The Recovery and Resilience Facility provides an opportunity for Europe to reverse certain trends and create new competences and markets. Given the fast-moving nature of today's economy, adopting a proactive stance with regard to this issue will prove indispensable. Under the Recovery and Resilience Facility EUR 672.5 billion in loans and grants will be available to support post COVID-19 recovery projects. **These will have to be committed by 2023 and implemented by 2026. Member States are encouraged to identify possibilities to allocate funding and develop recovery projects in the raw materials value chains, especially for critical raw materials and base metals.**

R&D investment. Under Action 3 of the action plan, research and innovation on waste processing, advanced materials and substitution will be undertaken using Horizon Europe, the European Regional Development Fund and national R&I programmes. **Under the first Work Programme of Horizon Europe 2021-2022, a set of raw materials-related research and innovation actions will be funded with a budget of almost 300 million EUR.** They will focus on exploration, mining, processing, refining, recycling and substitution, as well as developing skills, promoting responsible mining practices, fostering international cooperation with resource rich countries, mapping secondary sources in the EU and identifying investment needs.

International cooperation

Under Action 9 of the action plan, the Commission will develop **strategic international partnerships** to secure a diversified and sustainable supply of critical raw materials, including through undistorted trade and investment conditions, starting with pilot partnerships with Canada, interested countries in Africa and the EU's neighbourhood in 2021. Under the EU-Ukraine High Level Industrial Dialogue, the Commission is progressing with the strategic partnership on raw materials with Ukraine. The Commission also held an initial scoping meeting with Serbia.

From commodity to service. Many raw materials could be recycled and brought back into service. To better link the raw materials with products and customers, there is an opportunity to move away from the commodity model to a "Resource as a Service" model. This model could link investors, companies, suppliers and end-users. For example, instead of providing lithium as a commodity to battery manufactures, a service can guarantee a minimum level of electrochemical potential high energy-density rechargeable batteries. The raw materials will remain in the company's custody. They could be recovered after the end of the life of the battery for appropriate recycling.

Transparency and data. To achieve a more resilient economy, there is a need for efficient tracking of raw materials through technology, harmonised data requirements, and policy and regulation that carefully incentivise data collection and sharing worldwide. There is a range of technologies such as distributed ledgers and satellites that can help to improve traceability, transparency, and sustainability of the supply chains. Improved understanding of material flows, and data transparency will provide significant benefits, including increased recycling, reduced global supply chain vulnerability and reduced price volatility.

Raw materials from Europe

Public awareness, acceptance and trust. Sourcing from the EU (actions 5 to 8 of the action plan) needs to be accompanied by increased public awareness, acceptance and trust. Concerns of local communities about the degradation of the environment linked to extraction and refining projects would need to be addressed. Efforts would need to be undertaken at national, regional and local level, and by holding an open and transparent dialogue with local communities about the importance and benefits of raw materials activities for mitigating climate change and preserving biodiversity. In this context, the Commission is launching in 2021 a “**Roundtable on Environmentally and Socially Sustainable Raw Materials Mining**”, gathering together the Commission, public authorities, industry, NGOs and other social partners.

Under action 10 of the action plan, the EU promotes **responsible mining practices for critical raw materials** through the EU regulatory framework and relevant international cooperation. The Commission is developing a set of social, environmental and economic **principles for sustainable raw materials in the EU**. The principles should enable to better communicate with the public on the conditions at which sustainable raw materials extraction and processing takes place in Europe and increase public acceptance for this activity.

Permitting – a competence of Member States or their regions. While maintaining the highest environmental and social standards, there is a need to further streamline, accelerate and improve predictability of the diverse and lengthy planning and permitting procedures, in close cooperation with industry and social partners. This should apply in the first place to (critical) raw materials projects of strategic importance (e.g. for achieving climate neutrality and the digital agenda).

5.2 Active pharmaceutical ingredients

Medicinal products are critical for society. They offer therapeutic options for diagnosis, treatment and prevention of diseases and are important to address threats to public health, including the COVID-19 and any future pandemic. The New Industrial Strategy for Europe (March 2020) stresses that “*access to medical products and pharmaceuticals is crucial to Europe’s security and autonomy in today’s world*”. The bottom-up analysis developed in chapter 2 of this staff working document highlighted that the EU appears to be foreign dependent on a number of inputs and products in the health ecosystem.

This chapter provides first insights into the EU’s possible dependencies and vulnerabilities in the area of active pharmaceutical ingredients. It should be considered together with the analysis and actions in the Pharmaceutical Strategy for Europe (November, 2020),¹⁰⁶ which underlined the importance of access to safe, effective and high-quality medicines at an affordable price. The evidence presented in this chapter can notably provide information to the ongoing Structured Dialogue on the security of medicines supply launched under the Pharmaceutical Strategy, which specifically aims at developing further understanding of causes and drivers of potential vulnerabilities and dependencies in the pharmaceutical supply chain, together with a range of relevant actors.¹⁰⁷

a) Context

The pharmaceutical supply chain has a very complex structure (Graph 26). Pharmaceuticals are composed of active pharmaceutical ingredients (APIs)¹⁰⁸ and excipients¹⁰⁹. APIs are formulated via chemical synthesis, derived from starting animal sources, extracted from plants and herbs or via formation processes or cell culture, fermentation, extraction or isolation. In addition to those starting materials¹¹⁰, raw materials¹¹¹ and intermediates¹¹² are also needed in the production process of APIs. This production process is potentially polluting and very energy intensive if not properly managed. After an API is produced, it is then formulated into the final medicinal product. In many cases, the production process may also include drug delivery technologies (e.g. inhalators, injection pens). Once manufactured and formulated, medicinal

¹⁰⁶ COM(2020)761 final.

¹⁰⁷ For more details on the Structured Dialogue on the security of medicines: https://ec.europa.eu/health/human-use/strategy/dialogue_medicines-supply_en

¹⁰⁸ Active pharmaceutical ingredient is a substance or mixture of substances intended to be used in the manufacture of a drug (medical product) and intended to exert a pharmacological, immunological or metabolic action with a view of restoring, correcting or modifying physiological functions or to make a medical diagnosis

¹⁰⁹ Excipients are diverse materials from many origins (animal, vegetable or mineral) and are not exclusive to medicines (can be for example also used in food and cosmetics). Excipients can act as fillers or control the pace of the release. They are manufactured using traditional chemical or biosynthetic processes.

¹¹⁰ Any substance from which an active substance is manufactured or extracted.

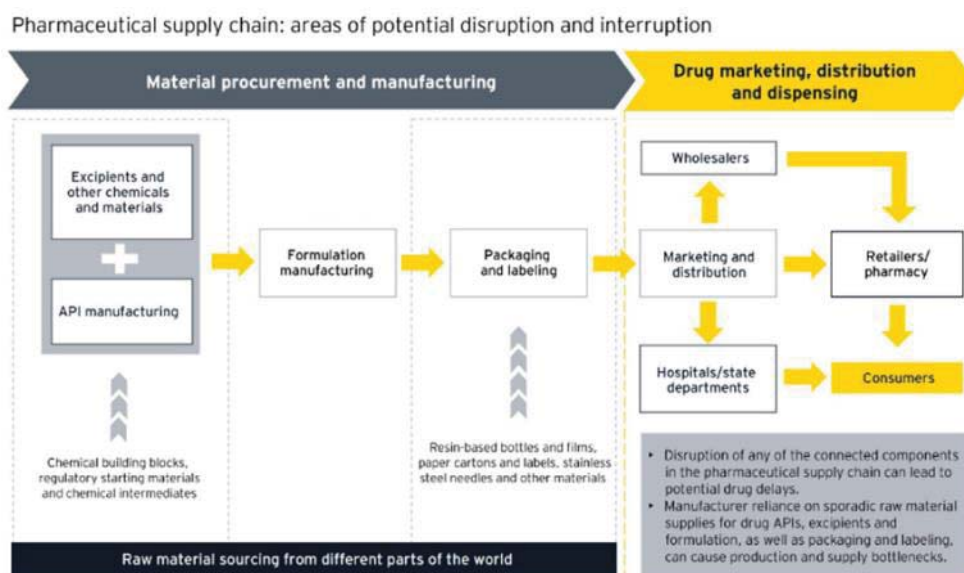
¹¹¹ Any substance, reagent or solvent intended for use in the production of an active substance and from which the active substance is not directly manufactured or extracted.

¹¹² Substances intended for further processing (one or several times). Further processing can be further molecular changes and /or purification and isolation processes until the active substance is of sufficient quality to be used in the production of a medicinal product.

products are packaged and transferred to wholesale distributors and then further distributed to hospital pharmacies and other authorised or entitled medicines retailers.

The pharmaceutical supply chain has in general lower risk exposure than other supply chains but remains susceptible to possible disruptions.¹¹³ Given the high trade intensity of the pharmaceutical supply chain, this sector is particularly sensitive to trade disputes as well as cyberattacks given the high level of digitisation, R&D, capital intensity and exposure to digital data flows.¹¹⁴ The COVID-19 outbreak has shown that an increased demand for medicines used to treat patients as well as uncoordinated stockpiling, together with difficulties in the supply chains within and outside of the EU (e.g. closing of sites, export restrictions and disruptions in logistics) can result into important disruptions in pharmaceutical supply chains with possible risks of medicine shortages in the EU. Furthermore, on-site accidents¹¹⁵, non-compliance with Good Manufacturing Practices (GMP) as well as transport issues are other factors threatening the supply and leading to possible important drug shortages.

Graph 26: Pharmaceutical supply chain



Source: https://www.ey.com/en_us/strategy-transactions/covid-19-risks-and-resiliency-in-the-drug-supply-chain

Biological medicines are taking up an increasing share in total drug expenditure. In the past decade, the focus of pharmaceutical research has moved from small molecules designed to control diseases to biologics.¹¹⁶ In 2018, in Europe over 30% of all healthcare spending was on

¹¹³ It has less exposure to climate-related events (e.g. heat stress and flooding) or to a pandemic due to its relatively high capital intensity

¹¹⁴ McKinsey Global Institute, Risk resilience and rebalancing in global value chains, 2020. Retrieved from <https://www.mckinsey.com/business-functions/operations/our-insights/risk-resilience-and-rebalancing-in-global-value-chains>

¹¹⁵ Explosion in Tianjin (China) in 2015 damaged storehouses and production lines of medicines. This accident led to shortages of supplies in the EU.

¹¹⁶ Biological medicines are derived or manufactured from a living source and work by targeting specific chemicals or cells involved in the body's immune system response.

biological medicines of which 1.5% are biosimilars (i.e. biological medicines highly similar to the already approved ones).¹¹⁷ The latter is expected to increase in the next five years as a number of biologics will fall off patent.

This review focuses on possible vulnerabilities and dependencies that manifest upstream, during the manufacturing process. There are also a number of other challenges, notably in the procurement and distribution of medicines that have manifested during the COVID-19 outbreak. In this context, the Health Union Package proposed by the Commission in November 2020 strengthens the role of the European Medicines Agency (EMA) in the monitoring of shortages and provides for a cooperation framework to confront crisis situations.

b) Origin of possible vulnerabilities

The pharmaceutical supply chain has become one of the most integrated supply chains in the world. Different stages of manufacturing towards a finished dosage form may take place in many different countries before the final product reaches the European patient. The supply chain of biological medicines is shorter than that of medicines produced in chemical synthesis, as such biological medicines are produced in final dosage forms (i.e. API production and formulation take place in a single location).

Global production of APIs

There is regional concentration in generic API production. According to a Chemical Pharmaceutical Generic Association Report (2015), the EU accounts for 24% of the world's value of API production. 66% are produced in Asia Pacific (India and China), 3% in North America and 7% in the rest of the world. APIs for biological products are not included in these statistics.

China and India are the world's key producers of generic APIs. Until mid-2010, India has been the world's top supplier of both APIs and intermediates. It remained self-dependent on those materials for both domestic consumption and export.¹¹⁸ In recent years, China has leveraged on its inherent cost advantage, leading to the displacement of part of the manufacturing capacity for certain APIs and their advanced intermediates from India to China. Today, India fulfils 20% of global demand for generic medicines in terms of volume, but it relies on Chinese imports for their 70% of APIs by volume. Europe imports 15.4% of Chinese and 16.4% of Indian API production.¹¹⁹

In addition, there seems to be a further increasing trend in the concentration of generic APIs being produced in India and China.¹²⁰ Looking at new approvals of Certification of

¹¹⁷ IQVIA: The impact of biosimilar competition in Europe, 2019

¹¹⁸ KPGM: Indian bulk drugs industry – Regaining the lost glory, 2017. Retrieved from <http://ciipharma.in/pdf/API-Report-2017.pdf>

¹¹⁹ Chemical Pharmaceutical Generic Association (CPA) Report: Competition in the World API markets, 2015

¹²⁰ MundiCare (2020) for Progenerica

suitability of European Pharmacopoeia monographs (CEPs, i.e. API quality certificates¹²¹) used for medicine approvals between 2000 and 2020, Asia significantly outperformed Europe. Asian manufacturers increased the number of their CEPs from 183 to 2,369, while European manufacturers only grew from 348 to 1,260 CEPs.

Data also indicates that there are specialisation patterns whereby certain medicines may no longer be produced in the EU due to cost pressures. A MundiCare Report¹²² finds that two thirds of the currently valid CEPs are held by Asian manufacturers. For 93 out of the 554 APIs with valid CEPs considered in the analysis, there is no European production at all. Furthermore, for more than half of the APIs that are placed in the EU market, there are only between 1 and 5 manufacturers being CEP holders.

Still, European manufacturers maintain their key position as regards specific (high-end) APIs with low production volumes and complex production processes. According to EudraGMDP, Member States with the highest number of registered manufacturing sites are Italy (185), France (149), Germany (92), Spain (87) and Poland (84). European APIs producers are reputed for the highest quality and maintain an important share in the global market.¹²³ Italy followed by Spain are the largest producers of generic APIs in Europe. They both export more than 95% of their production.¹²⁴ Production of APIs in Europe is subject to the most stringent environmental regulations and is well known for its high quality.¹²⁵ These together with relatively high energy prices increase the cost of APIs production in Europe.

On a global scale, China holds a strong APIs position in antibiotics, antiviral, anti-bacterial and anti-inflammatory (pain-relief segment). India leads in the central nervous system (CNS) and respiratory segments. China and India both have strong competitive positions in cardiovascular and oncology segments. However, when it comes to serving highly regulated markets, Italian companies keep a strong competitive position in all therapeutic segments with the exception of antibiotics and the anti-infective sector.

Trade data analysis

An analysis of the EU's API import volumes using the dependency indicators developed in chapter 2.2 points to an important level of concentration of extra-EU imports coming from a limited number of third countries. Applying the indicators developed in chapter 2.2.1 to the

¹²¹ Proof of the quality of active pharmaceutical ingredients, used for drug approvals. It should be noted that CEPs are not mandatory and there are API manufacturers that do not have a CEP but are still authorized and selling their APIs.

¹²² MundiCare (2020) for Progenerica

¹²³ One third of US finished dosage forms of APIs comes from Europe according to the 2019 FDA Shortages Report, retrieved from www.fda.gov/drugs/drug-shortages/report-drug-shortages-root-causes-and-potential-solutions

¹²⁴ Italy exports almost all of its production to the most regulated markets: 25.5% to Europe, 49.7% to North America and 15.3% to Japan

¹²⁵ *Good manufacturing practice (GMP)* describes the minimum standard that a medicines manufacturer must meet in their production processes to assure consistent quality for the final product. Independently of the GMP requirements, the environmental legislation applies to the API manufacturing plants.

extra-EU import *volumes*¹²⁶ of APIs¹²⁷ provides insights into the EU's possible dependencies in the area of APIs. The results show an average concentration of the EU's import volumes of around 0.4, indicating that most imports come from only a few sources. In fact, around 80% of the EU's total extra-EU import volume in APIs originates in five countries – China, US, United Kingdom, Indonesia, India – with China providing around 45% of the total extra-EU volume. Total extra-EU import volumes account for 53% of the EU's total import value of APIs, while a large part of the EU's total import volume of API originates in the EU (47%).

In addition, while data shows that the EU has capacity to produce APIs, there are important price differences between imports and exports. The indicator (also developed in chapter 2.2.1) on the substitutability of the extra-EU import volume of APIs with EU production (proxied by the total export volume of APIs), is characterised by an average of 1. This suggests that the volume of extra EU imports is equal to the volume of total EU exports of APIs. At the same time, in order to understand whether the EU produces the same types of products as the ones imported, the price differences between the imports and exports of APIs can provide an indication (see chapter 2.4). These show important differences in the average price between imports and exports.¹²⁸ Thus, in the event of a trade disruption, while the EU might have capacity to produce some APIs, the fact that it produces at a different price should be taken into account.

Looking at the extra-EU APIs imports in values provides complementary information to analyse foreign dependencies and shows that the EU is dependent on different third countries. The analysis of extra-EU import *values* of APIs allows to consider trade in high value and innovative products. Applying the dependency indicators to the EU's import values of APIs shows an average concentration of around 0.5, suggesting that most APIs import values originate in a few sources. However, these main sources of imports are different with around 80% of the total extra-EU import value of APIs coming from four countries – Switzerland, US, Singapore and China – with Switzerland and the US at the top, each of them supplying the EU with around 30% of the total import value. Moreover, extra-EU import values account for less than half of total EU import value of APIs.

Firm level data

Examining linkages between firms along the supply chain can shed further light on potential dependencies. Pharmaceutical companies can produce APIs themselves or they can enter into business relationships with Contract Manufacturing Organizations (CMOs). CMO

¹²⁶ Pharmaceuticals can be divided into two distinct groups: high value innovative/branded medicines (patent protected) and generic medicines. Generic medicines are traded at a significantly lower price than innovative ones. Analysing trade flows in values gives a greater weight to trade in innovative medicines, creating a bias towards them. For this reason, analysing trade volumes provides a clearer illustration. At the same time, looking at trade in volumes gives a higher weight to blockbuster drugs that are traded in high volumes.

¹²⁷ For the purpose of this analysis, API products are identified following the methodology put forward in CEIPE (2020) Key Trade Data Points on the EU Pharmaceutical Supply Chain retrieved from <https://www.efpia.eu/media/554792/key-trade-data-points-on-the-eu27-pharmaceutical-supply-chain.pdf>

¹²⁸ The average price difference for APIs is 1, suggesting that on average the price of extra-EU imports for APIs is 100% more different compared to the price of total exports (i.e. intra- and extra-EU exports).

activities cover both APIs used for production of small molecules and biological medicines. Sourcing from CMOs allows optimising resource utilisation and managing costs, as well as ensuring supply continuity in case of disturbances in in-house production. CMOs can also take responsibility for the whole production process up to formulation. For these reasons, they have become an indispensable part in the production of vaccines as many developers (including big pharma companies) while being able to establish in-house manufacturing for products in an investigational phase, do not have sufficient capacities to deploy large scale production.¹²⁹

Table 1: Number of CMOs, by geographical location of headquarters (2019)

Country ISO	All CMO	Biologics CMO	CMO supplying EU companies	CMO with EU GMP (*)
CN	102 (23)	4 (0)	12	36
IN	90 (56)	1 (0)	14	43
KR	40 (12)	13 (3)	5	10
EU	32 (3)	8 (1)	22	2*
US	31 (9)	9 (4)	17	5
TW	28 (14)	3 (2)	5	2
JP	19 (3)	2 (1)	4	7
CH	7 (5)	0	5	5
GB	6 (1)	1 (0)	4	1
Other	23 (11)	1 (1)	5	5
Total	378 (137)	43 (14)	93	116

Source: Based on FactSet and EudraGMP database

Notes: (*) Only sites located in third countries are considered.

There are 378 firms that can be classified as CMOs in the firm-level database *FactSet*¹³⁰, the majority of which are located in China or India. This sample includes biopharmaceutical conglomerates such as Pfizer or Merck, as well as specialized companies such as Zhejiang Huahai Pharmaceutical or Samsung BioLogics. Table 1 provides an overview of the geographical locations of the headquarters of these companies. Half of them are based in China and India, with China ranking first. However, when specialised firms are considered¹³¹, India is in the lead with 56. Only three EU based firms specialise in Contract Manufacturing services. This confirms the leading role of China and India in the production of APIs.¹³²

¹²⁹ Roots analysis (2019) Vaccine Contract Manufacturing Market (2nd Edition), 2019-2030

¹³⁰ See Box in the Annex for details on this data source. The data relies on FactSet's Revere Business Industry Classification System (RBICS) classification and includes companies that produce intermediate and active ingredient including large molecules of small compounds including biological products (antibodies, proteins or generic material) used in the production of biological medicines.

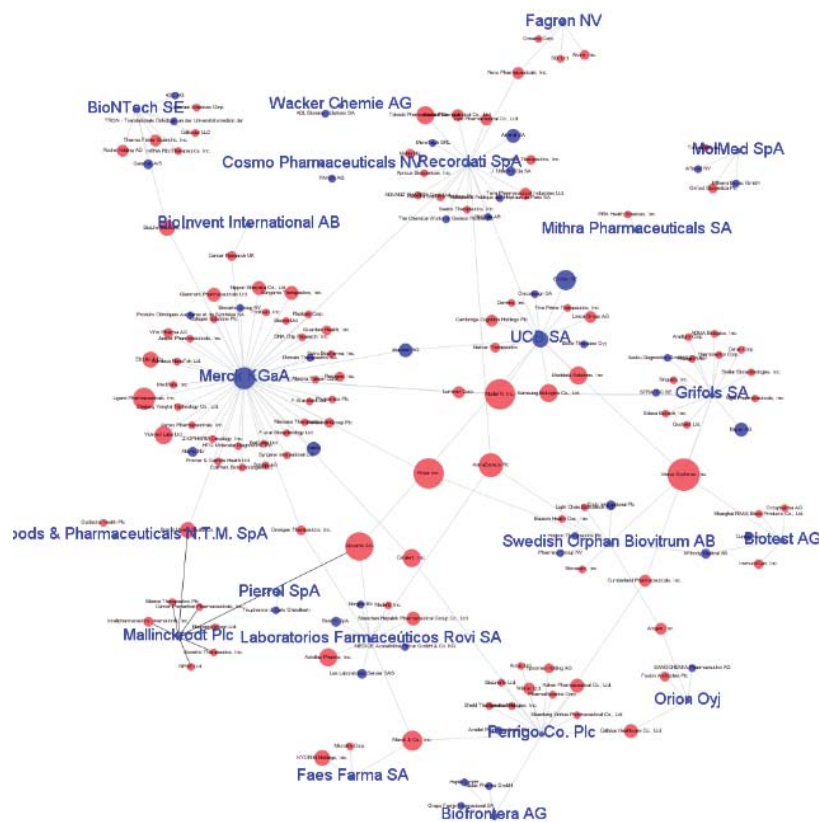
¹³¹ A firm is considered *specialized*, if it derives more than two thirds of its revenues from Contract Manufacturing services.

¹³² The main limitation of FactSet data is that it covers mostly listed and larger companies. As a result, the coverage of SMEs is not thorough enough to ensure that the scale of production in the EU is appropriately reflected, since

When it comes to biological products, other countries appear to play an important role. The second column in Table 1 shows the number of CMOs supplying biological products. The number of companies is smaller as this part of industry is still relatively young. Here developed countries are taking the lead, including South Korea, EU Member States and the US.

Looking specifically at CMOs with a European GMP certificate again appears to confirm the important role of China and India as suppliers to Europe. The third column shows the number of CMOs that supply to EU based pharmaceutical companies. It is important to note, that while only a few companies located in China and India are supplying EU-based pharmaceutical companies it could be that the FactSet data does not capture all links between companies. For this reason, the last column checks how many of FactSet CMOs have a European GMP certificate confirming that these are smaller than the actual number of CMOs and highlighting again the important role of China and India.

Graph 27: Supplying structure of major EU-based CMOs (2019)



Source: Based on FactSet database.

Note: Blue and red circles denote, respectively, EU- and non EU-based companies. Customers are identified by their name in large blue case, while suppliers are identified by their name in small dark case. The size of the circles is proportional to the company's supplier outdegree (i.e., the number of different companies that it supplies). Darker connecting arrows denote a stronger relation between the two companies concerned (measured as the total number of links between them).

many API producers in Europe tend to be SMEs. Still, the data indicates that CMOs in China and India have large scale production when compared to European counterparts.

It appears that EU companies rely on both EU and extra EU based suppliers (Graph 27). EU customers have bilaterally specific suppliers that are not connected to one another. However, EU companies have some suppliers in common that also tend to be supplier with high outdegree (i.e., relevant for the industry globally and not just at the EU level). At the same time, it is not fully clear based on the available data sources to what extent the EU relies on critical capacities in extra-EU countries and firms in the different steps in the manufacturing process of APIs.

c) Way forward and relevant (ongoing) measures

The elements of information presented in this review are a starting point for a broader assessment of the EU's potential vulnerabilities and dependencies in pharmaceutical supply chains. The EU has a strong production capacity and it is not sufficiently clear to what extent the EU relies on capacities in extra EU countries across the different steps and inputs required for the manufacturing of APIs. These steps are not sufficiently identifiable in available data sources. Furthermore, there is no pre-established list in the EU of essential APIs that would allow to narrow the assessment to a specific set of critical medicines.¹³³ It is essential to determine critical products, relevant from the point of view of public health, for which the EU does not have sufficient capacity to produce. In this respect, further analysis would be needed to provide evidence on:

- Which specific APIs, other key ingredients or technologies are critical?
- What is the share of medicinal products placed on the EU market relying on key ingredients imported from a limited number of extra EU countries?
- How many companies (in the EU and globally) rely on the same sources of supply? How does this affect resilience (at company, EU and global level)?
- Which specific APIs, other key ingredients or technologies are of concern?

Having a better understanding of vulnerabilities and potential dependencies in a first phase will serve to put forward, in a second phase, a set of possible measures to strengthen the resilience of pharmaceutical supply chains and ensure the security of supply of medicines to patients in Europe. As announced in the Pharmaceutical Strategy for Europe, the European Commission has initiated and will steer a structured dialogue initiative with and between relevant public and private actors of the pharmaceutical supply chain. The structured dialogue will first focus on identifying the causes and drivers of potential vulnerabilities, including dependencies in the often global and complex supply chains of critical medicines, their raw materials, APIs and intermediates. In the second phase, after closing knowledge gaps and gaining a better understanding of the current situation, the Commission will consider possible solutions to address issues identified.

¹³³ The WHO publishes a list of Essential Medicines containing the medications considered to be most effective and safe to meet the most important needs in a health system: <https://list.essentialmeds.org/>

5.3 Li-ion batteries

Technologies and products related to batteries are key to enable the EU's green and digital transformation, notably also in the area of mobility. They are at the heart of the European Green Deal that sets the ambition for the EU to 'become climate neutral by 2050' and 'help companies become world leaders in clean products and technologies'.

This review looks more in detail at the EU's dependencies and possible vulnerabilities in the strategic area of batteries as well as relevant ongoing actions to address them. Industrial Alliances, where proved well targeted, justified and efficient, emerged as an important tool that can be used in some specific sectors following the experience of the European Battery Alliance launched in 2017 to help address the lack of battery manufacturing capacity in the EU.

a) Context and possible weaknesses in the EU

In 2018, the EU only had about 3% of the global production capacity of Lithium-ion (Li-ion) battery cells, while China had about 66% and South Korea together with Japan and other Asian countries about 20%.^{134,135} While EU demand was also limited, in the short and mid-term reliance on imported cells or batteries could have made it more difficult for EU industry (including automotive original equipment manufacturers) to obtain tailor-made cells and ensure security of supply. Other risks that were raised include increased costs of transportation, loss of part of the value, time delays, relinquished control on quality and limitations on design options.¹³⁶ The supply of some relevant raw and processed materials were also identified as high risk, while a medium level of risk was anticipated for the supply of some components. Due to some of these considerations, the development of a European value chain for Li-ion cells was identified as priority through the Commission's Strategic Action Plan for Batteries.¹³⁷

While there are different battery technologies, Li-ion is a key component in a range of chemistries largely due to its superior performance (e.g. as regards energy and power densities) compared to various well-established and mature battery technologies. The energy density of Li-ion batteries has increased significantly in recent years (by more than 300% since their commercialisation in 1991¹³⁸). In addition, there is further potential for optimisation with the new generation of Li-ion batteries.¹³⁹ An additional important enabler of the Li-ion battery technology's significant market share growth is the rapid decrease of their cost in recent years from over USD 1100/kWh (Kilowatt Hour) in 2010 to USD 156/kWh in 2019.^{134,138} By

¹³⁴ Tsiropoulos I., Tarydas D., Lebedeva N. (JRC Science for Policy report and references therein): Li-ion batteries for mobility and stationary storage applications. Scenarios for costs and market growth, 2018

¹³⁵ Report on progress of clean energy competitiveness, COM(2020)953

¹³⁶ SET- Plan key action n°7, Declaration of Intent and Implementation Plan, available at: <https://setis.ec.europa.eu/implementing-integrated-set-plan/batteries-e-mobility-and-stationary-storage-ongoing-work>

¹³⁷ https://eur-lex.europa.eu/resource.html?uri=cellar:0e8b694e-59b5-11e8-ab41-01aa75ed71a1.0003.02/DOC_3&format=PDF

¹³⁸ L. Trahey, *et al*: Energy storage emerging: A perspective from the Joint Center for Energy Storage Research, 2020

¹³⁹ Lebedeva, N., Ruiz Ruiz, V., Bielewski, M., Blagoeva, D., Pilenga, A. (European Commission): Selected Advanced Lithium-ion, Post Lithium-ion and Non-Lithium-Ion Batteries Technology Development Report, 2020

2023, some forecasts suggest that average prices will be close to USD 100/kWh.¹⁴⁰ The USD 100/kWh point has traditionally been seen as the point at which, for mobility, electric cars become competitive with their internal combustion engine equivalent.

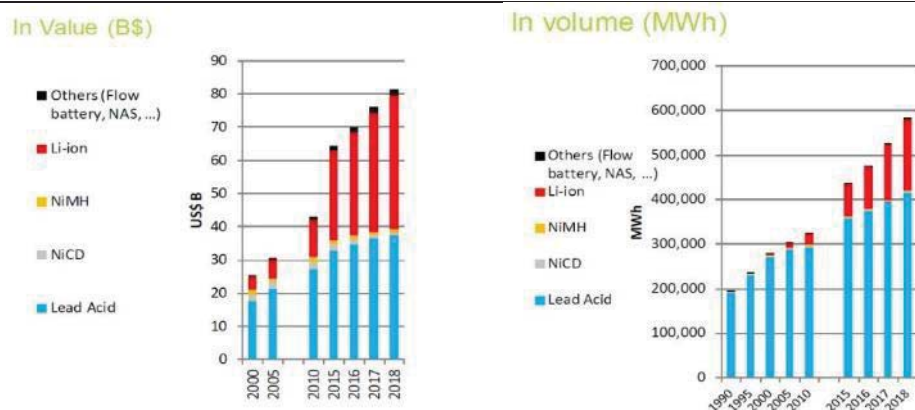
Access to relevant raw materials is a key element when considering dependencies and possible vulnerabilities in the Li-ion battery supply chain. Among the raw materials used in battery manufacturing, cobalt, natural graphite, lithium, fluorspar and phosphorous are in the 2020 list of critical raw materials. There is also research looking at silicon metal, titanium and niobium (also critical raw materials) to improve energy density, durability and safety in future Li-ion battery types. OEMs, cell manufacturers and suppliers will likely compete globally with each other to secure their battery supply chains and access to the five essential battery raw materials (lithium, cobalt, nickel, graphite and manganese).

In addition, value chains of other materials (in particular rare earths for high-energy density permanent magnets) are key to producing electric motors with the highest power densities. In some cases, access to these raw materials may be at risk (for example due to political instability or export restrictions), or challenged by the prevalent use of unethical and unsustainable mining practices. For these reasons, access to raw materials was identified as one of the six priority areas in the Strategic Action Plan for Batteries¹⁴¹ and subsequently in 2020 when the European Raw Materials Alliance was launched.

b) Origin of vulnerabilities and recent progress made

The EU is a major world market for electrical vehicles and consequently also for batteries. The battery represents a significant share of the total cost of an electric vehicle. Furthermore, batteries are also increasingly used for energy storage and in other industrial applications (machinery, power tools, forklifts, etc.).

Graph 28: The worldwide battery market



Source: Reproduced with permission from Pillot C., “The rechargeable battery market and main trends 2018-2030”, Avicenne Energy, presentation at AABC Europe 2020, 13-16 January 2020, Wiesbaden, Germany.

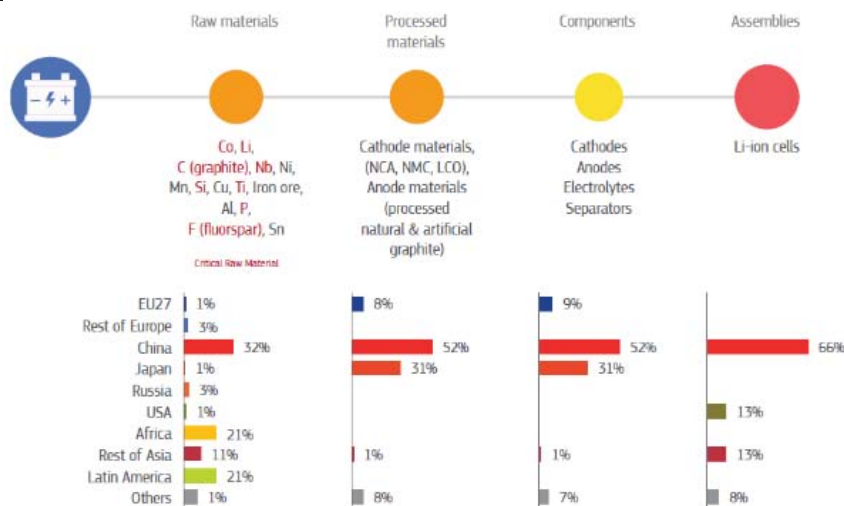
¹⁴⁰ Source: Bloomberg

¹⁴¹ COM(2018)293

At present the Li-ion battery technology dominates the rechargeable battery market in value (Graph 28). With a compound annual growth rate over 15%, it is expected to break-even, also in volume, with well-established and mature battery technologies (such as lead-acid) in the near future.¹⁴² Driven by a rapidly growing demand in batteries for electric vehicles, Li-ion batteries' global demand is projected to increase from about 90 Gigawatt hours (GWh) in 2016 to up to ca. 800 GWh by 2025, exceed 2 000 GWh by 2030, and possibly reach up to 4 000 GWh by 2040 under the most optimistic scenario.^{134,135} In Europe, demand is expected to be around 400 GWh by 2028.¹⁴³

As a result, future needs for raw materials are very significant, while the EU holds only a very limited level of production. Graph 29 shows the key players in the Li-ion cell supply chain in relation to global production. For batteries used in mobility and energy storage alone, the EU will need, compared to the current supply to the whole EU economy, 7-18 times more lithium and 2-5 times more cobalt in 2030, and almost 16-57 times more lithium and 3-15 times more cobalt in 2050.^{145,144} At the same time, the EU produces just 1% of all battery raw materials. These volumes cannot satisfy now the European demand for Li-ion batteries.

Graph 29: Li-ion batteries – an overview of supply risks, bottlenecks and key players along the supply chain



Source: European Commission, JRC¹⁴⁵

Also when it comes to processed materials and components, Asia delivers 84% while the EU again has only a relatively small share (around 8-9%). Furthermore, the low level of processed materials and components delivered by other countries (beyond China and Japan)

¹⁴² Pillot C.: The rechargeable battery market and main trends 2018-2030 (Avicenne Energy, presentation at AABC Europe 2020, 13-16 January 2020, Wiesbaden, Germany)

¹⁴³ COM(2019)176

¹⁴⁴ Cobalt: demand-supply balances in the transition to electric mobility

(https://publications.jrc.ec.europa.eu/repository/bitstream/JRC112285/jrc112285_cobalt.pdf)

¹⁴⁵ European Commission: Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020. Figures refer to the range between the low and the high demand scenario.

provides very little margin for supply diversification. Finally, regarding battery cells themselves a similar high level of dependence on foreign imports (notably from China) was also identified.

Recent investments in the EU

As a response to these identified vulnerabilities, public and private investments have been mobilised at scale over recent years, in particular through the European Battery Alliance. These are expected to lead to a significant increase of Europe's lithium demand being supplied from European Union sources by 2025. The ambition of the European Commission and the European Battery Alliance is to have 15 gigafactories in Europe offering enough battery cells by 2025 to power six million electric cars (around 360 GWh).¹⁴⁶ Based on the Transport & Environment (T&E) monitoring of current battery production intentions, the EU could be around 100 GWh above this target if the planned gigafactories come on schedule.

Developers of next generation Li-ion battery technologies play a major role in generating new investments in the EU. These innovators have managed to attract considerable levels of early and late stage venture capital (VC) investments as new technology developments emerged. About half of these are raised by US based companies, with the EU attracting around 40%. EU investments are mostly in Northvolt. While the majority of investors in EU projects are from the within the EU, they also include actors from the US, China, South Korea, the UK and Switzerland^{147,148}. The size of VC investments in Northvolt over the past 3 years is comparable to the investments in US start-ups of comparable scope since 2013.

Firm level data analysis

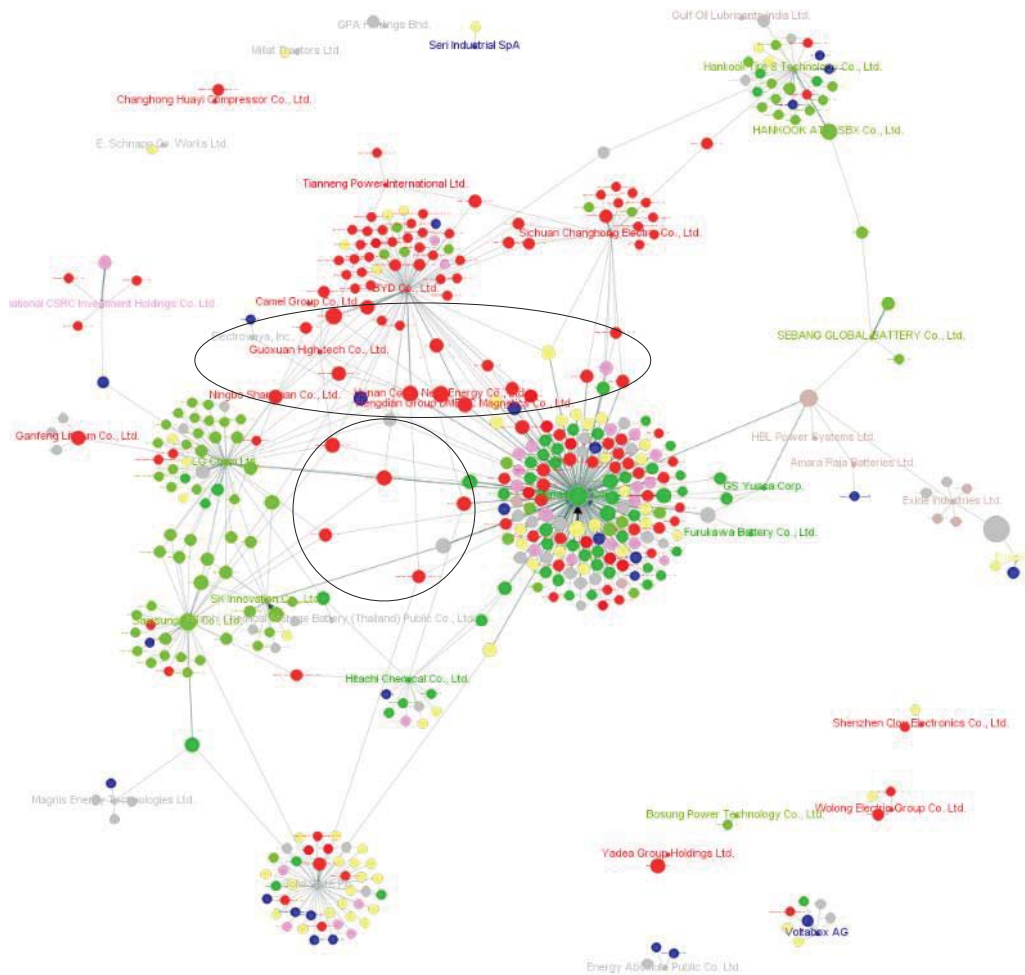
Looking at the currently established battery manufacturing companies in the EU, the pre-eminence of Asian-based companies is quite important. Graph 30 shows the supply structure of the major manufacturers in the EU of heavy-duty and high-end batteries. Most manufacturers display specific links with suppliers, with a limited number of suppliers simultaneously supplying several battery producers. Among those, there are Japanese and Korean firms, although the vast majority are Chinese companies (as highlighted in the circled areas of the figure) which, considered collectively, seem to play a central role in the supplying structure of the industry.

¹⁴⁶ See https://ec.europa.eu/commission/presscorner/api/files/document/print/en/speech_20_2202/SPEECH_20_2202_EN.pdf; https://www.transportenvironment.org/sites/te/files/publications/2021_02_Battery_raw_materials_report_final.pdf

¹⁴⁷ ICF (commissioned by European Commission): Climate neutral market opportunities and EU competitiveness study, Draft

¹⁴⁸ Commission elaboration of Pitchbook data

Graph 30: Supplying structure of major manufacturers of high-end and heavy-duty batteries



Source: Commission analysis based on FactSet supply chain data

Notes: Each circle represents an individual company. Circles are coloured according to the country of the firm's headquarters: EU (blue), China (red), US (yellow), Japan and Korea (green), Taiwan (pink), rest of the world (grey). For easier readability, the names of the suppliers are omitted, only the customers are named in the colour of their country of origin. The size of the circles is proportional to the company's supplier outdegree (i.e., the number of different companies that it supplies). Darker connecting arrows denote a stronger relation between the two companies concerned (measured as the total number of links between them).

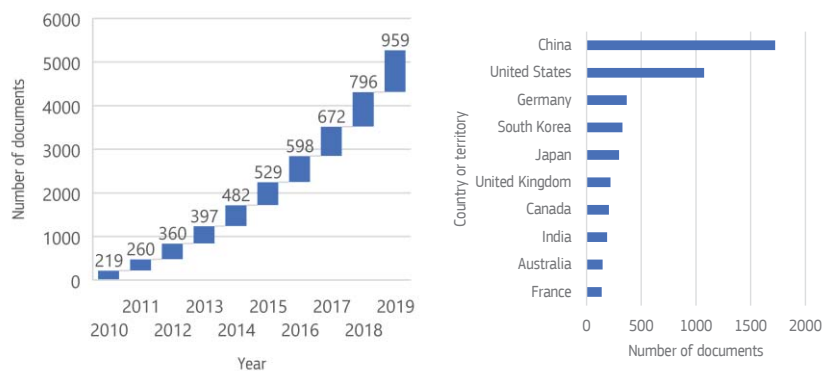
Role of Research and Innovation

Maintaining the leading edge in the quickly growing and competitive sector of batteries requires constant technological improvements and, hence, significant R&I effort. Research and innovation plays a key role in the area of batteries, with large ongoing efforts worldwide. A broad range of applications requires a variety of fit-for-purpose batteries, stimulating development of new types of batteries.^{138,149} A large effort worldwide is directed towards research and development for various advanced Li-ion as well as post-Li and non-Li-ion battery

¹⁴⁹ Y.E. Durmus, *et al*: Side by Side Battery Technologies with Lithium- Ion Based Batteries, 2020

technologies.^{138,139,150} For example, the evolution of peer reviewed scientific publications in the area of transport electrification in recent years shows an increase on ‘battery capacity’. China and the US are leading the research on this field with Germany in third place and France also making the top 10 from the EU (Graph 31).

Graph 31: Number of documents on battery capacity in the period 2010-2019 (left) and country of origin (right)



Source: European Commission, JRC based on Scopus¹⁵¹

Generally, Asian regions lead in battery research and innovation. This is the case concerning both contemporary Li-ion as well as advanced Li-ion such as ASSB, post-Li-ion such as Li-S and non-Li-ion (i.e. Na-ion and RedOx flow batteries¹³⁹).

At the same time, there is a considerable effort in R&I by EU industry. Batteries and e-mobility receive the highest share (over a fifth) of private R&I investments in the Energy Union R&I priorities. Even though the EU ranks third in high-value patents among major economies, quite a way behind Japan and Korea, it does display specialisation in this topic – meaning that it has a larger share of patents in this field than the world average¹⁵² and thus an increased focus of efforts. European research helped gaining a deep insight into fundamental aspects of advanced battery technologies (e.g. underlying reaction mechanisms, materials properties, interfacial processes, battery components safety, etc. as well as associated limitations).

Batteries for electric vehicles is a research area currently attracting a number of projects with significant EU funding. Improving the driving range of electric vehicles (EV) is a key research theme. The combination of the Horizon2020 programme and the preceding Seventh Framework Programme (FP7) contributed over EUR 310 million with support to research and innovation activities. Actions under road transport electrification include support for local production of batteries and components as well as the development of electro-chemical systems for future high energy density electric batteries.

Despite this progress in EU R&I efforts, it is key to ensure a systematic implementation of their results. Evidence shows that R&I results may not have been fully and systematically

¹⁵⁰ ICF (commissioned by EC): Climate neutral market opportunities and EU competitiveness study, Draft

¹⁵¹ www.scopus.com

¹⁵² JRC SETIS research and innovation data <https://setis.ec.europa.eu/publications/setis-research-innovation-data>

implemented by the European battery sector, which raises concerns related to the potential loss of Europe's knowledge base.^{136,139} For example, analysis¹⁵³ of EC-funded projects (FP7, Horizon2020) on developments and future needs within the scope of the Transport electrification STRIA roadmap¹⁵⁴ including batteries and energy management systems, shows lithium-ion batteries with novel anode/cathode materials to have an overall low level of maturity.

c) Way forward and relevant (ongoing) measures

Recognising the need and urgency for the EU to develop a battery value chain, the Commission launched the European Battery Alliance (EBA) in 2017¹⁵⁵ and adopted the Strategic Action Plan on Batteries (2018). Both have acted as a catalyst for major investments all along the battery value chain and already delivered some significant results. The amount of investment across the electro-mobility value chain in Europe, in 2019 alone, reached €60 billion, which was 3.5 times that of China¹⁵⁶. The vast majority of this is private investments, including investments from third country companies. This has been invested into many projects across the value chain including 15 new battery cell plants being built across Europe. These plants will provide by 2025 enough cells to power at least 6 million electric vehicles.

As a result, while production of batteries for electrification in transport has so far been dominated by companies in East Asia, notably Chinese companies, Europe may become the second (after China) manufacturer of the lithium-ion cells (batteries) by 2024. Compared to 5.9% in 2019, Europe's share in the global Li-ion battery production capacity may increase to 14.7% by 2024 and to 16.6% by 2029.

Actions have also been put in place to strengthen R&I efforts. The technology and innovation platform of EBA – Batteries Europe¹⁵⁷ – drives the implementation of battery-related research and innovation actions of the Strategic Energy Technology (SET) Plan¹³⁶ and the Strategic Transport Research and Innovation Agenda¹⁵⁸ and is tasked with coordination of R&I efforts at regional, national and European levels. A range of measures have been put in place, including strengthening Horizon 2020 with additional funding for battery research; and preparing specific instruments for Horizon Europe, such as for example the European Partnership for an Industrial Battery Value Chain¹⁵⁹ with a proposed budget of EUR 925M, including a long term research

¹⁵³ Tsakalidis, A., van Balen, M., Gkoumas, K., Marques dos Santos, F., Grosso, M., Ortega Hortelano, A., and Pekár, F.: Research and innovation in transport electrification in Europe: An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS), 2020

¹⁵⁴ Strategic Transport Research and Innovation Agenda <https://trimis.ec.europa.eu/stria-roadmaps/transport-electrification>

¹⁵⁵ https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en Following discussions with Member States and industry, a report on the implementation of the EBA was adopted by the Commission in 2019 (<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:176:FIN>)

¹⁵⁶ InnoEnergy

¹⁵⁷ https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/about-platform_en#governance

¹⁵⁸ https://ec.europa.eu/info/research-and-innovation/research-area/transport/stria_en;
<https://ec.europa.eu/transport/sites/transport/files/swd20170223-transportresearchandinnovationtomobilitypackage.pdf>

¹⁵⁹ https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/european-partnerships-horizon-europe/candidates-climate-energy-and-mobility_en

initiative on future battery technologies,¹⁶⁰ and continuing support to projects through EIT InnoEnergy¹⁶¹.

There are 5 main ongoing measures that will be a high priority in the short-term to secure the remaining objectives of the Battery Alliance.

- ***New legislative framework for batteries.*** On 10 December 2020 the Commission adopted its proposal to ensure that there are robust sustainability, safety and performance requirements for all batteries placed on the EU market. This proposal is being discussed with the European Parliament and Council with the aim of it coming into force in 2022. This also provides legal and regulatory certainty for investments;
- ***Important Project of Common European Interest (IPCEI).*** This State aid instrument has proved to be a key tool to unlock substantial private sector investment in the battery value chain that would not have happened without the approved Member State support. In December 2019, the Commission authorised State aid for the first battery IPCEI which involves 17 companies spread over 7 Member States and a range of innovative projects all along the value chain. The IPCEI decision authorised the granting of up to EUR 3.2 billion in state aid and this is expected to leverage a further EUR 5 billion in private sector investments¹⁶². State aid for a second IPCEI has just been approved by the Commission. This IPCEI involves 42 direct participants with activities in 12 Member States¹⁶³. The Commission's decision authorised the granting of up to EUR 2.9 billion in State aid with a further EUR 9 billion expected in private sector investments. Both will be critical in delivering beyond state-of-the-art innovation across the batteries value chain in the EU and the Commission will be involved in the governance of both IPCEIs to monitor progress and ensure the original objectives are delivered;
- ***Strengthening the resilience of the EU critical raw materials value chains.*** In September 2020, the Commission launched the Action Plan on Critical Raw Materials to secure the European Union's sustainable supply of critical raw materials as well as the European Raw Materials Alliance. Both initiatives will be high priorities in the coming years, with significant importance for the EU battery sector;
- ***Ensuring effective implementation of Horizon Europe funding of battery research;*** Under Horizon Europe, all battery-related research activities will be implemented through a co-programmed partnership set up between the Commission and an association bringing together industrial and research stakeholders from across Europe. This partnership (labelled Batt4Eu) will receive up to €925M of EU funding, to be implemented through annual calls and with the aim of addressing the research and innovation goals set out in a Strategic Research and Innovation Agenda (SRIA) jointly drafted and agreed between all partners. The ring-fenced budget and SRIA create stability and predictability for the sector, thus de-risking speculative research activities and creating a pathway towards bringing innovations to the market. The

¹⁶⁰ <https://battery2030.eu/>

¹⁶¹ <https://investmentround.innoenergy.com/>

¹⁶² Press release [IP/19/6705](https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705), "State aid: Commission approves €3.2 billion public support by seven Member States for a pan-European research and innovation project in all segments of the battery value chain", December 9, 2019.

¹⁶³ https://ec.europa.eu/commission/presscorner/detail/en/ip_21_226

progress and effectiveness of Batt4EU will be centrally monitored through annual reporting on mutually agreed KPI's, and its partnership board (composed of Association and EU delegates) is in charge of strategic orientation and technical coordination; and

- ***Developing a European skilled battery workforce***¹⁶⁴. In order to ensure that the battery sector has access to an appropriately skilled workforce to support its growth, the Commission has funded a 4 year Erasmus + project (ALBATTTS) to develop a strategy to identify the skills needed for the sector and to develop training courses and related initiatives to meet the challenge. This compliments the Erasmus+ project DRIVES looking at the skill needs for the automotive sector as a whole (due to be completed by the end of 2021) and the recently launched industry-led Automotive Skills Alliance¹⁶⁵ supported under the Commission's Pact for Skills initiative (expected to be operational by the end of 2021 on the back of pilot regional skill programmes planned for 2021).

The Commission will continue to pursue the implementation of the Strategic Action Plan on Batteries, especially in the areas mentioned above and to further promote additional investments in the full value chain. The Action Plan is also complementary to other policies to support the Green Deal ambitions of the Commission including the ongoing review of the CO2 standards for vehicles (cars/vans/trucks) that will impact directly on the demand for batteries.

¹⁶⁴ In the labour market, although some traditional jobs will be lost, the development of the battery production could create a positive effect. The Impact Assessment for the battery legislation estimated that 1 GWh creates between 100-150 direct jobs and 100 - 500 indirect jobs. This would translate to 60,000 – 90,000 direct jobs and 60,000 – 300,000 indirect ones.

¹⁶⁵ <https://automotive-skills-alliance.eu/>

5.4 Hydrogen

a) Context and possible weaknesses in the EU

The importance of hydrogen builds on its attributes and it has a wide range of applications across ecosystems. Hydrogen is the most abundant and lightest of the elements, having at the same time odourless and nontoxic characteristics. In addition, it has a high energy content per unit mass and it can be readily produced at an industrial scale. Hydrogen is not found free in nature and must be “extracted” from diverse sources such as fossil energy, renewable energy, nuclear energy and the electrolysis of water. Consequently, a separate energy source (electricity, heat or light) is required to “produce” (extract or reform) the hydrogen. It can be transported as a gas by pipelines or in liquid form by ships, similar to liquefied natural gas (LNG). Hydrogen use today is dominated by the chemical and refining industries but it has applications in various ecosystems of the economy including mobility, renewables, electronics, construction, energy intensive industries, defence or agrifood. It is used in applications in the metal production and fabrication, methanol production, food processing and electronics sectors.

Renewable or low-carbon hydrogen¹⁶⁶ can be used much more widely than its current applications and it can help to tackle critical challenges related to the decarbonisation and competitiveness of the industry. Renewable and low-carbon hydrogen production and related technologies and goods such as ammonia offer ways to decarbonise a range of sectors, including long-haul transport, chemicals and iron and steel, where it has been challenging to meaningfully reduce emissions. In this regard, renewable and low-carbon hydrogen production and related technologies are key enablers for the decarbonisation of EU energy, industries and mobility as they can replace or decarbonise fossil fuels. Hydrogen is also an option for storing renewable energy for long periods and in large quantities, and it is relatively inexpensive to deliver by pipelines, making it an enabler for significant expansion of the renewables capacities in the EU. The importance of hydrogen is therefore twofold as it fosters the decarbonisation of the economy but also the competitiveness of manufacturing industries, provided that renewable and low-carbon hydrogen can be sustainably offered at competitive prices. The EU’s consumption of hydrogen today is around 10 Mt, and it is primarily produced on the basis of natural gas. Virtually all of the EU’s hydrogen consumption is currently produced within the EU.

While current production of hydrogen mainly relies on the use of fossil fuels, there is a need to move to renewable and low-carbon hydrogen. Around 70 Mt of hydrogen are currently being produced globally. More than 70% of the hydrogen produced worldwide is produced by the steam reforming of methane or natural gas, which is currently the cheapest source. The remaining hydrogen is generated by gasification of coal, oil reforming or electrolysis. While electrolysis currently accounts for only 0.1% of global hydrogen production,¹⁶⁷ there is significant scope for this technology to provide more renewable hydrogen.

¹⁶⁶ Renewable hydrogen refers to hydrogen produced by electrolysis based on renewable power; low-carbon hydrogen encompasses fossil-based hydrogen with carbon capture and electricity-based hydrogen, with significantly reduced full life-cycle greenhouse gas emissions compared to existing hydrogen production.

¹⁶⁷ IEA: The Future of Hydrogen, 2019 <https://www.iea.org/reports/the-future-of-hydrogen>

The EU is a technology leader in several clean hydrogen technologies, but it depends on imports of raw materials for key components (such as electrolyzers and fuel cells) as well as the supply of renewable energy. Critical raw materials, especially platinum group metals and liquid electrolytes, are used for their catalysts. Therefore, general risks associated with the supply of raw materials (see chapter 5.1) also apply to the supply chain of hydrogen. In addition, given that renewable energy is the source for renewable hydrogen production, the supply of abundant and affordable renewable energy is a constraint for the development of clean hydrogen applications. The Hydrogen strategy for a climate-neutral Europe estimates that it will be necessary to connect 80-120 GW of solar and wind energy production capacity to the electrolyzers to provide the necessary electricity. Furthermore, risks associated with raw materials used in other renewable technologies could also have an impact on the deployment of these hydrogen technologies.

Systemic risks arise from the need of some sectors (e.g. industrial hydrogen users and the mobility sector) to have large and reliable supply available. Given these needs, lack of renewable and low-carbon hydrogen supply in the short term and lack of infrastructure are considered as important risks that delay investment decisions.

b) Origin of vulnerabilities

As of today, Europe is a global leader of electrolysis technologies, from components supply to final integration capabilities. Roughly half of electrolyser manufacturers are in Europe, including most of the larger ones.¹⁶⁸ Europe has particular strengths in key components of fuel cells for transport applications, such as catalysts, membrane electrode assemblies (MEA), bipolar plates and gas diffusion layers. Many companies also offer hydrogen handling solutions and hydrogen refuelling stations.¹⁶⁹

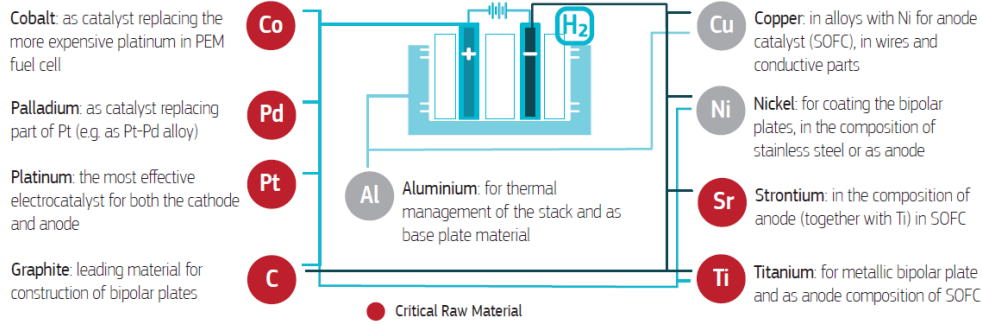
Nevertheless, there are some technology and regulatory gaps linked to green hydrogen production. For example, vulnerabilities in electrolyzers mostly relate to manufacturing scale-up and supply chain optimisation; large-scale manufacturing capacity is not yet built for most producers. The high-pressure hydrogen storage is one of the existing solutions for on-board transport applications. However, Europe lacks in production of high-quality carbon fibre, an important material used in the manufacture of compressed hydrogen tanks, which is mainly imported from Asia.

The Commission has established targets for 6 GW renewable electrolyser capacity by 2024 and 40 GW renewable electrolyser capacity by 2030, compared to less than 1 GW in 2020. This massive scale up of renewable hydrogen production will require the access to abundant and affordable renewable electricity, large-scale manufacturing of electrolyzers and relevant components and materials.

¹⁶⁸ E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc.: Study on value chain and manufacturing competitiveness analysis for hydrogen and fuel cells technologies (FCH contract 192, Evidence report), 2019 – SWOT analysis, p. 114

¹⁶⁹ E4tech: Study on value chain and manufacturing competitiveness analysis for hydrogen and fuel cells technologies (Summary report), 2019

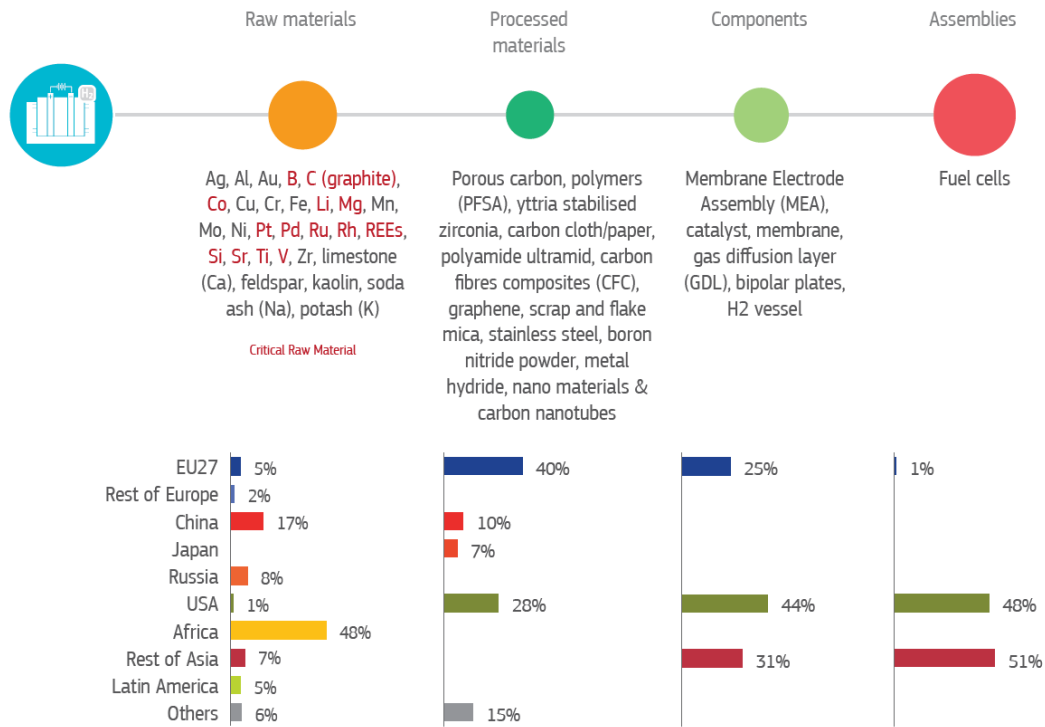
Graph 32: Relevant raw materials used in fuel cells



Source: European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020

Around 30 raw materials are needed for producing fuel cells, electrolysers and hydrogen storage technologies. Of these materials, 13 materials are deemed critical for the EU economy according to the 2020 CRM list. Most of the critical raw materials are in the catalysts, with platinum representing around half of the cost of a fuel cell stack. South Africa is the main producer of platinum in the world, followed by Russia and Zimbabwe. While currently the EU still has a relatively small production of fuel cells and electrolysers, risks related to the specific raw materials will become more apparent if large-scale manufacturing is to be developed in the EU.

Graph 33: Fuel cells and Hydrogen technologies: an overview of supply risks, bottlenecks and key players along the supply chain



Source: European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020

Europe is a major supplier of processed materials for fuel cells (40%), followed by the United States (28%), China (10%) and Japan (7%). At the same time, for four particular materials (CFCs, polymers (PFSA, perfluorosulfonic acid), carbon cloth/paper; and nanomaterials and carbon nanotubes) Europe produces between 15% and 20% of the global supply, which could be expected to be insufficient to satisfy European demand.¹⁷⁰

c) Way forward and relevant (ongoing) measures

A combination of measures are ongoing in the area of clean hydrogen. These measures aim to secure access to abundant decarbonised electricity and to the right quantity and quality of raw materials, as well as to build industrial capacities along the full hydrogen value chain, including components, assemblies and applications in downstream sectors. Several EU funding programmes contribute to the development of the hydrogen value chain, such as the future Clean Hydrogen partnership under Horizon Europe (building on the work of the Fuel Cell and Hydrogen Joint Undertaking), the Innovation Fund, the Connecting Europe Facility, the European Regional Development Fund and the Just Transition Fund.

The Commission has set up the European Clean Hydrogen Alliance announced in the March 2020 Industry Strategy. It will deliver an investment and project pipeline that implements the EU Hydrogen Strategy.¹⁷¹ The Alliance will propose concrete projects that deliver a robust foundation for the hydrogen value chain, starting from investments in renewables and hydrogen infrastructure and covering several hydrogen use sectors (i.e. industrial use, buildings, mobility and energy). The Alliance is also looking at bottlenecks and framework conditions to contribute to a favourable investment climate that supports EU policies.

In this context, there are ongoing discussions involving several Member States on the design of one or more potential IPCEIs. It should be noted that, beyond IPCEI, other State aid rules may be applicable to projects in the hydrogen value chain, notably the Environmental protection and Energy Aid Guidelines, which are currently being reviewed. The combination of these actions will contribute to launch simultaneously the complete value chain, bringing in stakeholders that alone could not implement projects due to the integrated nature of the hydrogen value chain.

In addition, the Commission is promoting cooperation with neighbouring countries to increase supply of renewable hydrogen and derivatives. **Global cooperation on research and development, standards and definitions of clean hydrogen will be essential** for the emergence of a global, rules-based market for hydrogen that contributes to a secure, sustainable and competitive hydrogen supply for the EU market.

As regards possible dependencies with a potential impact on relevant clean hydrogen technologies such as fuel cells and electrolysers, ongoing actions in the area of raw materials are of key importance. The actions under the Raw Materials action plan and the

¹⁷⁰ European Commission: Materials dependencies for dual-use technologies relevant to Europe's defence sector, 2019

¹⁷¹ COM(2020)301

European Raw Materials Alliance (see chapter 5.1) are of key importance to mitigate risks of access to raw materials relevant for these technologies. They include increased recycling, stronger intra-EU supply capacities and diversification of foreign supply. Furthermore, some additional technology specific options are relevant for these hydrogen technologies.

There is an ongoing effort to reduce the quantity of raw materials with supply risk needed for the production of fuel cells and electrolysers. Due to the high cost of platinum, the industry has already successfully reduced the quantity of platinum needed in some applications. Further efforts are needed to minimise or completely eliminate the need for various critical raw materials. In addition, dependencies on supply of specific raw materials are effectively reduced by substituting them with raw materials with lower risks of permanent or temporary disruptions in supply. For example, platinum could at least partially be replaced by palladium and other materials in fuel cells. Finally, to mitigate short- to medium-term supply disruptions in the event of a crisis, stockpiling options could also be examined at EU or Member State level, supporting corporate strategies to mitigate risks.

In addition, reduced needs for critical raw materials can also be achieved by in parallel developing alternative technologies. Different technologies could be applied based on best technical suitability, raw material supply and cost. While flexibility is limited in some applications (like in on-board mobile solutions), other sectors could utilise a wider selection of technologies that rely on a different combination of raw materials.

5.5 Semiconductors

Semiconductor chips are the basic building blocks of all digital products and services. Semiconductor components, among them processors, are today embedded in almost everything, from cars, aircraft and medical equipment to cell phones, networks and supercomputers. They determine the characteristics of the products into which they are embedded – including security, privacy, energy performance and safety – shaping how Europe’s green and digital transition will unfold. In essence, they underpin the digital value chain. This review looks in more detail at possible dependencies and vulnerabilities that the EU faces in the area of semiconductors as well as relevant possible (ongoing) measures.

a) Context and possible weaknesses in the EU

For decades the semiconductors industry has been driven forward by the capability to squeeze an ever-increasing number of transistors into a given area of semiconductor material.¹⁷² Miniaturisation of feature sizes is at the core of both faster and more power-efficient microprocessors used in communications, consumer electronics and computing, including supercomputing. The most advanced chips in production in 2020 are at 5nm. PCs and cell phones, which account for the highest market volume across the whole electronics sector, are the main drivers of miniaturisation. High production volumes in these market segments help to sustain the high cost of technology development.

Over time, leading-edge chips have become more difficult and more costly to produce. Designing and developing the most technologically advanced chips today can cost up to 1 billion EUR, while a leading-edge fabrication plant (“Fab”) requires investments up to 20 billion EUR. **This has led to a consolidation in the number of leading-edge chip manufacturers.** In 2020, only 2 companies, TSMC (Taiwan) and Samsung (S. Korea) manufacture chips at 5nm. Intel (US) announced that its 7nm technology has been delayed until 2022, illustrating the technological complexity of chip fabrication at such dimensions. Europe has no foundries that offer manufacturing of components with feature sizes below 22nm.

Energy performance of a system is highly dependent on the energy efficiency of the semiconductor chip(s) inside. The emergence of AI edge processing and applications such as highly automated driving combined with car electrification will generate huge amounts of data. Processing such data at the speed needed to capture widely its benefits will require an important shift in the way we conceive and produce electronic components and systems. Scaling up computing performance with today’s component technologies will however make computing one of the biggest energy-consuming activities. In fact, all these upcoming and future applications will require highly performant processor chips that exhibit radically lower energy consumption.

¹⁷² This progressive miniaturisation of feature sizes has come with a corresponding increase in performance, most notably a doubling of computing speed every two years (Moore’s Law). Today’s most advanced microprocessor chips contain some 10s of billions of transistors and can process 10s of trillions of operations per second. The generations of technologies are defined by the critical dimension of the transistors, which thanks to advanced photolithographic techniques, are on the order of some few nanometres (nm).

Bringing AI to the device: the US industry has set its sights on the burgeoning edge-AI market as illustrated with recent mergers.¹⁷³ Notable among emerging trends in AI based on different technologies are neuromorphic and quantum computing.

The biggest demand for semiconductors comes from outside the EU. In particular China represents more than 50% of today's semiconductor market and as such, Chinese demand significantly supports and drives the growth of the semiconductor industry worldwide. **The Covid-19 outbreak has sped up the digital transformation and led to short-term shifts in the demand across sectors.** On the one hand, the demand for cloud/data centre services, "working from home products" and medical devices has increased, on the other, lock-downs and loss of income reduced the demand for cars, mobile phones and consumer electronics.¹⁷⁴

The development and fabrication of chips has been increasingly subject to massive subsidies. In order to reduce its dependence on imports, notably from chips made in Taiwan, and more generally from US-developed technology which can be subject to unilateral US export control restrictions, China has set itself the ambition of reaching 70% autonomy in chip-making by 2025 with the revenues of its home-grown chip industry growing to USD 305 billion by 2030. To this end it has allocated USD 150 billion over 10 years under the "Made in China 2025" plan to build up research excellence and manufacturing capacity. **Such measures have served to support local industrial ecosystems.** In the wake of the COVID-19 crisis, the US has responded to China's bid for independence with a USD 25 billion plan over 5 years to support investments in R&D and manufacturing, to reduce its dependencies on other parts of the globe, notably Taiwan.¹⁷⁵ Meanwhile, the South Korean government announced a plan to spend KRW 1 trillion (USD 869 million) to develop AI chips through 2029.¹⁷⁶ The ICT ministry plans to put the next-generation chip on the Korean New Deal project list for KRW 20 trillion (USD 17,38 billion)

¹⁷³ Intel, leader in CPUs, acquired Altera (USD 17B) for their FPGAs and are now introducing their discrete GPUs, such as Xe, also for AI in data centres.

Nvidia, leading in programmable GPUs and AI, is planning to acquire ARM (USD 40B). GPUs, initially conceived to process images, are now being widely used for AI acceleration to speed up processes such as neural network and machine learning tasks. ARM has the IP needed to excel in CPUs (and low-power AI at the edge).

AMD, the challenger in both CPUs and GPUs, has acquired Xilinx (EUR 35B). The acquisition will reinforce its position as a credible alternative for the datacentre/AI market. Xilinx also offers SmartNIC for network acceleration, which for AMD can be another asset for data centres in view of Intel's acquisition of Infiniband and Nvidia's acquisition of Mellanox. Intel acquired Altera end of 2015; the announcements by Nvidia and by AMD were in 2020.

Worth noting is the fundamental difference between ARM and Intel (i.e. X86) approaches to CPUs/processing units and hence their different application markets. The former focuses on low-power consumption and the latter on advanced performance, which in turns leads to more power consumption and higher use of silicon space. The low-power approach of ARM has allowed ARM to offer the best balance of performance and energy efficiency for mobile devices including chips for cell phones and laptops.

¹⁷⁴ Accenture (2020) Semiconductor Companies: Business Resilience in the Wake of COVID-19 A guide to the disruptive impacts & practical actions for semiconductor companies to take, retrieved from https://www.accenture.com/_acnmedia/PDF-126/Accenture-High-Tech-Covid-19-SEMICONDUCTOR-Final.pdf

¹⁷⁵ In fact the plan earmarks 12 B\$ to attract TSMC to build a 5nm fabrication facility in Arizona with construction planned for 2021 and production for 2024. At the invitation of Japanese government TSMC is planning to set up a joint advanced packaging and testing plant in Japan. <https://focustaiwan.tw/business/202101050014>

¹⁷⁶ <https://techcrunch.com/2020/10/13/south-korea-pushes-for-ai-semiconductors-as-global-demand-grows/>
<https://en.yna.co.kr/view/AEN20201012007500320>

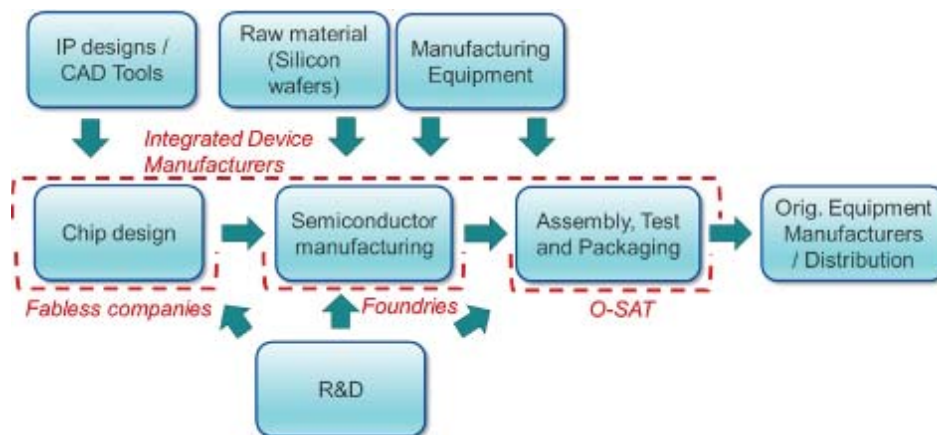
state aid to help attract more financial support, on top of KRW 70 billion from another fund tied to the semiconductor industry. The Japanese Ministry of Economy, Trade and Industry has invited Taiwan Semiconductor Manufacturing Co. (TSMC) to set up a joint advanced integrated circuit packaging and testing plant in Japan to address Japanese customers in power solutions, automotive, wind energy and industrial machinery.¹⁷⁷ **Geopolitical tensions and the lack of a level playing field harm the competition in this area.**

Europe’s semiconductor footprint is small compared to other regions in particular in the digital sector. Compared to its economic weight (close to 23 % of world GDP), the EU shares of global revenues for semiconductor chips is ~10% overall and ~6% for the computing and communication segments. Limited existing production capacity to serve future demand, high entry costs and lack of a level playing field (including inadequate access to financing) and different regulations in extra EU regions are threatening the EU firms’ capacity to fully seize the opportunity to capitalise on the digital transformation. Therefore, the digital sector will be an important area for Europe to focus on in order to reduce dependencies in the future and to fully seize the opportunity of the digital transformation.

b) Origin of vulnerabilities

The semiconductor industry is a global industry based on ever shorter cycles of very advanced technologies at all phases of the value chain with long learning cycles. The supply chain stretches from chip design, semiconductor manufacturing to test, assembly and packaging (also referred to as back-end processes), before reaching end-user companies, which integrate the chips into their products. Materials, equipment and related services and tools, including electronic design automation tools and functional blocks or IP blocks, enable design and manufacturing. The semiconductor supply chain is well-integrated, with no single country or company dominating all the different stages of the value chain (Graph 35).

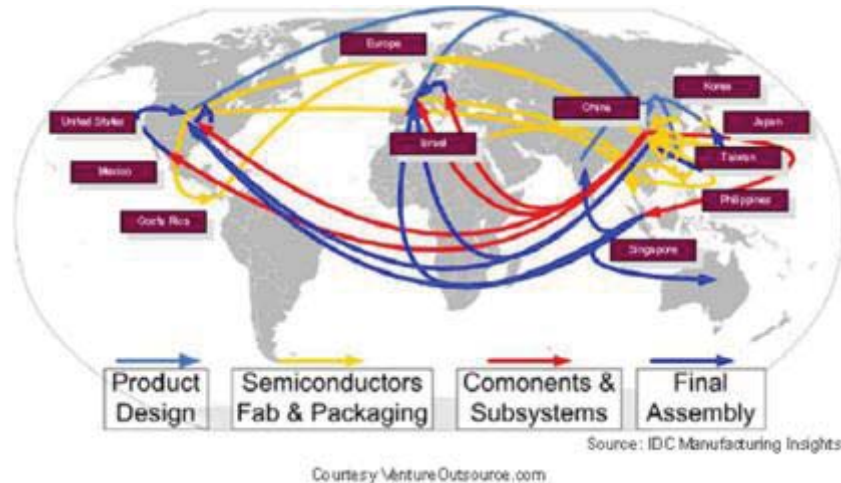
Graph 34: The semiconductor value chain



¹⁷⁷ <https://focustaiwan.tw/business/202101050014>

R&D is an integral part of the design, testing and deployment of new chip technologies including developing advanced production processes. Chipmakers typically invest about a third of their revenues in R&D and equipment. Because it is so capital intensive, aspects such as access to funding and market capacity (considering actual and future demand for goods & services) are vital to sustain technology development.

Graph 35: No single country or company dominates all of the stages of the value chain



Source: IDC Manufacturing Insights

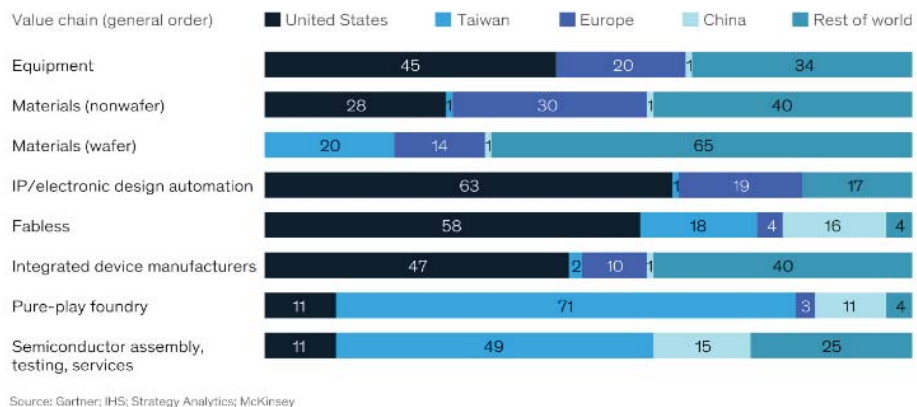
Development and production of semiconductor components in Europe is concentrated mainly in Germany, France, Italy, the Netherlands, Austria, Belgium and Ireland. An extensive ecosystem of companies distributed across Europe supplies materials, equipment and related services for semiconductor manufacturing. The major EU headquartered suppliers Infineon (DE), NXP (NL), ST Microelectronics (FR/IT) and Bosch Semiconductors (DE) operate globally, serving OEMs in automotive, industrial automation, security and healthcare (where they are global market leaders) as well as aeronautics, energy production and telecommunications.

The different shares in revenues across the semiconductor value chain shed more light on where strengths and weaknesses in the EU semiconductor value chain lie (Graph 36). Europe has notable weaknesses in design and design automation tools¹⁷⁸ as reflected in the small share of EU-based companies in “IP / electronic design automation” and “fabless” chip companies. These parts of the supply chain are mainly under US proprietary control. Packaging, assembly and testing, and chip fabrication are located mostly in Asia (see “semiconductor assembly, testing services” and “pure-play foundry”). Advanced packaging technologies – enabling integration of different functional components in single ‘chipllets’ – are increasingly important to address increasing power and energy efficiency needs that come with electrical vehicles on the one hand and the plethora of edge-computing applications driven by AI on the other. **Europe is**

¹⁷⁸ Chip design and electronic design automation environments enable the design of electronic devices and digital components.

thus strongly dependent on the US for general design tools and on Asia for advanced chip fabrication.

Graph 36: Share of revenues per region across the semiconductor value chain



Source: Gartner; IHS; Strategy Analytics; McKinsey

Note: Chips design and electronic design automation tools are protected with intellectual property rights and often referred to as intellectual property (IP).

The European electronic industry enjoys global leadership in innovation positions in power electronics, sensors and advanced chip-making equipment. The ongoing projects under the IPCEI on Microelectronics, approved in December 2018, have played an important role in stimulating additional private investments in innovation and eventually also in manufacturing in the EU¹⁷⁹, in particular for Automotive and IoT markets. Manufacturers of chips at leading-edge nodes (TSMC, Samsung, Intel) rely for their technology development on specific EUV photolithography machines produced by a unique global supplier, notably ASML (NL), which belongs to the European electronic ecosystem. ECSEL Joint Undertaking set up in 2014, which supported close to 80 research projects, was instrumental to advance equipment technology development in miniaturization through the pilot integration of 3nm semiconductor technology.¹⁸⁰

As set out above, **Europe has no foundries that offer advanced manufacturing of components with feature sizes below 22 nm (necessary for memory and processor chips)** and therefore has to rely on Samsung or TSMC to that end. Processors are critical enablers of growing importance in data processing for communication, edge-AI components, and high-end and general purpose computing.

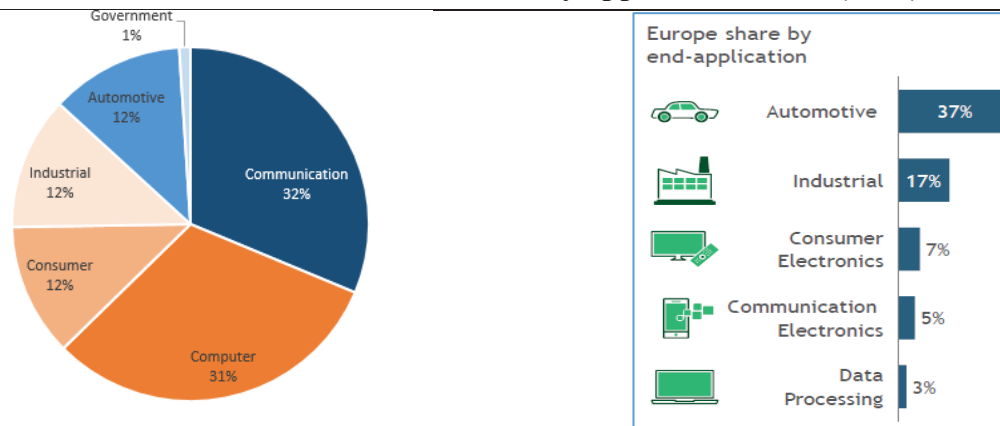
EU suppliers are strong in dedicated processors (micro-controllers) for embedded systems applications in automotive (37% global market share) and industrial uses including machinery (17% global market share). These markets are expected to grow significantly in the coming years. European companies are strong in power management and energy-efficient

¹⁷⁹ The technologies at focus in the approved IPCEI on Microelectronics are divided in 5 technology fields along the microelectronics value chain, namely energy efficient chips, power semiconductors, sensors, advanced optical equipment and compound materials. Automotive and IoT are the two main target markets.

¹⁸⁰ <https://www.ecsel.eu/projects/pin3s>

semiconductor technology solutions in these sectors. **The EU suppliers have currently very limited market presence in generic processor design and process technology design and manufacturing.** This is reflected in modest global market share in communication (e.g. mobile phones) and data processing (e.g. personal computers) amounting to 5% and 3% respectively. In the design of general-purpose processors, Europe relies almost entirely on design tools and design IP developed by US companies.

Graph 37: Global and EU market share in sales by application sector (2019)



Source: SIA and EU Study, respectively.

c) Way forward and relevant (ongoing) measures

With high entry cost, escalating trade tensions and subsidies at global level, dependence on Asia for advanced chip fabrication and on the US for chip design tools, the EU supply chain is left increasingly vulnerable. Europe needs to strengthen its own industrial position to minimise risks from trade disruptions and boost innovation and competitiveness in the application sectors.

Reinforce processors and semiconductor technology for data processing, communication and related data infrastructure, and new applications of AI

Joint European actions and initiatives will need to strongly focus on rebuilding capabilities in processors and semiconductor technologies critical to enable powerful and energy-efficient data processing, communication, infrastructure and the many applications of AI. In this respect, it will be fundamental to reduce critical dependencies in advanced technologies and process technology manufacturing at leading edge nodes, advanced packaging, and in critical IP design blocks and platforms for digital components. Indeed, in terms of manufacturing, high-end microprocessors such as CPUs and GPUs require leading-edge fabrication facilities. A new fab with the latest technology (2nm in 2025/6) is challenging both technologically and economically (EUR 20 billion upfront and EUR 5 billion p.a. to operate) and is not in the reach of any individual EU supplier today.

A joint European effort¹⁸¹ and an investment plan aiming at positioning Europe in emerging critical technologies and at consolidating areas of proven expertise

In a joint declaration ‘A European Initiative on Processors and Semiconductor Technologies’¹⁸² presented at the EU Competitiveness Council of 7 December 2020, a large number of Member States have agreed to work together in order to bolster Europe’s electronics and embedded systems value chain. This will include a particular effort to reinforce the processor and semiconductor ecosystem and to expand industrial presence across the supply chain, in order to address key technological, security and societal challenges. Member States agreed to consolidate and build on Europe’s position in areas of proven expertise, and aim to establish advanced European chip design capabilities and production facilities progressing towards leading-edge nodes for data processing and connectivity. In the joint declaration, the signatory Member States discuss a possible industrial alliance on microelectronics and processors, which could mobilise industrial partners, as well as possibly designing a proposal for an IPCEI.

Concretely, when it comes to cooperating and engaging in efforts to co-invest in next generation semiconductor technologies across the full value chain, the declaration highlights:

- *the mobilisation of industrial stakeholders through a future industrial alliance to establish strategic roadmaps and research and investment plans for processor design, deployment and fabrication that takes into account the full semiconductor ecosystem;*
- *addressing common challenges through various funding mechanisms, including where feasible through the national Recovery and Resilience plans, contributing to a substantial increase in the production capability in Europe of semiconductors and embedded systems across the value chain, and processor chips with significant improvements in energy performance and speed by 2025; and,*
- *the design of a multi-country and inclusive European Flagship Project through the development of a proposal for an Important Project of Common European Interest that aims to create a strong dynamic to bolster Europe’s electronics industry with a focus on the design ecosystem, supply chain capabilities and first industrial deployment of advanced semiconductor technologies, including scaling towards leading-edge process technologies for processor chips.*

European Recovery and Resilience Facility

EU plans for investment in semiconductors have to be considered in a global context of strong regional support to the sector. China, the US, Japan and South Korea are examples of countries devoting large amounts of public resources to minimise dependencies and strengthen their global presence in specific segments of the value chain (e.g. manufacturing, design).

In this respect it is worth noting that semiconductor technologies and notably processor chips, are among the areas identified for investment for the Recovery and Resilience Facility. 20% of the European Recovery and Resilience plans should go to digital transition; this is up to EUR

¹⁸¹ With the involvement of Industry, Member States and the European Commission

¹⁸² <https://ec.europa.eu/digital-single-market/en/news/joint-declaration-processors-and-semiconductor-technologies>

145 billion over the next 2 to 3 years. The Recovery and Resilience Facility presents a unique opportunity to help financing the efforts identified in the December 2020 Declaration mentioned above.

Europe can consolidate its position through joint initiatives and investments involving technology suppliers and users, targeting applications and products with high-added value and strong system integration.

The EU has an important position in mobile network infrastructure but communication equipment (radio base stations, switching centres, central offices) is powered today by components which are mainly designed and made outside the EU, such as critical semiconductor components, including secure processors, for 5G and next generation connectivity.

Research and industrial deployment driven by leading system manufacturers covering design and leading-edge manufacturing could support achieving the EU's objectives as set out in the Digital Decade.

Regulatory framework that boosts competitiveness and protects EU interests

The EU semiconductor sector has been left in a vulnerable position due to lack of investment. But investment alone is not sufficient as is evidenced by the acquisition of companies both large and small despite having been supported financially by the EU and Member States. A more holistic approach is needed.

The recent EU foreign direct investment (FDI) screening regulation that became operational on 11 October 2020 provides the European Commission the opportunity to assess the risks of foreign investments into all companies, including companies active in the semi-conductor sector from a European perspective in terms of impact on security and public order. This includes impact on programmes of Union interest regarding critical infrastructure, critical technologies or critical inputs.

Semiconductor supply chain resilience

Resilient supply chains are essential in times of crisis to absorb shocks, offer options to adjust and speed up recovery. Most supply chains have shown remarkable resilience during the crisis. However, structural problems such as massive distortive government subsidies, export restrictions and pandemic-related spikes in demand contributed to a shortage of chips that first emerged in the automotive sector and then extended to other sectors, including 5G and medical equipment. The EU semiconductor sector will require a resilient, diverse, and secure supply chain to prosper.

The EU strongly supports global efforts in the G20, the WTO and bilateral relations, to monitor critical supply chains, keep them open and undisrupted, and ensure fair and equitable access to critical goods. Enhancing the resilience and sustainability of supply chains is therefore a pillar of the EU's drive towards open strategic autonomy.

Further in-depth assessment and monitoring is needed as regards the risks associated with different stages of the semiconductor supply chain, including on the origins and sources of supplies beyond the EU. Such risks may be related to critical inputs and equipment for the industry, including digital products that may be vulnerable, manufacturing capacities and other

risks that may disrupt, compromise or negatively affect the supply chain (e.g. the existence of possible single or vulnerable suppliers, supply chains with a single point of failure, stages of the chain established in unreliable partner countries). The availability of substitutes or alternative sources for critical inputs are key elements to consider as well. Resilient and sustainable transport also plays an important role in facilitating international trade and preserving the EU's supply chains.

A coherent mix of industrial, research and trade policies can facilitate the process of diversification to alternative sources of supply and strengthening of existing supply chains through partnership and collaboration with likeminded countries. For example, the US review of its semiconductor supply chain (announced on 25 February 2021) directs the US administration to work with partners and allies to ensure that they too have strong and resilient supply chains. This could offer an opportunity for the EU to engage in joint work in the framework of the new Trade and Technology Council bilaterally, or possibly in plurilateral settings with Japan, Korea or Taiwan.

Monitoring of subsidy programmes and market access barriers will continue in multilateral, bilateral and plurilateral settings notably in the public-industry Government Authorities Meeting on Semiconductors (GAMS) for the six semiconductor manufacturing regions (US, Taiwan, Korea, Japan, China and EU), which contributes to achieving transparency and levelling the playing field. This monitoring will enable the Commission, together with other countries, to assess possible solutions to potential trade distortions.

5.6 Cloud and Edge Computing

a) Context and possible weaknesses in the EU

Data is becoming a strategic asset for any organisation in its digital and sustainable transformation. Cloud computing technologies provide the data processing capacities required to enable data-driven innovation, and thus represent a key enabling technology of strategic importance to Europe's industrial future, as emphasised in the New Industrial Strategy for Europe. Cloud computing is a technology that combines hardware and software to allow on-demand remote access to a scalable and elastic pool of shareable and distributed computing resources. Those computing resources include resources such as networks, servers or other infrastructure, operating systems, software, storage, applications and services.¹⁸³

Cloud technologies are crucial for the digital transformation of businesses and the public sector as they offer faster, cheaper and more flexible computing methods than conventional ones. They offer the possibility to scale up company business processes according to varying user demands for data processing and often in a much cheaper way than traditional in-house IT solutions. The accessibility of documents, software or videoconferencing from outside of the traditional office structures made cloud an indispensable technology for running the daily business operations of European companies during the pandemic.

Cloud is also crucial in contributing to common European sustainability goals of the Green Deal by enabling the transformation of different economic sectors of the European economy, while becoming themselves more climate-neutral and sustainable. In the context of **Europe's recovery**, cloud technologies enhance the delivery of public services to citizens and will boost the growth of small and medium-sized enterprises by enabling the creation of new, added-value products and services.

Several trends emphasise the critical importance of cloud and data processing technologies for our society and economy. As highlighted in the **European data strategy**,¹⁸⁴ we are witnessing a shift in the data paradigm. The volume of generated data is greatly increasing and a growing proportion of data is being processed **at the edge**. Edge computing generally refers to a form of delivery of cloud computing services in a highly distributed form, closer to where data are being generated or collected, thus moving from the traditional centralised model of data processing to a highly distributed one. By 2025, 80% of all generated data are expected to be processed at the edge.¹⁸⁵ This shift will require the development and deployment of fundamentally new data processing technologies encompassing the edge, moving away from centralised cloud-based infrastructure models. Cloud and edge will continue to co-exist and new data management techniques will enable to determine where data are best processed, in centralised or in more distributed capacities, closer to the users. The integration of these different data processing capacities with more local computing resources will form a **computing continuum** that is the seamless integration of diverse computing environments spanning from

¹⁸³ COM(2020)823 final, Recital 16

¹⁸⁴ COM(2020)66 final

¹⁸⁵ COM(2020)66 final, p. 2

high performance computing and big data centres to edge, fog, swarm (highly distributed intelligence) and embedded computing.

The data paradigm shift also means that cloud technologies are increasingly becoming strategic innovation enablers for the uptake and effective functioning of technologies such as artificial intelligence, and Internet of Things. In this new data paradigm, less data will be stored in data centres and more data will be spread in a pervasive way closer to the user ‘at the edge’. Processing data much closer to where they are generated or collected allows faster reaction times, which in turn enables new services and applications. The need for abundant computing power crunching data for deep learning and distributed ledgers can be satisfied through the computing continuum formed by the integration of high-performance computing, cloud and edge computing. In the future, one of the main trends for AI hardware computation will indeed be the move to ‘the edge’, on devices that are closer to the users of real-time AI applications. This will also be the case for many other new emerging digital technologies (data analytics, security of transactions, automation, etc.). AI services are estimated to be among the most transformational services leveraging cloud capabilities across the computing continuum, particularly at the edge to execute AI algorithms.¹⁸⁶

Furthermore, cloud computing technologies are crucial for increasing the innovation potential of data sharing and data re-use services. To make the most out of the increasing amount of data produced, the European data strategy foresees the **deployment of EU common data spaces** in key public and private sectors. Data spaces will foster ecosystems (of companies, civil society and individuals) creating new products and services based on more accessible data, and as such increase Europe’s capacities to become a world leader in the data economy. Such common data spaces will heavily rely upon the availability and access to secure, energy-efficient, affordable and high-quality data processing capacities.

The current COVID-19 crisis has further highlighted the critical importance of availability of data processing technologies for our economy and society. The crisis had the effect of a growing use of cloud-enabled services, such as videoconferencing, data analytics and collaborative platform services. Secure processing, storage, sharing and analysis of public and industrial data as well as collaborative services, such as distance learning and teleworking have become essential services to EU citizens, businesses and the public sector. Cloud played also a crucial role in coronavirus research, as it enables availability and effective sharing of massive quantities of biochemical data.¹⁸⁷

The New Industrial Strategy for Europe emphasised that the strengths of the European industry needs to be channelled towards gaining leadership in areas where the EU still lags behind, such as on cloud technologies and data applications.¹⁸⁸ Currently, the public cloud infrastructure market is converging globally around four large non-European companies. The United States has the most significant companies in the global cloud market, and in particular,

¹⁸⁶ IDC Future Scope: Multiplied Innovation Takes Off, Powered by AI, Distributed Public Cloud, Microservices, Developer Population Explosion, Greater Specialization and Verticalization, and Scaling Trust, 2019.

¹⁸⁷ <https://www.h-cloud.eu/news/cloud-computing-and-covid-19/>

¹⁸⁸ COM(2020)102 final, p. 2

the public cloud infrastructure market that generates the biggest revenues,¹⁸⁹ while Europe currently has no significant global cloud infrastructure companies. This market structure could create entry barriers for new or smaller companies, which lack the necessary resources to scale-up their services notably across borders, or deploy the latest state-of-the-art technologies. Furthermore, a strong degree of vertical integration of different cloud services (such as bundling of infrastructure and software services) especially by large cloud providers¹⁹⁰ may also make market entries of the new providers more difficult. Several Chinese companies are also starting to invest heavily and will increasingly enter the EU cloud market. Also, the public cloud infrastructure market largely overshadowed by the US players also raises concerns over the European cloud users' ability to maintain control over strategic and sensitive personal and non-personal data. Unfair commercial practices¹⁹¹ and a lack of interoperability and data portability between cloud providers create risks of vendor lock-in, undermining users' trust in cloud computing services and cloud uptake.

However, Europe has a unique market opportunity in the next five years to strengthen its data processing technologies by capitalising on the changes to come, in particular related to edge computing. To seize it, Europe can build on its industrial expertise and strength in some areas of the computing value chain, such as business-to-business application, system integration, industrial Internet of Things systems and 5G. Finally, the EU has a unique regulatory framework to become a standard setter also in a global merit for non-discriminatory norms on data storage and processing. This would also allow to address European users' demand for increased transparency and control over legitimate access, processing and storage of their personal and commercially sensitive data.

b) Origin of vulnerabilities

The vulnerabilities of the EU cloud market lay predominantly in the market's structure.¹⁹² A few large, foreign cloud providers dominate the public cloud market in the EU. The top four global leaders on the public cloud infrastructure market – often referred to as hyperscalers (Amazon Web Services (AWS), Microsoft Azure, Google Cloud and Alibaba Cloud) will account for over 80% of global revenues in 2021.¹⁹³ They are also among the most popular cloud providers for European businesses. According to Synergy Research Group's data, a few EU cloud and telco providers (OVH cloud, Deutsche Telecom, Orange, KPN) challenge their popularity to a limited extent within selected national markets in the EU.

¹⁸⁹ Synergy Research Group, 2021: <https://www.srgresearch.com/articles/cloud-market-ends-2020-high-while-microsoft-continues-gain-ground-amazon>

¹⁹⁰ See section b) below

¹⁹¹ The most prevalent unfair practices in cloud contracts are mapped in the European Commission's *Study on the Economic Detriment to Small and Medium-Sized Enterprises Arising from Unfair and Unbalanced Cloud Computing Contracts*, 2019: https://ec.europa.eu/info/publications/study-economic-detriment-small-and-medium-sized-enterprises-arising-unfair-and-unbalanced-cloud-computing-contracts_en

¹⁹² COM(2020) 66 final, p. 9

¹⁹³ <https://www.gartner.com/en/newsroom/press-releases/2020-08-10-gartner-says-worldwide-iaas-public-cloud-services-market-grew-37-point-3-percent-in-2019>

Graph 38: Europe Cloud services leadership

Rank	Total Europe	Germany	France	Netherlands	Rest of Europe
Leader	Amazon	Amazon	Amazon	Amazon	Amazon
#2	Microsoft	Microsoft	Microsoft	Microsoft	Microsoft
#3	Google	Google	OVH	Google	Google
#4	IBM	Deutsche Telekom	Orange	KPN	IBM
#5	Salesforce	IBM	Google	IBM	Salesforce
#6	Deutsche Telekom	Oracle	IBM	Oracle	Swisscom

Source: Based on IaaS, PaaS and hosted private cloud revenues in Q1 2020. The data come from Synergy Research Group, 7 May 2020.¹⁹⁴

Compared to the non-European hyperscalers, the EU-based cloud providers hold a relatively small market share, both at the European and global level. The largest European cloud service provider accounts for less than 1% of total revenues generated in the European market.

This asymmetric market share is exacerbated by an asymmetric investment gap of EUR 11 billion annually in cloud,¹⁹⁵ which represents the estimated difference between what the EU competitors (US/China) and the EU (both private and public actors) invest in cloud.¹⁹⁶ This disproportion in investments is also reflected in the higher **innovation capacity** of the leading cloud providers towards European cloud providers.

Large foreign cloud companies are also effective in closing strategic acquisitions,¹⁹⁷ **forming strategic partnerships**¹⁹⁸ **and performing strategic investments**¹⁹⁹. Acquisitions of software providers allow them to provide a **whole stack (i.e. integrated suite) of cloud services** (Software as a Service (SaaS), Platform as a Service (PaaS)) on top of Infrastructure as a Service (IaaS),²⁰⁰ which are cheaper and more convenient for customers than paying for each component

¹⁹⁴ <https://www.srgresearch.com/articles/amazon-microsoft-lead-cloud-market-all-major-european-countries>

¹⁹⁵ See SWD(2020) 98 final, p. 18, Table 2 which identified investment gaps in several EU digital sectors including cloud

¹⁹⁶ On average, the US cloud providers invest ten times more in the research and innovation at the different cloud layers than their EU competitors do

¹⁹⁷ For example, IBM's acquisition of Red Hat (2019), Microsoft's acquisition of GitHub (2018), Salesforce's acquisition of Mulesoft (2018)

¹⁹⁸ For example, Microsoft and Volkswagen partnership (2019) to create new automotive cloud; Deutsche Bank and Google Cloud partnership (2020) to co-innovate the next generation of cloud-based financial services

¹⁹⁹ For example, Microsoft's USD 1.5 billion investment plan to accelerate digital transformation in Italy (2020) as well as its data center region investments in Greece (2020) and Austria (2020); Google's USD 2 billion investment in a data center in Poland

²⁰⁰ For an explanation of these different cloud service models see for example p. 33-34 of [annex](#) to the Commission's communication COM(2017) 476 final 'Making the most of NIS – towards the effective implementation of Directive (EU) 2016/1148 concerning measures for a high common level of security of network and information systems across the Union' or definitions of these service models in [ISO/IEC 2014:17788](#)

separately, although often leading to vendor lock-in effects.²⁰¹ Strategic partnerships and investments on the other hand allow them to intercept early the specific geographic or product markets in need of specific cloud solutions, and to establish and further build their strong presence on these markets.

From an EU industrial perspective, the market position and scale of the hyperscalers on these markets makes market entries by other competitors less rewarding (the first mover advantage and economies of scale) and prevents the rise of European leadership on new market segments. Specific EU cloud users' needs (including processing capacities that are close to the user with demonstrated compliance with EU privacy and personal data processing legislation, providing for highly-secured processing environments, preventing unilateral access to the data by foreign authorities or any third party and with the reassurances on data processing locations) may not be served.

In addition, vendor lock-in by hyperscalers,²⁰² but also smaller specialized cloud-based software service providers creates direct dependencies of the EU users' base on these cloud providers.²⁰³ The cloud users have in practice a very limited if non-existing possibility to switch between different cloud service providers or to port their data to other service providers and to their own data processing systems.²⁰⁴ This is caused not only by the vertical integration of the hyperscalers making it less profitable for users to seek European alternatives, but also because of the lack of interoperability between the different cloud solutions that technically hampers data portability. Recent developments towards hybrid and/or multi-cloud strategies by cloud users may mitigate the effect of vendor lock-in, if users can bear the additional costs of handling multiple cloud contracts. The use of so-called container technology allows applications to run in any type of environment, including different public and private clouds. Vendor lock-in ultimately hampers the flow of data across the EU and beyond, a profitable functioning of data value chains and the creation of an open, innovative, and sustainable European data economy.

Another reason for dependency of EU cloud users on the hyperscalers is the (purported) non-existence of an equivalent cloud products offer by the European providers. This is **despite EU cloud users and public authorities frequently expressing their concerns with the use of foreign cloud services for reasons of personal data protection, cybersecurity or questions over applicable law.**²⁰⁵ These concerns regarding potential unlawful access to their data by third

²⁰¹ IDC and Arthur's Legal - Switching of Cloud Services Providers (2018) <https://op.europa.eu/en/publication-detail/-/publication/898aeca7-647e-11e8-ab9c-01aa75ed71a1>

²⁰² See SWD(2017) Impact Assessment accompanying the proposal for a framework for the free flow of non-personal data in the European Union: <https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/1088-2nd-Data-Package>

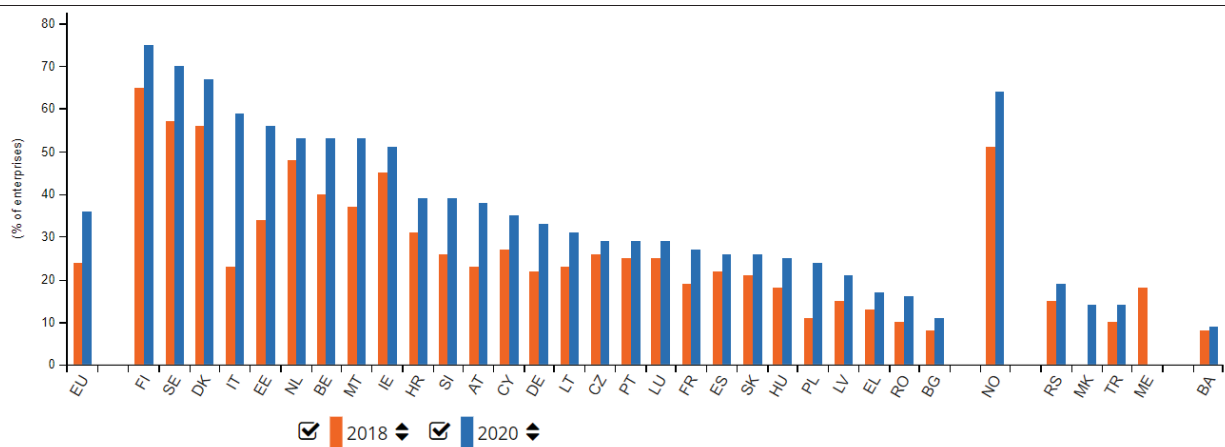
²⁰³ Ibid study "Switching of Cloud Services Providers" (2018)

²⁰⁴ Ibid

²⁰⁵ See for example the recommendations by French national data protection authority in relation to use of foreign cloud provider for hosting the French Health Data Hub: <https://www.cnil.fr/en/council-state-asks-health-data-hub-additional-guarantees-limit-risk-transfer-united-states> or the German data protection authorities ruling on Microsoft Office 365 data protection: <https://www.datenschutz.saarland.de/ueber-uns/oeffentlichkeitsarbeit/detail/pressemitteilung-vom-02102020-stuttgart-muenchen-ansbach-wiesbaden-saarbruecken>

countries, if the data is hosted with the providers falling under the foreign jurisdiction, exacerbated after the findings of the Court of Justice of the EU regarding national intelligence measures of third countries.²⁰⁶ The EU is acting to mitigate such concerns through mutually beneficial international cooperation, such as the proposed EU-U.S. Agreement to facilitate cross border access to electronic evidence²⁰⁷, alleviating the risk of conflict of laws and establishing clear safeguards for the data of EU citizens and companies. Additionally, in its recent proposal for the Regulation on European data governance of 25 November 2020²⁰⁸, the Commission continues in its open but assertive approach of the EU Data Strategy, and introduces provisions fully safeguarding the protection of public data held by public sector bodies, users reusing that public data, data intermediaries or recognised data altruism organisations when transferred abroad.²⁰⁹

Graph 39: Use of cloud computing services (2018, 2020)



MK: 2018 not available
 ME: 2020 unreliable
 Note: IS: data not available
 Source: Eurostat (online data code: isoc_cicce_use)

eurostat

Source: Eurostat, 2020²¹⁰

The vendor lock-in practices, unfair contract terms, data protection and cybersecurity risks as well as the lack of suitable cloud offering satisfying the needs of the EU cloud customers are the most proliferating problems for the EU-based cloud users²¹¹ and as such are the main reasons for low cloud uptake in the EU. According to Eurostat’s data, while

²⁰⁶ See Judgment of the Court (Grand Chamber) of 16 July 2020 in *Data Protection Commissioner v Facebook Ireland Limited and Maximilian Schrems*, C-311/18, ECLI:EU:C:2020:559.

²⁰⁷ https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_19_5890

²⁰⁸ Proposal for a Regulation of the European Parliament and of the Council on European data governance (Data Governance Act), COM/2020/767 final

²⁰⁹ See Article 30 of the Data Governance Act proposal

²¹⁰ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Cloud_computing_-_statistics_on_the_use_by_enterprises (the difference in results with the statistics on uptake of technologies outlined in chapter 3.1 can be explained by the fact that the survey used as a reference in chapter 3.1 has been more oriented towards large organisations)

²¹¹ See the Summary Report on the open public consultation on the European strategy for data, 2020, <https://ec.europa.eu/digital-single-market/en/news/summary-report-public-consultation-european-strategy-data>

improved compared to 2018, only 36% of EU enterprises used cloud services in 2020, mostly for simple services such as for e-mail and storage of files. Only 55% of those enterprises use advanced cloud services relating to financial and accounting software applications, customer relationship management or to the use of computing power to run business applications. The difference between the top performers and the Member States with the lowest cloud uptake is also still significant. Cloud uptake in the EU is even lower among public administrations. Apart from the above mentioned reasons, an additional reason for this situation appears to be the lack of common criteria for procurement of cloud services in Europe.²¹²

The **dependencies of the EU cloud customers on foreign cloud providers** lead to a loss of investment potential for the European digital industry in the data processing market, putting the European open strategic autonomy at risk.

The dependencies are however not necessarily the same across all segments of the cloud market and computing continuum. In particular, EU industry is for now less dependent in the currently nascent edge computing segment and certain market sub-segments of the cloud service offerings (e.g. in software as a service and data analytics) and in the system integration of smart and low power cloud platforms and middleware.

European companies also have the potential to grow in many industrial and business sectors like smart energy systems, smart home appliances, enterprise systems, manufacturing, smart mobility, smart agriculture and food, as well as green technologies in general. They master well the technologies in today's cyber-physical and Internet of Things (IoT) systems including industrial cloud solutions. European companies largely control today's complex value chains in these sectors including their digital components from sensors and electronic control units to systems technologies. European Telecom suppliers and operators are strong in 5G, which has the potential to become the standard network technology – for the first time – enabling direct and seamless network communication from the far-edge level to the cloud, thus supporting the emerge of a European cloud computing continuum. In addition, they still today enjoy a much stronger proximity with their clients, both physically and culturally.

Opportunities for the European computing market

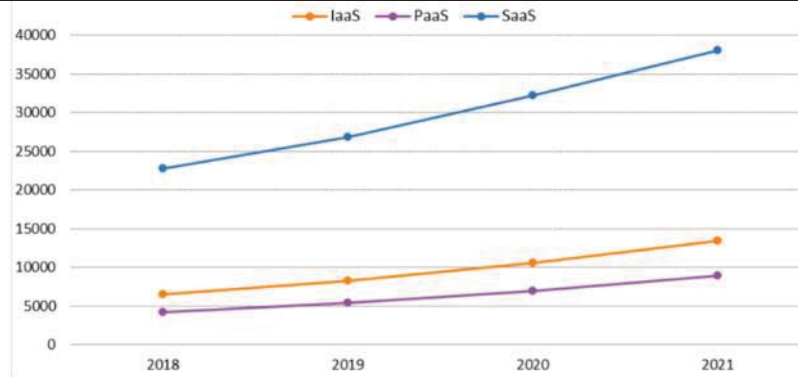
Software as a Service (SaaS) market

The total revenues generated by public cloud services (Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS)) across the EU market increased by 21% between 2018 and 2019. The 2020 DESI report forecasts that their total revenues are expected to continue to grow by 50% between 2019 and 2021.²¹³ In 2019, SaaS represented almost two thirds of total public cloud revenues generated within the EU market, a trend poised to continue until at least 2021.

²¹² See p. 26 of [H-CLOUD Green Paper](#), which names further reasons for the low uptake of cloud technology in the public sector

²¹³ Digital Economy and Society Index (DESI) 2020, Integration of digital technology report, p. 8 https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67076

Graph 40: EU public cloud service revenues per deployment model, 2018 – 2021 (€ million)

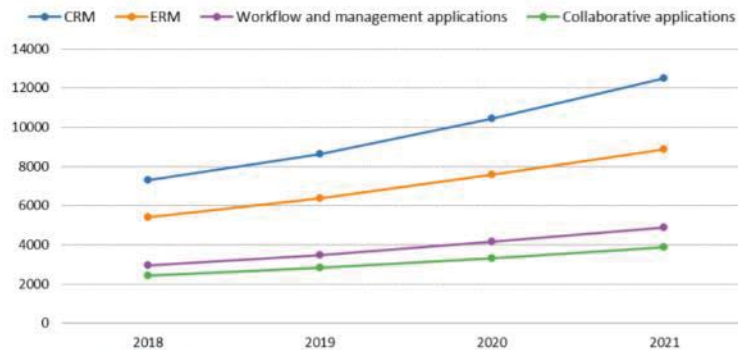


Source: European Commission based on IDC.

Source: European Commission based on IDC

Between 2018 and 2019, four applications (customer relationship management, enterprise risk management, workflow and management and collaborative applications) contributed the most to SaaS revenues across the EU market. They are expected to remain the most prominent until at least 2021 with respective revenue growth rates of 40.1 %; 44.6 %; 40%; and 37.5 % between 2019 and 2021.²¹⁴ Furthermore, in 2019 software security provided as SaaS application, contributed with EUR 115.5 million to total SaaS revenues within the EU market. With its revenue growth rate expected to increase by 48% between 2019 and 2021, it should be the fastest growing SaaS application over this period. **This strong growth in software services constitutes a major opportunity for European providers to leverage their position in the SaaS market.**

Graph 41: Revenue of the top four SaaS applications in share of total SaaS EU revenues, 2018 – 2021 (€ million)



Source: European Commission based on IDC.

Source: European Commission based on IDC

²¹⁴ DESI 2020, Integration of digital technology report, p. 9

Edge computing

Furthermore, as introduced earlier, the way in which data is stored and processed is progressively changing²¹⁵ with **edge computing gaining momentum**.²¹⁶ The main users of edge services are healthcare, transport, financial, manufacturing, retail and energy and utilities sectors as well as governments, which need to process large volumes of data in a real time. Considering the increasing trend where more and more data will be generated at the edge, this will **give a market advantage to those actors who deploy the edge nodes**. According to IDC's forecast, the worldwide edge computing market will reach USD 250.6 billion (around EUR 206.5 billion) in 2024.²¹⁷

Today, there are no dominant players or world regions for edge computing.²¹⁸ However it is expected that over the next several years the investments on edge computing will be concentrated mostly in the US, China and Western Europe (IDC estimates that the EMEA region will capture 27.9% of the overall global edge market spending²¹⁹).

The combination of (1) a new technical paradigm (cloud to edge computing), (2) an emerging edge computing market, and (3) initial conditions where European providers (telecommunication sector, cloud providers, edge providers) have some strengths, constitutes the **best opportunity for Europe to revert today's cloud market structure and regain autonomy in a market dominated by non-EU providers**. European focus could also be on supporting the emergence of smaller providers at the edge market and their growth, in order to prevent the situation where a few big actors dominate this market.

Telco-cloud and multi-cloud computing

The roll-out of 5G networks around the globe, sometimes referred to as **telco-cloud solutions**,²²⁰ **constitutes another opportunity**. Being home to a number of strong telecommunications providers that have a key role in investing and operating edge computing capabilities over their

²¹⁵ The reasons for the increasing popularity of edge technologies include the increased use of connected devices that are generating progressively more data and are demanding increasingly more computing capacities to provide real-time insights. The other factors for the rise of edge computing include 5G use cases (URLLC) requiring low latency; augmented/virtual/mixed reality that are requiring faster processing capabilities to unlock the technology value; large volumes of videos that are a significant burden for network workloads; AI that is demanding high amounts of computations closer to where the data are being produced; data analytics requiring large volumes of computer operations to accelerate speeds of insights.

²¹⁶ Benefits of edge computing include localized computing power close to the user, low latency, hybrid storage capacity, security, energy-efficiency and increased control of the user over their data.

²¹⁷ Forecast by IDC's Worldwide Edge Spending Guide, 2020, <https://www.idc.com/getdoc.jsp?containerId=prUS46878020#:~:text=According%20to%20the%20new%20Worldwide,the%202019%E2%80%932024%20forecast%20period>.

²¹⁸ It is expected that half of the edge computing market will be captured by cloud providers, the other half will be captured by software, IoT, AI, consulting, telecommunication, infrastructure, system integrator and semiconductor companies.

²¹⁹ IDC's Worldwide Edge Spending Guide, 2020

²²⁰ Telco edge-cloud can be described as small data center resources required for local data processing of different services, with data transfer capabilities by carrier companies. Telco edge-cloud solutions typically include network function virtualization (NFV) that accelerates the speed of launching 5G networks, software-defined data centers (SDDC) and networking (SDN), as well as multi-access edge computing (MEC).

networks in Europe, the EU also has an advantageous position to establish a visible presence in the telco-cloud market. Utilizing the expertise of European telecom providers combined with the specialization of European cloud providers, Europe can build telco-cloud solutions notably at the edge – leveraging the joint deployment of 5G and edge computing infrastructures – in a way that meets the security and environmental requirements of the European market.

A further opportunity for Europe is the market for **multi-cloud**.²²¹ Multi-cloud solutions gain their popularity as a risk-mitigation tool in order to minimise the risks of data loss or downtime caused by local component failure in the cloud environment. While the foreign cloud hyperscalers are moving towards extending their leadership also on this market, a competitive European alternative for a multi-cloud solution would be needed, building on an open source and governance by an independent organisation.

c) Way forward and relevant (ongoing) measures

While the recent proposal for a Digital Markets Act²²² aims to achieve a fairer and more competitive business environment between business users of cloud services and so-called **gatekeepers** among the providers of cloud computing services,²²³ the vulnerabilities identified in the EU cloud market also concern a broader category of cloud service providers, including smaller cloud providers. There is a need to safeguard practical compliance with the EU legislative framework, enable data portability, resolve vendor lock-in issues and address the innovation needs in a setting that applies to all cloud service providers in the EU market.

In line with Europe’s data, green and industrial strategies and in order to capitalise on the data paradigm shift and next wave of innovation, a coordinated European action between the EU, Member States and industry is critical to trigger major investments in the next generation cloud technologies meeting the key EU rules and standards. The advent of edge computing could serve to strengthen the position of EU businesses in the cloud market, to provide a complementary European supply alternative. Building on its strength in industrial and business applications, industrial IoT systems and 5G, Europe has a one-time opportunity to bring its industrial actors back to playing a significant role in the computing market by 2025, improving its open strategic autonomy.

The EU will support research and development, and the large-scale deployment of next generation cloud infrastructures and services across the EU. In the European data strategy, the European Commission sets out its ambitions for the period 2021-2027 to co-invest in European data spaces and a **European cloud federation**. These investments will be channelled through the *Digital Europe Programme*, *Connecting Europe Facility 2* and *Horizon Europe*. The focus must be on fostering a competitive, secure, trustworthy, sustainable, distributed, end-to-end European computing supply that will adapt to a multiple vendor environment and enable the

²²¹ Multi-cloud can be described as a use of several cloud computing services under a single heterogeneous cloud architecture

²²² COM(2020) 842 final. The Digital Markets Act complements (EU and national) competition law which remains fully applicable.

²²³ See Article 2(1) of the Digital Markets Act proposal COM (2020)842 final

deployment of European data spaces. This supply should enable the transition to a computing continuum with strong capacities at the edge and far edge in an energy efficient and trustworthy manner. It will ensure the gradual rebalance between centralised data infrastructures in the cloud and highly distributed and smart data processing at the edge across the EU.

EU investments will be complemented by private and national co-investments. In October 2020, all Member States signed the **joint Declaration** ‘Building the next generation cloud for business and public sector in Europe’²²⁴ and agreed to work together via DEP, CEF2 and the Recovery and Resilience Facility (RRF), to upgrade existing data processing capacities, shape the next generation cloud supply for Europe and stimulate the uptake of cloud services across the EU. The **Recovery and Resilience Facility ‘Scale up’ Flagship** (as part of Next Generation EU) will be a significant channel for Member States’ investments in data processing capacities. Under the Scale-up, cloud is identified as one of the areas for strategic investments and reforms, with the aim to close Europe’s cloud investment gap and foster cloud adoption. The 2021 Annual Sustainable Growth Strategy establishes a ‘Scale-up’ *EU Flagship* with the ambition of **doubling the use of advanced cloud services**²²⁵ by 2025 across the EU compared to 2018 levels (i.e. from 16% to 32%). Member States also have the possibility to co-invest in the context of **multi-country-projects** to foster the access to cloud and edge capacities from anywhere across the EU territory.

The Industrial Strategy from March 2020 stated that future Alliances should include Industrial Clouds and Platforms. A European Alliance for Industrial Data, Edge and Cloud would be launched in 2021 to facilitate the emergence of a European offering of next generation, trustworthy, energy efficient and competitive cloud and edge services. The European Council’s conclusions of 1-2 October 2020 and the Member States joint declaration on cloud of October 2020, called for the creation of such an Alliance to strengthen Europe’s industrial position in cloud and edge and foster cloud uptake. In this context, the Commission will also aim at creating synergies between national and cross-border initiatives, to enhance and broaden their scale and coverage.²²⁶ This would also increase the sustainable and competitive adoption of cloud by European businesses and public administrations, and increase access and choice for these professional users across the EU.

In parallel, several Member States launched an open and inclusive process to jointly prepare with other interested Member States a possible **Important Project of Common European interest (IPCEI)** focusing on **next generation cloud and edge infrastructure and services**.²²⁷ The

²²⁴ <https://ec.europa.eu/digital-single-market/en/news/towards-next-generation-cloud-europe>

²²⁵ Such as financial and accounting software applications, customer relationship management or to the use of computing power to run business applications.

²²⁶ The Gaia-X initiative for “a European federated data infrastructure” is a leading example of a public-private initiative aiming at a broad European scope. Together with this, many Member States already have national cloud initiatives that can provide the basis for further cooperation.

²²⁷ As part of Germany’s Presidency of the Council of the EU, on 17 December 2020 Germany held a high-level online event on Important Projects of Common European Interest (IPCEIs) during which it jointly with France, Italy and Spain announced the intention to develop a possible IPCEI focusing on cloud and edge. Since then the Member States participating in the preparatory work of this possible IPCEI organised several workshops for the public

European Commission will accompany Member States in order to set this up in accordance with the requirements in the IPCEI Communication.²²⁸

Other EU investments on cloud will support the emergence of vivid data, computing and Artificial Intelligence ecosystems. EU investments for rolling out AI into all sectors of the economy, support advanced skills and maximise the availability of data through the deployment of common European data spaces, calls for capacities for secure hosting, access, sharing and use of data at scale across the EU. At the same time, it will stimulate the deployment of pan-European cloud to edge data infrastructures and services. The 2018 Coordinated Plan on Artificial Intelligence points to the importance of deploying European data spaces and pan-European computing infrastructure and cloud-services, especially given the international competition for access to data. The new Data Governance Act²²⁹ will set the right enabling conditions for companies and individuals to voluntarily make their data available for the wider common good and provide the framework for European data spaces. The future European Alliance for Industrial Data, Edge and Cloud will support connecting the building up of European data spaces with the rollout of pan-European cloud to edge data infrastructures and services. This will contribute to the emergence of thriving and resilient European-grown data, computing and AI ecosystems, including small and medium enterprises.

Finally, enhance access to fair, competitive and trustworthy cloud solutions. Next to the supply side, EU investments through *Digital Europe* will also be directed at deployment on the market: the Commission intends to co-invest in setting up an **EU online cloud marketplace**, enabling EU customers with specific needs to access pre-approved cloud services. By Q2, 2022, an **EU Cloud Rulebook** will create a comprehensive overview of a common set of EU rules and standards applicable to cloud services operating on the EU market.²³⁰ Such a compendium will provide legal certainty to businesses and the public sector using cloud services, as well as raise the profile of those European providers meeting the requirements. The EU Cloud Rulebook will serve as a reference for services offered on the future **EU online cloud marketplaces**. To stimulate the **public sector demand** and increase legal certainty, the Commission will also develop common requirements for public procurement of cloud services, in close cooperation with Member States authorities.

administration and industry participants, to gather their support and to shape the project further. The project is open for participation to all Member States.

²²⁸ Communication from the Commission: Criteria for the analysis of the compatibility with the internal market of State aid to promote the execution of important projects of common European interest (2014/C 188/02)

²²⁹ European Commission, Proposal for a Regulation on European data governance (COM/2020/767 final).

²³⁰ Areas of attention are: cybersecurity, energy efficiency, fair market practices (e.g. portability), data protection, business continuity and data sovereignty

6 Conclusions

This staff working document has highlighted the existence of possible strategic dependencies in some more sensitive ecosystems. A bottom-up (quantitative) mapping using external trade flows in goods across the more sensitive ecosystems as its starting point, shows the existence of certain dependencies notably in the energy intensive industries ecosystem (including raw/processed materials and chemicals), the health ecosystem (including active pharmaceutical ingredients and other health related products) as well as other inputs and products that are relevant to support the green and digital transformation. Furthermore, an assessment of the EU's performance in advanced technologies shows strengths but also certain weaknesses (e.g. for cloud, semiconductors), highlighting risks of possible (future) dependencies in this area emerging or further materialising. Finally, also internal dependencies may exist within the Single Market whereby the EU relies on a limited number of firms within the Single Market. Further discussion with Member States and industry will allow assessing the exact nature of identified dependencies in more detail.

Any measures to address strategic dependencies would need to be tailored and proportionate based on a policy mix that considers the potential of both external and internal actions. The assessment confirmed the need to intensify already ongoing efforts to identify and address strategic dependencies, including in the context of the Action Plan on Critical Raw Materials and the Raw Materials alliance, the Pharmaceuticals Strategy, the Chemicals Strategy as well as other specific actions with regard to key products or inputs necessary for the green and digital transformation (e.g. batteries, semi-conductors, hydrogen). Also concerning possible dependencies in the area of advanced technologies, ongoing efforts can facilitate an important step forward, including investments and research under the Recovery and Resilience Facility and Digital Europe, the Horizon Europe programme, as well as recent actions announced under the Digital Decade Communication and the Action plan on synergies between civil, defence and space industries (including the EU Observatory of Critical Technologies). IPCEIs and industrial alliances can also play important roles in specific sectors, where proved well targeted, justified and efficient tools. Finally, regarding possible internal dependencies, a well-functioning Single Market and competition policy enabling strong business dynamics play an essential role by diversifying sources of supply within the EU. Strong and diversified trade relationships and commercial partnerships with third countries also help to reduce any such internal dependencies.

Annex

FactSet's database

Firm level data on relationships between companies comes from FactSet's Supply Chain Relationships database. The data covers listed and other major companies globally. Therefore, the dataset is not a census and it may underrepresent SMEs, but its coverage is sufficient to capture the major trends in a given sector. The database records the existence of a link between a given pair of firms, but not the type of product or service traded. For each company, the most prominent customers, suppliers and partners are identified according to the information disclosed in annual reports, press releases and other sources. As a result, relationships of smaller importance or magnitude may be kept out of the scope of the database. It is also possible to identify the areas of activity of a firm according to a detailed FactSet Revere Business Industry Classification System (RBICS). The data use for the analysis does not control for ultimate ownership of corporate groups. Each company is given the nationality of its headquarters location. For some multinational groups this may imply that foreign subsidiary information and trade flows are assimilated to the mother company.