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Assessing Open Strategic Autonomy

A two-dimensional index to quantify EU-27 autonomy in industrial ecosystems and strategic technologies

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Abstract

The objective of this report is to help increase the EU's open strategic autonomy (OSA) by providing data that help monitor and take steps to achieve OSA in the innovation and production domains. The report operationalises the concept and provides empirical insights into the current situation. It finds that the EU's digital sector has obvious vulnerabilities that impair its OSA, most prominently in the areas of artificial intelligence and big data. Other areas of innovation also display some vulnerabilities, but which less obviously impair Europe's OSA, at least on the surface. In addition to pure economic dependencies, the changing geopolitical landscape has increased potential vulnerabilities stemming from international collaboration on innovation. Accordingly, increased attention should be paid to latent risks that might produce non-obvious or indirect innovation and production dependency relations in the future. In this respect, the role of the US is particularly critical, as US technologies and firms play a substantial role in innovation processes in Europe.

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Executive Summary

Objectives and policy context

Open strategic autonomy (OSA) is a political concept encompassing strategic, technological, autonomy and vulnerability considerations. 'Strategic autonomy' refers to the capacity of the EU to act autonomously in strategically important policy areas. The addition of 'open' stresses that the EU aims for multilateral cooperation wherever possible and appropriate. Since 2020, these concepts have taken on greater relevance due to the political discussion surrounding two interrelated challenges: geopolitical tensions and strains on global value chains. Both of these challenges are rooted in different crises (such as the COVID-19 pandemic, supply chain bottlenecks, and the Ukraine war)[1]. Sometimes the terms 'strategic autonomy' and 'OSA' are used interchangeably, and it is not easy to distinguish between them.

The EU has been one of the world's leading innovators for decades, but it relies heavily on imports of energy and raw materials. The afore-mentioned crises have therefore been a particular challenge for the EU, both socio-economically and geopolitically. They have increased the risk of weakening the EU's global position in innovation. A weaker and less innovative EU might ultimately limit the capacity of European policy makers to act according to Europe's strategic goals and historic core values. At the same time that OSA is an increasing priority for the EU, the EU is also facing the challenge of leading the green and digital transformations (Diodato et al. 2023).

Some studies have looked at how best to balance industrial competitiveness and OSA. In the context of the European Commission's 2021 'strategic foresight' agenda, a JRC report[2] presented scenarios for how to approach this balance, but this report has now largely been overtaken by the current trend for 'de-globalisation'. Another report issued in 2021, the Foresight report[3], outlined ten strategic areas of action to address the issue of OSA, but the report did not encourage any action by Member States or the Commission in these areas.

In addition, Europe's innovation leadership is being challenged by global competitors, and by the US and China in particular. The US and China are leading innovation in key sectors such as health and information and communications technology (ICT), and their achievements are already challenging the EU's innovation leadership in the automotive sector, a historically strong area for European innovation. The question now arises as to how Europe can boost industrial innovation while striking a proper balance between different policy objectives, and in particular how Europe should approach the potential trade-offs between OSA, the transformative green and digital transition agendas, and global industrial competitiveness. From the point of view of industrial innovation, this means that new approaches are needed for policies dealing with key sectors and technologies.

The EU's industrial policy (European Commission, 2020) strives to support the twin green and digital transitions, to make EU industry more competitive globally, and enhance Europe's open strategic autonomy. Its update due to COVID (European Commission, 2021) adds the resilience aspect in the light of supply chain bottlenecks and monitoring of vulnerabilities in supply chains[4]. In this context, certain sectors and technologies, such as energy, mobility, health, food supply, digital, and space-defence-security, have become critical not only regarding current vulnerabilities but also with respect to establishing innovative capabilities to ensure future prosperity.

Therefore, industrial innovation and OSA policy agendas are closely related in practice and could produce mutual synergies. OSA is at the core of the EU's industrial and innovation policy and requires transformative changes rather than incremental innovation and business-as-usual strategies (Amoroso et al., 2023). Industrial policy initiatives since 2020 thus combine with OSA objectives and ambitions to foster leadership in key technologies, e.g. the US Chips Act, or the "Made in China 2025" policy. EU policy initiatives undertaken within the EU's updated Industrial Policy Strategy (European Commission, 2021), and implemented via the Chips Act, the Net Zero Industrial Act and the Raw Materials Act. The September 2023 Strategic Technologies for Europe Platform (STEP[5]), address the need to further boost investments in critical technologies in Europe. They seek to reinforce, leverage and steer EU funds to invest in deep and digital, clean and bio technologies in the EU, and in people

[1] EPSR (2022).

[2] See https://publications.jrc.ec.europa.eu/repository/handle/JRC125994.

[3] See https://commission.europa.eu/strategy-and-policy/strategic-planning/strategic-foresight/2021-strategic-foresight-report_en.

[4] This includes a monitoring of products for their vulnerabilities, see https://single-market-economy.ec.europa.eu/ publications/enhanced-methodology-monitor-eus-strategic-dependencies-and-vulnerabilities_en, as well as in-depth review of areas of strategic interest for Europe, see https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy/depth-reviews-strategic-areas-europes-interests_en.

[5] https://commission.europa.eu/strategy-and-policy/eu-budget/strategic-technologies-europe-platform_en

who can implement those technologies in the economy. STEP also introduces the Sovereignty seal – an EU quality label for sovereignty projects. The European Council's October 2023 Granada Declaration emphasises the focus on long-term competitiveness with the ambition to reduce external dependencies in key areas where the EU needs to build a sufficient level of capacity to guarantee its economic and social welfare, such as digital and net-zero technologies, critical medicines and raw materials, while also strengthening those already with a competitive edge or the potential to become frontrunners[6].

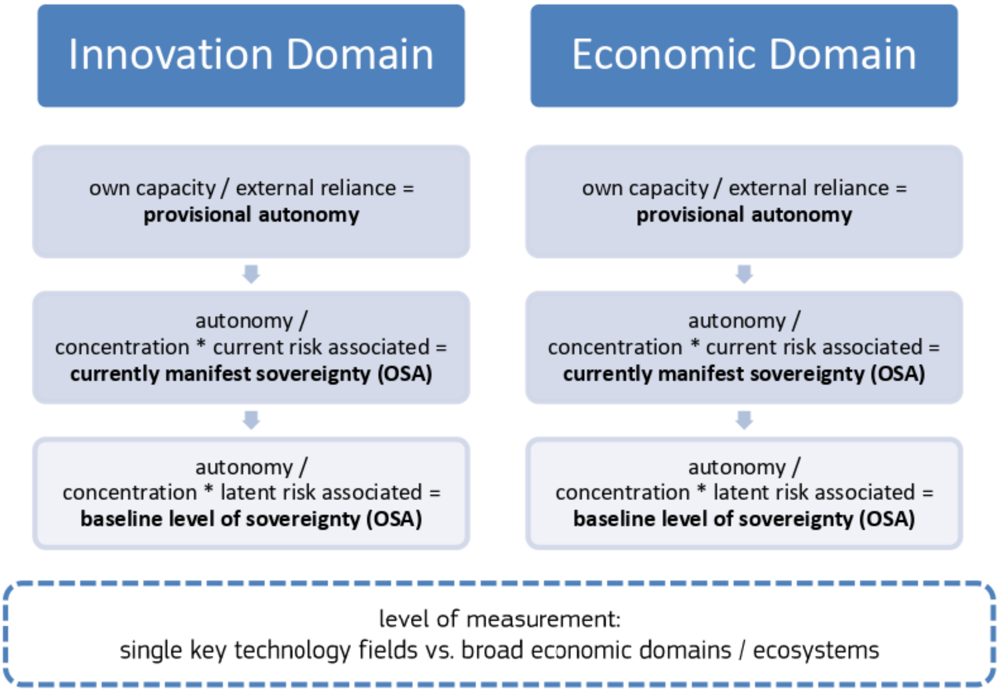
The objective of this report is to contribute to the operationalisation of OSA by developing an empirical concept to measure it and provide policy intelligence. The idea is that Europe needs to identify and secure minimum capabilities in sectors and technologies relevant for OSA in order to ensure future prosperity and the ability to promote European values at the global scale. Operationalisation focuses on the innovation dimension linked to several datasets in order to provide quantitative results that help in the monitoring and mapping of OSA. Thus, the report provides evidence that can help to bridge between the economic, trade and industrial innovation dimensions of autonomy and dependency.

Concept and ambition of study

- 'Strategic Autonomy' refers to the capacity of a country or region to pursue strategically important activities free of foreign interference.
- 'Open Strategic Autonomy' (OSA) adds international openness, cooperation and partnerships to strategic autonomy, recognising that no country or region can achieve complete independence or self-sufficiency in today's interconnected world.
- The presence or absence of OSA depends on several factors:
  - domestic capacities, e.g. for the EU as a whole or at the Member State (MS) level;
  - provisional autonomy, defined by the relation of own capacity and external dependency;
  - current focus of external dependencies on specific partners, determining how easily they could eventually be substituted by others; and
  - manifest and latent risks, complexities and tensions in relations with specific external partners.
- If the combined consideration of these factors yields a sustained positive result, the country or region can be considered to have achieved OSA. If not, the country or region has to be considered vulnerable.
- At its core, OSA could be considered equivalent to what individual EU Member States refer to as 'technological sovereignty', except that OSA consciously includes the broader industrial dimension in addition to the technological one.
- At the same time, the OSA concept does not restrict its focus to only material trade dependencies. Instead, it explicitly acknowledges the implicit yet crucial link between technological innovation and economic competitiveness.
- Against this background, this paper proposes a two-dimensional "**OSA index**" to operationalise the aforementioned aspects towards empirical measurement and comparison of different dimensions.
- The study's ambition is primarily conceptual - first empirical results are presented primarily to demonstrate the validity and robustness of the approach.

[6] https://www.consilium.europa.eu/en/press/press-releases/2023/10/06/granada-declaration/

Figure 1: Overview of the concept



Source: Own concept

Dimensions

- An analysis of Open Strategic Autonomy should be applied to at least two main dimensions: innovation autonomy (aspects relating to knowledge creation) and economic autonomy (aspects relating to value creation and production).
- Innovation autonomy is determined by the influence that outside stakeholders have on innovation processes in Europe.
- Economic autonomy in industry is determined by material and production dependencies in Global Value Chains.
- Economic autonomy stems from present capacities to create value and societal well-being. In contrast, Innovation autonomy has a longer-term projection because knowledge and creativity are prerequisites for inventions that give rise to and shape long-term economic growth and socio-economic futures.
- Innovation autonomy is a natural ambition of all leading nations and is often largely free of conflict with market forces. However, decisions to strengthen economic autonomy may often come at an economic cost. There may be countervailing market forces, e.g. against relocating production to high wage environment.

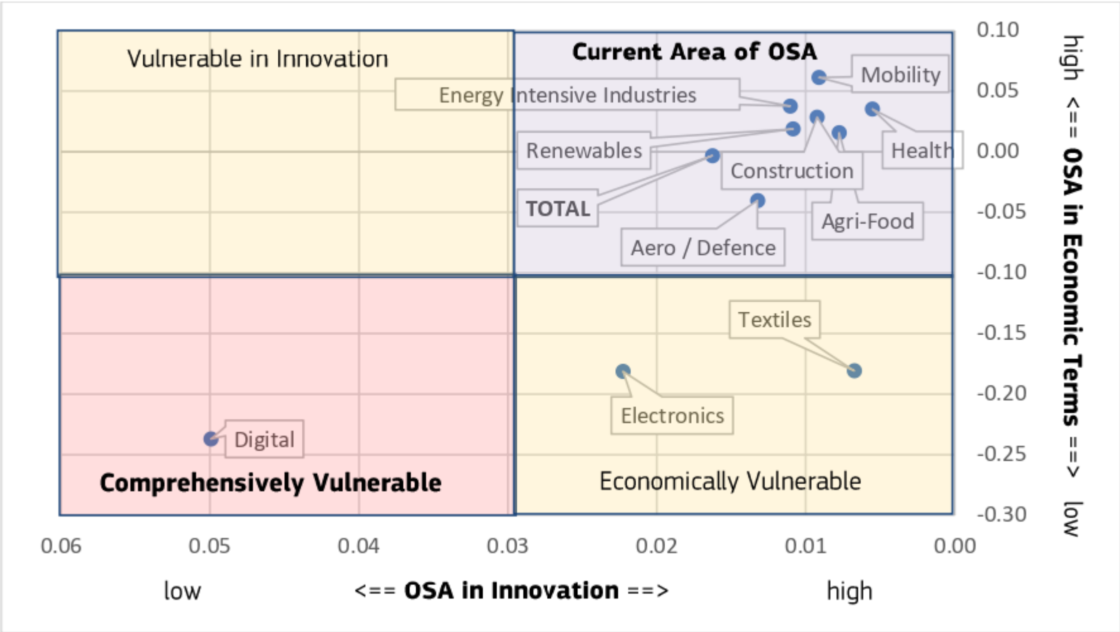
Levels of analysis

- This paper presents a basic approach for the operationalisation of OSA of the European industrial innovation system at two levels:
  - For entire industrial ecosystems
    (where any lack thereof indicates a substantial challenge), and
  - For specific technologies
    (where bottlenecks can constitute notable, yet part inevitable challenges).
- Below we provide a grid of basic results at these two levels to which future analysis for more specific technologies or domains can relate (i.e. the vulnerability of specific areas can then be easily compared to that of others for which it is intuitively known, as in 'in this area the EU is even more vulnerable than even the digital sector').

Findings for Open Strategic Autonomy (Examples)

- The digital sector in the EU shows obvious vulnerabilities, most prominently with regard to artificial intelligence and big data, and mostly related to China.
- Europe also displays some vulnerabilities in other domains like biotechnology, the internet of things and advanced materials, but here OSA is not substantially impaired, at least as long as existing exchange relations remain reliable.
- The changing geopolitical landscape has increased potential vulnerabilities stemming from established innovation collaboration with other long-term partners whom, for the time being, are still considered reliable.
- Increased attention should be paid to not-yet manifest vulnerabilities and the risk that currently stable exchange relations turn problematic in the future, in particular in the innovation domain.
- The US is particularly critical from this point of view, as its corporates control substantial elements of the European innovation process, in particular in the health and in the agri-food ecosystems, but also in bio- and nanotechnologies.
- While these findings are not in themselves surprising, they validate the robustness of the proposed two-dimensional indicator - which could be tailored to investigate more detailed questions in the future.
- The intention of the analysis in this report is to provide policy intelligence at the macro-level. It does not presume to provide technical information about concrete flows of individual goods, but about the systemic autonomy of Europe within certain value creation domains. Subsequent, more granular analysis would help to reveal more specific challenges within value chains.

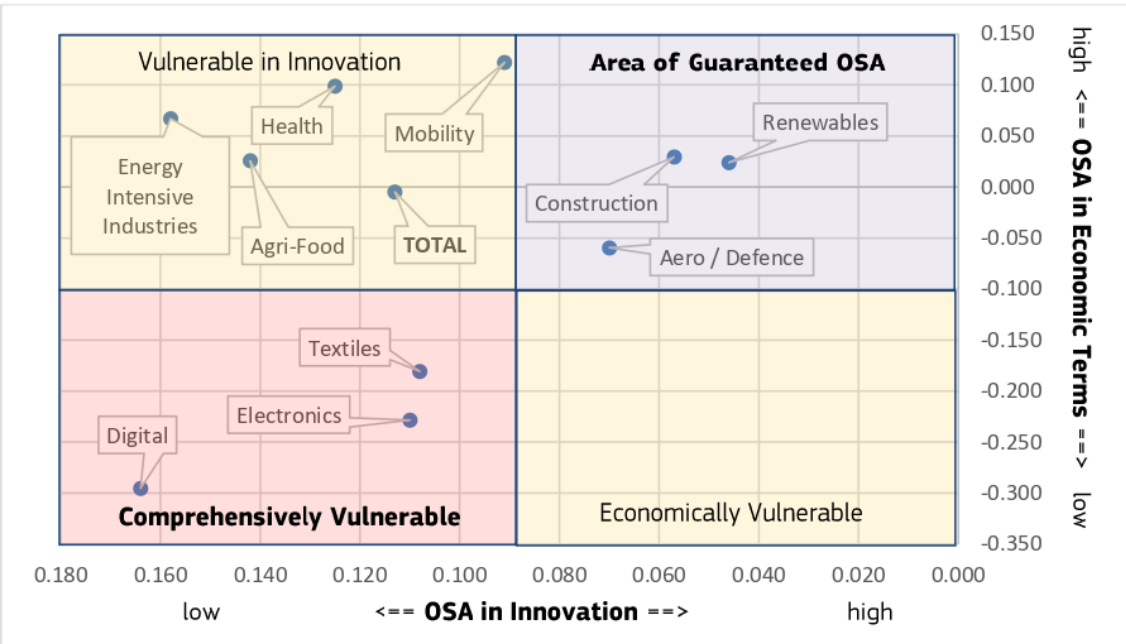
Figure 1a: Degree of OSA in **industrial ecosystems** as of **today**
Considering: External dependence and concentration of reliance on high-risk partners
x-axis: innovation dimension, y-axis: economic dimension



Note: The indices are aggregate, capacity-centred measures, based on a formula

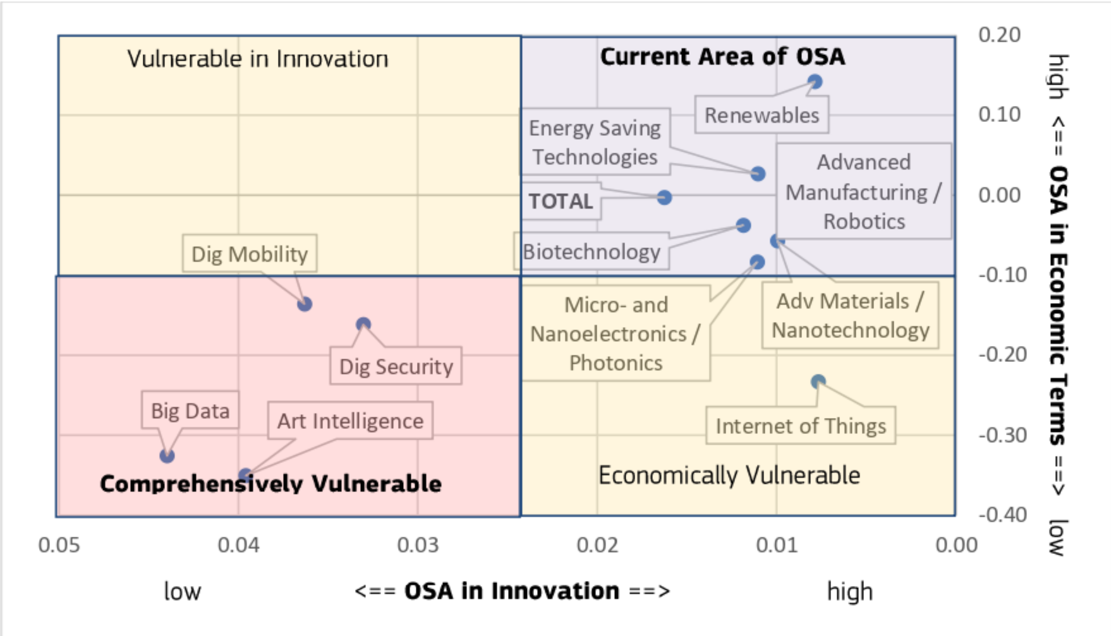
Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

Figure 1b: Degree of OSA in **industrial ecosystems** ascertained for **tomorrow**
Considering: External dependence and concentration of reliance on high-risk partners
x-axis: innovation dimension, y-axis: economic dimension



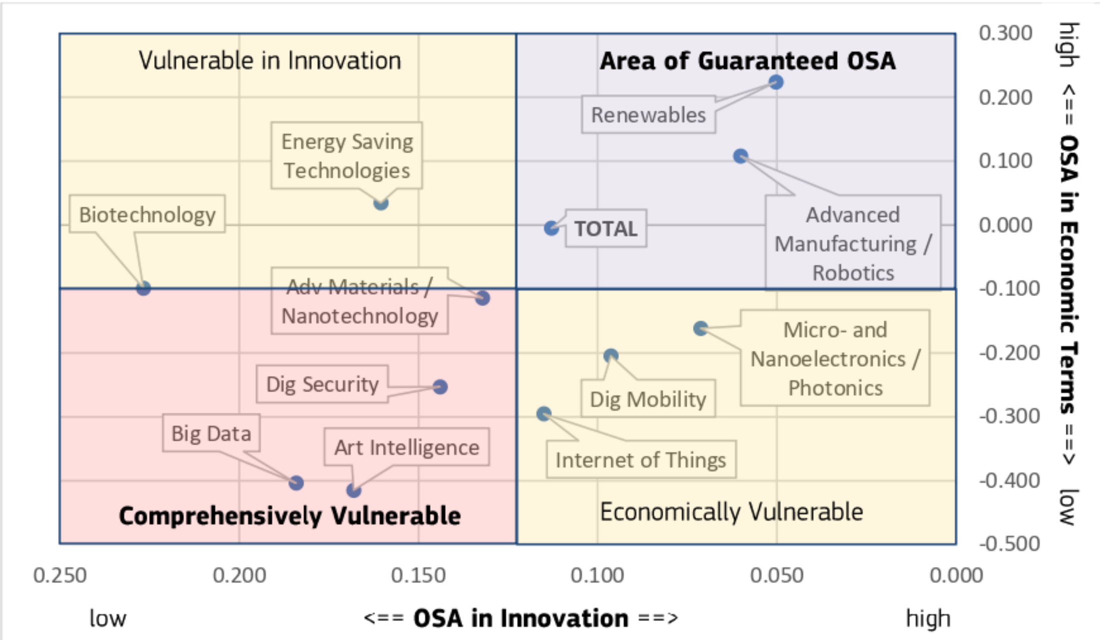
Note: Energy-saving technologies also refers to a distinct group in the economic dimension
Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

Figure 2a: Degree of OSA in **key enabling technologies** as of **today**
Considering: External dependence and concentration of reliance on high-risk partners
x-axis: innovation dimension, y-axis: economic dimension



Note: The indices are aggregate, capacity-centred measures, based on a formula
Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

Figure 2b: Degree of OSA in **key enabling technologies** ascertained for **tomorrow**
Considering: External dependence and concentration of reliance on high-risk partners
x-axis: innovation dimension, y-axis: economic dimension



Note: Energy-saving technologies also refers to distinct group in the economic dimension
Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

Main findings

For the time being, Europe's OSA is at risk primarily at the level of core technologies and less so at the level of entire industrial ecosystems - with the exception of the digital sector.

As per the index developed in this paper, Europe is generally more sovereign at the level of entire industrial ecosystems than at the level of specific technologies. The results confirm that few industrial ecosystems (with the possible exception of digital ecosystems) show an unacceptable degree of vulnerability or dependence on foreign innovation. This conclusion was foreseeable, as Europe continues to keep pace with global industrial and technological development, even if it no longer leads in all critical areas. In fact, the stability at the overall ecosystem level may thus be provisional and not durable, while the focus on individual technologies already reveals long-term vulnerabilities.

Europe's dependence on foreign technology and innovation in the digital sector could increase further if more countries were to become risky partners.

Europe's key problem areas that threaten its OSA are currently limited to the domains of big data and artificial intelligence, and to a lesser extent the areas of digital security and digital mobility. This has resulted in structural problems for industrial ecosystems in the digital and electronics sectors that are primarily due to dependencies on China.

The EU also faces challenges in its dependence on countries that are not currently considered high-risk. These challenges are in areas such as biotechnology, the internet of things and advanced materials, where the EU is dependent on partners currently considered friendly and mostly reliable, primarily the United States and Japan. However, the EU's OSA could be threatened if these countries were to be become more risky partners. The EU also lacks sovereignty in industrial ecosystems like textiles, agri-food, and carbon-intensive industries, where it is substantially dependent on other - so far reliable - countries.

Material dependencies should be distinguished from those related to external control.

Strategic autonomy in the innovation and in the economic domain are interrelated, but they can differ substantially in nature. Sometimes, high innovation sovereignty may be accompanied by a lesser degree of economic sovereignty and vice versa. Two examples of this are: (i) textiles, where the EU has an import dependency; and (ii) agri-food, where much intellectual property is held by non-European companies.

In general, our analysis reveals that neither autonomy nor dependency are one-dimensional. Different types of dependencies exist in different domains, from foreign corporations controlling expertise in European production to knowledgeable European companies being dependent on imports of components, to comprehensive dependency in both dimensions where European companies are dependent on both non-EU expertise and non-EU material imports.

Key conclusions

This paper argues that it would be unwise to boost strategic autonomy by limiting interactions and linkages with companies and countries outside the EU. Conceptually, it is ***only the combination of external reliance, concentration (focus on few partners) and risk that causes manifest vulnerability***. Extensive external relations between the EU and other countries will only be problematic if they coincide with low levels of capacity within the EU. Even external reliance as such may not be a problem, as long as it is not overly concentrated or built on too many risky relations associated.

An economy ***can protect its strategic autonomy without necessarily having to incur the cost of comprehensive reshoring***. For this to be the case, it has to structure the pattern of its international relations consciously and avoid risky partners. In fact, the decreasing presence of European stakeholders in international fora may be part of the problem rather than its solution.

The empirical results in this report show that the biggest potential threat to Europe's OSA is the ***continued reliability of partners*** which are currently considered to be of limited risk in international collaboration and transactions. If some of these relations sour, then Europe will face increased risk to its strategic autonomy in two ways: firstly, Europe's weaknesses at industrial ecosystem level, which is currently only in the digital domain, could soon extend more broadly to already affected fields like the health sector and the agri-food industry; secondly, Europe's OSA vulnerability, that has so far turned critical mostly in the economic domain (relating to shortages of material supplies) could spread to areas such as the governance and financing of industrial innovation.

1 Introduction

This paper contributes to the debate on OSA on a conceptual level by developing a clearer notion of: (i) what this concept implies; (ii) what the primary dimensions of OSA are; and (iii) what conditions have to be met within these dimensions to achieve OSA.

As a first main contribution, the paper proposes **a general notion of open strategic autonomy (OSA) or sovereignty in the innovation and economic domains.** OSA is the capacity to innovate and develop, to shape markets and create value to a sufficient degree on one's own terms. OSA is closely related to and conditional on the EU's politico-economic agency, but different from its geopolitical engagement as such (Edler et al., 2022). In consequence, it does not primarily address the question of strategic access to raw materials[7]. Undoubtedly, the consideration of trade policy instruments to make accessible what is locally unavailable is an important perspective that has entered the innovation policy debate but is not at the centre of this analysis.

Instead, it focuses on the parallel debate on required changes to interventions in the established domains of research and industrial policy (Edler et al., 2022). This debate addresses areas in which innovation or production capacities could - at least in theory - be locally built. This contribution seeks to establish a methodology to aid judgements about the degree and risks of exposure while retaining as a core tenet that Europe benefits from international collaboration in both the innovation and the production domain. It does not seek to technically trace individual products, but to provide corroborating information about systemic imbalances that may help to *justify and initiate* more specific action. The paper also argues that there is limited value in considering the level of external reliance alone as this is relevant only as baseline information.

There are different possible interpretations of the term 'autonomy'. The interpretation that is relevant to determining the EU's level of strategic autonomy in specific areas is 'the absence of *unilateral* dependency' and not that of 'self-sufficiency' (Edler et al., 2020). Accordingly, we suggest that analyses of external reliance be closely associated with the **concentration of external reliance** (i.e. dependency on a rather limited group of partners). Moreover, genuine sovereignty cannot be assessed based only on a technical analysis of external reliance and its concentration. It must also take into account the nature of all relevant relations. For example, could the partner actively exploit their power to reduce the EU's agency or could established relations fall victim to political developments at different levels? Therefore, analyses should also consider the nature of the partners that the EU engages with, before deriving conclusions on strategic autonomy.

As a second main contribution, this paper differentiates between two main **dimensions of autonomy,** as different types of activities are subject to different internal logic and result in different mechanisms of influence and control. These are: **(i) *autonomy in the innovation domain***, characterised by processes of knowledge exchange and learning (and the effort invested in protecting the results of such processes); and **(ii) *autonomy in the economic domain***, characterised by the production and provision of material goods and components. Both types of autonomy are closely related, but both remain distinct, and should therefore be discussed together in subsequent analyses in order to illustrate where exactly the limitations to strategic autonomy arise in different areas.

As a third contribution, this paper reports findings related to two current key policy concerns: one is the focus on *key enabling technologies* and their strategic contribution to the twin transitions, the other is the focus on *industrial ecosystems*. While these ecosystems are defined in extremely diverse ways, they share that they are the domains where value is created and transitions occur. Only at the level of industrial ecosystems is it possible to determine the extent to which the EU retains sovereignty at a more general level, i.e. the extent to which it remains a geo-economic actor capable of creating value and sustaining societal well-being without external support. From an innovation economics perspective, both approaches are equally necessary and relevant to considerations of strategic autonomy and sovereignty.

At the level of individual technologies, an analysis would instead focus on the extent to which the EU remains able to determine a strategy in areas such as: (i) invention; (ii) the provision of material key components; and (iii) comprehensive processes of production.

These three main contributions form the structure for more detailed sub-chapters in the rest of this report. They are summarised in Table 1 Some further clarifications on these three levels of contribution are set out in the following four bullet points.

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[7] Various reports and contributions by the Joint Research Centre, DG TRADE and DG GROW are already available on this issue, providing comprehensive insights [add sources].

- Any understanding of strategic autonomy must be grounded in a consideration of capacity, both conceptually and empirically. Without consideration of the EU's own domestic capacity, analysis of its external reliance will not yield meaningful information on strategic autonomy – since without own capacity, autonomy can hardly be leveraged for strategic purposes.
- Any analysis of strategic autonomy or sovereignty that seeks to move beyond an analysis of mere autonomy must also consider both concentration of external reliance and the risk associated with specific relations. To understand sovereignty, it is not enough to analyse generic relations of external reliance and capacity on their own.

Table 1: This report's fundamental understanding of strategic autonomy

(over-)concentrated & risk-frought ext. reliance / own capacity	high	low
high	position of vulnerability despite own strength	**position of open-strategic autonomy**
low	dependency	position of weak autonomy without strategic capacity

Source: Own concept

In its analysis and choice of indicators, this report will bear the important role of capacity in mind, but primarily focus on the dimension of external reliance – and how its potentially detrimental effect on strategic autonomy can best be assessed and measured. On this, two main points need to be made:

- When looking at strategic autonomy and sovereignty based on capacities which can be built locally within the EU, it is important to distinguish between autonomy in the innovation domain and autonomy in the economic domain. This is because autonomy in these two domains follow different logics and describe different aspects of control.
- When considering different levels of analysis, it is important to distinguish between a targeted focus on specific key technologies and a broader focus on industrial ecosystems in which value is created and concrete, material dependencies play a larger role than in very specific technology areas. Both these types of focus are complementary and both can be analysed in two ways: (i) from an innovation perspective; and (ii) from an economic perspective.

Table 2 summarises these two important dimensions that future analysis need to consider.

Table 2: Overview of this paper's conceptual approach

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Focus of analysis
(level of aggregation,
reference policy debate)</td></tr>
<tr><td>Key enabling technology level</td><td>Industrial ecosystem level</td></tr>
<tr><td rowspan="2">Conceptual dimension of autonomy</td><td>Innovation dimension
(inventions,
knowledge generation)</td><td>OSA, Innovation Domain –
Key Enabling Technologies</td><td>OSA, Innovation Domain –
Industrial Ecosystems</td></tr>
<tr><td>Economic dimension
(production,
value creation)</td><td>OSA, Economic Domain –
Key Enabling Technologies</td><td>OSA, Economic Domain –
Industrial Ecosystems</td></tr>
</table>

Source: Own concept

The rest of this paper will feature more detailed insights on these issues.

In Chapter 2, the paper will: (i) review the existing scholarly literature on this topic; (ii) explain the reasons for the authors' specific definition of both autonomy and sovereignty; (iii) explain the implications these definitions have for promoting the EU's OSA; and (iv) explain how these conceptual notions of autonomy and sovereignty can be translated into **general formulas for autonomy and sovereignty**.

In Chapter 3, we will explain in more detail the above-mentioned differentiation between innovation autonomy and economic autonomy as key conceptual dimensions of autonomy.

In Chapter 4, we will present two specific, concrete **formula to calculate indices for strategic autonomy (or sovereignty)** for each dimension.

Having thus clearly outlined the conceptual contribution, in Chapter 5 we will guide the reader in more detail through these empirical measures of sovereignty, justifying the integration of measures of external reliance, concentration of external reliance, and risk association.

To conclude, this paper will summarise the empirical findings so far, bearing in mind that the primary objective of this report is not yet to provide a complete and detailed empirical analysis, but to present a conceptual approach and a related empirical method. Throughout this paper, we will discuss this conceptual approach and a related empirical method for both key enabling technologies and industrial ecosystems in parallel, seeking to integrate perspectives in our final summary of the results.

2 Conceptual basis of strategic autonomy and sovereignty

This section develops the main concept and framework for this paper's empirical operationalisation of strategic autonomy based on a short literature analysis. The dimensions of this concept are developed in more detail in the following sections.

2.1 Literature analysis

In recent years, the debate around OSA has gained prominence at the European level. In various Member States, national debates have discussed this issue under the conceptual umbrella of 'technological sovereignty' (Edler et al., 2020; EPRS, 2020; FIIA, 2020; BMBF, 2021; JRC, 2021; Lorenzani/Szapiro, 2023). Driven by a parallel dynamic of increasing geopolitical contestation and a fundamental techno-economic shift of capacity to Asia, Europe finds itself in a position where its ability to act and build economic and technological capacity independently has become constrained in different domains (JRC, 2021, Roberts et al., 2019; Choer Moraes/Wigell, 2022). At the same time, the EU has become more willing to reassert itself (Lorenzani/Szapiro, 2023).

Observing this public debate, which is often inchoate or openly populist, academic studies have initially sought to introduce clarity. These studies have stressed that sovereignty should be understood as a measure of an agent's freedom to make choices and investments to provide for public needs in the best interest of a particular political agent's constituencies (Edler et al., 2021). Put differently, the concept of strategic autonomy should not be read as an attempt at self-sufficiency but as an attempt to increase sovereignty, or to reduce vulnerability. Vulnerability thus understood refers to: (i) the risk of losing agency or access to critical capacities that are necessary to perform public functions; or (ii) the risk of the entire technological system failing due to disruptive external events (Edler et al., 2021). Following Edler et al. (2020), the main functional contexts in which it is essential for a state to have sufficient agency and therefore determine critical technologies are:

- tasks related to **sustaining political sovereignty**, mainly related to defence, public security, preventing or conducting military attacks, or geopolitical positioning (including related priorities such as the independent operation of communication/surveillance networks and data infrastructure);
- tasks related to **serving societal needs**, such as the general provision of public services, healthcare, and infrastructure, but also the capacity to address the needs of society in the event of idiosyncratic disturbances like the recent COVID-19 pandemic or natural disasters; and
- tasks related to: (i) fostering present and future **economic competitiveness, jobs and value creation**, by sustaining the viability of current business models; and (ii) enabling the development of future business models in the context of the ongoing twin transitions in the industrial sector.

Traditionally, Europe - alongside the United States and Japan - held sway in the global innovation domain to a degree that allowed it to independently: (i) perform these tasks without substantive limitations; and (ii) shape the course of future technological development at its own pace. This degree of independence, autonomy and freedom in innovation was first challenged with the rise of the so-called tiger economies of East Asia. As the tiger economies developed, the former dominance of the 'Triad countries' (the EU, US, and Japan) as a primary production location waned. As a result, many high-tech production capacities were relocated outside the Triad countries during the 1980s and 1990s. As capacities grew in these new primary places of production in East Asia (like Taiwan), some central aspects of process learning started to happen almost entirely outside the classic Triad nations. This had already started by the mid-2000s. However, the overall 'technological balance of power' remained intact, with Europe, the US, and Japan remaining responsible for both: (i) most original product development; and (ii) the shaping of future markets by means of standardisation. This overall state of affairs continued to characterise the global economic system until approximately the late 2000s or early 2010s (DG GROW, 2021; Frietsch/Kroll, 2022). By and large, it was only then that the twofold dynamics of the digital revolution and China's fully-fledged ascent into the ranks of leading technological nations led to a more fundamental change of affairs during the second half of the 2010s.

More precisely, the following key features (and reasons) of a substantial shift in in the global technological system can be identified (JRC, 2021; Kroll et al., 2021).

In the production domain, two main features of this substantial shift are evident.

- Since the 1990s, Europe has become dependent on imports of various technological components. And since the 2000s, Europe has become dependent on the import of complete products and solutions as many local production sites within Europe were shut down.

- Where such final production capacities remain in Europe, they are often dependent on the input of natural resources that are not available on European soil. More importantly, such final production capacities are often also dependent on the import of high-tech components without which final production is impossible.

In the innovation domain, two other features of this substantial shift are evident.

- The digital revolution changed what constitutes a key enabling technology with relevance for the future. To its detriment, Europe holds more limited capacities in those technologies that are now becoming central drivers of economic transformation (the 'digital race').
- While more and more European R&D activities are controlled by non-European firms, European firms' control of global R&D chains has decreased. This can be seen in both their limited standardisation activities and their decreasing part in foreign R&D investments.

Against this background, Europe's strategic autonomy (OSA) must be understood as a, part latent, capacity for agency - rather than a purely static acknowledgement of momentary external reliance. Open Strategic Autonomy is something that emerges in the tension between external restraint and uncertainty and the agent's own capabilities. Accordingly, strategic autonomy in both the economic and the innovation domain need to be understand as fundamentally grounded in own, domestic capacity. To what extent this capacity can really manifest itself in strategic autonomy (i.e. sovereignty) will indeed depend on the degree of external inputs that this capacity relies upon and the exposure to risks that these external dependencies bring. Nonetheless, a country or economic area's own capacity remains the necessary basis of autonomy and sovereignty in all cases.

2.2 Capacity qualified by external reliance: the basis of all autonomy

Because sovereignty is exercised through action, many commentators have argued that the EU's domestic capacity deserves at least as much attention as the presence or absence of external reliance. And while it is true that recent geopolitical changes have led to fundamental shifts that could restrain the EU's capacity to ensure that it can obtain resources from abroad, limitations on domestic capacity are indeed another cause for worry - as they curtail Europe's capacity to act, shape markets and to proactively influence the international rules of the game (Edler et al., 2021).

So far, much of the political debate, in particular at European level, has centred on the question of access to resources (Bardt, 2019; EC, 2021; DG TRADE, 2022). Undoubtedly, this is of tremendous significance for the continent's future technological capacity. However, this debate about access to resources remains fundamentally based on the traditional notion of Europe as a production site in complete value chains where the main worry is access to primary resources (such as oil, gas, metal ores, etc.). But this traditional production-site notion of Europe is no longer adequate in many advanced technology domains. Instead, the problem has become more fundamental at different levels (DG GROW, 2021; Kroll et al., 2022). The problem is that, while In some areas, Europe has held onto technological skills, it has become dependent on a limited number of trade partners – typically in Asia – to secure relevant components in technologically advanced areas. One obvious example is the much-referenced situation in the microelectronics sector (Bardt et al., 2022), but it can also be seen in many other specific domains. Starting out in low-cost, low-value-added assembly, leading countries like Taiwan and Korea have now taken over almost all steps in certain value chains and have come to lead in process innovation at a level that Europe can no longer match (DG GROW, 2021). In other areas, Europe has already lost technological leadership completely and thus lost its ability to wield influence and hold sway over international markets. In these technology sub-sectors, product innovation happens in other nations, and international value chains are no longer coordinated from within Europe. As a result, Europe has become dependent not only on imports of components (Bardt et al., 2022), but on imports of complete finished products and solutions. Europe may also no longer be sufficiently integrated in international networks of technological collaboration (DG GROW, 2021).

The problem is therefore not that Europe no longer has secure access to *basic* inputs, but that domestic EU corporations lack capabilities and strategic capacity over *much more sophisticated and innovative* inputs and products. This makes Europe dependent on external innovation and leaves its innovators vulnerable to external control. While this situation has so far only fully developed in some – mostly digital – domains, Europe remains better positioned in others. Nevertheless, it still serves to underline two fundamental aspects of our argument, set out in the two paragraphs below.

Fundamentally, it is true that external reliance may render domestic capacities irrelevant, if, without external inputs or decisions, these capacities cannot yield any local benefit in terms of innovation and value creation. At the same time, limitations to autonomy thus resulting from external reliance cannot be separated from limitations to domestic capacity and often only become a problem when this domestic capacity decreases below a certain threshold (Edler et al., 2021).

Even in a static, non-strategic perspective **provisional autonomy** thus has to be understood as based on the relation between external reliance and own capacity. If a country or economic areas has more own capacity, it can afford higher external reliance in absolute terms without the overall system becoming unstable and, by extension, strategically vulnerable.

2.3 Risk and exposure: from provisional to strategic autonomy

Despite the great importance of capacity in determining Europe's OSA, external factors restricting agency also remain important, and addressing these factors should be a policy concern. Furthermore, this question of agency and restricted agency has seen fundamental changes in recent years, without which the largely dormant debate around increasing limitations to European sovereignty might have never been reinvigorated. Conceptually, the problem of restricted strategic agency can be best approached through the lens of risk exposure. Rather than simply looking at current relations between capacity and external reliance, the analysis has to consider why and to what potential effect they could change and what room remains for their adaptation if needed. In hindsight, both corporations and governments have too long relied on three assumptions about their risk exposure:

- the stability of global supply chains can be considered as given, and production locations can be chosen from a purely commercial perspective;
- the global economic system will remain free of serious political conflict, i.e. free of direct structural limits on collaboration and sourcing; and
- where needed, emerging nations can be convinced to comply with a global system of rules created by – and considered appropriate by – the Triad nations.

Quite evidently, these three assumptions are no longer true. Apart from idiosyncratic events like the COVID-19 pandemic or the Russian invasion of Ukraine, the fundamental error in these assumptions is that they consider the world order to be stable when it is in fact dynamic (Gehrke, 2022). One of the significant changes in the world order has been China's increase in bargaining power. As China has acquired more and more technological capacities, it has sought to influence the status quo rules in a way that is largely compliant with international law. That said, increased economic rivalry almost always happens at the same time as political contestation, even if all-out military conflict can be avoided. As recent years have shown, this may in part also result in the testing or outright breach of existing conventions (Blustein, 2019; Kroll et al., 2021, Choer Moraes/Wigell, 2022, Kroll/Frietsch, 2022).

As a result, both the stability of established trade relations and the viability of R&D/production in certain locations often come with notable risks. This becomes problematic mostly where a country or economic area's exposure is too concentrated or too focused on a single other nation, such that a single event and/or politically motivated decision may reduce the viability of existing innovation or component-sourcing strategies (EC/HRFASP, 2019; Edler et al., 2020).

Concentrated external reliance can be cause for concern in such situations, characterised as they are by: (i) a rebalancing of power; (ii) a destabilised international rule system (Choer Moraes/Wigell, 2022); and (iii) a lack of adherence to even basic agreements by some. And these concentrated cases of external reliance can become problematic in two main ways.

- They can in themselves become a bargaining chip in political conflict, as has been witnessed in recent years in various trade disputes and conflicts.
- Political turmoil – and even war – becomes possible, and this would detrimentally affect many third parties that are not involved in the conflict (Edler et al., 2021).

As can be seen above, the problem with unilateral exposure to external reliance is rarely a purely political problem in the sense of bilateral disagreement and animosity. Instead it is a problem that indirectly derives from the increased prevalence of political conflicts worldwide. For countries other than the US, worries about unilateral exposure to a country is therefore less of a purely 'Chinese problem' than is at times assumed. For example, the experience of Brexit and the Trump administration – and concerns about the possible return of Trump as US president – have spurred concerns about the need to reconsider relations within the community of Western nations as well. In addition, any consideration of the risk associated with a partner requires not only an assessment of that partner's own reliability but also of their potential exposure to external political disruptions (as is obvious in the case of Taiwan or Korea, both of which are vulnerable to military pressure from their neighbours).

2.4 Analytical approach, generic formulas

In summary, this report's approach to OSA can be expressed in the formula below, which does two things. Firstly, it puts capacity at the centre of questions about OSA, but qualifies this by the degree to which these capacities rely on external inputs or decisions. Secondly, it differentiates between autonomy and sovereignty in that sovereignty additionally requires a consideration of the concentration of external reliance as well as the risk associated with the partners on which external reliance is concentrated.

$$(Provisional)Autonomy = \frac{own\ capacity}{external\ reliance})$$

$$Strategic\ Autonomy\ (Sovereignty) = \frac{(Provisional)Autonomy}{Concentration_{risk\ associated}})$$

3 Dimensions of autonomy and conditions of sovereignty

This section develops the detail on the conceptual dimensions of strategic autonomy in relation to the different autonomy concepts and proposes a way to measure external reliance/vulnerability.

3.1 Conceptual dimensions of autonomy

3.1.1 Innovation autonomy

Innovation autonomy means autonomous capacity to generate certain technologies that act as enablers for a variety of other fields. These enablers are important as they can be readily combined with other technologies to generate new methods and solutions. Put differently, an absence of autonomy in such enabling technologies makes it more difficult to carry out certain necessary functions of an innovation system. The country or economic area that lacks these enabling technologies will lose the ability to plan for its own future and shape future developments in the global innovation system. The relevant question is less one about specific inputs or transfers but rather ***whether a country is in control of the innovation processes within its boundaries.*** More precisely, it is about the extent to which decisions on the path that innovators follow are taken by national/domestic actors. In other words: (i) can a given country or economic area independently set the pace and directions for its research and development community? and (ii) is it able to make independent contributions to innovation.

Innovation autonomy remains important even though international collaboration is often needed to solve problems (international collaboration in innovation is often desirable rather than problematic). Decades of research on emerging economies and Eastern Europe have demonstrated that the overt dependency of national innovation systems on non-domestic multinational corporations is detrimental to domestic innovation autonomy, and can swiftly become problematic by hampering long-term development. External ownership of key innovation can sometimes also lead to a lower level of integration of important research and development activities with a country's innovation system. It also leads to a risk that external actors withdraw or end their innovation activities for reasons unrelated to the external actors' local success. Accordingly, innovation autonomy is closely related to any highly developed economy's capacity to shape its own future and there is no fundamental, conceptual argument against pursuing innovation autonomy.

3.1.2 Economic autonomy

A potential lack of autonomy in the sourcing of key components relates to a different kind of problem. Countries can become externally dependent on parts and components that they have stopped producing domestically and are therefore no longer able to produce domestically. Moreover, the newer generations of specific types of goods may never have been produced in Europe in the first place. In either case, these choices have been motivated by commercial considerations that remain pertinent, despite changing geopolitical circumstances. One of those considerations is that specific - typically early - stages of the value chain have been offshored almost completely due to a restructuring of global value chains focused almost entirely on labour costs. Another consideration is that more non-European countries have developed near monopolies in the production of novel key components like microchips, which are needed in many sectors, while European countries never even started to develop these capacities.

This means that most attempts to increase economic autonomy would, to some degree, have to work against existing market forces and hence most likely come at a higher price and offer less return on investment than an ambition to gain and retain innovation leadership. In general, many production steps – and even development steps – early in the value chain would still be better situated in low-wage locations (with a view to comparative and competitive advantages) and would hardly be sustainable in a European environment without a loss of public welfare. The 're-shoring' or new development of production capacities in novel technological areas is structurally more reasonable, but might require duplicating investments already made and reconsidering business models developed for another business environment. Furthermore, global networks also allow access to friendly partner countries' relative specialisation advantages.

3.2 Conditions for strategic autonomy (sovereignty)

We will now discuss in more detail the concept of autonomy and seek to integrate it with the concept of sovereignty. In both the innovation and the economic domains, the current division of labour emerged based on a shared political paradigm which assumed: (i) international relations to be at least stable; and (ii) global value chains to be reliable and resilient. However, these assumptions have now been called into question and sometimes even proven wrong .

Importantly, a lack of autonomy becomes problematic only if: (i) the resulting external reliance is concentrated on a limited group of partners; and (ii) there is a substantial risk that the respective partners may decide to no longer sustain existing relations (or if there is a risk that the partners might end up in a situation in which they are no longer able to sustain existing relations). When a lack of autonomy is combined with (i) and (ii), then this leads to a lack of sovereignty.

In the following, we will use the term 'external reliance' to denote a general lack of autonomy, while we will use the term 'vulnerability' to denote a lack of strategic autonomy (sovereignty).

3.2.1 Concentration of external reliance

As a first and necessary condition, vulnerability - rather than mere external reliance - stems from a situation where a disengagement of specific partners could undermine: (i) the means of research and development; or (ii) the provision of goods such that systemic shortages arise. In principle, even high levels of dependency can be unproblematic as long as the country or economic area in question does not rely on a single partner – or on very few partners – whose disengagement would lead to substantial shortages. This means that we must not focus on dependency alone, but, in line with the European Union's recent conceptualisation of 'dependency' (European Commission, 2021), on the **concentration of external reliance**.

To analyse the concentration of external reliance, one approach could be to consider the overall diversification of a country or economic area's external reliance (e.g. by means of concentration coefficients). However, such an approach would misjudge the situation that most polities, including the European Union, are in. As the literature on international relations and official statistics confirms, most innovation and innovative production activities remain concentrated in the Triad countries, now complemented by China and some former 'tiger' economies. Accordingly, the more pertinent question to ask is to what extent a single country or a 'top group' of very few countries holds leverage over existing dependencies. A related question is whether the observed concentration is such that single external events or political changes could substantially undermine existing innovation and economic linkages. In practical terms, this 'top group' for the EU will most often be composed of the US, China, Japan, Taiwan and Korea, as well as neighbouring EFTA countries, Switzerland and the UK. Unlike the situation in the domain of raw materials, any concentration of dependency outside of this group will be rare, rather idiosyncratic, and - in the innovation domain - almost irrelevant.

3.2.2 Associated risk

A second necessary condition for turning dependency into vulnerability is when adversarial political actions or other harmful external events are both potentially impactful and increasingly likely. Although concentration of dependency means that the disengagement of specific partners would cause substantive problems, ***it remains crucial to determine the likelihood of such a partner disengaging.*** In summary, **problems with sovereignty** will result if specific relations have already turned risky.

At least two dimensions of risk associated with partnerships in research and innovation must be covered in this regard:

- risk associated with a partner's own geopolitical positioning/repositioning and/or its unprovoked involvement in geopolitical conflict;
- risk associated with the partner's own potential domestic instability.

So far, more research has been carried out on the second type of risk associated with the partner's own potential domestic instability (e.g. in the context of credit ratings). On the geopolitical side, less information is available. Some efforts to assess geopolitical insecurity been made in the context of decision making on export guarantees, but they have often been *ad hoc* and politicised, aiming to promote investment *in spite of* conservative commercial risk assessments.

4 Operationalisation of OSA and thematic analysis

In this section, the aforementioned concepts are filled with relevant indicators and their quantification is explained in detail. Also, the two levels of thematic analysis, industrial ecosystems and key enabling technologies, are described.

4.1 Empirical operationalisation of OSA

4.1.1 Innovation autonomy

When analysing innovation autonomy, it is important to acknowledge that cross-border collaboration and exchange of knowledge in research and development are beneficial to knowledge production. This is because they increase options for: (i) recombining knowledge; (ii) creativity at the intersections of different fields of knowledge; and (iii) innovation prompted by chance encounters triggered by the interaction of people. A country is not technologically dependent simply because its share of international co-patents in overall patenting is high. On the contrary, such a high share could be evidence that a country's sovereign position in a certain technological area makes it an indispensable player. A more suitable way to assess innovation autonomy is to determine the share of inventions that are being generated in a specific territory but subsequently externally owned, i.e. the share of inventions that are subject to non-domestic decisions. While knowledge thus created may remain within a country or economic area, decisions on its deployment and commercialisation will be taken elsewhere. An indicator for this is the ***share of externally owned patents***. If a large share of domestically invented patents is filed by a foreign applicant, this is a strong indication that the inventive activity has taken place in an organisation whose legal headquarters are outside the country and whose strategic decisions are most likely taken abroad as well.

4.1.2 Economic autonomy

To measure economic autonomy, we suggest an approach based on the level of domestic capacity, similar to what we have proposed for measuring innovation autonomy, both provisional and strategic. We propose a formula for measuring economic autonomy based on domestic production volume which 'relates the domestic need for imports to what is locally present. More precisely, we propose ***share of locally available product volume that has to be imported***, as the measure of economic autonomy from a demand-side perspective.

Technically, this can be computed as the ratio of *overall economic volume of locally-available goods* [i.e. the sum of goods produced locally (domestic production) plus imported goods (imports) minus exported goods (exports)] to *net imports* (i.e. the difference between imports and exports), designating thus the net proportion of a specific material good which enters the country by means of trade. In this approach, we differ from most other studies, which primarily refer to trade data alone and neglect the domestic core of value creation. Compared to that, our demand-side approach seems more comprehensive and closely in line with a concept of strategic autonomy that focuses on the ability to provide for oneself and downstream sectors in relevant domains.

4.1.3 Concentration of external reliance

Following on from our earlier discussion of how leverage only becomes problematic if a country or economic area is dependent on 'one or very few' players, future analysis should include this as a criterion. For example, future analysis should present the 'share of top-X countries' in a specific technology or domain to portray whether there is a problematic concentration in the sense referred to above, by which the disengagement of one or very few partners would threaten the stability of provision of a certain technology. In the broader economic domain (trade/production), we suggest that a focus on the share of a country or economic area's top-five partners in a specific technology or domain adequately reflects whether policy makers retains sufficient room for manoeuvre to swiftly diversify trade relationships. In the innovation domain (foreign applied domestic patents/all patents), where capacities are generally more concentrated, we suggest focusing on the top-three partners to determine whether the trade relationship in question retains any alternative options in its portfolio.

The reason why we decide against a simple focus on the Top-1 or Top-2 nations' share in a specific technology or domain's trade or innovation relations is that, in nearly all domains, 2-3 neighbouring countries (like the UK or Switzerland) will almost always technically rank top as 'natural partners', so that sufficient variance only emerges when the next 1-3 ranks are considered as well, which mostly means taking into account the role of the US, China and Japan.

4.1.4 Associated risk

In the two main domains of potential risk associated with countries, we propose a new composite indicator in this paper. This indicator aggregates information from the following specific sources to determine which risk of intentional or unintentional disengagement from existing relations can be attributed to a specific partner nation.

To assess external geopolitical reliability, we consider:

- NATO membership or close association (Korea, Japan, Switzerland, Sweden, AUKUS);
- the level of sanctions imposed by the US;
- the level of sanctions imposed by the European Union;
- the track record of WTO non-compliance (number of conflict cases per unit of trade volume).

To assess internal stability, we consider:

- the OECD country risk rating;
- the Allianz investment risk rating;
- the Global Terrorism Index[8];
- the Global Economy Political Stability Index[9];
- the Economist Intelligence Unit, political stability index;
- the JRC NFORM Institutional Coping Capacity;
- the World Bank's worldwide governance indicator on 'rule of law';
- the World Bank's worldwide governance indicator on 'no violence'.

We took all information from these sources and x-standardised it and compiled it into two aggregate indices (external and internal) with a scale from 0 (Norway) to 1 (Syria). Naturally, there are some notable differences between both perspectives (internal stability and external stability), mostly because of countries like China that are stable internally, but adversarial externally. For the purposes of the study, both the external and internal indices have therefore been aggregated into a joint index based on which a one-dimensional cut-off point can be defined (i.e. 0.35 - see below). Different, more complex approaches could be chosen, but this one appeared suitable for this first proof-of-concept.

On this basis, we can – in the overall equation – replace the *share of the group of top-5/top-3 countries* by the *share of the top-5/top-3 countries that are associated with substantive risk*. This shifts the question from whether there are *any potential limitations to sovereignty* to whether, under the given geopolitical circumstances, *manifest sovereignty* has already become substantially impaired.

4.1.5 Formulae for autonomy and sovereignty indices

In summary, the final analytical approach can thus be formalised as follows:

$$Provisional\ Innovation\ Autonomy\ (technology\ t) = \frac{inventive\ capacity_t}{external\ ownership_t})$$

$$Provisional\ Economic\ Autonomy\ \ (component\ c) = \frac{(production\ capacity_c + imports_c - exports_c)}{imports_c - exports_c})$$

$$Strategic\ Innovation\ Autonomy\ (t)\ = \frac{inventive\ capacity_t}{external\ ownership_t} \times \frac{1}{share\ top3\ nations_{\ (all\ //\ high-risk)}})$$

$$Strategic\ Economic\ Autonomy\ (c) = \frac{production\ capacity_c}{import\ dependency_c} \times \frac{1}{share\ top5\ nations_{\ (all\ //\ high-risk)}})$$

[8] https://www.visionofhumanity.org/maps/global-terrorism-index/#/.
[9] https://www.theglobaleconomy.com/rankings/wb_political_stability/.

4.2 Levels of thematic analysis

Having thus established the concrete methodological approach and formulae by means of which innovation and economic sovereignty can be computed, the final step remains to decide to which thematic area these considerations should be applied. It seeks to identify potentially problematic areas and give a first indication of the nature and extent of the problems related to strategic autonomy. In addition, it also aims to prepare the ground for further, more detailed analysis.

Elsewhere, several studies have focused on specific technologies that consider in detail to what extent these can technically substitute for each other. This is not the ambition of this study. It does not presume to provide technically accurate information about concrete flows of individual goods within specific value chains, but to inform at a strategic policy level. Instead, our approach seeks to inform two important policy discussions at European level: (i) a discussion around Europe's positioning with regard to key enabling technologies; and (ii) a discussion around the strategic viability of its different industrial ecosystems (cf. Table 3).

4.2.1 Key enabling technologies

A natural starting point of reference for analysis is ***key enabling technologies***[10]. Moving beyond the original list of key enabling technologies from the early 2010s, the European Commission currently uses several continuously updated lists of key enabling technologies. These lists focus on a number of digital domains and technologies contributing to sustainability ('greening'), such as renewable energy or energy-saving technologies. Although deficiencies in sovereignty in some of these technologies are relevant to our discussion, such deficiencies are to be expected as a natural outcome of decades of the global division of labour in both the innovation and the economic domains. These deficiencies in sovereignty highlight specific bottlenecks that can, in principle, be fixed by targeted policy action, even if such action would be expensive and require time. Hence, such deficiencies are not immediately connected to threats to welfare.

4.2.2 Industrial ecosystems

In addition to technologies, the ***industrial ecosystems*** defined in the European Commission's industrial strategy can be used as an even more systemic point of reference. This approach differs from a focus on key technologies because it is broader and more general in assessing the ability of important domains of the European economy to function independently. If an economy has become vulnerable at such an aggregate level, this implies that entire sectors are incapable of operating independently if external partners disengage. This situation has traditionally characterised developing nations rather than those with the ambition to be technological leaders, and it is immediately detrimental. Analyses at this level detect structural issues in the set-up of the overall economy, be they primarily material, related to external control over the innovation process, or both.

Table 3: Levels of thematic analysis

		key enabling technology level	**industrial ecosystem level**
Conceptual dimension of autonomy	**innovation dimension (knowledge generation)**	OSA, Innovation Domain (Innovation Sovereignty)	OSA, Innovation Domain (Innovation Sovereignty)
	economic dimension (value creation)	OSA, Economic Domain (Economic Sovereignty)	OSA, Economic Domain (Economic Sovereignty)

Source: Own concept

[10] The conceptual foundation of thematic delineations and concrete empirical evidence for industrial ecosystems and key technologies used in this report has been developed as part of a series of DG GROW projects which started as the Key Enabling Technologies Observatory in the early 2010s. These projects were later consolidated under the Advanced Technologies for Industry Monitor (ATI) and are being continued under the heading of European Monitor of Industrial Ecosystems (EMI). This line of research has developed definitions in several dimensions of analysis for both industrial ecosystems and key enabling technologies: (i) for patents (by IPC and keywords); (ii) for trade (by HS codes); and (iii) for production (by PRODCOM codes). These have been developed with the intention of corresponding to the level of substance and can thus be integrated into composite indicators or juxtaposed in figures displaying multiple aspects of sovereignty (Advanced Technologies for Industry - Methodological report).

5 Findings

In this section, we will provide a quick overview of the results arrived at when the above methodology is applied to the two previously-mentioned main levels of thematic analysis (key enabling technologies and industrial ecosystems). It starts by reporting on each thematic level separately, and then presents them side-by-side in a combined x-y chart. This should enable the reader to intuitively understand the primary nature of any autonomy/sovereignty issue.

5.1 Autonomy

At the level of **industrial ecosystems**, Europe's provisional level of *economic autonomy* is in most cases comparatively unproblematic (Figure 1), i.e. trade balances are oftentimes not dramatically negative and the relations between trade balance and local production acceptable. Despite having significant levels of imports in many areas, which is evidence of international integration, 6 out of the 10 ecosystems considered here have slight export surpluses. That said, net import reliance can be as high as 30% in textiles, electronics and digital ecosystems. There are also high net import reliances in the aerospace and defence areas. Apparently, Europe's economic autonomy is being fundamentally challenged in important areas.

The same worrying picture emerges in *innovation autonomy*, where the share of externally owned patents in all patent activities varies from about 8% (aeronautics, construction, renewables) to about 20% (digital, health) (Figure 2). On average, the share of externally owned patents in all patent activities ranges between 10% and 15%. Although most industrial ecosystems are not structurally dependent on the provision of components and goods, the innovation activities connected to these industrial ecosystems appear to be externally controlled to a similar extent.

When considering both economic autonomy and innovation autonomy in industrial ecosystems together (Figure 3), we find that Europe's lack of autonomy is comprehensive in the digital domain, i.e. it extends to both the economic and the innovation domains. In the textiles and electronics sectors, the main issue is Europe's lack of economic autonomy (reliance on imports), whereas in the energy-intensive, agri-food and health sectors, Europe's main issue is its lack of innovation autonomy (external corporate control of the innovation process). In other sectors, in particular renewables and construction, Europe displays a higher level of autonomy to start with, while the aerospace and defence sectors retain a certain dependency on external inputs and the mobility sector remains somewhat influenced by external ownership of its inventions. In any case, the high level of aggregation may hide several, more specific vulnerabilities that do not yet affect the autonomy of the system as a whole but may constitute the roots of that happening in the future.

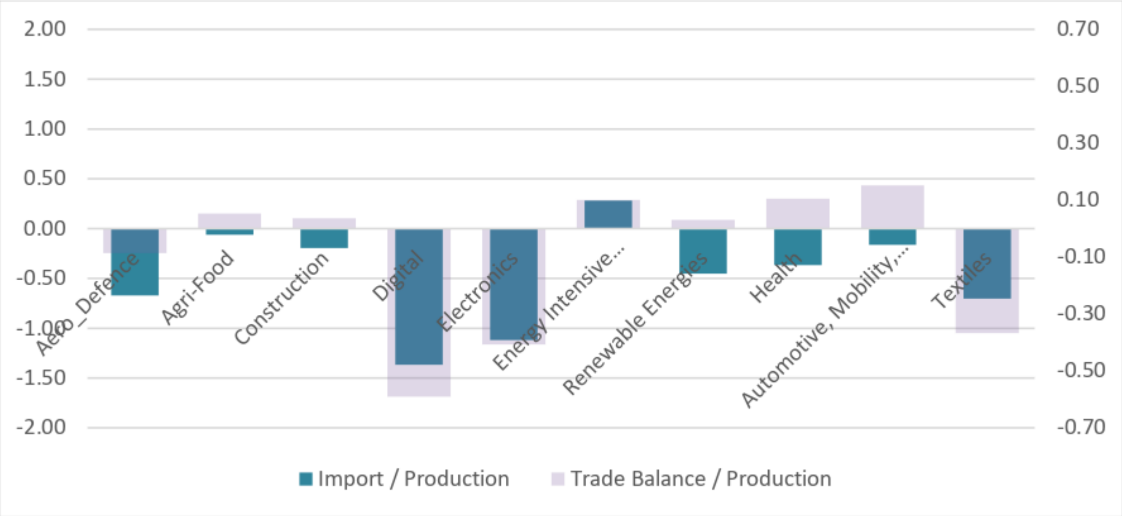
Among the ***key enabling technologies***, the picture is even more discouraging than for economic autonomy. Europe faces net import reliance in all but 3 out of 11 domains. Many of the eight key enabling technology domains in which Europe faces net import reliance are in the digital field (Figure 4). The only three areas left where Europe does not face a net import dependency are advanced manufacturing technologies/robotics; renewable energies; and energy-saving technologies. In other areas, such as artificial intelligence (AI) and big data, net external reliance amounts to over 50%.

Turning to *innovation autonomy*, we find more KET areas with higher external reliance - at 20% or more - than for industrial ecosystems. This finding is due to the greater granularity of data in the digital domain (AI, big data, digital security) but also due to Europe's additional external reliance in the areas of biotechnology, and energy-saving technologies. Overall, Europe's innovation dependency is lowest in the areas of micro- and nanoelectronics (around 9%) and renewable energy technologies (around 4%).

When considering both innovation autonomy and economic autonomy in key enabling technologies together (Figure 6), we find that Europe's lack of autonomy is comprehensive in particular for AI and big data, followed at some distance by digital security, advanced materials, and nanotechnologies. Technologies with a greater emphasis on economic dependency (reliance on component imports) include the internet of things, digital mobility and micro- and nanoelectronics. Technologies with a greater emphasis on innovation dependency (external corporate control over inventions in the field) include biotechnology and energy-saving technologies. Only in the fields of advanced manufacturing technology, robotics and renewable energy technologies can one speak of Europe having both economic and innovation autonomy.

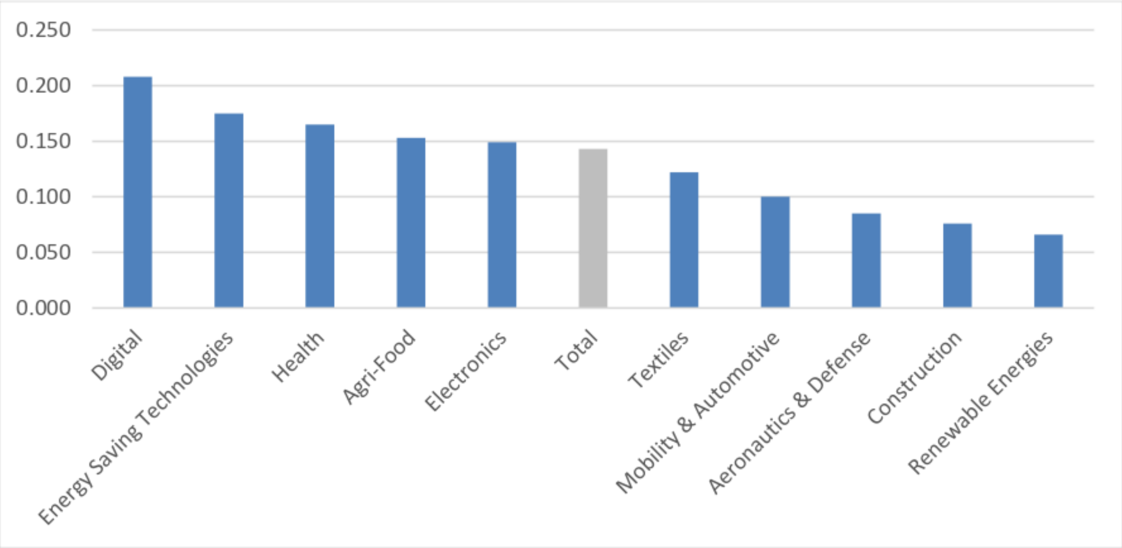
In summary, our analysis of autonomy shows a picture of a European Union deeply integrated in international production and innovation chains, with its primary, known areas of strength in the domains of advanced manufacturing and renewable energies. To some degree, this integration in international production and innovation chains provides evidence of a well-established – and commercially beneficial – division of labour, such as in the textiles sector. On the other hand, the level of Europe's external dependency in the digital domain, and Europe's even greater external dependency on many of the core technologies related to the digital domain, can only be considered as alarming.

Figure 1: Overview of economic dependency 2018-2020, Industrial Ecosystems
(Left axis: Relation Import/Production, Right axis: Relation Net Imports in All Goods)



Note: Energy-intensive industries refers to all activities in energy-intensive industries in both dimensions[11].
Source: Own analysis, based on PRODCOM, UN COMTRADE.

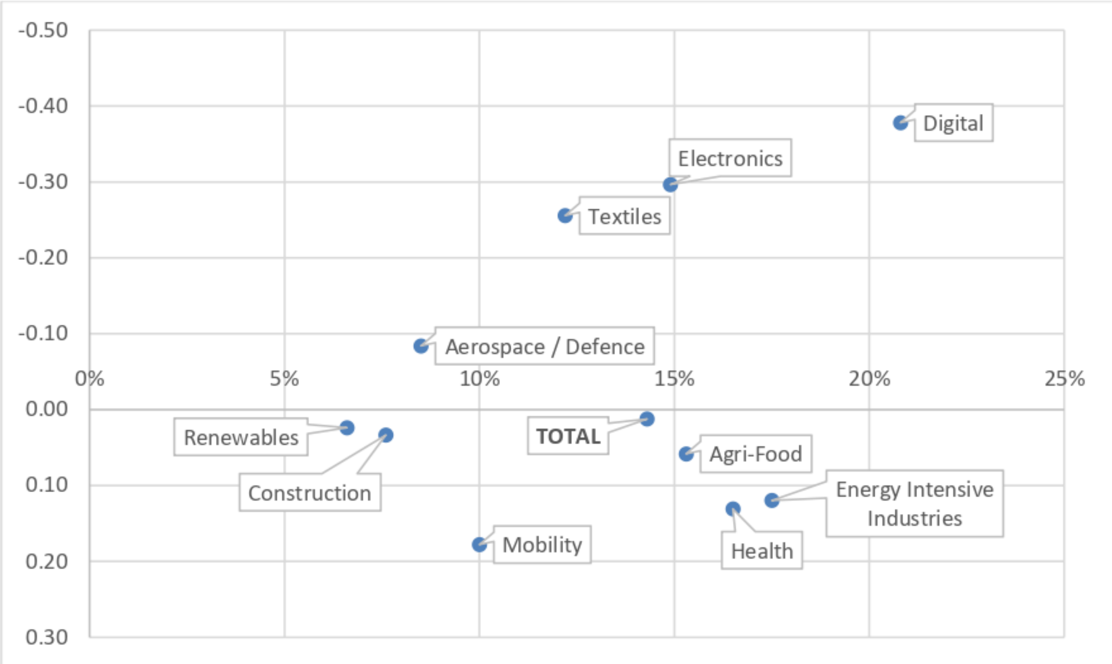
Figure 2: Overview of innovation dependency 2018-2020, Industrial Ecosystems
(Share of externally owned patents in all domestic inventions)



Source: Own analysis, based on EPO PATSTAT.

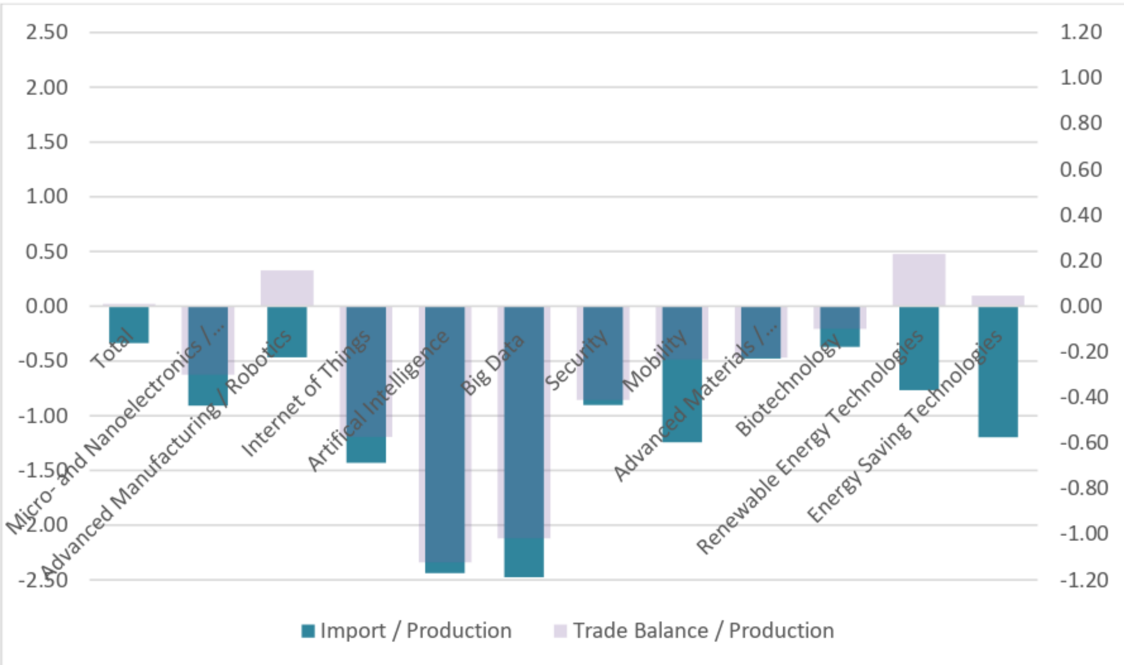
[11] The domain of energy-intensive industry presents a specific challenge in documentation, as the ecosystem in which the twin transitions have to be effected is in this case very broad (including, for example, the entire steel industry) whereas the domain of energy-saving technologies is comparatively narrow. As this differentiation is more pronounced than it is in other ecosystems, such as the digital ecosystem (which is 'represented' by more technologies), we will refer to it in all relevant figures.

Figure 3: Dimensions of autonomy (by industrial ecosystem)
x-axis: foreign-owned patents, y-axis: share of net imports in available goods



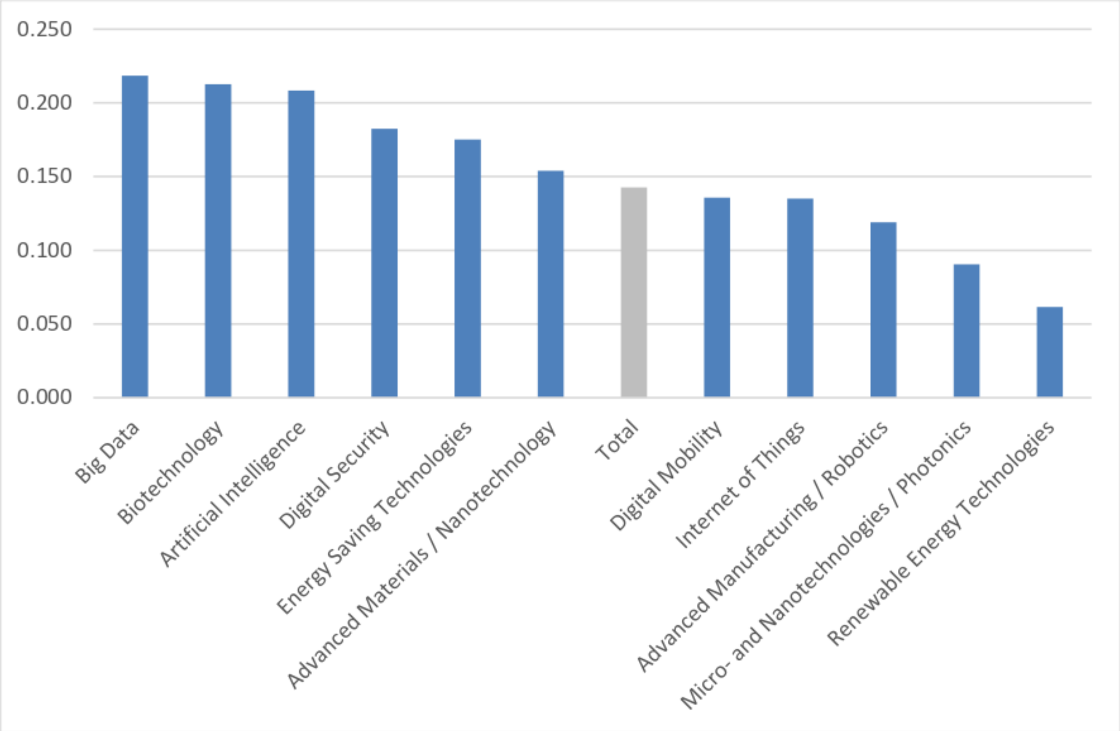
Note: Energy-intensive industries refers to all activities in energy-intensive industries in both dimensions.
Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT.

Figure 4: Overview of economic dependency 2018-2020, Key technologies
(Left axis: Relation Import/Production, Right axis: Relation Net Imports in All Goods)



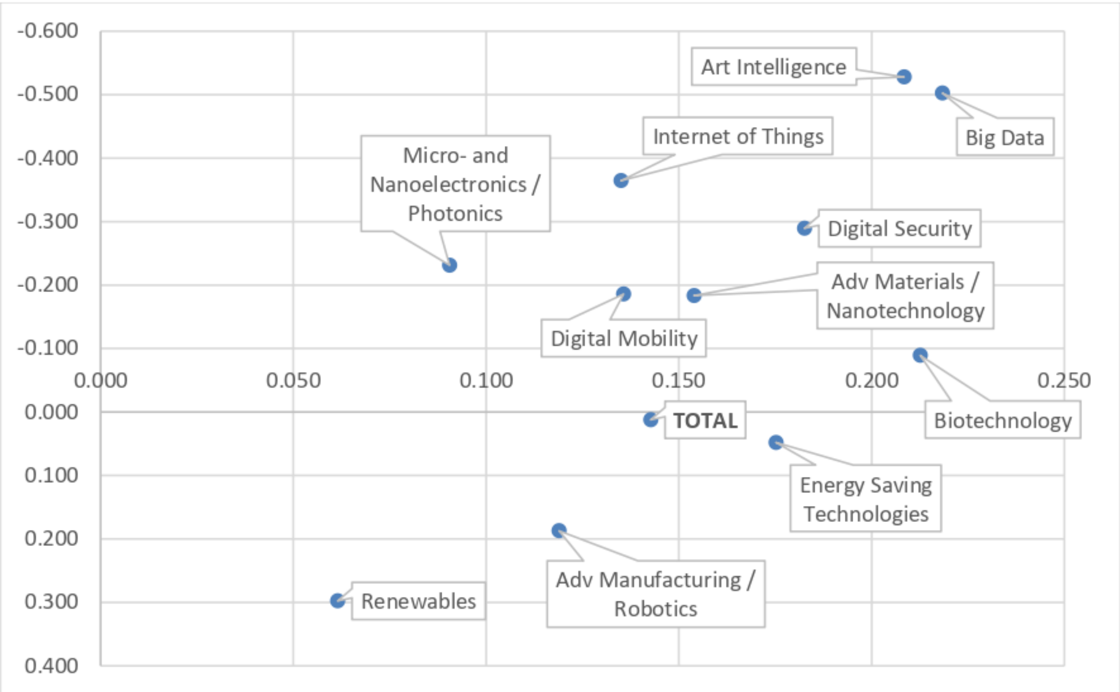
Source: Own analysis, based on PRODCOM, UN COMTRADE.

Figure 5: Overview of innovation dependency 2018-2020, Key technologies
(Share of externally owned patents in all domestic inventions)



Source: Own analysis, based on EPO PATSTAT.

Figure 6: Dimensions of autonomy (by key enabling technology)
x-axis: foreign-owned patents, y-axis: share of net imports in available goods



Note: Energy-saving technologies also refers to distinct group in the economic dimension

Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

5.2 Concentration, associated risk and sovereignty

5.2.1 Concentration of external reliance

As our analysis below demonstrates, Europe's concentration in the *economic domain* (as measured by the share of top-5 import partners in total imports) ranges between 45% and 85% for the industrial ecosystems (Figure 7), with the lowest shares in agri-food and the highest shares in health, digital, electronics, aerospace and defence and construction. For the key enabling technologies, we typically find Europe's concentration to be between 72% and 82% with relatively limited overall variation (Figure 8). The comparatively lowest values for concentration in key enabling technologies are found in renewable energy technologies, energy-saving technologies, and micro- and nanoelectronics. However, concentration values are higher in artificial intelligence, big data, biotechnology, the internet of things and digital mobility. But the most remarkable finding is that Europe's concentration of external reliance in the economic domain is substantially higher at the level of individual technologies (and substantially above the overall total of 55%) than it is for overall industrial ecosystems. This finding is conclusive as broader economic domains require a broader range of inputs than specific fields, and it confirms that material bottlenecks may often be rather specific and systemically hidden.

In the *innovation domain*, the concentration of patent ownership in the EU (as measured by the share of top-3 external patent owners in all externally owned patents) ranges between 70% in the mobility and renewables ecosystems and about 95% in the health and agri-food ecosystems (Figure 7). In the innovation domain, diversity is greater in key enabling technologies. There is a large variety between concentrations of external patent ownership on the top-3 countries of no more than 50% (in advanced manufacturing technologies/robotics) to close to 100% (in biotechnology) (Figure 8). In the middle is a variety of other technologies, with energy-saving technologies (concentration of patent ownership of ~90%) marking the upper and digital mobility (concentration of patent ownership of ~70%) marking the lower limit of that cluster. To some extent, it is surprising to find exceptions to the overall highly concentrated governance of innovation in single fields, such as advanced manufacturing technologies rather than in broader ecosystems. This may partly be due to the more mature nature of this technology, although that does not explain the continued concentration of innovation in more mature ecosystems like textiles and construction. Possibly, the degree of corporatisation is higher in the latter two sectors, resulting in a countervailing effect whereby corporatisation promotes concentration, but maturity of ecosystems promotes dispersal of innovation.

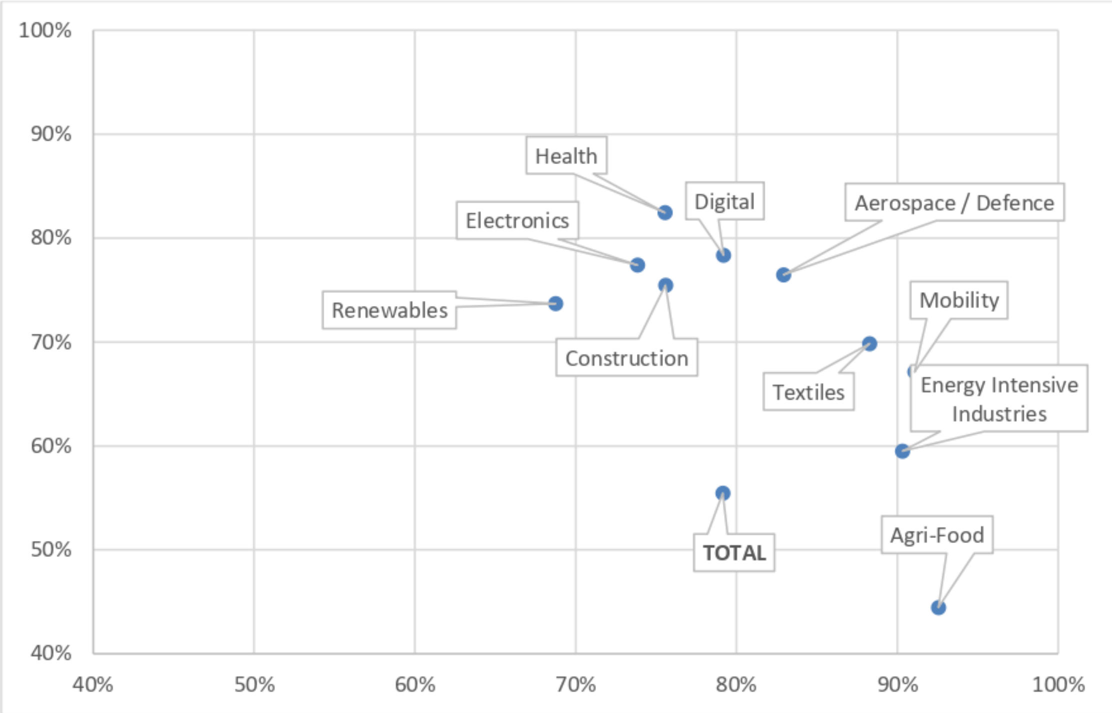
Finally, it is interesting that our analysis for industrial ecosystems seems to suggest that areas with greater concentrations in external economic reliance tend to be areas with lower concentrations of external innovation reliance and vice versa (Figure 7). This may partly be explained by the different nature of more mature (agri-food and energy-intensive) and more innovative (health, digital, electronics) ecosystems. However, this does not really explain the positioning of the construction sector in the category of more innovative ecosystems. In summary, our analysis provides evidence that the specific reasons for the concentration of external reliance may differ from sector to sector – and that some concentrations of external reliance may primarily be the result of corporate logics thinly veiled by a national surface of measurement.

5.3 Associated risk

Figures 9-11 illustrate the outcomes of our calculation of the composite indicator for risk associated with a particular partner, with Figure 9 focusing on external risk, Figure 10 focusing on domestic risk, and Figure 11 focusing on a composite indicator that combines both dimensions at equal weight.

Based on these analyses, it is possible to single out ***partners with an above-threshold level of associated risk*** (i.e. those partners that may have the inclination to disengage or become unable to live up to commitments). For this analysis, a cut-off point was set at 0.35 (at the mentioned scale of zero to one) which, beyond the EFTA nations, considers the following major countries as associated with acceptable risk: the United Kingdom, the United States, Canada, Singapore, Japan, Korea, Australia, New Zealand, Israel, Chile, the United Arab Emirates, Taiwan and Hong Kong (all Member States would also be considered reliable, but that is not relevant as they do not constitute 'trade partners'). Important trading and collaboration partners that are considered to be associated with high risk according to this analysis include South Africa (0.37), Brazil (0.38), India (0.38), Mexico (0.40), China (0.43), Turkey (0.45), Argentine (0.48), Ukraine (0.53), Belarus (0.62), and Russia (0.73).

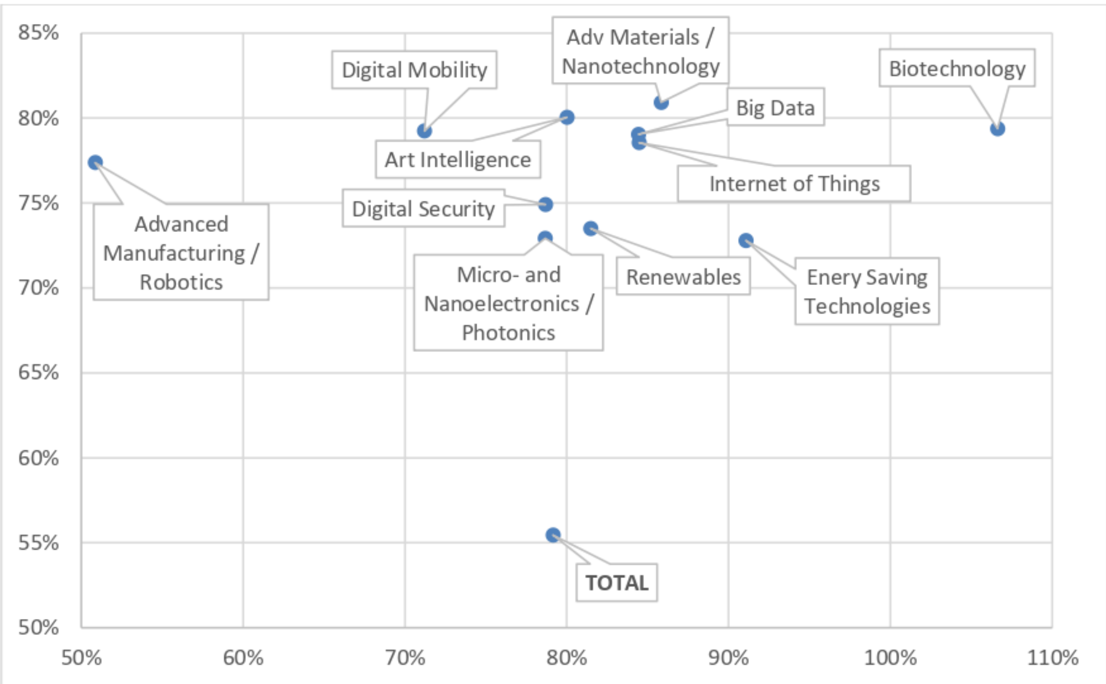
Figure 7: Concentration by industrial ecosystem (main partners' share in total)
x-axis: share of top-3 external patent owners, y-axis: share of top-5 top import partners



Note: Energy-intensive industries refers to all activities in energy-intensive industries in both dimensions. Patent share can exceed 100% as no fractional counting was applied to the inventor count.

Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

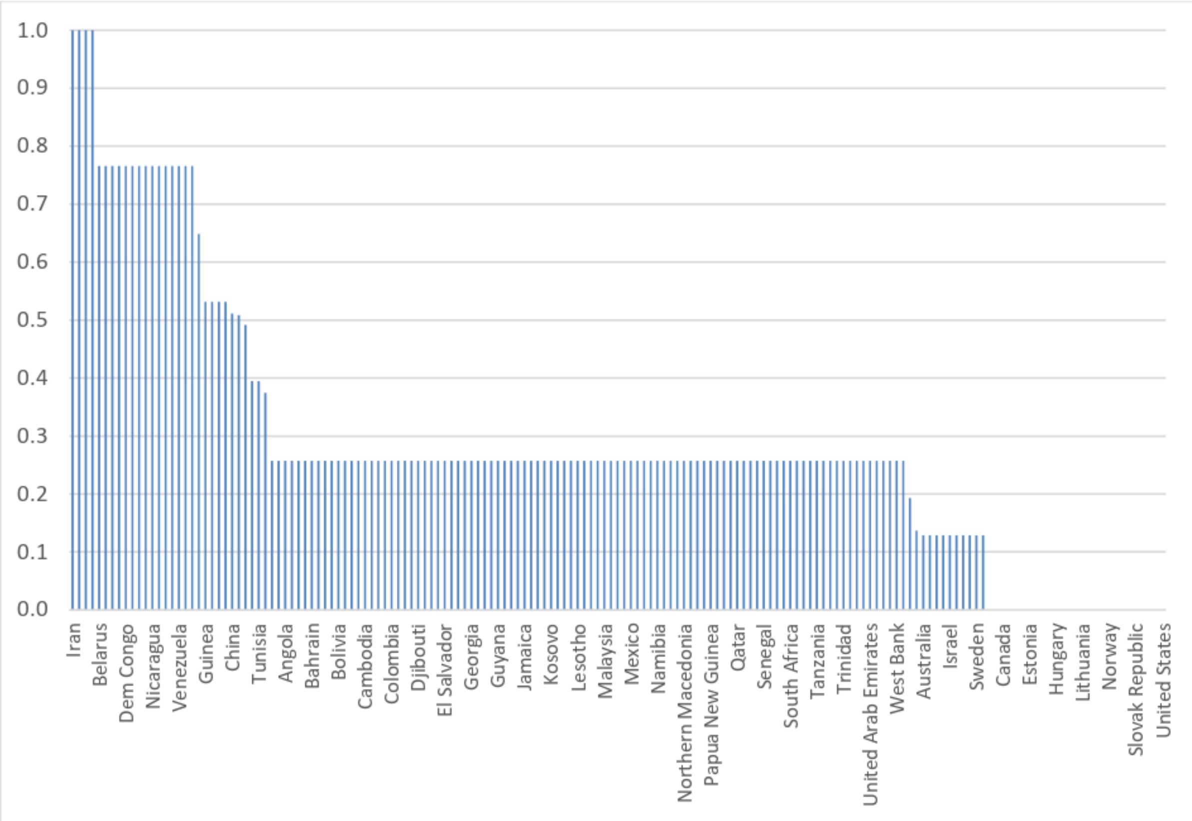
Figure 8: Concentration by key enabling technology (main partners' share in total)
x-axis: share of top-3 external patent owners, y-axis: share of top-5 top import partners



Note: Energy-saving technologies also refers to a distinct group in the economic dimension. Patent share can exceed 100% as no fractional counting was applied to the inventor count.

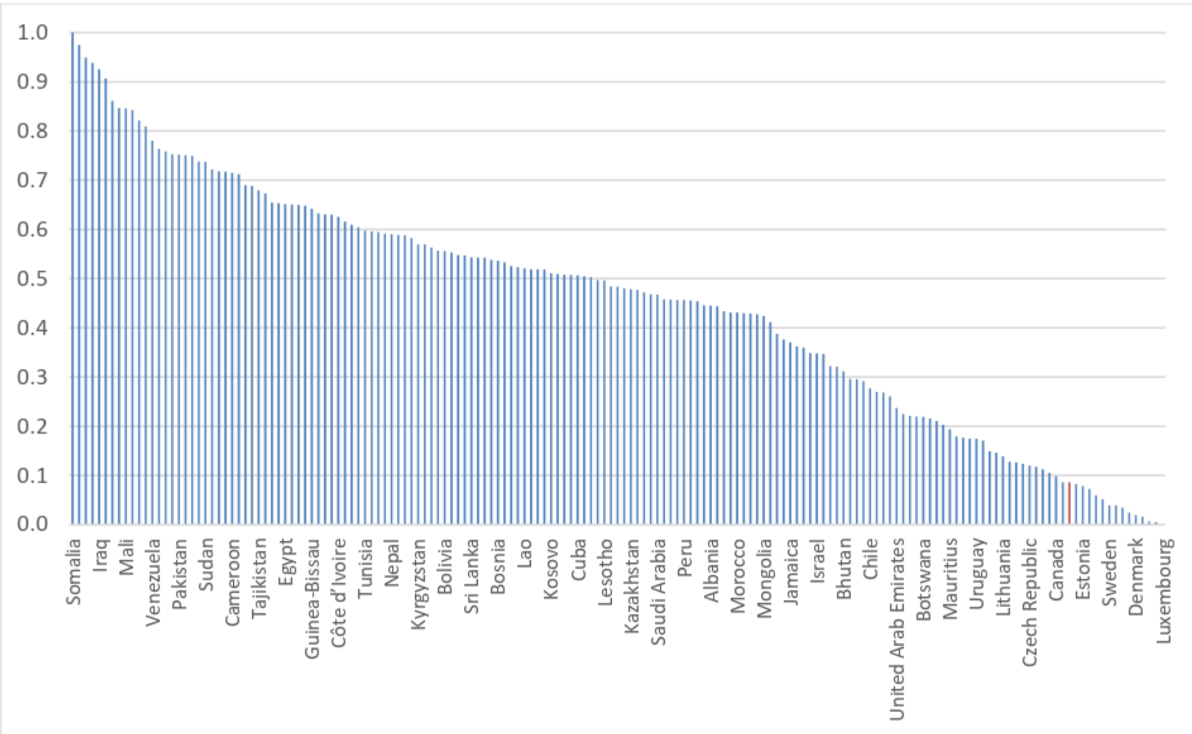
Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT.

Figure 9: Risk associated with countries due to potential geopolitical repositioning and conflict



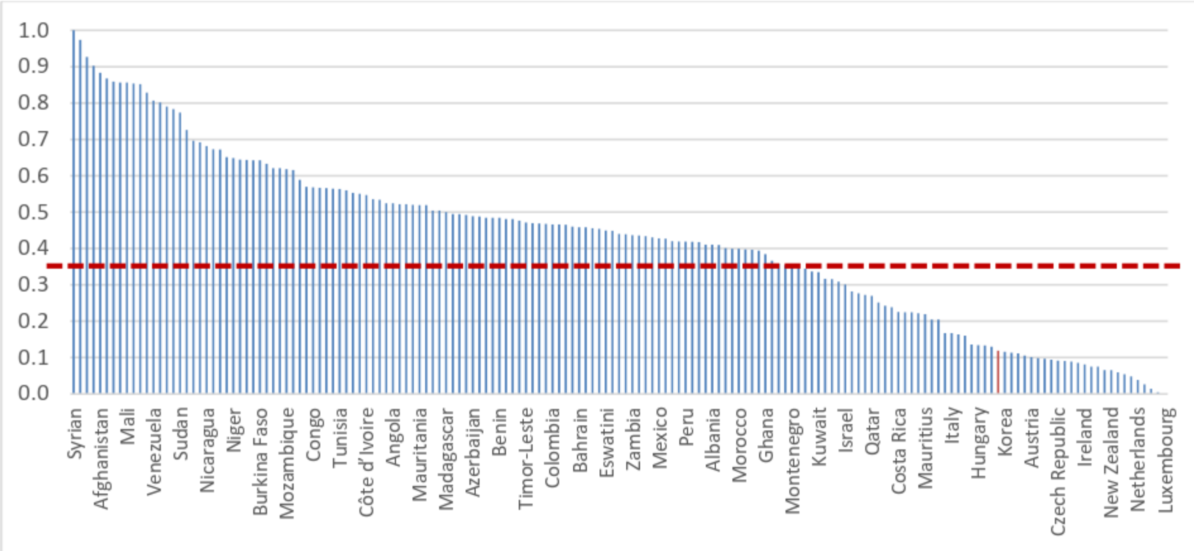
Source: Own analysis

Figure 10: Risk associated with countries due to potential domestic instability



Source: Own analysis

Figure 11: Overall risk currently associated with countries as partners



Source: Own analysis

5.4 Sovereignty / Strategic Autonomy

5.4.1 Concentration for partners associated with high risk

When the top-5/top-3 partner-concentration approach is applied to the group of *top-5/top-3 high-risk partners* only, the distribution of concentration becomes a lot more diverse – both between industrial ecosystems (Figure 12) and between key enabling technologies (Figure 13).

Overall, the concentration of external reliance in the *economic domain* (share of top-5 high-risk import partners in total imports) ranges between 30% (for agri-food, health, and energy-saving technologies) and 70-75% (textiles[12], construction[13]) at the level of industrial ecosystems. At the level of key enabling technologies, it ranges between 35% (advanced manufacturing technologies / robotics) and 65% (internet of things[14] / AI[15] / big data[16]).

In the *innovation domain*, patent-ownership concentration (share of top-3 high-risk patent owners in all externally owned patents) ranges between 3-5% (in health, textiles, and agri-food) and about 20-25% (in renewable energies and digital[17]) for the industrial ecosystems; and between 6-9% (in advanced manufacturing and biotechnology) and 20-30% (in AI, big data, digital security, and digital mobility[18]) in the key enabling technologies. Patent-ownership concentration at the technological level is thus in general substantially lower than the concentration of external reliance at industrial ecosystem level, but not necessarily at the level of specific, often digital, key enabling technologies.

Arguably, the most prominent changes are due to whether the main partner nation on which activities in a certain domain are concentrated is China or the United States. For example, external reliance in the area of biotech-health often results from the strong role of American multinationals – and thus companies from a - so far - low-risk country. There is therefore a very limited concentration of external reliance on high-risk partners the among the top-5/top-3 partner countries in these areas, in particular in the innovation domain. However, the situation in AI/big data-digital/electronics remains problematic, as Chinese firms have come to play a much larger role in these domains.

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12 Resulting from a combined reliance on China, Turkey, and Vietnam.

13 Resulting from a combined reliance on China, Bangladesh, and Turkey.

14 Resulting from a combined reliance on components from China, Vietnam and Malaysia.

15 Resulting from a combined reliance on components from China, Thailand and the Philippines.

16 Resulting from a combined reliance on components from China, Thailand and Mexico.

17 All resulting from ownership by firms registered in China.

18 All resulting from ownership by firms registered in China.

5.4.2 Resulting final index – Currently manifest sovereignty / strategic autonomy

Figure 14 and Figure 15 provide a final summary of our empirical analysis with an index of sovereignty based on the formula presented in Chapter 4, focusing on *obvious and already manifest vulnerability*.

Overall, the results at the level of *industrial ecosystems* (Figure 14) show a serious structural problem for sovereignty only in one case: the digital ecosystem. The electronics and the textiles domains also display some limitations of sovereignty that deserve attention, but they are notably less critical, and there is no immediate problem. All other industrial ecosystems cluster around the mean for the entire economy or are positioned even more favourably for Europe. The slightly more limited sovereignty of the aerospace and defence sector merits further note, given its character and function in the economy.

At the level of *key enabling technologies*, the situation is more varied (Figure 15), with four clear groups emerging. Europe's exposure is greatest for artificial intelligence and big data, followed by digital mobility and digital security, where there is a slightly lower, but still substantial level challenge to strategic autonomy. This general analysis for the digital ecosystem confirms the known, substantive sovereignty issue within micro- and nanoelectronics. In those areas, Europe clearly lacks strategic autonomy. In contrast, it displays such strategic autonomy in renewable energy technologies, energy-saving technologies and advanced manufacturing technologies. Findings for the remaining technologies are slightly less positive, but this is primarily due to a lack of economic sovereignty.

In both industrial ecosystems and key enabling technologies, Europe's level of sovereignty or open strategic autonomy in the innovation and the economic domains remains by and large in balance, and there are no fundamentally different profiles, with the exception of textiles and electronics at the ecosystem level, and the internet of things at the technology level, all of which are more exposed in the economic than in the innovation domain.

5.4.3 Alternative sovereignty index – Baseline sovereignty, potential vulnerability

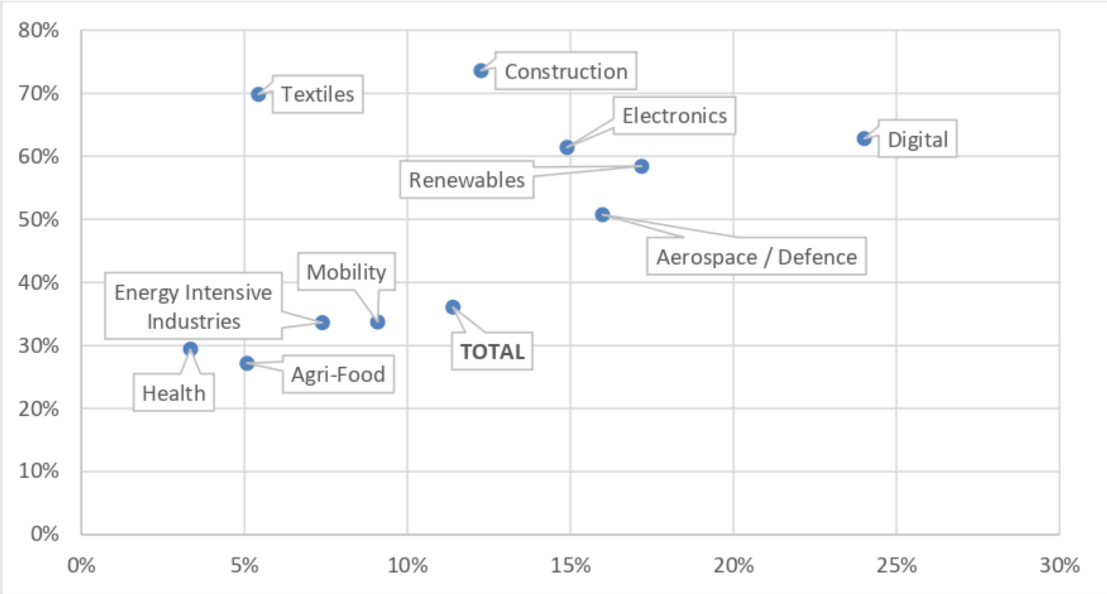
As mentioned above, it is reasonable to calculate the sovereignty index for manifest sovereignty based on both necessary criteria for vulnerability: concentration of external reliance and current risk associated with partners. However, in order to account for changes in political reliability or exposure to crisis , the cut-off threshold for 'risky relations' was removed completely to produce Figures 16 and 17. While the baseline sovereignty indices in these figures reflect leverage through concentration, they explicitly abstain from discriminating between partners.

If we do not discriminate between partners, the results at the level of industrial ecosystems change (Figure 16). The reason for this is that: (i) Europe is now more exposed because of the textiles and electronics ecosystems (based here in part on now included relations with friendly Asian nations); and (ii) Europe is also exposed to a significant increase in potential innovation sovereignty issues in energy-intensive industries, the agri-food sector, and the health sector. To a certain degree, the analysis also indicates the same for the textiles and the electronics ecosystem where many inventions are not owned in the European Union but are instead owned by companies in a few friendly nations. Seen from this perspective, only the renewable energy and the construction sector appear free of potential vulnerability.

For key enabling technologies (Figure 17), diversity is now even higher. Again, however, the primary difference is the much higher leverage of foreign firms who control the innovation process. In this case, freedom from the potential threat of vulnerability can only be claimed in the areas of renewable energy technologies as well as in advanced manufacturing/robotics. Areas in which Europe has suffered particularly pronounced potential losses of sovereignty in the innovation dimension include biotechnology and energy-saving technologies. Furthermore, there is now a potentially adverse situation in both dimensions (i.e. in both key enabling technologies and industrial ecosystems) in advanced materials, components for the internet of things, and digital security. In digital mobility however, the situation has not disproportionately deteriorated. In addition to these areas, the most vulnerable domains continue to be in artificial intelligence and big data, in both of which there is a strong external influence from America.

In conclusion, it should be noted that this visual comparison between Figure 14/15 and Figure 16/17 must of course be seen as relative and indicative. Naturally, the overall shares of top-5/top-3 countries will always be higher for all countries than for the top-5/top-3 countries with risk associated. In that sense, the above comparison seeks to: (i) compare relative configurations; and (ii) at ecosystem level highlight the rather different relation of 1:3.3 between (max.) manifest and potential vulnerability in the innovation (Index ~ 0.05/0.16) and that of 1:1.25 in the economic domain (Index ~ 0.3/0.4).

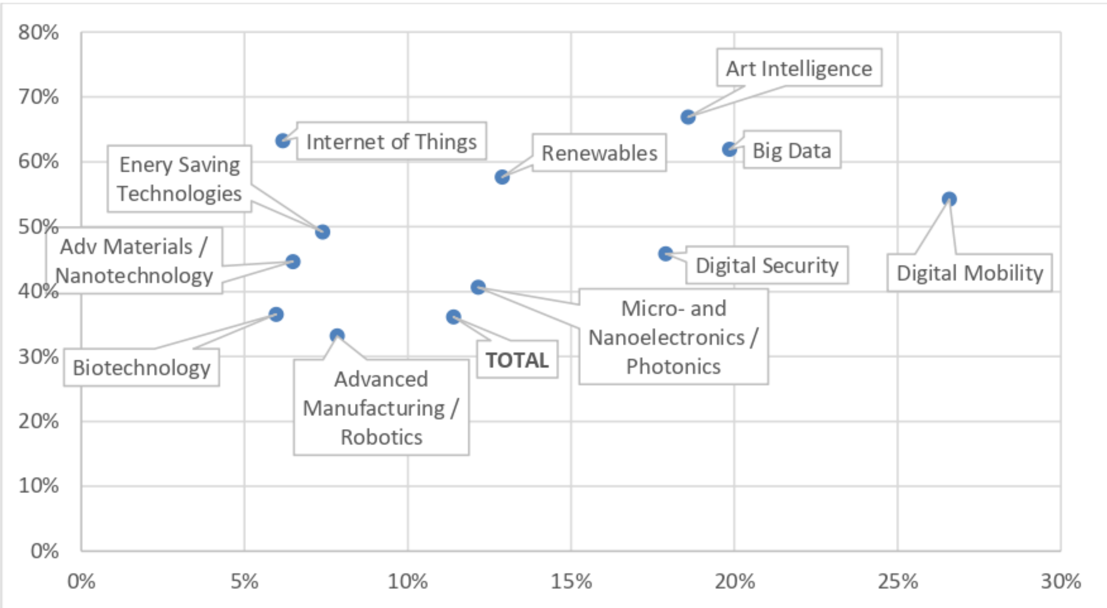
Figure 12: Industrial ecosystem concentration on partners with risk associated
x-axis: share of top-3 high-risk patent owners, y-axis: share of top-5 high-risk import partners



Note: Energy-intensive industries refers to all activities in energy-intensive industries in both dimensions. Partner countries are considered high risk, if their risk associated is > 0.35 as per Figure 11.

Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT.

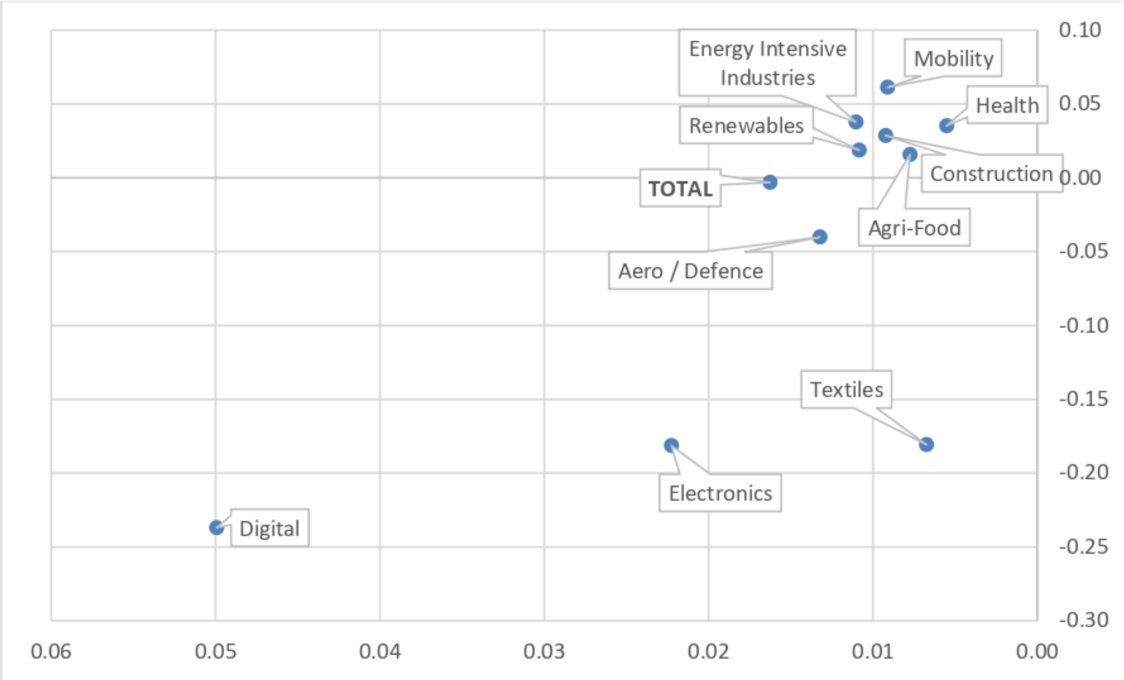
Figure 13: Key enabling technology concentration on partners with risk associated
x-axis: share of top-3 high-risk patent owners, y-axis: share of top-5 high-risk import partners



Note: Energy-saving technologies also refers to distinct group in the economic dimension. Partner countries are considered high risk, if their risk associated is > 0.35 as per Figure 11.

Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

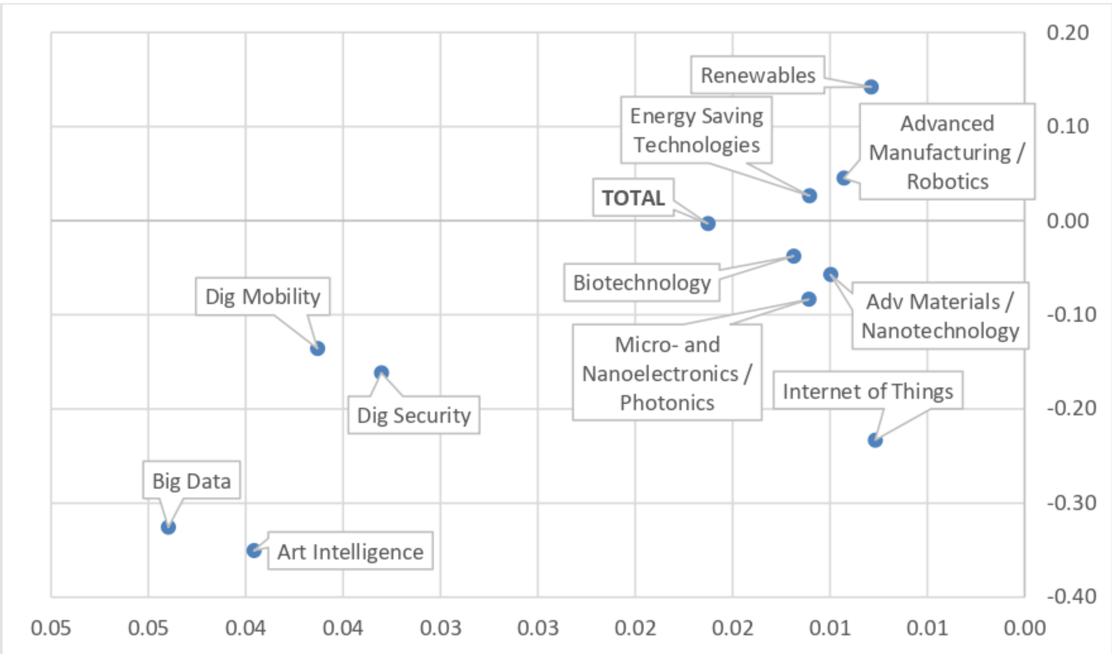
Figure 14: Sovereignty Index / OSA Index (manifest vulnerability)
The Sovereignty Index is calculated as autonomy * concentration of reliance on high-risk partners
x-axis: innovation dimension, y-axis: economic dimension



Note: Energy-intensive industries refers to all activities in energy-intensive industries in both dimensions. Partner countries are considered high risk, if their risk associated is > 0.35 as per Figure 11.

Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

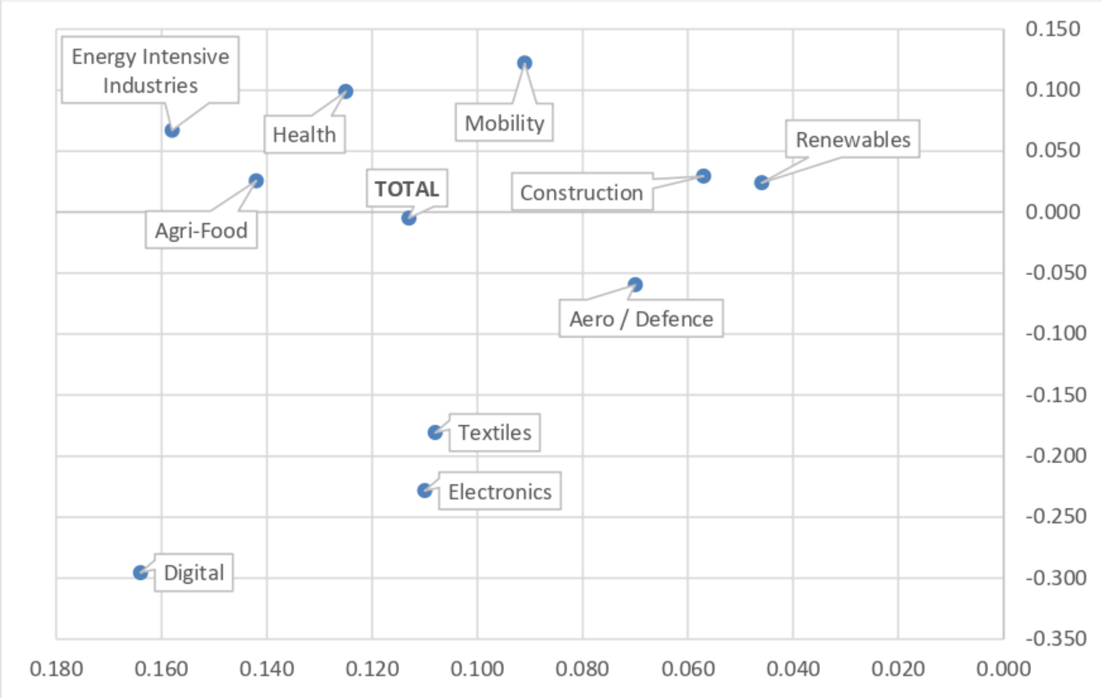
Figure 15: Sovereignty Index / OSA Index (manifest vulnerability)
The Sovereignty Index is calculated as autonomy * concentration of reliance on high-risk partners
x-axis: innovation dimension, y-axis: economic dimension



Note: Energy-saving technologies also refers to distinct group in the economic dimension. Partner countries are considered high risk, if their risk associated is > 0.35 as per Figure 11

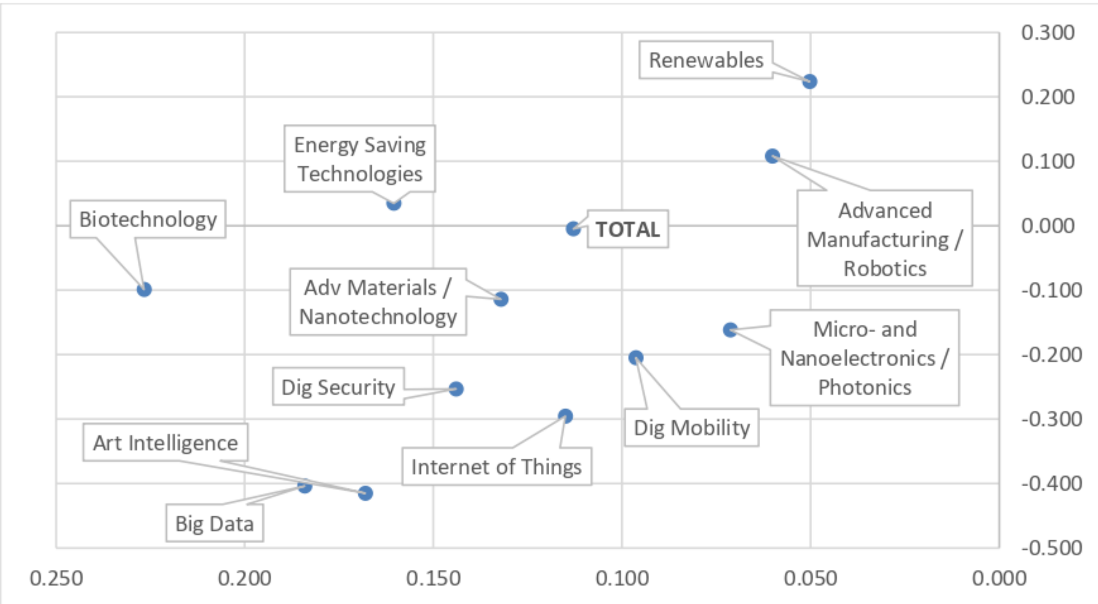
Source: own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

Figure 16: Sovereignty Index / OSA Index (potential issues)
The Sovereignty Index is calculated as autonomy * concentration of reliance
x-axis: innovation dimension, y-axis: economic dimension



Note: Energy-intensive industries refers to all activities in energy-intensive industries in both dimensions
Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT

Figure 17: Sovereignty Index / OSA Index (potential issues)
The Sovereignty Index is calculated as autonomy * concentration of reliance
x-axis: innovation dimension, y-axis: economic dimension



Note: Energy-saving technologies also refers to distinct group in the economic dimension.
Source: Own analysis, based on PRODCOM, UN COMTRADE, EPO PATSTAT.

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List of abbreviations and definitions

Open Strategic Autonomy	A political concept developed by the EPRS and subsequently adopted throughout the European Commission, covering diverse perspectives including both technical autonomy and its geopolitical context ('strategic autonomy') relating it closely to questions of political agency, geopolitical agency. In this report used interchangeably with *Sovereignty*.
Capacity	Ability to generate knowledge or produce material goods domestically.
External Reliance	Reliance on external partners in knowledge generation or material production. The text avoids the equivalent term 'Dependency' as it has been specifically defined in European Commission SWD(2021)352
Concentration	Degree to which external reliance focuses on relations with a limited group of key partners (here: top-5 in trade, top-3 in innovation).
(Momentary) Autonomy	Structural freedom of external reliance, relation of capacity and dependency.
Innovation Autonomy	Structural freedom of external reliance in the domain of knowledge generation.
Economic Autonomy	Structural freedom of external reliance in the domain of material production.
Risk Associated	The likelihood that a certain relation currently sustaining external reliance may fail or turn unfavourable due to the partner's choices or circumstance.
Sovereignty	A polity's ability to design its own knowledge-creation and material-production processes independent of the decisions of external partners. In this report used interchangeably with *Open Strategic Autonomy*.
Manifest Sovereignty	A polity's *current* ability to design knowledge-creation and material-production processes independent of partnerships to which risk is *currently* associated.
Baseline Sovereignty	A polity's *certain* ability to design knowledge-creation and material-production processes independent of the fact whether more partnerships should turn risky.
Key Enabling Technologies	A group of technologies central to the twin transitions, as defined by DG RTD https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/key-enabling-technologies_en.
Industrial Ecosystems	A group of economic domains in which the twin transitions are to be effected according to the European Industrial strategy, documented by DG GROW here https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en. For analytical reasons, this report only considers those ecosystems that are related to material production, avoiding pure service domains like tourism.
Production	Monetised value of overall European production as per the PRODCOM statistic [PRODVAL Indicator].
Import and Export	Monetised value of trade as per the UN COMTRADE statistic, correcting for trade internal to the single market, converted from USD to Euro based on the ECB's annual mean exchange rates.
Patent Application	a) documentation of successful outcomes of knowledge-generation processes. b) documentation of IP ownership and hence control over such processes.
Transnational Patent	Patent application either through the WIPOs PCT process or directly at the EPO (removing duplicates in the count) - established quality standard for patents.
Net import	The additional volume of goods available domestically from foreign sources, imports minus exports.

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society