ANALYSIS OF THE EU'S POSITIONING IN CRITICAL TECHNOLOGY VALUE CHAINS

A report prepared for DIGITALEUROPE

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Contents

frontier economics

EXECUTIVE SUMMARY

In 2023, the European Commission (EC) published a European Economic Security Strategy, with the aim “to minimise the risks to economic security in the context of increased geopolitical tensions and accelerated technological shifts”[1].

The EC since identified ten “critical technologies” that it considered highly likely to present sensitive and immediate risks to technology security and leakage. The EC’s Strategy proposes a thorough assessment of risks to economic security as they relate to these critical technologies. Critical technologies are ones that are deemed to be central both to the EU’s economic security, and to the competitiveness of its industries. Indeed, the EC sees the promotion of competitiveness as a key plank in the mitigation of risks that may imperil the EU’s economic security.

Given the interplay between economic security and competitiveness, it is opportune to begin by defining these concepts. By “economic security" we mean the ability of the EU to avoid or limit impact or exposure to external and geopolitical risks from supply chains. Exposure to external risks may include: risks to critical infrastructure (e.g. connectivity, energy supply, healthcare), risks compromising European or national security, as well as risks to the effective functioning of supply chains. By “competitiveness” we mean the ability of EU industries and businesses to maintain or improve their position in global markets by capturing value-added along the supply chain of relevant critical technologies.

In considering the interplay between economic security and competitiveness in relation to critical technologies, it is important to recognise that these technologies have emerged because of, and are embodied in, global value chains. The emergence of these value chains reflects gains from specialisation in particular tasks. It is that specialisation that generates productivity gains that in turn generate economic value and growth. Being “competitive” in these value chains relies, in the first place, on the ability to capture gains from specialisation, and to appropriate significant shares of value added. Moreover, sectors that rely on critical technologies benefit from the lower costs, and consequent productivity gains, that are delivered from specialisation at a global level.

At the same time, it is the very fact that critical technologies operate through global value chains that also raises concerns about economic security. Specifically, the concern is that specialisation may create dependencies that leave the EU exposed to external shocks, including geopolitical ones.

The interaction between economic security and competitiveness is therefore complex. There are complementarities and trade-offs. These will need to be considered in structuring policy reforms. The instruments that support competitiveness are not necessarily those that will manage economic security, and vice versa. For example, trying to appropriate control of more extensive parts of a value chain, may come at significant resource cost and economic costs through foregone gains from

1 https://ec.europa.eu/commission/presscorner/detail/en/QANDA_24_364

specialisation. These would need to be set against assessments of the payoffs in economic risk mitigation. Moreover, some types of policy intervention may impose higher costs than others.

This broader context leads to four important questions that this study, commissioned by DIGITALEUROPE and delivered independently by Frontier Economics seeks to address:

1. In which of the critical technologies does the EU have the highest underlying exposure to supply chain risk?
2. How competitive is the EU in each of these critical technologies, and where are its areas of strength and weakness?
3. To what extent does the competitiveness of the EU mitigate the current or future risk associated with these technologies?
4. What are the implications of the questions above for the EU's policy? Specifically, what policy options might best support mitigating the exposure to supply chain risk whilst minimising any negative impact on the competitiveness of the EU in these technologies?

This study aims to answer the first three questions for five priority technologies: Advanced semiconductors, Artificial Intelligence (AI), Quantum computing, Advanced connectivity and Biotechnologies. We also provide a competitiveness assessment for three further technology areas: energy technologies, additive manufacturing, and space technologies.

Given the importance of these issues, any assessment should be evidence-based to the fullest extent possible. This work is based on a broad evidence base: for each priority technology, a review of the EU's presence across the supply chain and related exposure to supply shocks was conducted, based on relevant secondary evidence collection and verified by industry experts. This was complemented by analysis of competitiveness assessed across fifteen indicators for a group of leading countries.

EU exposure to supply risk

The figure below summarises the overall findings of our study as relates to question 1 above. This shows the underlying exposure of the EU to supply chain risk in each technology. The study finds that the EU is most exposed to underlying supply chain risk in Semiconductors, but there is also significant underlying risk in Artificial Intelligence (AI), Quantum Computing and Biotechnologies. Whilst avoiding all supply risk in an international supply chain is unlikely, the EU does appear exposed in these technologies where supply is concentrated in a small number of businesses or countries. EU exposure to supply risk in semiconductors and AI remains significant when its competitiveness in the supply chain is taken into account but is somewhat mitigated in Quantum Computing and Biotechnologies. In semiconductors, the issues faced by the EU are particularly acute and suggest a role for policy action. There also appears to be a stronger case for policy support in Artificial Intelligence (AI).

Technology	EU underlying supply risk
Advanced semiconductors	High
Artificial Intelligence	Moderate to High
Quantum computing	Moderate to High
Biotechnology	Moderate to High
Advanced connectivity	Moderate

EU competitiveness across technologies

This study has also generated important findings related to question 2: the EU's competitiveness across technologies, and its areas of strength and weakness. EU competitiveness is a combined assessment covering the EU's proximity to 'global best practice' reflecting whether the EU is at the cutting edge of technological development, and the EU's current presence in across stages of the supply chain. This competitiveness assessment also has a broader interpretation, being indicative of the EU's ability to mitigate some exposure to supply risk.

Technology	EU proximity to 'global best practice'	EU presence in (high value) stages of value chain	EU competitiveness
Advanced semiconductors	45%	●○○○○	Low
Artificial Intelligence	53%	●●○○○	Low to Moderate
Quantum computing	57%	●●●○○	Moderate
Biotechnology	57%	●●●●○	Moderate
Advanced connectivity	71%	●●●●○	High

Note: Proximity to global best practice scores are classified (and colour-coded) as follows: < 50% Low; 50-70% Moderate; > 70% High. A score of 100% is not feasible, but instead represents a hypothetical perfect score for that technology. No country scores very close to 100% for any of the technologies, however the global technological leader (US) scores are reflected by a red line for each technology, as a benchmark for EU performance.

The EU is found to trail other countries in its proximity to 'global best practice', for all but one of the critical technologies (Advanced Connectivity). For the other technologies the EU finds itself a significant distance from 'global best practice', and a significant distance behind the US as the benchmark technological leader across all technologies.

The EU's presence across stages of the supply chain is more limited for semiconductors and AI. It is to be expected that the EU would not have a presence across all aspects of the supply chains of these technologies as to do so would involve losing the significant benefits from geographical specialisation. That said, the very limited EU presence in the semiconductor supply chain stands out.

After factoring in our findings from both sets of analysis, there is significant room for the EU to improve competitiveness in most of these technologies, aside from Advanced Connectivity. Again, semiconductors stands out as the technology with the lowest overall competitiveness, and the most obvious area to prioritise policy support. Here the EU's area of weakness broadly relates to its industry strength and ability to translate its research expertise into new and improved products. This is reflected by the EU's particularly low number of semiconductor-related patent applications. AI is the other technology with the largest scope for the EU to improve competitiveness. The quality and quantity of the EU's research output is its main area of weakness in AI, although again the EU has a relatively low number of AI patent applications.

High-level assessment of the EU's economic security

Bringing together our findings, we provide a high-level assessment of the level of risk to economic security the EU is faced with, for each of the priority technologies. This overall level of risk depends on the extent of the EU's exposure to supply chain risks, and on the extent to which the EU's competitiveness mitigates that exposure. Our reading of the evidence indicates that the EU's moderate to high competitiveness in the Advanced connectivity, Biotechnology and Quantum computing technology areas partially mitigates its exposure to supply chain risk in those technologies. As described above, the underlying supply risk for these technologies is Moderate (Advanced connectivity) or Moderate to High (Biotechnology and Quantum). However, taking into account the EU's competitiveness in these areas, we assess the overall level of risk for the EU's economic security as somewhat more limited (Low to Moderate for Advanced connectivity, and Moderate for Biotechnology and Quantum computing).

Technology	Overall assessment of risk to EU economic security
Advanced semiconductors	High
Artificial Intelligence	Moderate to High
Quantum computing	Moderate
Biotechnology	Moderate
Advanced connectivity	Low to Moderate

Policy implications & areas for further research

The analysis highlighting the interplay between economic security and competitiveness, and by the same token highlights the costs of pursuing an approach to critical technologies based on the notion of “technological sovereignty”. That is, one that emphasises the use of restrictive policy instruments, such as local content requirements, in order to control the operation of the value chains that underpin these technologies. Such an approach is likely to be counterproductive, in the sense that it is unlikely to address underlying constraints to competitiveness, nor is it likely to enhance economic security. In this sense, the analysis validates the EC’s position of pursuing an approach to critical technologies that is consistent with a broader commitment to an open, rules-based approach to international trade and economic governance.

The detailed findings also support the need to further strengthen single market integration, to increase the efficiency of key inputs into critical technologies (such as ICT services), and to create an enabling environment in which investors in critical technologies can take better advantage of opportunities for scale effects. The gap between the EU’s scientific capabilities, on one hand, and its industrial performance on the other, also point to the need for interventions that strengthen the ability to move from research to commercialisation.

1 Introduction

1.1 Context and objectives of this work

Frontier Economics has been commissioned by DIGITAL EUROPE to undertake a study on the EU's relative strengths and weaknesses in a number of "critical technologies" identified by the European Commission. Specifically, we examine how close the EU is to achieving global leadership in these technologies, and its positioning in global value chains that are based on these technologies

The EC has identified ten "critical technologies" that it considered highly likely to present sensitive and immediate risks to technology security and leakage. The technologies are the focus of the EU's approach to economic security, as reflected in the European Economic Security Strategy published in June 2023. The EC also sees the promotion of competitiveness as a key plank in the mitigation of risks that may imperil the EU's economic security.

Given the interplay between economic security and competitiveness, it is opportune to begin by defining these concepts. By "economic security" we mean the ability of Europe to avoid or limit impact or exposure to external and geopolitical risks from supply chains. Exposure to external risks may include: risks to critical infrastructure (e.g. connectivity, energy supply, healthcare), risks compromising European or national security, as well as risks to the effective functioning of supply chains. By "competitiveness" we mean the ability of European industries and businesses to maintain or improve their position in global markets by capturing value-added along the supply chain of relevant critical technologies.

In considering the interplay between economic security and competitiveness in relation to critical technologies, it is important to recognise that these technologies have emerged because of, and are embodied in, global value chains. The emergence of these value chains reflects gains from specialisation in particular tasks. It is that specialisation that generates productivity gains that in turn generate economic value and growth. Being "competitive" in these value chains relies, in the first place, on the ability to capture gains from specialisation, and to appropriate significant shares of value added. Moreover, sectors that rely on critical technologies benefit from the lower costs, and consequent productivity gains, that are delivered from specialisation at a global level.

At the same time, it is the very fact that critical technologies operate through global value chains that also raises concerns about economic security. Specifically, the concern is that specialisation may create dependencies that leave the EU exposed to external shocks, including geopolitical ones.

The interaction between economic security and competitiveness is therefore complex. There are complementarities and trade-offs. These will need to be considered in structuring policy reforms. The instruments that support competitiveness are not necessarily those that will manage economic security, and vice versa. For example, trying to appropriate control of more extensive parts of a value chain, may come at significant resource cost and economic costs through foregone gains from specialisation. These would need to be set against assessments of the payoffs in economic risk mitigation. Moreover, some types of policy intervention may impose higher costs than others.

This broader context leads to four important questions that this study, commissioned by DIGITALEUROPE and delivered independently by Frontier Economics seeks to address:

1. In which of the critical technologies does the EU have the highest underlying exposure to supply chain risk?
2. How competitive is the EU in each of these critical technologies, and where are its areas of strength and weakness?
3. To what extent does the competitiveness of the EU mitigate the current or future risk associated with these technologies?
4. What are the implications of the questions above for the EU's policy? Specifically, what policy options might best support mitigating the exposure to supply chain risk whilst minimising any negative impact on the competitiveness of the EU in these technologies?

1.2 Scope

The European Commission (EC) lists ten critical technologies in its European Economic Security Strategy, eight of which are assessed in this study. The eight includes all five technologies identified as "priority" by the EC: Advanced semiconductors, AI, Quantum computing, Biotechnologies and Advanced Connectivity as well as Energy Technologies, Space & Propulsion and Additive Manufacturing. In some of the eight, the EU's definition for the technology is broad, and includes several examples with different supply chains. Where this is the case, we have refined the definition of the critical technology to focus on a subset of the technology, for the purpose of mapping its supply chain.

Annex A presents a table with each critical technology and our definition.

Advanced Sensing technologies and Robotics & Autonomous Systems are the two technologies listed by the EC that have not been covered. Advanced Sensing technologies was excluded due to data and information limitations. Military and security uses are more likely for these technologies, which naturally means there is less information online, making it challenging to accurately define what these technologies are and how their supply chains operate through desk-based research. Robotics & Autonomous Systems were not separately included because of the substantial overlap with a combination of Space and Additive Manufacturing technologies.

1.3 Structure of the report

The remainder of this report is structured as follows.

- Section 2 describes our empirical methodology.
- Section 3 presents findings from proximity to "global best practice", value chain analysis – including both the EU's presence across the supply chain and the EU's exposure to supply risk – for Advanced semiconductors, AI, Quantum computing, Biotechnologies, Advanced connectivity ("priority technologies").
- Section 4 presents findings from proximity to "global best practice" analysis for Energy technologies, Additive manufacturing, and Space technologies.
- Section 5 presents key findings from the study.

2 Approach & Methodology

A four-stage approach is used to deliver the study, by generating findings on the four research questions presented in section 1.1. In doing so, it aligns with the context for the study: it provides an overall assessment of risks to the EU's economic security, as resulting from the EU's exposure to supply risk and from the extent to which these are mitigated by the EU's competitiveness in each critical technology. More detailed evidence on the EU's areas of competitive strength and weakness in these critical technologies is also provided. The four-stage approach is as follows.

1) Summary **value chain representations** are produced for each priority critical technology. These diagrams mapped the key stages of supply across the value chain, and identified the short-list of leading global businesses operating at each stage, including the best-performing EU businesses. The value chains provide important context for understanding the nature of supply and the presence of EU businesses across technologies, and as such feed into our analysis in stages 2) and 3).

2) We assessed the **underlying exposure to supply risk** in these value chains. This is based on evidence collection related to two key drivers of risk exposure: market structure risk and geographic concentration in various stages of supply. The output from this analysis is a qualitative classification of exposure to supply risk for each technology. The classification is mapped to a range of five points between Low to High.

3) We assessed **EU competitiveness** in these value chains. The output from this analysis is a similar qualitative five-stage classification of EU competitiveness for each technology. The final classification is based on two sets of analysis.

    a. Proximity to the global best practice. To establish global leadership in these technologies, the EU needs capability at the cutting edge, both by being scientifically advanced and having industrial power to translate research into new products. The EU's international competitiveness in each technology is assessed along these dimensions, by comparing the EU's value for a set of performance indicators against the global-leading country's score (i.e. the "best practice" for each indicator).

    b. EU presence in high value stages of the supply chain. To establish global leadership in these technologies, the EU should have a significant presence in key, higher value added stages of supply, as well as a broader presence across most stages of supply. The EU's presence is assessed by reviewing the EU's position in each value chain diagram, and through broader secondary evidence collection across literature, interviews and secondary data.

4) We assessed the extent of overall risk to the **EU's economic security** for each technology, by combining our findings on the underlying exposure to supply risk and the EU's competitiveness and ability to influence supply. This accounts for the EU's

ability to mitigate its risk exposure through leveraging its capabilities and position in the supply chain. These findings should form the basis for EU policy in relation to economic security.

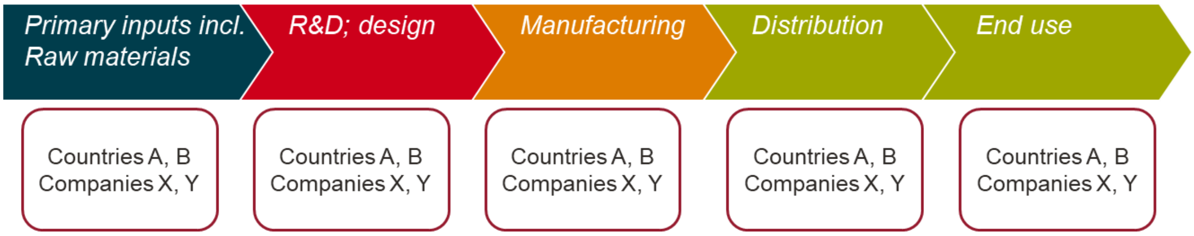
The full set of analysis (outputs from stages 1 to 4) was delivered for the five "priority" technologies, and analysis only on the EU's proximity to "global best practice" (stage 3a) was performed for the remaining three technologies in scope.

The remainder of this section describes the methodology and evidence used to deliver outputs in each stage of our approach in turn.

2.1 Stage 1: Value chain representations

The starting point for this analysis was to build summary graphical representations of the value chain and understand what companies and countries are active at each stage. Figure 1 presents an example value chain representation for a critical technology.

Figure 1 Example value chain representation



Source: Frontier Economics

The summary value chain representations are based on:

- Review of existing analysis and evidence on the value chain from a range of sources including academic papers, think-tank and non-profit organisations, government publications (e.g. government sector strategies including evidence on the value chain);
- Broader desk research on the key players at each stage including reviewing publicly available information from market analysts (e.g. estimates of global revenues for activities relevant to each technology); and
- Interviews with industry experts. Typically these interviews were used to test the accuracy of a draft value chain representation that had already been made based on evidence collected from the above sources.

2.2 Stage 2: Underlying exposure to supply risk

The EU's exposure to supply shocks is also assessed for the priority critical technologies in scope: Advanced Semiconductors, AI, Quantum Computing, Biotechnologies, and Advanced Connectivity.

Supply shocks could be due to a range of factors, including transport link disruptions, factory disruptions, war, labour market issues, technical failures and others. However, the EU's *exposure* to supply shocks is higher under the following two conditions.

1) There is significant **market structure risk**. In addition, if there are a relatively small number of non-EU businesses accounting for a large proportion of production at any given stage of supply, then any business-specific shock is more likely to impact the broader supply chain – and by extension, EU businesses and end users. This condition is also assessed based on a targeted review of available, relevant literature and the value chain representation for each technology.

2) There is a high degree of **geographic concentration** outside the EU. If there is a relatively small number of non-EU countries accounting for a given stage of production, then any country-specific shock is more likely to impact the broader supply chain – and by extension, EU businesses and end users. This condition is assessed based on a targeted review of available, relevant literature and the value chain representation for each technology.

Please note that other forms of risk are outside the scope of our assessment, including geopolitical[2] and demand-side[3] risks.

As per the methodology for assessing EU presence, evidence is collected against these two conditions. An overall assessment of exposure to supply risk is made, mapped to a range of five points between Low to High[4]. The assessment is made according to a review of evidence in the round across both conditions. This includes the strength of evidence on the existence of underlying risks (i.e. whether there is a consensus across studies for any underlying risks) and the quality of evidence reviewed (i.e. whether evidence from secondary reports and publications exists, either from academia, national bodies or professional advisory businesses). The assessment also accounts for mitigating factors in relation to either the nature of supply of technologies or future trends.

2 The EU's exposure to control of key stages of supply by geopolitical rivals (e.g. US/EU exposure to China's control over rare earths; China's exposure to US control on IP and design).

3 For example, concerns about traceability or ESG compliance.

4 More specifically, the assessment varies between Low, Low to Moderate, Moderate, Moderate to High, and High.

2.3 Stage 3: EU Competitiveness

The EU's competitiveness in each technology is assessed, according to the degree to which the EU holds a position of global leadership. This is based on two key conditions: (i) the extent to which the EU has capability at the cutting edge of technological development, and (ii) the extent to which the EU has a significant presence across all stages of supply chain as a whole, and also in key stages of supply that are identified as higher value added.

These conditions are assessed through two sets of analysis: EU 'proximity to global best practice' and an assessment of EU presence across (high value) stages of supply.

Together, our findings on each of these sets of analysis determine the EU's broader competitiveness in each technology.

2.3.1 Proximity to 'global best practice'

The EU's capability at the cutting edge of each technology is assessed, by comparing the EU's position across a set of performance indicators against the global-leading country for that indicator.

To select the indicators that best capture leadership in a critical technology, we apply the following principles. A position of leadership in any of the critical technologies is likely to require a combination of:

- scientific excellence in the technology's foundations;
- business capability, with both established and emerging players and a strong broader funding ecosystem for start-ups and scale-ups;
- innovative track record, with businesses consistently spending large amounts on research and development, and making new patent applications; and
- specialisation relative to and in collaboration with other key countries in the global value chain for a given technology.

Applying these principles, we select the indicators that are grouped into two pillars:

1) **Scientific performance**, with indicators reflecting each country's scientific excellence in the technology's foundations.

2) **Industry strength**, with indicators reflecting business capability, innovative track record and specialisation relative to and in collaboration with other countries in the supply chain.

We have gathered data on EU Member States and non-EU OECD countries, plus China and Taiwan. The indicators are listed in the table below.

Where possible, we define indicators in both absolute terms (e.g. number of publications, funding received by start-ups and scale-ups) and a value relative to the size of the country's population (e.g. number of publications per capita, funding received by start-ups and scaleup over GDP). In doing this, we take into account both a country's overall output relevant to a technology (in terms of scientific publications, exports, etc) and its ability to produce this output relative to its resources[5].

Table 1 Indicators used in proximity to 'global best practice' analysis

Pillar	Indicator (source)	Reasoning
Scientific performance	Number of scientific publications (ASPI)	Measures scientific expertise through quantity of publications
	Number of scientific publications, per 1 million population (ASPI)	Measures scientific expertise through quantity of publications, relative to that country's resource base
	Number of leading scientific publications (ASPI)	Measures scientific expertise through quality of publications
	Number of leading scientific publications, per 1 million population (ASPI)	Measures scientific expertise through quality of publications, relative to that country's resource base
	H-Index (ASPI)	Measures scientific expertise, as a proxy for the impact of scholarly output
Industry strength	A country's share of global value added for related sectors	Measures business capability through quantity of production
	Count of leading global R&D businesses	Measures innovative track record
	Business patent applications	Measures innovative track record
	Business patent applications, per 1 million population	Measures innovative track record, relative to that country's resource base
	USD value of start-up and scale-up funding	Measures business capability, through the broader support ecosystem for new start-up and scale-ups

5 Note the relative value for the trade-based indicators relate to "*Exports for related sectors as a proportion of total exports for a country*" and "*Domestic value added that is embodied in foreign exports, as a share of a country's gross exports*".

Pillar	Indicator (source)	Reasoning
	Start-up and scale-up funding as a proportion of GDP	Measures business capability, through the broader support ecosystem for new start-up and scale-ups, relative to that country's resource base
	A country's share of global gross exports for related sectors	Measures business capability and specialisation relative to other countries, through strong sales in international markets
	Exports for related sectors as a proportion of total exports for a country	Measures business specialisation, through a greater exporting outperformance for the technology, relative to the country's broader exporting performance
	Domestic value added that is embodied in foreign exports, as a share of a country's gross exports	Measures business specialisation in collaboration with other countries in the supply chain, where a country's exports are re-exported by the destination country
	A country's share of global exports of intermediate goods in related sectors	Measures business specialisation in collaboration with other countries in the supply chain, by exporting products used in production overseas

Note: a full list of sources is provided in Annex A.

It is worth noting that the availability of data varies across technologies, in particular for industry strength indicators such as share of global value added, number of leading R&D businesses, and export-related indicators. For technologies such as advanced semiconductors, which are physical products, data is generally available at the level of detail required by our analysis. For technologies such as Artificial Intelligence or Quantum Computing, which are more nascent, much more intangible and often used in the process of producing broader goods or services (e.g. data analytics services, predictive maintenance, predictive components of consumer applications, …), data on the indicators listed above is often unavailable. In these cases, we use data on the closest product or industry definitions available.

We aggregate this data for each technology into overall indices on a scale from 0 to 100%, where a higher number indicates a closer proximity to "global best practice" values for that indicator. The aggregation process is to generate a score between 0 and 100% separately for Scientific performance and Industry strength pillars, calculated as a simple average of the scores across indicators for each pillar. Then the Scientific performance and Industry strength scores are combined as a weighted average to an overall index score between 0 to 100%.

The weights used are 33% for Scientific performance and 67% for Industry strength for all technologies[6] apart from Quantum Computing[7], where the weightings are 50% for each.

It is important to note that 100% on all indicators for a given technology is a theoretical maximum. In practice, no country ranks "best" across all indicators for a given technology, and therefore no country or region would achieve a 100% score at technology level. To support the interpretation of the EU's results, benchmark values are estimated for the US, which is identified as the global leader with the highest average score across all indicators for seven out of the eight technologies. Where the US is the global leader (outside the EU), its score ranges between 56% and 87% across all technologies.

Our guide for interpreting the index values based on a review of the technological leader's overall score for each technology is: less than 50% relates closer to Low competitiveness; 50-70% is Moderate; and over 70% relates to High competitiveness.

Finally, it is worth noting the broader relevance of the final four trade-based indicators within the industry strength pillar. These indicators measure the participation of the EU in global value chains for each technology. This reflects the fact that these technologies have emerged through, and operate within value chains where different countries or regions specialise in particular tasks.

2.3.2 EU presence across (high value) stages of the supply chain

The other block of competitiveness analysis relates to assessing the EU's presence across the value chain, which reflects the capability of the EU to account for a high proportion of value added for the technology as a whole.

Evidence was collected against the following two research questions and analysed to provide a rating of low, moderate or high EU presence. The evidence base included a targeted review of existing analysis and broader desk research, as well as the value map representations.

1) To what extent is there **significant EU presence across the supply chain**, including its individual stages? EU businesses could account for a higher proportion of value added for a technology where the EU has a significant presence[8] at more stages of value generation, i.e. at more stages of supply.

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6 These weights reflect the relative number of indicators in Scientific performance (5) and Industry strength.

7 The weighting for Industry strength is reduced, given that the Quantum Computing value chain is at an earlier stage of development than other technologies. Therefore, current industry strength in Quantum Computing is a less reliable measure of the EU's leadership.

8 Ideally, "significant presence" would be measured using market shares. However, high-quality information on this is typically not readily available. Therefore, we rely on a qualitative assessment, where the EU is identified as having "significant presence" at a given stage of the supply chain based on the value chain representation for a technology or other evidence from a targeted review of the available literature.

2) To what extent is there **significant EU presence at higher value added stages of supply**? EU businesses could account for a higher proportion of value added if the EU also has a significant presence at the highest value added stages[9] of the supply chain. This assessment is made based on a targeted review of the most relevant, available literature[10].

2.4 Stage 4: overall risk to EU economic security

In the final stage, an overall assessment of the risks to EU's economic security is produced, drawing on the findings from stages 2 and 3.

The starting point is the assessment of the underlying supply risk faced by the EU in stage 2. Where the EU has a limited competitiveness this underlying risk exposure is passed through in its entirety to the EU's economic security risk. Where the EU has greater competitiveness (and the ability to mitigate its risk exposure), the risk to the EU's economic security is downgraded.

A 'Moderate' or 'High' level of EU competitiveness is required to downgrade the EU's exposure to supply risk.

[9] Evidence from the literature estimating the proportion of value related to individual stages of supply is not always available: in these cases, a more flexible approach to determining the stages of supply that are higher value added is taken, which again draws on evidence from studies on the drivers of greater profitability for particular technologies.

[10] Note that this research question is not assessed for AI or Quantum Computing, because it is not possible to determine with confidence where most value added is generated in their respective supply chains. In the case of AI, this is because the supply chain is still developing (albeit at a fast pace). In the case of Quantum Computing, this is because the supply chain is particularly nascent.

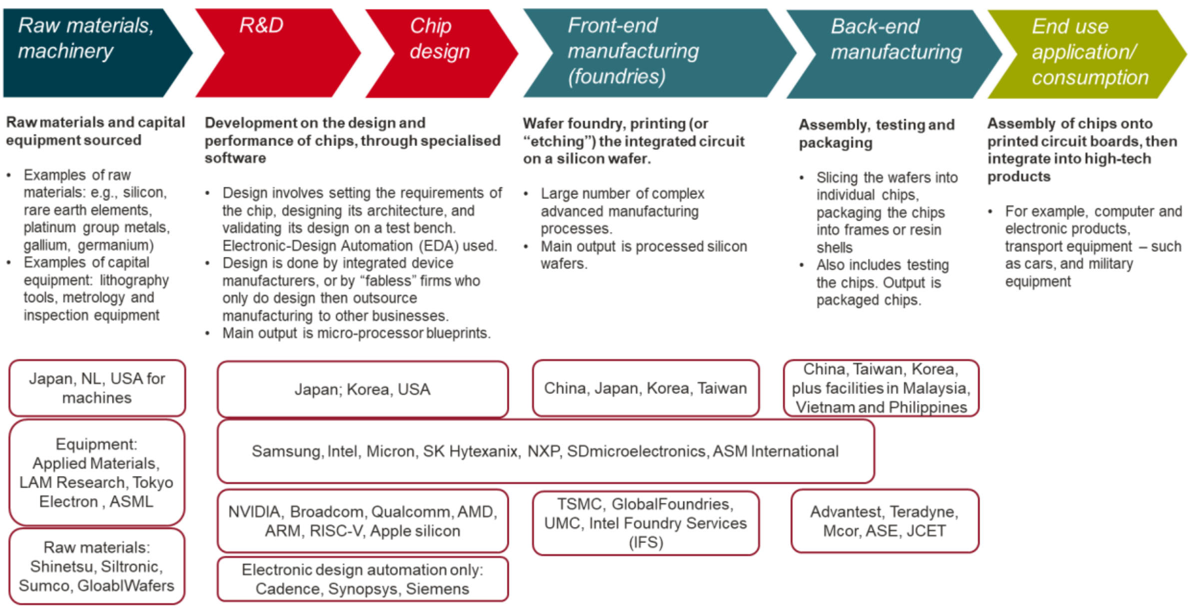
3 Results on priority technologies

3.1 Advanced semiconductors

Semiconductors are an essential component of electronic devices and more specifically electronic circuits, enabling advances in communications, computing, healthcare, military systems, transportation, clean energy, and countless other applications. Advances in semiconductor technology is making them faster, more powerful, and more energy-efficient.

Figure 2 describes the semiconductors value chain, setting out the various stages of supply and key businesses at each stage. The semiconductors value chain spans raw materials extraction and provision of machinery equipment, through chip design, to manufacturing of microchips in semiconductor foundries, then back-end assembly into products and packaging.

Figure 2 Advanced semiconductors value chain representation



Source: Frontier Economics

Our analysis (summarised below) indicates that the EU currently has a high underlying exposure to supply risk. EU competitiveness in this supply chain is low and so does little to mitigate any supply risk meaning overall exposure remains high. This is the highest exposure out of all technologies analysed suggesting that semiconductors could be a priority area for the EU.

Underlying exposure to supply risk	EU competitiveness	Risk to EU economic security
High	Low	High

Sections 3.1.1 to 3.1.2. provide further detail on our findings for each component of analysis.

3.1.1 Underlying exposure to supply risk

Our overall assessment is that the EU has a **High** exposure to supply chain risk, due to both a high exposure to market structure risk and geographic concentration.

Market structure risk: High

A relatively small group of large conglomerate businesses are present across several stages of the value chain: Samsung, Intel, Texas Instruments, Micron, SK Hynix. This suggests that there could be a significant amount of market structure risk in the Semiconductors value chain.

Furthermore, there is very high market structure risk specifically at the foundries manufacturing stage of supply, where TSMC alone accounts for nearly 60% of production[11].

Geographic concentration: High

Semiconductor production is highly geographically concentrated with the top five countries accounting for around 75% of global value added in 2018[12].

There is a leading group of five or six countries in this sector: US, Taiwan, China, Japan, South Korea and to a lesser extent the Netherlands. There is a clear gap between these countries and others, reflected in our semiconductors Industry Strength analysis within the 'proximity to best practice' analysis. In particular, the US not only has some of the largest global semiconductor companies, but it also has a strong wider business ecosystem with very high levels of start-up and scale-up funding for semiconductor businesses.

- US semiconductor businesses receive at least four times the start-up and scale-up funding of any other country[13].

11 https://www.visualcapitalist.com/semiconductor-foundry-companies-ranked/

12 Vulnerabilities in the semiconductor supply chain | OECD Science, Technology and Industry Working Papers | OECD iLibrary (oecd-ilibrary.org)

13 Source: Frontier Economics analysis of Crunchbase data.

- There are significantly more globally-leading semi-conductor businesses headquartered in the US, compared to other countries. Over 15 leading US companies were identified through the value chain representation and associated desk research[14].

There is also very high geographic concentration specifically at the foundries manufacturing stage of supply. This is due to the size of two Taiwanese businesses: TSMC, which accounts for nearly 60% of production, and UMC which is also in the top 5 semiconductor foundry businesses worldwide[15].

3.1.2 EU competitiveness

Our analysis (summarised below) indicates that the EU currently demonstrates a low level of competitiveness in the semiconductor supply chain, with both limited scientific and industrial strength compared to other countries, and limited presence of EU businesses across the value chain. This indicates low EU influence over the semiconductors supply chain.

Proximity to 'global best practice'	EU presence across stages of the supply chain	EU competitiveness
45%		Low

It is also worth noting that the EU's competitiveness is the lowest out of all critical technologies analysed, both due to a low 'proximity to global practice' and limited EU presence across stages of the supply chain.

Proximity to 'Global best practice'

Figure 3 presents our overall findings for the EU in terms of its proximity to 'global best practice' for Semiconductors. The US is added as a comparator as it is the leading global country for this technology based on data collected across all indicators.

[14] Understanding the Semiconductor Value Chain - Quartr Insights

[15] https://www.nasdaq.com/articles/an-overview-of-the-top-5-semiconductor-foundry-companies-2021-10-01

Figure 3 Overall EU proximity to global best practice in Semiconductors

	Overall score	Scientific Performance (Weight 33%)	Industry Strength (Weight 67%)
EU27	45%	67%	35%
US (non-EU leader)	62%	77%	54%

Source: Frontier Economics

Figure 3 shows that for Semiconductors, the EU has **Low** proximity to global best practice (scoring 45%). The EU is also a significant distance behind the US, the global leader in this technology area (scoring 62%).

In semiconductors, the EU scores significantly higher in its Scientific Performance (67%) compared to its Industry Strength (35%). Notably, the EU's Industry Strength score is a particularly large distance behind the US score (54%). Therefore, the EU's weaker Proximity to Frontier score appears to be less about the quantity of research performed, and more closely related to a limited impact of that research, and as such relatively weak EU Semiconductors Industry strength.

Looking at the results by indicator, the EU scores particularly poorly on its patent applications (both in total, and relative to its population), as well as some of the trade-based indicators related to degree of participation in international supply chains[16] compared to the leader, Taiwan. Interestingly, the US's performance is also relatively weak for these indicators.

Figures 4 and 5 present the EU and US evidence on Scientific Performance and Industry Strength respectively, across all indicators, underlying our findings. The leader for each indicator is also identified, along with the EU's ranking.

16 Specifically, the EU has very low scores on 'Exports for the technology as a proportion of country exports' and 'Domestic value added embodied in foreign exports as a share of gross exports'.

Figure 4 Scientific performance indicators for semiconductors

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Number of publications	EU	1st	1.00	0.90
Publications per 1 million people	Taiwan	3rd	0.36	0.31
Number of leading publications	US	3rd	0.81	1.00
Number of leading publications, per 1 million people	Taiwan	2nd	0.77	0.62
H-Index	US	5th	0.39	1.00
		Average scores	**0.67**	**0.77**

Source: Frontier Economics analysis of ASPI data

Figure 5 Industry strength indicators for semiconductors

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Market share of global value added	China	3rd	0.35	0.80
Count of leading global R&D businesses	US	5th	0.22	1.00
Patent applications	South Korea	5th	0.19	0.43
Patent applications, per 1 million people	South Korea	4th	0.10*	0.14*
Value of Start-up & Scale-up funding	US	3rd	0.48*	1.00
Start-up & Scale-up funding as % GDP	Canada	4th	0.92	0.98
Global gross exports market share	China	4th	0.52	0.45
Exports for the technology as a % of country exports	Taiwan	6th	0.14*	0.19*
Domestic value added embodied in foreign exports as a share of gross exports	Taiwan	7th	0.14	0.28
Global exports of intermediate goods market share	China	2nd	0.39	0.17
		Average scores	**0.35**	**0.54**

Source: Frontier Economics analysis of OECD, Crunchbase, COMTRADE, EU R&D Scoreboard data

Note: For measures market with asterisk (*),proximity to frontier value calculated as the EU value divided by the average of the top 3 global leading country values. This is because the top 1 or 2 countries for this indicator are a very large distance ahead of all other countries, misrepresenting the gap between the EU and a broad set of market leaders

EU presence across (high value) stages of supply

Our overall assessment is that EU companies have a **low to moderate** presence in the semiconductors value chain, based on a low presence across all stages of supply, and moderate presence in the highest value added stages of supply.

EU presence across all stages of the supply chain: Low

Our research indicates that the EU has a significant presence in some stages of supply, but a limited presence in manufacturing, suggesting an overall assessment of "Low".

- There is significant presence of EU companies at stage 1 of the value chain (raw materials extraction and equipment manufacturing). This includes ASML, recognised in the short-list of leading equipment manufacturers.
- There are some EU companies with significant presence at stage 2 of the value chain (research & development and chip design). This includes NXP, recognised in the short-list of leading businesses designing semi-conductor chips.
- No EU companies appear to have a significant presence at stage 3 (foundries). This stage is dominated by businesses from Taiwan, China, Japan and South Korea. The EC identifies that there is negligible turnover of EU-owned chip producers[17], and the EU's share of semiconductor manufacturing production has fallen from 24% in 2000 to 8% in 2021[18].
- No EU companies appear to have a significant presence at stage 4 (back-end manufacturing). This stage is dominated by businesses from Taiwan and China.

EU presence in highest value added stages of supply: Moderate

OECD (2023)[19] identifies the Design stage of the value chain as generating 50% of value added for the technology as a whole, which is the highest contribution of any stage of supply.

Our assessment is that the EU has a Moderate presence in the Design stage. The EU has a significant presence in semiconductor design, through NXP. However, while other EU-based semiconductor design companies may exist, they are not commonly considered to be among the global-leading businesses in this space. Instead, the US, Japan and South Korea are seen as the leading countries in semiconductor design, with multiple businesses headquartered in each. Furthermore, NXP's focus is designing chips for applications in industrial, automotive

17 https://joint-research-centre.ec.europa.eu/system/files/2022-04/JRC129035.pdf

18 https://www.institutmontaigne.org/ressources/pdfs/publications/europe-new-geopolitics-technology-1.pdf

19 https://www.oecd.org/publications/vulnerabilities-in-the-semiconductor-supply-chain-6bed616f-en.htm

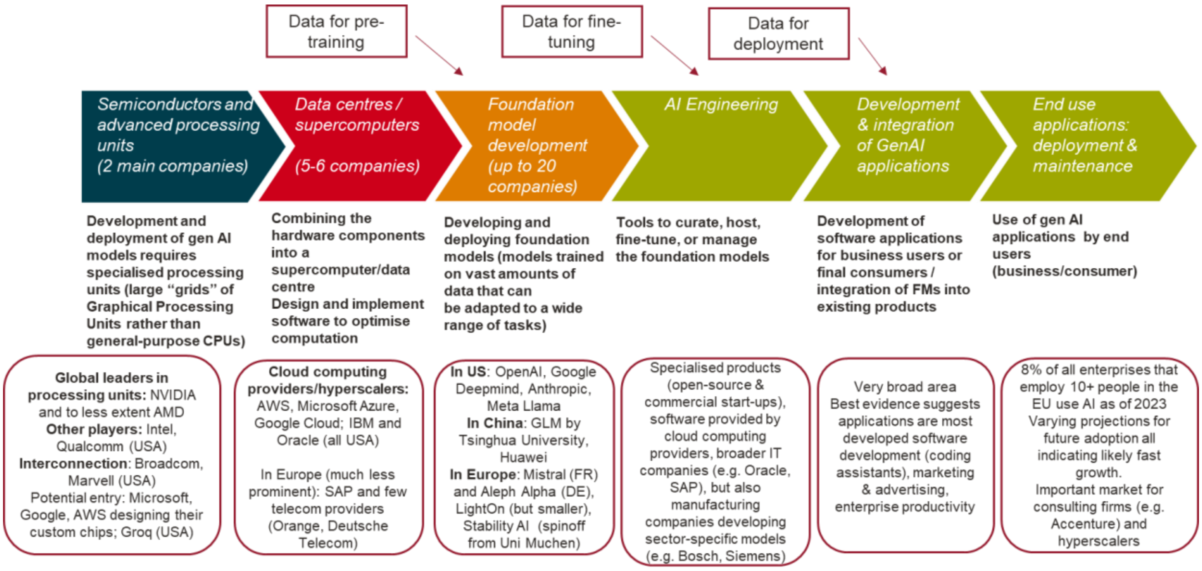
and communication applications. Therefore, there does not appear to be significant EU presence in the design of chips for high-performance computing applications.

3.2 Artificial Intelligence

Artificial intelligence relates to the development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making and analytics, and translation between languages. In our analysis, we focus on the **generative AI** value chain[20].

Figure 6 describes the AI value chain, outlining the various stages of supply and key businesses. The AI value chain spans high-performance computing (including cloud), developing and training AI models, and developing and deploying AI applications.

Figure 6 AI value chain representation



Source: Frontier Economics, based on desk research and conversations with DIGITALEUROPE members.

Note: This diagram does not aim to provide a fully comprehensive list of the companies active at each stage of the value chain. Moreover, the categorisation of economic activities into separate stages is a necessary simplification and does not aim to fully reflect the complexity of the value chain or differences relevant to specific geographies.

Our analysis (summarised below) indicates that the EU currently has a relatively weak position in the AI supply chain. There is a Moderate to High risk to the EU's economic security in this technology area, driven by the EU's limited competitiveness in this technology and the significant degree of exposure to underlying supply risk.

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[20] This is for two reasons: firstly, the high level of interest in generative AI at the time of writing, driven by the recent pace of development and rapid increase in adoption of this technology. Secondly, the generative AI value chain is similar to the supply chain for AI more generally, but with additional complexity of distinction between foundation models and applications which might create greater potential for supply risks.

EU underlying supply risk	EU competitiveness	Risk to EU economic security
Moderate to High	Low to Moderate	Moderate to High

It is worth noting that Artificial Intelligence is still at a relatively early stage in its journey to being fully applied by industry, and as such there is scope for the EU's position to dramatically change.

Sections 3.2.1 to 3.2.2. provide further detail on our findings.

3.2.1 Underlying exposure to supply risk

Our overall assessment is that the EU has **a Moderate to High** exposure to supply chain risk in this technology. This is based on a Moderate exposure to market structure risk and a Moderate to High geographic concentration.

Market structure risk: Moderate

A relatively small group of large conglomerates are present across several stages of the value chain: Google, Amazon Web Services, Microsoft and Meta. This alone could indicate significant market structure risk in the Generative AI value chain. However, various countervailing factors limit this risk leading to an assessment of moderate risk overall.

- A variety of other businesses have significant presence at different stages of the supply chain. For example, Nvidia accounts for a large proportion of value at the Processing unit manufacturing stage of supply, and OpenAI is a key player in foundation model development, but not in processing units and compute.
- While there are a few foundation models that are considered "state of the art", such as OpenAI's GPT4, Anthropic's Claude 2, Meta's Llama, Google's Gemini, Mistral's models, there are hundreds of others that are often at or close to state of the art on several performance metrics.[21]
- Activity at later stages of supply – particularly in Generative AI applications, but also to some extent Foundation model development – is widely spread across a large number of businesses, geographies and sub-sectors.
- The Generative AI technology and supply chain is evolving quickly, and competition could evolve rapidly.

[21] https://aiindex.stanford.edu/wp-content/uploads/2024/04/HAI_2024_AI-Index-Report.pdf ; https://huggingface.co/spaces/HuggingFaceH4/open_llm_leaderboard

Geographic concentration: Moderate to High

There is very significant geographic concentration of production and investment in the US, for the Generative AI supply chain:

- The four large conglomerates are all US-owned companies, identified through the supply chain representation.
- The US is the clear leader in business research and development in the related field of Software and Computer services. The EU Industrial R&D Investment Scoreboard[22] identifies the top 1000 businesses spending on R&D globally, and 95 of these businesses are US-based operating in 'Software and Computer services'. China is the next-highest country, with 25 'Software and Computer services' businesses in the top 1000 list.
- The US is the clear leader in Start-up & scale-up funding for AI businesses. Frontier analysis of Crunchbase data estimates that €111 billion was invested in US AI start-up and scale-up businesses. The EU is the next-highest, with €16 billion.

It is also worth noting that a significant amount of manufacturing of advanced processing units takes place in Taiwan (as noted in our semiconductor value chain analysis), and therefore the activities of US companies are in turn affected by exposure to geographic concentration in the semiconductors value chain.

In combination, these two factors point to a high risk of geographic concentration. However, the risk is downgraded from High to Moderate. This is because there is an important factor that mitigates this risk. Namely that cloud data centres used for deployment of generative AI applications (as opposed to development of foundation models) tend to need to be located close to end users to minimise latency and comply with data residency requirements. Therefore, while a significant amount of computing power for AI deployment is provided by companies owned outside the EU, in practice a large proportion of this supply is located within the EU, provided to EU developers and users of generative AI applications.

3.2.2 EU competitiveness

Our analysis (summarised below) indicates that the EU currently has limited competitiveness in the AI supply chain, particularly driven by a limited presence of EU businesses across the value chain. This translates into Low to Moderate EU competitiveness in the AI supply chain.

22 https://iri.jrc.ec.europa.eu/scoreboard/2023-eu-industrial-rd-investment-scoreboard

Proximity to 'global best practice'	EU presence across stages of the supply chain	EU competitiveness
		Low to Moderate

The following sub-sections present our findings and evidence collected in relation to the EU's proximity to 'global best practice' and presence across stages of the supply chain.

Proximity to global best practice

Figure 7 presents our findings for the first indicator related to the EU's proximity to global best practice for Artificial Intelligence. The US is added as a comparator as it is leading global country for this technology based on data collected across all indicators.

Figure 7 Overall EU proximity to global best practice in AI

	Overall score	Scientific Performance (Weight 33%)	Industry Strength (Weight 67%)
EU27	53%	46%	57%
US (non-EU leader)	70%	64%	72%

Note: a 100% score is a theoretical maximum. In practice, no country ranks "best" across all indicators, and therefore no country or region would achieve a 100% score.

Figure 7 shows that for AI, the EU has a moderate proximity to global best practice (scoring 53%). However, it is a significant distance behind the US the global leading country (scoring 70%). The EU scores slightly higher in its Industry Strength (57%) compared to Scientific Performance (46%), although in both cases the EU is a significant distance behind the US scores.

Figures 8 and 9 present the EU and US results on Scientific Performance and Industry Strength respectively, across all indicators. The leader for each indicator is also identified, along with the EU's ranking.

The EU performance appears particularly low in relative terms for its research quality, measured by the H-index and the Number of leading publications. While the EU scores higher in its Industry strength, it still appears to under-perform when translating research into patentable ideas. While the EU is a large distance behind the US in its start-up and scale-up funding, it does rank second globally in this area. The EU's stronger areas of Industry performance relate to its performance in international trade, notably its participation in international value chains[23] and export performance in service that are closely related to AI.

When interpreting Figures 8 and 9, it is worth noting that the AI indicator data available focusses largely on the early and middle stages of the value chain, rather than the later stage (applications). As such, these results might understate the EU's proximity to global best practice in AI, since our value chain mapping indicates that the EU may have a stronger presence at the application stage.

Figure 8 Scientific performance indicators for AI

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Number of publications	China	3rd	0.51	0.53
Publications per 1 million people	South Korea	4th	0.65	0.62
Number of leading publications	China	3rd	0.38	0.54
Number of leading publications, per 1 million people	Australia	7th	0.43	0.52
H-Index	US	10th	0.31	1.00
		Average scores	**0.46**	**0.64**

Source: Frontier Economics analysis of ASPI data

23 The EU has strong performance in its 'Domestic value added embodied in foreign exports as a share of total gross exports'.

Figure 9 Industry strength indicators for AI

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Market share of global value added	US	2nd	0.65	1.00
Count of leading global R&D businesses	US	3rd	0.23*	1.00
Patent applications	Japan	5th	0.35	0.98
Patent applications, per 1 million people	South Korea	5th	0.42	0.32
Value of Start-up & Scale-up funding	US	2nd	0.34*	1.00
Start-up & Scale-up funding as % GDP	US	4th	0.27	1.00
Global gross exports market share	EU	1st	1.00	0.38
Exports for the technology as a % of country exports	India	3rd	0.52	0.12
Domestic value added embodied in foreign exports as a share of gross exports	USA	2nd	0.87	1.00
Global exports of intermediate goods market share	EU	1st	1.00	0.42*
		Average scores	**0.57**	**0.72**

Source: *Frontier Economics analysis of OECD, Crunchbase, COMTRADE, EU R&D Scoreboard data*

Note: *For measures market with asterisk (*),proximity to frontier value calculated as the EU value divided by the average of the top 3 global leading country values. This is because the top 1 or 2 countries for this indicator are a very large distance ahead of all other countries, misrepresenting the gap between the EU and a broad set of market leaders]*

EU presence in the value chain

Our overall assessment is that EU companies have a **Low to Moderate** presence in the value chain. This is based on a Low to Moderate assessment across all stages of supply, given that it is not currently possible to assess the EU's presence in the highest value stages of supply at this point[24].

EU presence across all stages of the supply chain: Low to Moderate

Our research indicates that the EU has a significant presence in some stages of supply, but a limited presence across other stages and no companies operating across multiple stages of the supply chain, suggesting an overall assessment of "Low to Moderate".

This is based on a combination of our supply chain representation for AI, collection of secondary data and broader desk research.

[24] The Generative AI value chain is developing quickly, making it hard to assess whether there are stages of the value chain that are particularly high value added.

- No EU companies are identified as having a significant presence in stage 1 of the value chain (advanced processing units and other hardware components). The global-leading businesses at this stage are identified as Nvidia and AMD. Both are US-based e.
- There is a limited presence of EU companies at stage 2 of the value chain (building supercomputers and providing access to computing power through the cloud): EU cloud services providers such as Ionos or OVHCloud have a small share of the cloud computing market.[25]
- There are some EU companies active among the key global players at stage 3 (foundation models), such as Aleph Alpha (Germany) and Mistral (France).
- There is limited presence of EU companies at stage 4 (AI engineering), which includes business-to-business IT companies (such as SAP) and companies that support the use of foundation models for sector-specific applications (for example, Siemens or Bosch).
- There is significant presence of the EU at stage 5 of the value chain (development and integration of generative AI applications), particularly in business-to-business (B2B) applications. EU presence in the development of consumer-facing generative AI applications is more limited.[26]
- The EU also does not have any businesses that are active across multiple stages of the generative AI supply chain, unlike other countries such as the US.

[25] Sources: see for example the cloud services market studies carried out by the Netherlands' Authority for Consumers and Markets (ACM) and the UK communications regulator Ofcom.

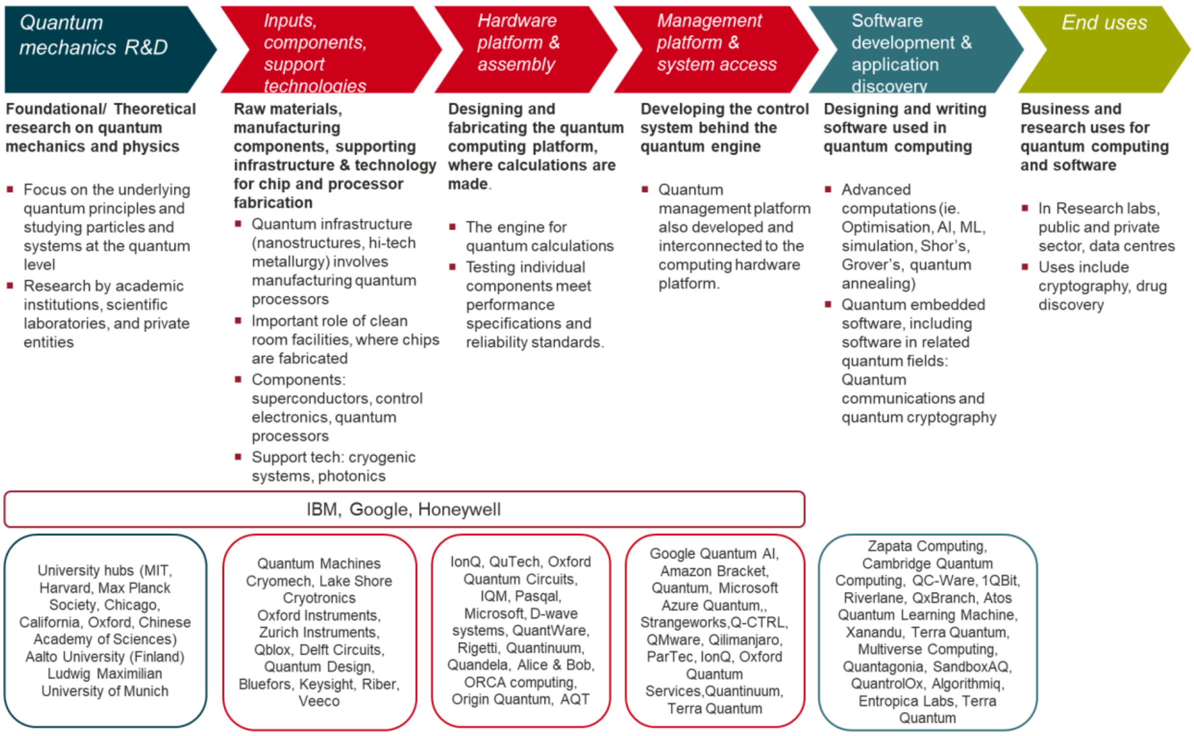
[26] Based on mapping of companies active in the value chain to each stage, stakeholder interviews and analysis of Crunchbase data. Indeed, 34 of 41 EU-headquartered AI scaleups that have received over $100m in total funding as of May 2024 are B2B (rather than B2C or serving both businesses and customers. Moreover, some of the EU's largest digital companies are active in the areas of digital transformation (e.g. Capgemini, Atos, Tietoevry), enterprise applications (e.g. SAP), industrial automation (e.g. Siemens, Bosch).

3.3 Quantum computing

Quantum computing utilises quantum mechanics to solve complex problems faster than on classical computers. Our definition of the quantum computing critical technology is centred on the development and manufacturing process to build a quantum computer, with associated software to run the quantum computer and applications using quantum computers. Quantum cryptography and quantum communications are both noted as applications of quantum computing, but are outside the scope of this study[27].

Figure 10 describes the Quantum Computing value chain, outlining the various stages of supply and key businesses. The value chain spans research in quantum mechanics, through to development and construction of the quantum computer itself including provision of physical components, then development and manufacturing of hardware and management platforms. The final stage of supply is development of applications and related software.

Figure 10 Quantum Computing value chain representation



Source: Frontier Economics, based on desk research and conversations with DIGITALEUROPE members.

Note: This diagram does not aim to provide a fully comprehensive list of the companies active at each stage of the value chain. Moreover, the categorisation of economic activities into separate stages is a necessary simplification and does not aim to fully reflect the complexity of the value chain or differences relevant to specific geographies.

[27] Quantum cryptography and communications are advanced technological fields in their own right, with their own supply chains and applications. Therefore, it was more appropriate to remove them from the broader Quantum Computing value chain when performing the assessment of EU presence and exposure to supply risk, to avoid drawing inappropriate findings for Quantum Computing, which do not also relate to Quantum Cryptography and Communications.

Our analysis (summarised below) indicates that the EU currently has a reasonable position in the Quantum Computing supply chain. There is Moderate risk to the EU's economic security in this value chain, since underlying risks are mitigated somewhat by the EU's Moderate competitiveness in Quantum Computing. This technology is at an early stage of being applied by industry, and as such there is scope for the EU's position to dramatically change.

EU underlying exposure to supply risk	EU competitiveness	Risk to EU economic security
Moderate to High	Moderate	Moderate

Sections 3.3.1 to 3.3.2. provide further detail on these findings.

3.3.1 EU underlying exposure to supply chain risks

Our assessment is that the EU has a **Moderate to High** exposure to supply risk in the Quantum Computing value chain. This is based on the EU having a Moderate to High exposure to both Market structure risk and geographic concentration.

Market structure risk: Moderate to High

A relatively small group of large conglomerates are present across several stages of the value chain: the main ones are US businesses IBM, Google and Honeywell. In particular, McKinsey identifies that the hardware stage of supply is subject to high barriers to entry, due to the complex nature of developing the technology[28]. As such, production at this stage of supply is mainly accounted for by larger technology conglomerates, including those businesses listed above.

To the contrary, McKinsey also states that there is a greater presence of start-ups downstream in the software and applications development stage. The existence of a growing ecosystem of start-up businesses downgrades the assessment from High risk to Moderate to High risk.

Geographic concentration: Moderate to High

There is significant geographic concentration of production and investment in the US and China, for the Quantum Computing supply chain.

- The three largest leading conglomerates identified through the supply chain representation are all US-owned companies.

[28] mckinsey-quantum-technology-monitor-202109.pdf

- The US and China have committed very large amounts of investment to Quantum Computing, and considerably more than other countries. In particular, the US has invested $2.1 billion between 2001 and 2021[29], compared to $294 million for the EU over the same period. China has also committed to invest $15 billion in quantum computing[30] over the next five years through state-sponsored programs and national strategies. McKinsey also identifies US and Chinese-owned businesses as accounting for the majority of production in the hardware development stage of supply[31].

- US start-up and scale-up Quantum Computing businesses are receiving almost three times as much funding as their EU counterparts[32].

The growing number of quantum computing start-ups spread across a range of countries again somewhat mitigates this geographic concentration. McKinsey[33] identifies that the US and EU had the highest number of quantum computing start-ups in 2021. However, Canada, UK and South East Asia had 23, 19 and 18 start-ups respectively, compared to the US's 59 and the EU's 53. Furthermore, there had been a high growth rate in start-ups for these geographies between 2015 and 2021.

3.3.2 EU competitiveness

Our analysis (summarised below) indicates that the EU currently has reasonable competitiveness in the Quantum Computing supply chain, across both proximity to 'global best practice' and the degree of EU presence across stages of the supply chain.

Proximity to 'global best practice'	EU presence across stages of the supply chain	EU competitiveness
57%		Moderate

The following sub-sections present our findings and evidence collected in relation to the EU's proximity to 'global best practice' and presence across stages of the supply chain.

29 mckinsey-quantum-technology-monitor-202109.pdf

30 China invests billions in quantum computing, race with US now neck-and-neck - SDxCentral

31 mckinsey-quantum-technology-monitor-202109.pdf

32 Source: Frontier Economics analysis of crunchbase data.

33 mckinsey-quantum-technology-monitor-202109.pdf

Proximity to global best practice

Figure 11 presents our overall findings for the EU in terms of its proximity to global best practice for Quantum Computing. The US is added as a comparator as it is leading global country for this technology based on data collected across all indicators.

Figure 11 Overall EU proximity to global best practice in Quantum Computing

	Overall score	Scientific Performance (Weight 50%)	Industry Strength (Weight 50%)
EU27	57%	66%	48%
US (non-EU leader)	70%	76%	64%

Note: a 100% score is a theoretical maximum. In practice, no country ranks "best" across all indicators, and therefore no country or region would achieve a 100% score. Quantum Computing is at an earlier stage of industry adoption, and therefore the Industry Strength weight for this technology is reduced to 50%.

Figure 11 shows that for Quantum Computing, the EU has a moderate proximity to global best practice (scoring 57%). The EU is a significant distance behind the US (scoring 70%), which is the global leading country. The EU scores higher in its Scientific Performance (66%) compared to Industry Strength (48%), although in both cases the EU is a significant distance behind the US scores.

Figures 12 and 13 present the EU and US results on Scientific Performance and Industry Strength respectively, across all indicators. The leader for each indicator is also identified, along with the EU's ranking.

The EU scores higher in scientific research, both in terms of the quantity and quality of its research publications. However, as with other technologies it appears to under-perform when translating research into impact through patentable ideas, ranking fourth globally in the number of patents (and ninth in patents per 1 million population).

Figure 12 Scientific performance indicators for Quantum Computing

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Number of publications	China	2nd	0.93	0.86
Publications per 1 million people	EU	1st	1.00	0.67
Number of leading publications	US	2nd	0.63	1.00
Number of leading publications, per 1 million people	Switzerland	2nd	0.38	0.26
H-Index	US	8th	0.33	1.00
		Average scores	**0.66**	**0.76**

Source: Frontier Economics analysis of ASPI data

Figure 13 Industry strength indicators for Quantum Computing

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Market share of global value added	US	3rd	0.56	1.00
Count of leading global R&D businesses	US	3rd	0.61*	1.00
Patent applications	US	4th	0.09	1.00
Patent applications, per 1 million people	Israel	9th	0.17	0.96
Value of Start-up & Scale-up funding	US	2nd	0.61	1.00
Start-up & Scale-up funding as % GDP	EU	1st	1.00	0.22
Global gross exports market share	China	2nd	0.53	0.25
Exports for the technology as a % of country exports	Taiwan	9th	0.46	0.20
Domestic value added embodied in foreign exports as a share of gross exports	Taiwan	6th	0.29	0.47
Global exports of intermediate goods market share	China	2nd	0.49	0.33
		Average scores	**0.48**	**0.64**

Source: Frontier Economics analysis of OECD, Crunchbase, COMTRADE, EU R&D Scoreboard data

Note: For measures market with asterisk (*),proximity to frontier value calculated as the EU value divided by the average of the top 3 global leading country values. This is because the top 1 or 2 countries for this indicator are a very large distance ahead of all other countries, misrepresenting the gap between the EU and a broad set of market leaders

The EU's presence in the value chain

Overall, EU businesses have a **Moderate** presence in the Quantum Computing value chain. This is based on a Moderate assessment of EU presence across all stages of the supply chain, given that it is not currently possible to assess the EU's presence in the highest value stages of supply at this point.

EU presence across all stages of the supply chain: Moderate

EU businesses appear to have a significant presence in all stages of supply, aside from Quantum mechanics furthest upstream. This is based on a combination of our supply chain representation for semiconductors, collection of secondary data and broader desk research.

- No EU companies are identified as having a significant presence in Stage 1 (research in quantum mechanics). To the contrary, US businesses IBM, Google and Honeywell are identified as the leading businesses with a significant presence at this stage of supply.
- In each of stages 2 to 5 of the value chain[34], there are some EU businesses which collectively have a significant EU presence. These businesses tend to be SMEs, including QuTech, IQM, QMWare, Terra Quantum and others.

The European Policy Centre also states that EU businesses are not consistently among the largest Quantum Computing businesses globally[35]. This matches the insight from our value chain representation, that while the EU appears to have some presence across most stages of the value chain, it is mainly through SMEs, where the short-list of leading Quantum Computing businesses does not include many that are EU-based. Therefore, our assessment is that the EU has a Moderate presence across all stages of the supply.

[34] In order, these stages are Inputs & Components, Hardware platform & assembly, Management platform, Software development & applications.

[35] Quantum_Technologies_DP.pdf (epc.eu)

3.4 Biotechnologies

Biotechnology relates to the exploitation of biological processes for industrial and other purposes, especially the genetic manipulation of microorganisms for the production of antibiotics, hormones. This is a broad technological field, with a range of techniques and applications. Our value chain analysis focuses on genetic modification and synthetic biology with health applications.[36]

Figure 14 describes the Synthetic biology value chain, outlining the various stages of supply and key businesses. The value chain spans the sourcing of raw materials from biobanks, through research, development and manufacturing of product which are often performed by vertically integrated businesses. Later stages of supply relate to distribution of product before it is administered to patients.

Figure 14 Illustration of key players across synthetic biology value chain

Source: Frontier Economics, based on desk research and conversations with DIGITALEUROPE members.

Note: This diagram does not aim to provide a fully comprehensive list of the companies active at each stage of the value chain. Moreover, the categorisation of economic activities into separate stages is a necessary simplification and does not aim to fully reflect the complexity of the value chain or differences relevant to specific geographies.

Our analysis (summarised below) indicates that the EU currently has a reasonable position in the Biotechnologies supply chain. There is a Moderate risk to the EU's economic security in this value chain, since underlying exposure to supply risk is mitigated somewhat by the EU's Moderate competitiveness – critically, the EU's significant presence across stages of the supply chain.

EU underlying exposure to supply risk	EU competitiveness	Risk to EU economic security
Moderate to High	**Moderate**	**Moderate**

[36] The definition has been refined, to ensure meaningful analysis of a single supply chain. This is a necessary adjustment, given the range of biotechnology techniques and applications.

Sections 3.4.1 to 3.4.2. provide further detail on our findings.

3.4.1 Underlying exposure to supply chain risks

Our assessment that the EU has a **Moderate to High** exposure to supply risk in the Synthetic biology value chain. This is driven by a Moderate to High geographic concentration and Moderate exposure to market structure risk.

Market structure risk: Moderate

Historically, large conglomerate businesses have accounted for a large proportion of production in the biotechnology industry[37]. While this introduces some market structure risk, there is a significant number of these conglomerates, as identified by our supply chain representation, which limits this risk exposure somewhat.

Furthermore, McKinsey identifies a rapid growth in production and market share of smaller, specialist biotechnology businesses. In particular, the turnover of these businesses is predicted to grow at an annual rate of 11% between 2020 and 2025, compared to 5% for larger pharmaceutical businesses[38]. This ongoing growth of CDMOs and smaller specialist biotechnology businesses will continue to diversify production across a broader group of biotechnology businesses, further reducing the exposure to market structure risk.

Geographic concentration: Moderate to High

Across the supply chain as a whole, there is some geographic concentration risk faced by the EU. Precedence Research finds that North America is the region with largest biotechnology production, accounting for 38% of global market share. Europe and Asia Pacific also have a significant share with 29% and 24% respectively[39]. The EU is therefore somewhat exposed to geographic concentration, with the remaining two of the top 3 regions globally accounting for approximately 60% of production.

There is also evidence of geographic concentration in specific stages of supply, particularly upstream. Interviews with DIGITALEUROPE industry experts identified that the provision of raw materials (in stage 1 of the value chain) and CDMO activity is concentrated in China.

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[37] As referenced by Deconinck (2020), for example.

[38] Outsourcing pharma resourcing to specialists | McKinsey

[39] Precedence Research

- These views are supported by McKinsey research[40] in relation to specific raw materials and broader Bain[41] and McKinsey[42] evidence on the reliance of the pharmaceutical industry on supplies from the Asia-Pacific region, and China in particular.
- PWC[43] also finds that CDMOs appear to be highly concentrated in the Asia Pacific region, with a projected 51% share in 2025; North America and Europe account for 22% and 11%, respectively.

In the round, our overall assessment is that the EU is exposed to Moderate to High geographic concentration, driven upwards by the concentration risk towards China in relation to raw material extraction and the use of CDMOs.

3.4.2 EU competitiveness

Our analysis (summarised below) indicates that the EU currently has reasonable competitiveness in Biotechnology, particularly through its significant presence across stages of the supply chain.

Proximity to 'global best practice'	EU presence across stages of the supply chain	EU competitiveness
57%		Moderate

The following sub-sections present our findings and evidence collected in relation to the EU's proximity to 'global best practice' and presence across stages of the supply chain.

Proximity to the global best practice

Figure 15 presents the EU's proximity to global best practice for Biotechnology, as well as the score for the US, which is the global leading country for the technology based on data collected across all indicators.

[40] Four ways pharma companies can make their supply chains more resilient | McKinsey

[41] A Strategy to Make Pharma Supply Chains More Resilient | Bain & Company

[42] Risk, resilience, and rebalancing in global value chains | McKinsey

[43] Current trends and strategic options in the pharma CDMO market (pwc.de)

Figure 15 Overall EU proximity to global best practice in Biotechnologies

	Overall score	Scientific Performance (Weight 33%)	Industry Strength (Weight 67%)
EU27	57%	50%	61%
US (non-EU leader)	67%	59%	70%

Note: a 100% score is a theoretical maximum. In practice, no country ranks "best" across all indicators, and therefore no country or region would achieve a 100% score.

Figure 15 shows that for Biotechnology, the EU has a moderate proximity to global best practice (scoring 57%). The EU is a significant distance behind the US (scoring 67%), which is the global leading country. The EU scores slightly higher in its Industry Strength (61%) compared to Scientific Performance (50%), although in both cases the EU is a significant distance behind the US scores.

Notably, while the EU's scientific performance raw score of 50% may appear low, the EU is not a large distance behind the technological leader, the US. In the context, the EU appears to be reasonably competitive in its biotechnology scientific expertise, by international standards.

Figures 16 and 17 present the EU and US results on Scientific Performance and Industry Strength respectively, across all indicators. The leader for each indicator is also identified, along with the EU's ranking.

The EU's areas of strength relate to its integration in global value chains, measured by its ability to export goods in international markets for related sub-sectors. This contrasts with the US, whose comparative area of strength is in business performance through investment in research, funding for start-up and scale-ups and business patent applications. The EU trails the US significantly in all of these indicators.

Figure 16 Scientific performance indicators for Biotechnologies

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Number of publications	China	2nd	0.54	0.50
Publications per 1 million people	Australia	2nd	1.00	0.74
Number of leading publications	China	3rd	0.40*	0.63*
Number of leading publications, per 1 million people	Singapore	7th	0.26	0.27
H-Index	China	8th	0.28	0.83
		Average scores	**0.50**	**0.59**

Source: Frontier Economics analysis of ASPI data

Note: For measures market with asterisk (*),proximity to frontier value calculated as the EU value divided by the average of the top 3 global leading country values. This is because the top 1 or 2 countries for this indicator are a very large distance ahead of all other countries, misrepresenting the gap between the EU and a broad set of market leaders

Figure 17 Industry strength indicators for Biotechnologies

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Market share of global value added	US	2nd	0.81	1.00
Count of leading global R&D businesses	US	3rd	0.35	1.00
Patent applications	US	3rd	0.46	1.00
Patent applications, per 1 million people	Switzerland	5th	0.39	0.39
Value of Start-up & Scale-up funding	US	2nd	0.29*	1.00
Start-up & Scale-up funding as % GDP	US	4th	0.36	1.00
Global gross exports market share	EU	1st	1.00	0.25
Exports for the technology as a % of country exports	Switzerland	2nd	0.50	0.11
Domestic value added embodied in foreign exports as a share of gross exports	US	2nd	0.95	1.00
Global exports of intermediate goods market share	EU	1st	1.00	0.29
		Average scores	**0.61**	**0.70**

Source: Frontier Economics analysis of OECD, Crunchbase, COMTRADE, EU R&D Scoreboard data

Note: For measures market with asterisk (*),proximity to frontier value calculated as the EU value divided by the average of the top 3 global leading country values. This is because the top 1 or 2 countries for this indicator are a very large distance ahead of all other countries, misrepresenting the gap between the EU and a broad set of market leaders

The EU's presence in the value chain

Our assessment is that overall, EU businesses have a **Moderate to High** presence in the Synthetic biology value chain. This is based on a High presence in higher value added stages of supply and a Moderate to High presence more broadly across all stages of supply.

EU presence across all stages of the supply chain: Moderate to High

EU businesses appear to have a significant presence across all stages of supply, based on a combination of our collection of secondary data and broader desk research. Markets & Markets identifies the EU as one of the strongest geographies in biotechnology[44], and our secondary data collection identified EU biotechnology / pharmaceutical businesses also account for 50 of the top 1000 global businesses investing in research and development in any industry.

Our supply chain representation for biotechnologies also identifies a significant EU presence across two of the three stages of supply.

- In Stage 1 (Raw materials and Biobanks), Biobank Graz is identified in the short-list of leading businesses, although no systematic evidence is identified of other EU businesses in the short-list of leading businesses in this stage of supply.
- In Stage 2 (Research, process development and manufacturing), several EU businesses are identified in the short-list of leading businesses: Novo Nordisk, Sanofi, Bayer, Fareva, Recipharm, and BioNTech.
- In Stage 3 (Distribution and logistics), several EU businesses are identified in the short-list of leading businesses: Novo Nordisk, Sanofi, Bayer, Fareva and Recipharm.

Our overall assessment is Moderate to High. A lack of systematic evidence related to multiple EU businesses with significant presence in Stage 1 of the value chain downgraded the assessment from High.

[44] The Global Biotechnology Industry Outlook - 2024 (marketsandmarkets.com)

EU presence in highest value added stages of supply: High

No secondary evidence exists estimating the proportion of value added at different stages of the synthetic biology value chain.

However, desk research does indicate that most value added is generated at the process development and manufacturing stage of supply. This is based on biotechnology's high disruptive potential for manufacturing processes across many industries[45], and previous studies identifying that biotechnologies will make the highest contribution in terms of employment at this stage of supply[46].

Several EU-based businesses are identified in the short-list of leading businesses in this stage of supply (Stage 2), and therefore our assessment is High.

45 Synthetic Biology Is About to Disrupt Your Industry (bcg.com)

46 Policy paper on Bio-based Economy in the EU.pdf (greengran.com)

3.5 Advanced connectivity

Advanced connectivity technologies are networks and devices that enable fast, reliable and secure communication between devices, systems and individuals. There is a wide range of developing Advanced connectivity technologies. The EC includes under this term[47]:

- Secure digital communications and connectivity, comprising RAN and Open RAN (Radio Access Network) and 6G.
- Cyber security technologies, including cyber-surveillance, security and intrusion systems, and digital forensics.
- Internet of Things (IoT) and Virtual Reality (VR)
- Distributed ledger and digital identity technologies
- Guidance, navigation and control technologies, including avionics and marine positioning.

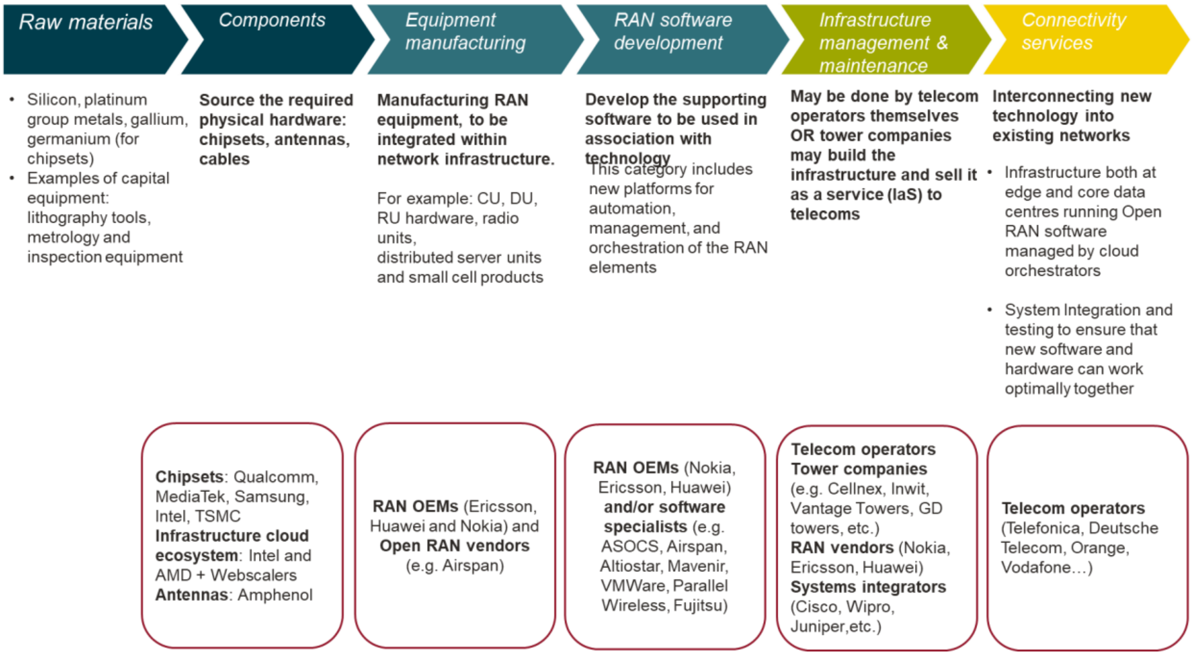
Many of these technologies have distinct supply chains. This supply chain analysis has been refined to focus on RAN and Open RAN. These are a part of the mobile telecommunications system that uses cellular radio connections to link end user devices to other parts of the network[48].

Figure 18 describes the Open RAN value chain, outlining the various stages of supply and key businesses. The value chain spans the sourcing of raw materials and components, through manufacturing of RAN equipment and then development of RAN software. In later stages, key associated infrastructure is delivered and then RAN technology is interconnected into existing networks.

[47] European Commission (2023). Annex to the Commission Recommendation on critical technology areas for the EU's economic security for further risk assessment with Member States.
https://defence-industry-space.ec.europa.eu/document/download/d2649f7e-44c4-49a9-a59d-bffd298f8fa7_en?filename=C_2023_6689_1_EN_annexe_acte_autonome_part1_v9.pdf

[48] We chose to focus on RAN and Open RAN given its wide use cases, including for other Advanced connectivity technologies, such as IoT, 5G and 6G, and guidance and navigation.

Figure 18 Value chain representation for RAN technologies



Source: *Frontier Economics, based on desk research and conversations with DIGITALEUROPE members*

Note: *This diagram does not aim to provide a fully comprehensive list of the companies active at each stage of the value chain. Moreover, the categorisation of economic activities into separate stages is a necessary simplification and does not aim to fully reflect the complexity of the value chain or differences relevant to specific geographies.*

Our analysis (summarised below) indicates that the EU currently has a strong position in the Advanced Connectivity supply chain. There is a Low to Moderate risk to the EU's economic security in this technology area. There is some underlying supply risk, but these are mitigated by the EU's high competitiveness – critically, our proximity to 'global best practice' analysis indicates that the EU is the leading region at the cutting edge of Advanced Connectivity technology.

EU underlying supply risk	EU competitiveness	Risk to EU economic security
Moderate	High	Low to Moderate

Sections 3.5.1 and 3.5.2. provide further detail on our findings.

3.5.1 Underlying exposure to supply chain risks

Our assessment is that the EU has a Moderate exposure to supply risk in the Advanced connectivity value chain. This is driven upwards by a Moderate to High geographic concentration faced by the EU in RAN equipment. There is a Low to Moderate exposure to Market structure risk.

Market structure: Low to Moderate

The RAN industry is dominated by a few big players (Ericsson, Nokia, Huawei, ZTE, and Samsung). These include EU businesses Ericsson and Nokia, so while the RAN industry as a whole has market structure risk, the presence of EU businesses mitigates this risk to the EU.

However, Open RAN could disrupt the market, as its reliance on open, interoperable components and software, as opposed to proprietary hardware from large suppliers could foster market entry[49]. While deployments of Open RAN to date are still limited and focused on suburban and rural areas, they are expected to ramp-up in the near future.

Our assessment is Low to Moderate. The current state of the RAN market has low market structure risk, given the role played by EU businesses. However, it is possible that the nature of RAN technology will change in future with increased take-up of Open RAN. The degree of market structure risk related to Open RAN provision is less well known, and on that basis the risk level is upgraded to Low to Moderate.

Geographic concentration: Moderate to High

Chinese vendors, primarily Huawei and ZTE, account for a large share of the 5G equipment market in the EU. For instance, in 2022, 59% of the 5G RAN equipment in Germany was sourced from Chinese vendors. Overall, 41% of mobile subscribers in Europe have access to 5G networks using Chinese equipment[50].

As we have mentioned in the previous section, although Open RAN can diversify the vendor landscape, many of the key players in this space are US-owned. Moreover, the O-RAN Alliance, which plays a key role in setting standards, includes significant participation from Chinese telecom operators. Hence, although Open RAN is likely to facilitate entrance in the market, it is not provided that it will lead to EU's self-reliance. In addition to the significant presence of non-EU infrastructure, the EU is also reliant in semiconductors and chipsets manufactured by companies in the US and Asia[51].

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[49] European Centre for International Political Economy (2020). Open RAN: The Technology, its Politics and Europe's Response. https://ecipe.org/wp-content/uploads/2020/10/ECI_20_PolicyBrief_08_2020_LY03.pdf

[50] Strand Consult. The Market for 5G RAN in Europe: Share of Chinese and Non-Chinese Vendors in 31 European Countries. https://strandconsult.dk/the-market-for-5g-ran-in-europe-share-of-chinese-and-non-chinese-vendors-in-31-european-countries/ [Retrieved on May 31, 2024]

[51] European Centre for International Political Economy (2020). Open RAN: The Technology, its Politics and Europe's Response. https://ecipe.org/wp-content/uploads/2020/10/ECI_20_PolicyBrief_08_2020_LY03.pdf

Considering the reliance in non-EU technology at relatively-concentrated stages of the value chain, our assessment of geographical risk is Moderate to High.

3.5.2 EU competitiveness

Our analysis (summarised below) indicates that the EU has strong competitiveness in Advanced Connectivity, and is identified as the global-leading geography in our proximity to 'global best practice' analysis at the cutting edge of the critical technology.

Proximity to 'global best practice'	EU presence across stages of the supply chain	EU competitiveness
71%		High

The following sub-sections present our findings and evidence collected in relation to the EU's proximity to 'global best practice' and presence across stages of the supply chain.

3.5.3 Proximity to global best practice

Figure 19 presents our overall findings for the EU in terms of its proximity to global best practice for Advanced connectivity. The EU is compared to the US, a global leader based on data collected across all indicators. Advanced connectivity is one of only two technologies (the other being additive manufacturing) where the EU is closer to the global best practice than the US.

Figure 69 Overall proximity to global best practice in Advanced connectivity

	Overall score	Scientific Performance (Weight 33%)	Industry Strength (Weight 67%)
EU27	**71%**	82%	65%
US (non-EU leader)	**60%**	34%	73%

Source: Frontier Economics

Note: a 100% score is a theoretical maximum. In practice, no country ranks "best" across all indicators, and therefore no country or region would achieve a 100% score.

Figure 19 shows that for Advanced Connectivity, the EU has a high proximity to global best practice (scoring 71%). The EU is the technological leader in advanced connectivity, ahead of the US overall. The EU scores very high in its Scientific Performance (82%), which is also very large distance ahead of the US. The EU's Industry Strength result is also reasonably high (scoring 65%), although in this case, as with all priority technologies, the EU trails the US.

Figures 20 and 21 present the EU and US results on Scientific Performance and Industry Strength respectively, across all indicators. The leader for each indicator is also identified, along with the EU's ranking.

The EU's clearest area of strength relates to its scientific performance, in terms of both the quantity and quality of its research. This is observed through performance across a range of countries – Greece, Sweden, Denmark, Ireland, Portugal, Spain, Italy, and, in particular, Finland. Conversely, the US's comparative area of strength is in business performance through investment in research and funding for start-up and scale-ups, as is the case in most priority technologies. The EU again trails the US significantly in all of these indicators.

Figure 20 Scientific performance indicators for Advanced connectivity

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Number of publications	EU	1st	1.00	0.37
Publications per 1 million people	EU	1st	1.00	0.14
Number of leading publications	China	2nd	0.66	0.31
Number of leading publications, per 1 million people	EU	1st	1.00	0.13
H-Index	China	8th	0.43	0.74
		Average scores	**0.82**	**0.34**

Source: Frontier Economics analysis of ASPI data

Figure 21 Industry performance indicators for Advanced connectivity

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Market share of global value added	US	3rd	0.56	1.00
Count of leading global R&D businesses	US	2nd	0.54	1.00
Patent applications	Japan	4th	0.57	0.78
Patent applications, per 1 million people	South Korea	3rd	0.63	0.24
Value of Start-up & Scale-up funding	US	3rd	0.49*	1.00
Start-up & Scale-up funding as % GDP	Israel	6th	0.23*	0.29*
Global gross exports market share	EU	1st	1.00	0.67
Exports for the technology as a % of country exports	China	3rd	0.77	1.00
Domestic value added embodied in foreign exports as a share of gross exports	UK	2nd	0.70	0.50
Global exports of intermediate goods market share	EU	1st	1.00	0.84
		Average scores	**0.65**	**0.73**

Source: Frontier Economics analysis of OECD, Crunchbase, COMTRADE, EU R&D Scoreboard data

Note: For measures market with asterisk (*),proximity to frontier value calculated as the EU value divided by the average of the top 3 global leading country values. This is because the top 1 or 2 countries for this indicator are a very large distance ahead of all other countries, misrepresenting the gap between the EU and a broad set of market leaders.

The EU's presence in the value chain

Our assessment is that the EU has a Moderate to High presence in the RAN value chain. This is based on a Moderate presence of EU companies across all stages of the supply chain, and a Moderate to High presence in the highest value added stages of supply.

EU presence across the supply chain: Moderate

Our assessment of the presence of the EU across the supply chain reflects its strong position at some stages but lack of presence at the raw materials stage:

- Our research shows that the EU is not a major player in the first stage of the value chain – components. This stage consists of companies that either produce chipsets, build antennas, or work on the development of an infrastructure cloud ecosystem. In none of these categories we find presence of leading EU businesses.

- In stages 2 and 3, equipment manufacturing and RAN software development, the presence of the EU is stronger, mainly driven by two of the market leaders[52] – Ericsson, and Nokia - being EU firms.
- At stage 4, infrastructure management and maintenance, the EU is present through businesses as Inwit, Vantage Towers, and GD Towers.
- Finally, at stage 5, connectivity services, the EU is present through major telecom operators – Telefonica, Deutsche Telecom, Orange, Vodafone, etc.

EU presence in highest value added stages: Moderate to High

No secondary evidence exists estimating the proportion of value added at different stages of the "traditional" RAN value chain. However, in this value chain, radio access network equipment software and services are often provided in an integrated way, and as such it is reasonable to believe that value is distributed relatively evenly across stages of supply. The key players (among which we find Nokia, Ericsson) are present across the different stages of the value chain. Therefore, EU companies are likely to have a significant presence in the highest value added stages of the RAN supply chain.

In "Open" RAN, secondary evidence indicates that RAN services captures the most value added[53] (38% of revenues in RAN services, 24% in RAN hardware). The EU has a significant presence in RAN services.

Overall, in the round, our assessment is Moderate to High.

[52] UK's Department for Digital, Culture, Media & Sport (

[53] Deutsche Telekom, Orange, Telecom Italia (TIM), Telefónica, Vodafone (2021). Building an Open RAN ecosystem for Europe. https://www.vodafone.com/sites/default/files/2021-11/building-open-ran-ecosystem-europe.pdf

4 Results on other technologies

4.1 Energy technologies

4.1.1 Proximity to frontier

Renewable energy technologies relate to the generation and extraction of energy from a source that won't run out. This covers a wide range of energy sources, including nuclear energy, hydrogen and new fuels, net-zero technologies, as well as smart grids and batteries. In practice, the metrics used in performing the proximity to 'global best practice' analysis are based on a different mix of renewable energy sources, including photovoltaics, electric batteries and biofuels, due to data availability restrictions.

Figure 22 presents our overall findings for the EU in terms of its proximity to 'global best practice' for energy technologies, including China – the global leader in this technology – and the US.

Figure 22 Overall EU proximity to global best practice in energy technologies

	Overall score	Scientific Performance (Weight 33%)	Industry Strength (Weight 67%)
EU27	61%	45%	68%
China	62%	73%	56%
US	45%	37%	48%

Source: Frontier Economics

The EU and China present very close overall performances – with the former standing out in Industry strength and the latter in Scientific performance. Both geographies obtain across both domains better scores than the US.

Figures 23 and 24 present the EU and China results on Scientific Performance and Industry Strength respectively, across all indicators. The leader for each indicator is also identified, along with the EU's ranking.

On the Scientific Performance side, which is detailed in Figure 23, China is the leader both in terms of total and leading publications, while the EU shows higher per capita value across these measures.

On the Industry Strength side, detailed in Figure 24, China shows an advantage with respect to the EU in its share of the overall value added captured and across several trade indicators. Nevertheless, the EU does not lag significantly across these indicators, and it shows promising results across the start-up and scale-up side, being the clear market leader.

Figure 23 Scientific performance for Energy technologies

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	China score versus leader (per indicator)
Number of publications	China	2	68%	100%
Publications per 1 million people	South Korea	4	44%	26%
Number of leading publications	China	2	44%	100%
Number of leading publications, per 1 million people	Switzerland	7	41%	37%
H-Index	China	10	27%	100%
Average scores			**45%**	**73%**

Source: Frontier Economics analysis of ASPI data

Figure 24 Industry strength indicators for Energy technologies

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	China score versus leader (per indicator)
Market share of global value added	China	2	82%	100%
Count of leading global R&D businesses	EU	1	100%	100%
Patent applications	Japan	2	76%	59%
Patent applications, per 1 million people	Korea	3	41%	3%
Value of Start-up & Scale-up funding	United States	2	51%	17%
Start-up & Scale-up funding as % GDP	Canada	2	100%	8%
Global gross exports market share	China	2	47%	100%
Exports for the technology as a % of country exports	China	5	37%	100%
Domestic value added embodied in foreign exports as a share of gross exports	Norway	2	50%	
Global exports of intermediate goods market share	EU	1	100%	17%
		Average scores	**68%**	**56%**

Source: Frontier Economics analysis of OECD, Crunchbase, COMTRADE, EU R&D Scoreboard data

Note: Data point for China on 'Domestic value added embodied in foreign exports' is not reliable, and has been removed.

4.2 Additive manufacturing

4.2.1 Proximity to frontier

Additive manufacturing is an industrial process that deposits materials layer by layer to create geometric three-dimensional objects. A major example of additive manufacturing is 3-D printing, technique around which we have based our review.

Figure 25 shows that for Additive Manufacturing, the EU has a moderate proximity to global best practice (scoring 69%), as it is the global leader in this space, scoring above the US (56%).

Figure 25 Overall proximity to global best practice in Additive manufacturing

	Overall score	Scientific Performance (Weight 33%)	Industry Strength (Weight 67%)
EU27	**69%**	62%	73%
US	**56%**	64%	51%

Source: Frontier Economics

In additive manufacturing, the EU performs somewhat better in the industry domain than in the scientific domain. The difference with the US steams from a superior Industry Performance (scoring 22 percentage points higher), mainly driven by the EU capturing a higher share of the global value added and leading R&D businesses, and a stronger trade performance. Hence, contrarily to other technologies, the scientific strength of the EU is able to translate into having a similarly strong impact in the industry.

Figures 26 and 27 present the EU and US results on Scientific Performance and Industry Strength respectively, across all indicators. The leader for each indicator is also identified, along with the EU's ranking.

On the Scientific Performance side, the EU and US results paint a similar picture – they both lead the table with similar numbers of total and leading publications, but are more distant in per capita measures. Figures 26 and 27 present the evidence on the EU's and US's Scientific Performance and Industry Strength, respectively, across all indicators, underlying our findings.

Figure 26 Scientific performance indicators for Additive Manufacturing

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Number of publications	EU	1	100%	97%
Publications per 1 million people	Singapore	10	55%	38%
Number of leading publications	China	3	99%	100%
Number of leading publications, per 1 million people	Singapore	10	27%	18%
H-Index	China	11	28%	70%
Average scores			**62%**	**64%**

Source: *Frontier Economics analysis of ASPI data*

Figure 27 Industry strength indicators for Additive manufacturing

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Market share of global value added	China	2	72%	47%
Count of leading global R&D businesses	China	3	49%	33%
Patent applications	USA	2	97%	100%
Patent applications, per 1 million people	Switzerland	2	100%	38%
Value of Start-up & Scale-up funding	United States	8	3%	100%
Start-up & Scale-up funding as % GDP	Norway	16	24%	56%
Global gross exports market share	China	2	86%	32%
Exports for the technology as a % of country exports	EU	1	100%	14%
Domestic value added embodied in foreign exports as a share of gross exports	EU	1	100%	61%
Global exports of intermediate goods market share	EU	1	100%	34%
		Average scores	**73%**	**51%**

Source: *Frontier Economics analysis of OECD, Crunchbase, COMTRADE, EU R&D Scoreboard data*

4.3 Space technologies

4.3.1 Proximity to frontier

Aerospace technology includes the research, design, manufacture, operation, or maintenance of both aircraft and spacecraft, as well as satellites.

Figure 28 shows that that the EU has a relatively high proximity to global best practice. Nevertheless, regardless the EU positive results, there is still a clear gap with the US (scoring at 87%), which is the clear scientific and industry leader in this technology.

Figure 28 Overall proximity to global best practice in Space technologies

	Overall score	Scientific Performance (Weight 33%)	Industry Strength (Weight 67%)
EU27	**69%**	85%	61%
US (non-EU leader)	**87%**	78%	92%

Source: Frontier Economics

While our analysis shows the leading position of the US, it also shows that the EU performance is ahead in the scientific side, scoring at 85% compared to 78% of the US. This advantage is explained by the EU performing better on leading scientific publications.

The Industry Strength of the EU, on the other hand, clearly lags behind the one of the US (31 percentage points lower). While the EU's performance is lower across the board, the highest differences are found in the value of start-ups and scale-ups and trade.

Figures 29 and 30 present the EU and US results on Scientific Performance and Industry Strength respectively, across all indicators. The leader for each indicator is also identified, along with the EU's ranking.

Figure 79 Scientific performance indicators for Space technologies

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Number of publications	US	2	86%	100%
Publications per 1 million people	EU	1	100%	61%
Number of leading publications	EU	1	100%	88%
Number of leading publications, per 1 million people	EU	1	100%	43%
H-Index	US	5	40%	100%
Average scores			**85%**	**78%**

Source: Frontier Economics analysis of ASPI data

Figure 30 Industry strength for Space technologies

Indicator	Leader per indicator	EU Position	EU score versus leader (per indicator)	US score versus leader (per indicator)
Market share of global value added	USA	2	39%	100%
Count of leading global R&D businesses	US	2	80%	100%
Patent applications	USA	2	63%	100%
Patent applications, per 1 million people	EU	1	100%	99%
Value of Start-up & Scale-up funding	United States	3	27%	100%
Start-up & Scale-up funding as % GDP	Singapore	2	68%	30%
Global gross exports market share	USA	2	48%	100%
Exports for the technology as a % of country exports	USA	7	18%	100%
Domestic value added embodied in foreign exports as a share of gross exports	USA	4	69%	100%
Global exports of intermediate goods market share	EU	1	100%	87%
		Average scores	**61%**	**92%**

Source: Frontier Economics analysis of OECD, Crunchbase, COMTRADE, EU R&D Scoreboard data

5 Conclusions and policy implications

Our key findings for this study in relation to the EU's exposure to economic supply risk and competitiveness are presented below, for the priority critical technologies in scope.

Technology	EU underlying supply risk	EU competitiveness	Overall assessment of risk to EU economic security
Advanced semiconductors	High	Low	High
Artificial Intelligence	Moderate to High	Low to Moderate	Moderate to High
Quantum computing	Moderate to High	Moderate	Moderate
Biotechnology	Moderate to High	Moderate	Moderate
Advanced connectivity	Moderate	High	Low to Moderate

Our findings highlight that for all sectors, the EU faces challenges in regards both to competitiveness and economic security. This raised the question as to how far both can be promoted, especially in light of the EU's ambition of reinforcing economic security via strengthened competitiveness.

At an overarching level, the policy approaches need to be cognizant of the globalised nature of these value chains, which is underscored by our analysis. This militates against an approach to economic security based on "technological sovereignty", in which restrictions on trade and investment play a prominent role. Such measures (for example, local content requirements) would not address the underlying constraints identified in the analysis; and would likely involve losses associated with foregone gains from specialisation that are reflected in the existing operation of value chains. A rejection of approaches driven by the notion of technological sovereignty is also consistent with the European Commission's declared preference of retaining and open and rules-based approach to international trade and investment.

The findings also reinforce the need for the EU, identified in the economic security strategy, of further fostering single market integration. This in turn offers the scale, in terms both of demand and in the provision of specific inputs, including skills, that are required to stimulate investment in these technologies. For example, OECD work on services trade restrictions within the EU and the European Economic Area points to challenges in ICT sectors. Collectively, these services play an important role, both as direct inputs and in creating an enabling environment. In telecommunications, the OECD found that EU integration had a modest effect on bringing down barriers within the EU relative to those applying to non-EU services providers. It also found that regulatory heterogeneity across the EU could create further barriers. Regulatory transparency was also an issue for computer services[54].

In general, the industry performance indicators, when set against scientific performance indicators, highlight the long-standing challenge faced by the EU in translating its scientific capabilities into value generation. This is partly another aspect of the previous point made in relation to the remaining single market agenda: while there may be pools of research excellence across EU member states, harnessing these at scale might be difficult given sources of single market fragmentation.

Bringing research to market typically involves navigating various market failures. It involves addressing capital constraints and coordination problems (e.g. a prototype can be developed at scale if there is sufficient demand, but there may only be sufficient demand if users are satisfied that the prototype can be commercialised at scale). The extent to which these market failures can be addressed is not simply a question of using interventions such as subsidies, but also a matter of designing these correctly. For example, through the development of accelerators and scale-up facilities, including through private-public partnerships. Such approaches would need to be pursued at an EU-wide level. The IPCEI[55] process, and the European Commission's on-going effort to strengthen this, is an example of such an approach.

54 Benz, S. and F. Gonzales (2019-01-28), "Intra-EEA STRI Database: Methodology and Results", OECD Trade Policy Papers, No. 223, OECD Publishing, Paris.

55 Important Project of Common European Interest

Annex A – Further detail on proximity to global best practice analysis

A.1 Further detail on methodology

Applying critical technology definitions

Sections 3 and 4 present definitions for the eight critical technologies. Our 'proximity to global best practice' analysis collected data on indictors related to each of the critical technologies.

The data collected did not always exactly match these definitions due to constraints on the level of disaggregation in the available secondary data. In general, the data is most granular for Scientific Performance indicators where search terms in the ASPI Technology tracker closely related to the specific critical technologies (with the exception of Energy technologies[56]). The level of granularity varied more for Industry strength indicators. In some cases, specifically for the trade-based exporting indicators sourced from the OECD Trade in Value Added data, only more aggregated data was available. For example, no secondary data was identified relating to exports of 'synthetic biology products' in Biotechnology. On that basis, data was collected instead on exports of 'Pharmaceuticals, medicinal chemical and botanical products', which was the closest available definition.

The findings from our 'proximity to global best practice' analysis are therefore subject to the caveats that detailed data directly related to the definitions of each specific critical technology was not always available. However, the data collected on the indicators was as close as possible to the precise definitions used in sections 3 and 4, and reflects reasonable proxies for each critical technology. This analysis is based on a wide range of data sources that have all been reviewed in detail.

Tables 2 to 9 present the level of aggregation in the data collected and how it relates to the precise definitions of each critical technology.

Table 2 Semiconductors

Indicator	Definition	Source
Number of publications		ASPI Technology Tracker

56 The Energy technologies definition related to renewable energy technologies. However, ASPI data was only available for specific technologies (e.g. photovoltaic, biofuels, electric batteries) rather than renewable energy as a broader group of technologies. Therefore, data was collected for the three individual technologies and averaged to generate values for the 'renewable energy' technologies group.

Indicator	Definition	Source
Publications per 1 million population	Advanced integrated circuit design and fabrication[57]	
Number of leading publications	Advanced integrated circuit design and fabrication[57]	
Leading publications per 1 million population	Advanced integrated circuit design and fabrication[57]	
H-Index	Advanced integrated circuit design and fabrication[57]	
Global production market share	Sector C26: Computer, electronic and optical products	OECD Trade in Value added
Count of leading global R&D businesses	Industry filter "Technology hardware & equipment" and "Electronic & electrical equipment"	EU R&D Investment scoreboard
Number of patents filed	Semiconductors	OECD
Patents filed per 1 million population	Semiconductors	OECD
Value of start-up and scale-up funding (USD)	Industries filter contains "semiconductor"	Crunchbase
Start-up and scale-up funding as a % of GDP	Industries filter contains "semiconductor"	Crunchbase
Global exports market share	Product code 8486, 8541, 8542 (see footnote)[58]	Comtrade
Exports % for the technology as a % of country exports	Product codes 8486, 8541, 8542	Comtrade and OECD Trade in Value added (for total country exports)
Domestic value added embodied in foreign exports as a % of gross exports	Sector C26: Computer, electronic and optical products	OECD Trade in Value added
Global intermediate goods export market share	Sector C26: Computer, electronic and optical products	OECD Trade in Value added

57 This is the most appropriate search term for semiconductors, used in this ASPI report.

58 8486 'machines and apparatus used solely or principally for the manufacture of semiconductor boules', 8541 'semiconductor devices (e.g. diodes, transistors, transducers)', 8542 'electronic integrated circuits'.

Table 3 Artificial Intelligence

Indicator	Definition	Source
Number of publications	Machine Learning	ASPI Technology Tracker
Publications per 1 million population		
Number of leading publications		
Leading publications per 1 million population		
H-Index		
Global production market share	Sector J62_63 Computer programming, consultancy and information services activities	OECD Trade in Value added
Count of leading global R&D businesses	Industry filter 'Software and computer services'	EU R&D Investment scoreboard
Number of patents filed	'Technologies related to artificial intelligence'	OECD
Patents filed per 1 million population		
Value of start-up and scale-up funding (USD)	Industries filter contains 'artificial intelligence'	Crunchbase
Start-up and scale-up funding as a % of GDP		
Global exports market share	Sector J62_63 Computer programming, consultancy and information services activities	OECD Trade in Value added
Exports % for the technology as a % of country exports		
Domestic value added embodied in foreign exports as a % of gross exports		
Global intermediate goods export market share		

Table 4 Quantum Computing

Indicator	Definition	Source
Number of publications	Quantum Computing	ASPI Technology Tracker
Publications per 1 million population		
Number of leading publications		
Leading publications per 1 million population		
H-Index		
Global production market share	Both sectors C26 and C62_63	OECD Trade in Value added
Count of leading global R&D businesses	Both Industry filters 'Software & computer services' and 'Technology hardware & equipment'	EU R&D Investment scoreboard
Number of patents filed	Quantum Computing	Quantum Consortium Patent Trends Update Figure 3
Patents filed per 1 million population		
Value of start-up and scale-up funding (USD)	Industries filter contains 'Quantum Computing'	Crunchbase
Start-up and scale-up funding as a % of GDP		
Global exports market share	Both sectors C26 and C62_63	OECD Trade in Value added
Exports % for the technology as a % of country exports		
Domestic value added embodied in foreign exports as a % of gross exports		
Global intermediate goods export market share		

Table 5 Biotechnologies

Indicator	Definition	Source
Number of publications	Synthetic biology	ASPI Technology Tracker
Publications per 1 million population		
Number of leading publications		
Leading publications per 1 million population		
H-Index		
Global production market share	Sector C21 Pharmaceuticals, medicinal chemical and botanical products	OECD Trade in Value added
Count of leading global R&D businesses	Industry filter 'Pharmaceuticals & Biotechnology'	EU R&D Investment scoreboard
Number of patents filed	Biotechnology	OECD
Patents filed per 1 million population		
Value of start-up and scale-up funding (USD)	Industries filter 'Biotechnology'	Crunchbase
Start-up and scale-up funding as a % of GDP		
Global exports market share	Sector C21 Pharmaceuticals, medicinal chemical and botanical products	OECD Trade in Value added
Exports % for the technology as a % of country exports		
Domestic value added embodied in foreign exports as a % of gross exports		
Global intermediate goods export market share		

Table 6 Advanced Connectivity

Indicator	Definition	Source
Number of publications	Advanced radiofrequency communications	ASPI Technology Tracker
Publications per 1 million population		
Number of leading publications		
Leading publications per 1 million population		
H-Index		
Global production market share	Sector J61 Telecommunications	OECD Trade in Value added
Count of leading global R&D businesses	Industry filter 'Mobile telecommunications' and 'Fixed Line telecommunications', plus manual identification of other relevant businesses	EU R&D Investment scoreboard
Number of patents filed	Telecommunications	OECD
Patents filed per 1 million population		
Value of start-up and scale-up funding (USD)	Industries filter 'Telecommunications' and 'internet services'	Crunchbase
Start-up and scale-up funding as a % of GDP		
Global exports market share	Sector J61 Telecommunications	OECD Trade in Value added
Exports % for the technology as a % of country exports		
Domestic value added embodied in foreign exports as a % of gross exports		
Global intermediate goods export market share		

Table 7 Energy technologies

Indicator	Definition	Source
Number of publications	Average of Photovoltaic, Biofuels, Electric Batteries	ASPI Technology Tracker
Publications per 1 million population		
Number of leading publications		
Leading publications per 1 million population		
H-Index		
Global production market share	Sector D Electricity, gas, steam and air conditioning supply	OECD Trade in Value added
Count of leading global R&D businesses	Industries filter 'Alternative energy', plus manual identification of other relevant businesses	EU R&D Investment scoreboard
Number of patents filed	Climate change mitigation technologies related to energy generation, transmission or distribution	[OECD]()
Patents filed per 1 million population		
Value of start-up and scale-up funding (USD)	Industries filter 'Renewable Energy'	Crunchbase
Start-up and scale-up funding as a % of GDP		
Global exports market share	Product code 854140, 854142, 854143, 850231 (see footnote)[59]	Comtrade
Exports % for the technology as a % of country exports		Comtrade, OECD Trade in Value added (for total country exports)

59 854140 Electrical apparatus; photosensitive, including photovoltaic cells, 854142 Electrical apparatus; photosensitive semiconductor devices, photovoltaic cells not assembled in modules or made up into panels, 854143 Electrical apparatus; photosensitive semiconductor devices, photovoltaic cells assembled in modules or made up into panels, 850231 Electric generating sets; wind-powered.

Indicator	Definition	Source
Domestic value added embodied in foreign exports as a % of gross exports	Sector D Electricity, gas, steam and air conditioning supply	OECD Trade in Value added
Global intermediate goods export market share	Sector D Electricity, gas, steam and air conditioning supply	

Table 8 Additive Manufacturing

Indicator	Definition	Source
Number of publications	Additive manufacturing	ASPI Technology Tracker
Publications per 1 million population		
Number of leading publications		
Leading publications per 1 million population		
H-Index		
Global production market share	Sector C28: Machinery and equipment n.e.c	OECD Trade in Value added
Count of leading global R&D businesses	Industries filter 'Construction & Materials', plus manual identification of other relevant businesses	EU R&D Investment scoreboard
Number of patents filed	3D printing technologies	IAM
Patents filed per 1 million population		
Value of start-up and scale-up funding (USD)	Industry filter '3D printing'	Crunchbase
Start-up and scale-up funding as a % of GDP		
Global exports market share		

Indicator	Definition	Source
Exports % for the technology as a % of country exports	Sector C28: Machinery and equipment n.e.c	OECD Trade in Value added
Domestic value added embodied in foreign exports as a % of gross exports		
Global intermediate goods export market share		

Table 9 Space technologies

Indicator	Definition	Source
Number of publications	Small satellites	ASPI Technology Tracker
Publications per 1 million population		
Number of leading publications		
Leading publications per 1 million population		
H-Index		
Global production market share	Sector C30 Other transport equipment[60]	OECD Trade in Value added
Count of leading global R&D businesses	Industry filter 'Aerospace & Defence'	EU R&D Investment scoreboard
Number of patents filed	Cosmonautic patents	D Young & Co
Patents filed per 1 million population		
Value of start-up and scale-up funding (USD)	Industries filter 'Aerospace'	Crunchbase

60 Note that OECD sector code C30 for Other transport equipment includes Space transport.

Indicator	Definition	Source
Start-up and scale-up funding as a % of GDP		
Global exports market share	Product code 88: Aircraft, spacecraft, and parts thereof	Comtrade
Exports % for the technology as a % of country exports	Product code 88: Aircraft, spacecraft, and parts thereof	Comtrade, OECD Trade in Value added (for total country exports)
Domestic value added embodied in foreign exports as a % of gross exports	Sector C30 Other transport equipment	OECD Trade in Value added
Global intermediate goods export market share		

Time frame of available data

Data was collected from the latest available time periods.

- Scientific indicators are all based on academic papers published between 2018 and 2022, collected from ASPI Technology tracker.
- Industry indicators are collected for the latest time period available, which varies as follows:
  - Startup/scaleup funding data is cumulative to date as reported on Crunchbase
  - Value added and export data is collected for the latest available year, typically 2020 when collected from OECD Trade in Value Added. Where data is collected from Comtrade (e.g. for semiconductors), data is collected for 2023.
  - Data on the largest business R&D spenders is for 2023
  - For patent applications, the latest year available is typically 2020 or 2021.

Calculations worked example

Section 2.3.1 outlines our approach to calculating 'proximity to global best practice' values for the EU, based on the data collected across indicators. This annex describes each step of the calculations in further detail.

We describe in this section the process followed to obtain the results used for the different indicators. While there might be specific nuances in this process across indicators, the construction of most of them followed these steps:

- We downloaded data for the EU as whole, and different EU and non-EU countries on the different sources used (e.g., ASPI, OECD, Crunchbase).
  - In cases in which data at the EU level was not available, we calculated its value by averaging the values of the top 5 EU countries in that list.
- For each indicator, we divided the value for the EU, US, China by global leading country for that indicator to get a measure of proximity to global frontier.
- To determine the value of the Scientific Performance and Industry Strength "pillars", we averaged the proximity to global frontier across each indicator within the pillar.
- Finally, to calculate the overall score for each technology we averaged the values of Scientific Performance and Industry Strength, giving 33% and 66% weights, respectively.

Tables 2 and 3 present a worked example of EU's scientific and industry 'distance to global best practice'. In the case of Scientific Indicators , our approach was:

- We downloaded data on the EU, and top EU and non-EU countries on the different indicators (number of publications, number of leading publications, and H-index) number of publications from ASPI's Critical Technology Tracker[61].
- We divided the number of total and leading publications by the countries' population to get the measures on publications per million people we include in the report.
- We calculate the quotient of the EU's value and the one of the leading country in the respective indicator. In Tables 2 and 3, this is reflected in the column "EU proximity to global best practice index".
- We average the results of these quotients to get the overall proximity to global best practice in scientific performance.

A similar process is followed for the different industry performance indicators. Finally, the overall proximity to frontier is obtained by a weighted average of scientific and industry performance, given a 33% weight to the former and 66% to the latter. In the case of advanced semiconductors, the 67% in scientific performance (from Table 2) and 35% in industry strength (from Table 3) results in a weighted average of 45%.

[61] https://techtracker.aspi.org.au/

Table 10 Example of calculations done to assess Scientific performance proximity to global best practice – Advanced semiconductors

Indicator	EU value (A)	Leading country	Leading country's value (B)	EU proximity to global best practice index (A/B)
Number of publications	1441	EU	1441	100%
Publications per 1 million population	4.5	Taiwan	12.3	36%
Number of leading publications	142	US	175	81%
Leading publications per 1 million population	0.64	Taiwan	0.83	77%
H-Index	13.4	US	34.0	39%
Average of proximity scores				67%

Source: Frontier Economics

Table 11 Example of calculations done to assess Industry strength proximity to global best practice – Advanced semiconductors

Indicator	EU value (A)	Leading country	Leading country's value (B)	EU proximity to global best practice index (A/B)
Global production market share	10%	China	29%	35%
Count of leading global R&D businesses	15	US	67	22%
Number of patents filed	688	Korea	3644.4	19%
Patents filed per 1 million population	3.4	Korea	70.12919058	10%
Value of start-up and scale-up funding (USD)	3,670 (million USD)	United States	17,044 (million USD)	48%

Start-up and scale-up funding as a % of GDP	0.063%	Canada	0.068%	92%
Global exports market share	13%	China	26%	52%
Exports % for the technology as a % of country exports	3%	Other Asia (Taiwan)	34%	14%
Domestic value added embodied in foreign exports as a % of gross exports	1%	Taiwan	10%	14%
Global intermediate goods export market share	18%	China	47%	39%
			Average scores	**35%**

Source: Frontier Economics

Other methodological decisions

Approach to outlier values

The data we collected includes several cases where the highest value of an indicator for a given technology is noticeably well above the second highest across all countries (e.g. the highest values was around ten times the second highest). This includes, for example, several indicators calculated on a per capita basis, where countries with a small population such as Singapore often have very high values due to a low denominator. In these cases, using our baseline approach to obtaining proximity to global best practice scores yielded much lower scores for most countries compared to other indicators and technologies and likely underestimated the proximity to global frontier of the countries that were not the global leader on that particular indicator. Therefore, to mitigate this, in these cases we calculate a country A's proximity to global best practice score on indicator X (e.g. patent applications per million people) as the value of the indicator for that country A, divided by the average of the three highest values across all countries in our sample.

Approach to weighting

The construction of the proximity to global best practice scores involves an explicit weighting of the two pillars (scientific performance and industry performance), and a choice to weigh all indicators within a pillar equally. We assign the industry performance pillar a greater weight compared to the scientific performance pillar to reflect the focus of this report on the EU and other countries' current ability to generate value added in the technology areas of interest, rather than on scientific research per se. The exact choice of weight (2/3 for scientific performance and 1/3 for industry performance) is a matter of judgement, but small changes in this weighting would not substantially alter the results presented in this report.

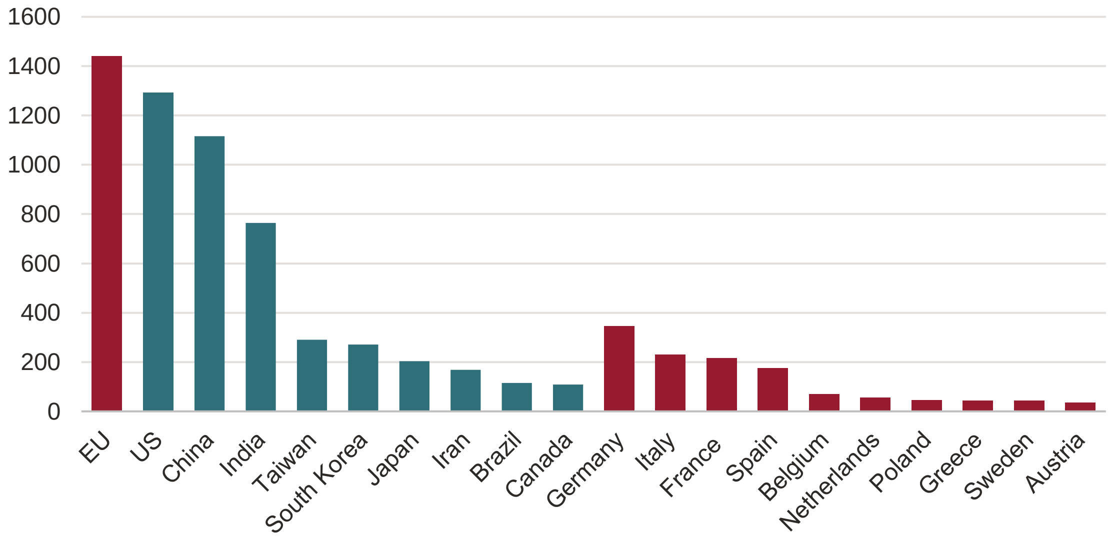
Within each pillar, we do not have any strong theoretical or empirical reason for assigning a greater or smaller weight to any of the indicators. Therefore, we use equal weighting across all indicators within each pillar.

A.2 Further results

This section includes charts representing the values of each indicator used in our analysis, ordered by technology. The countries included in each chart vary between different indicators due to variation in data availability.

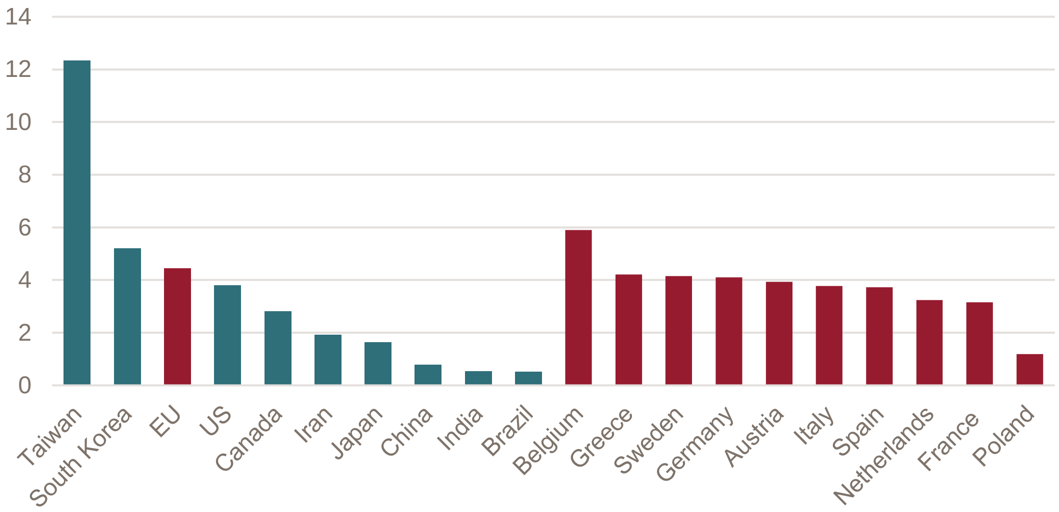
Advanced semiconductors

Figure Number of publications for advanced semiconductors



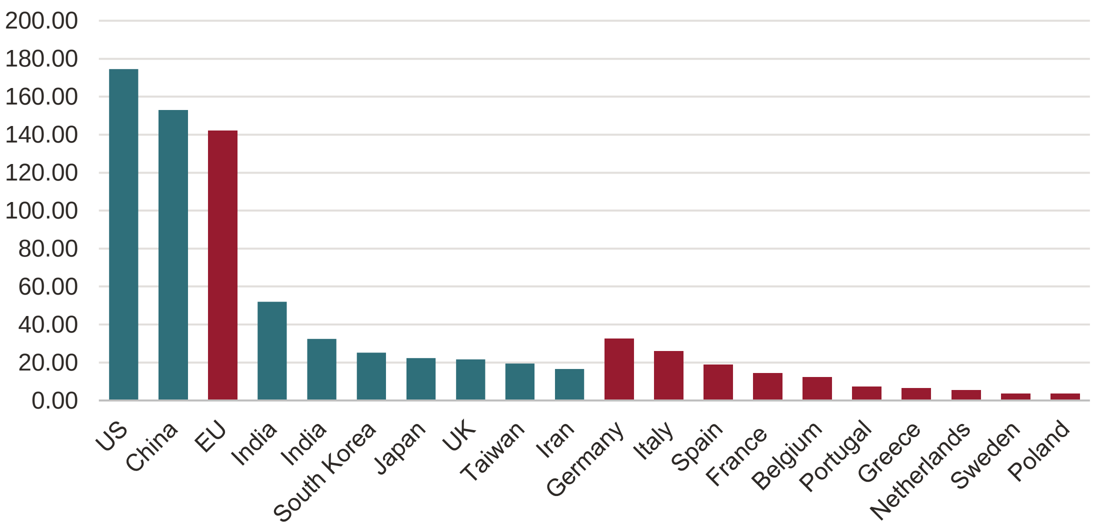
Source: ASPI

Figure Number of publications per million people for advanced semiconductors



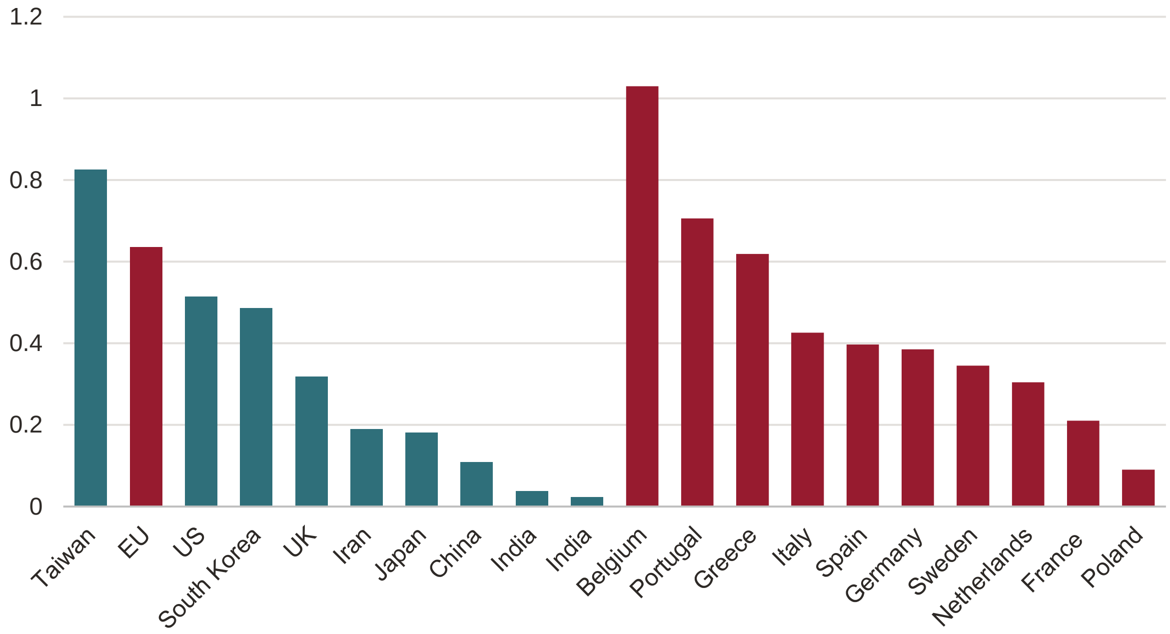
Source: ASPI

Figure Number of leading publications for advanced semiconductors



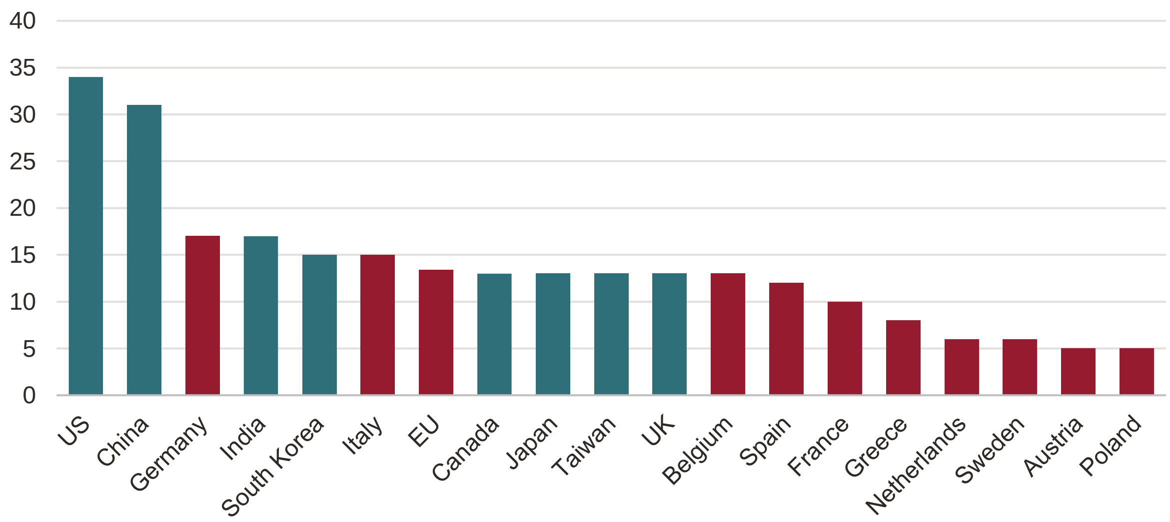
Source: ASPI

Figure Number of leading publications per million people for advanced semiconductors



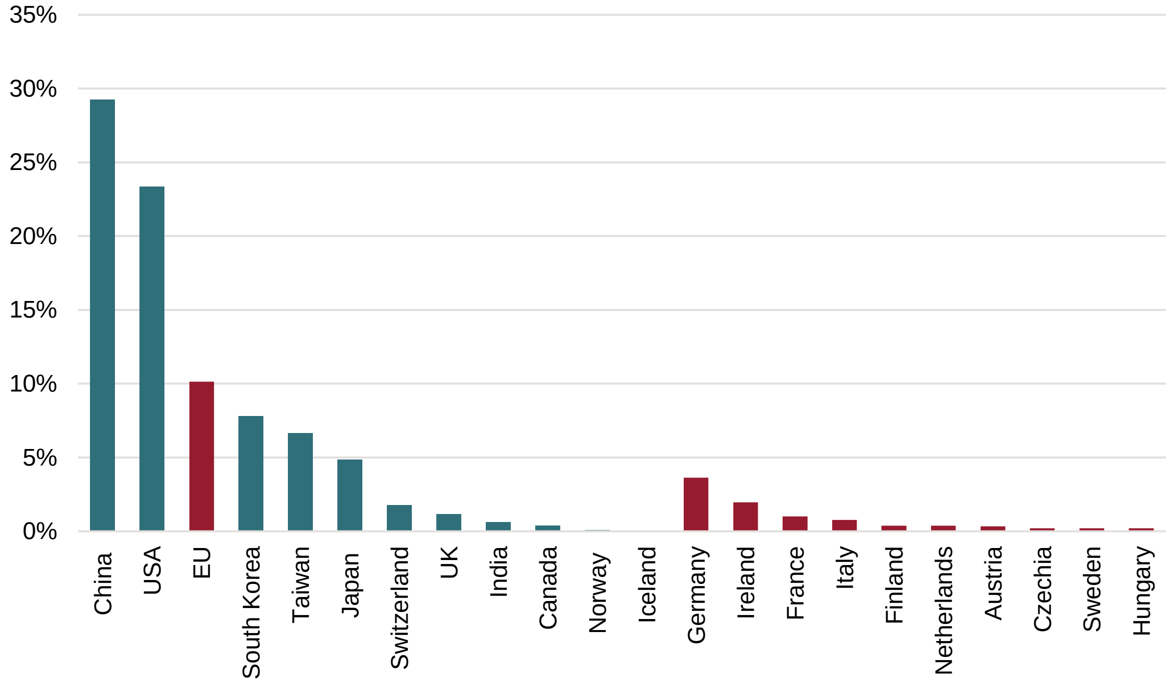
Source: ASPI

Figure H-index for advanced semiconductors



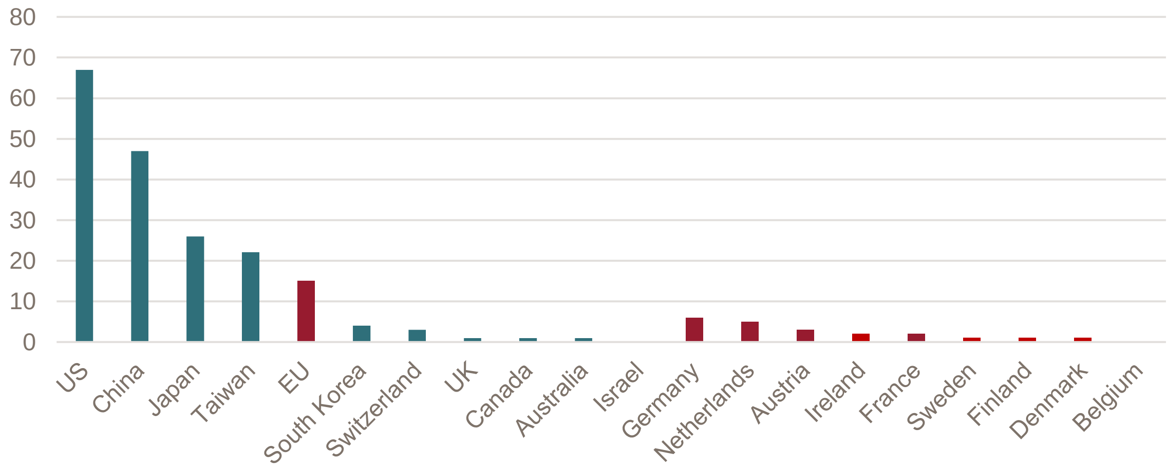
Source: ASPI

Figure Market share of global value added for advanced semiconductors



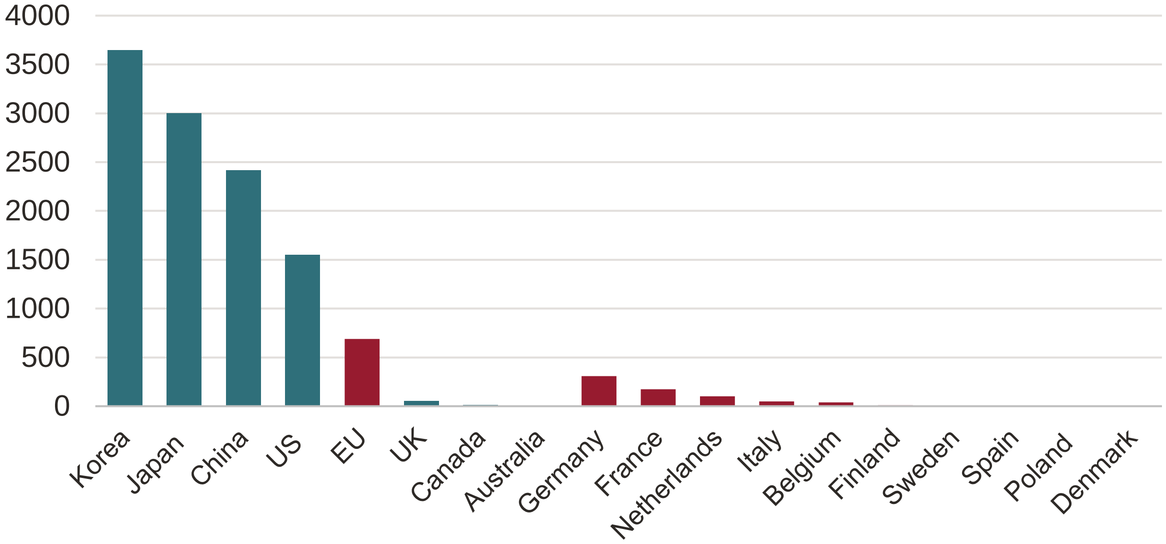
Source: OECD

Figure Count of leading R&D businesses for advanced semiconductors



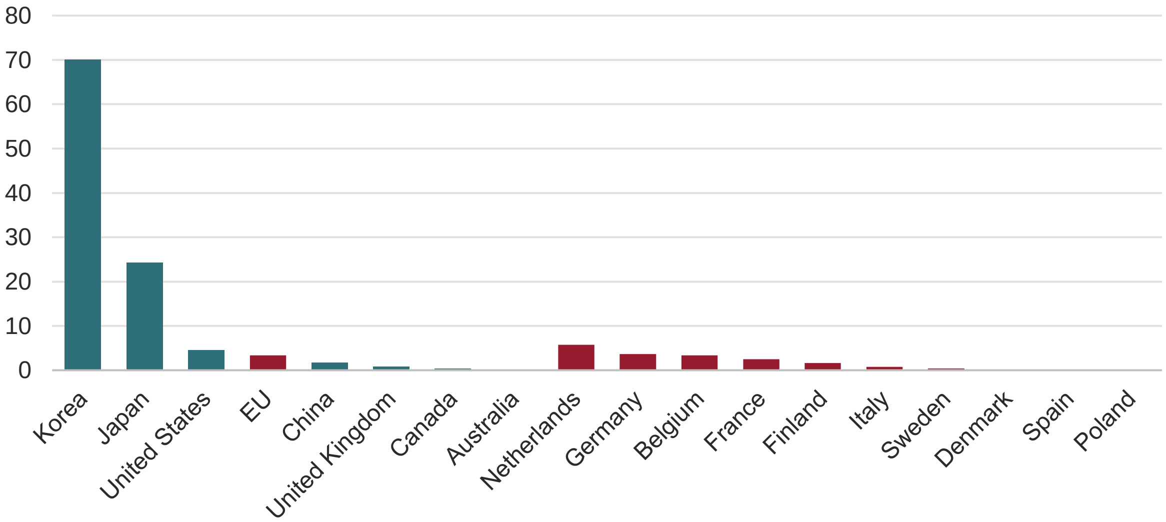
Source: European Commission - European innovation scoreboard.

Figure Number of patents filed for advanced semiconductors



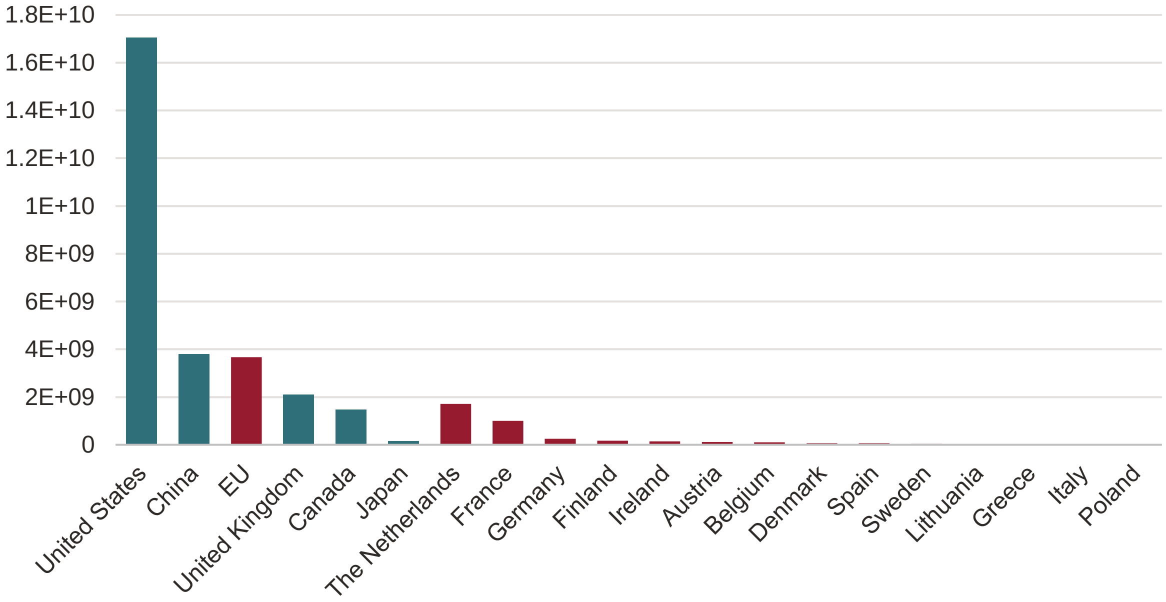
Source: OECD

Figure Number of patents filed per million people for advanced semiconductors



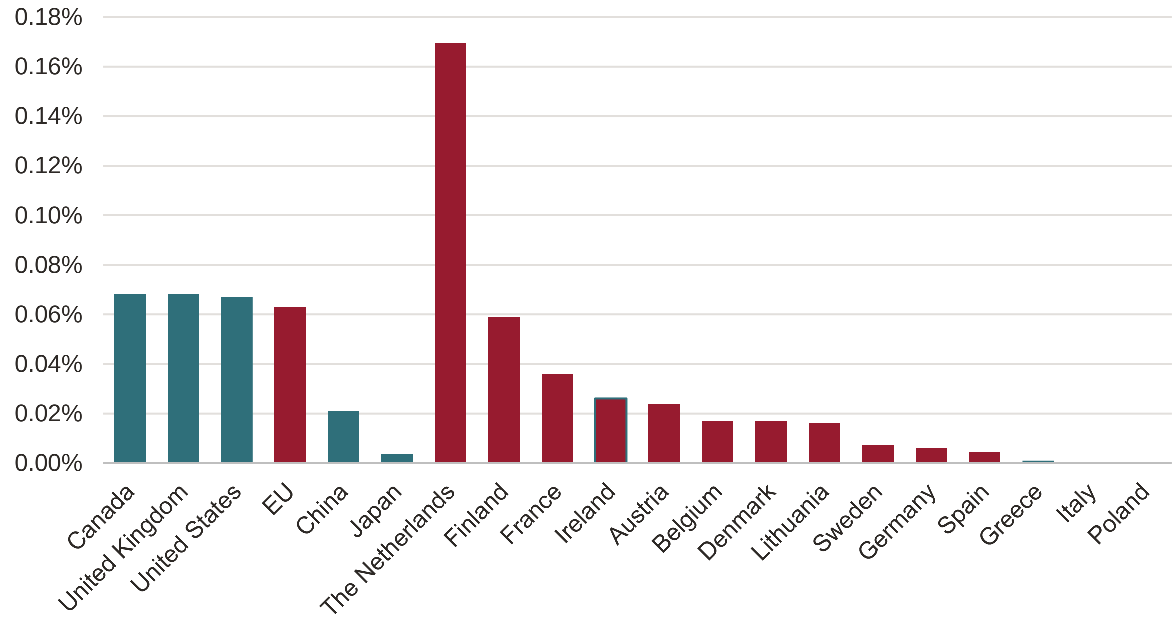
Source: OECD

Figure **Value of start-up and scale-up funding (USD) for advanced semiconductors**



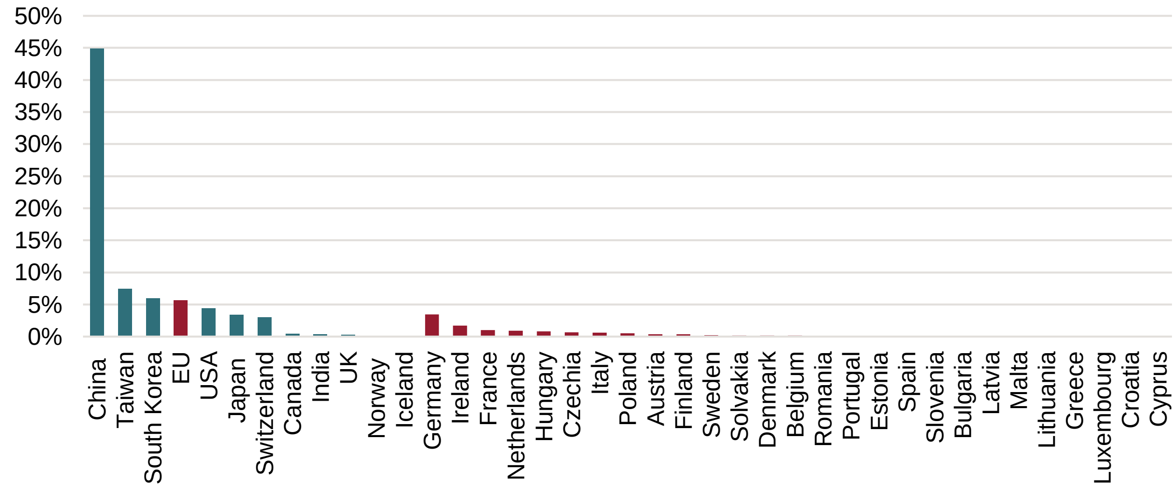
Source: Crunchbase

Figure Start-up and scale-up funding as a share of GDP for advanced semiconductors



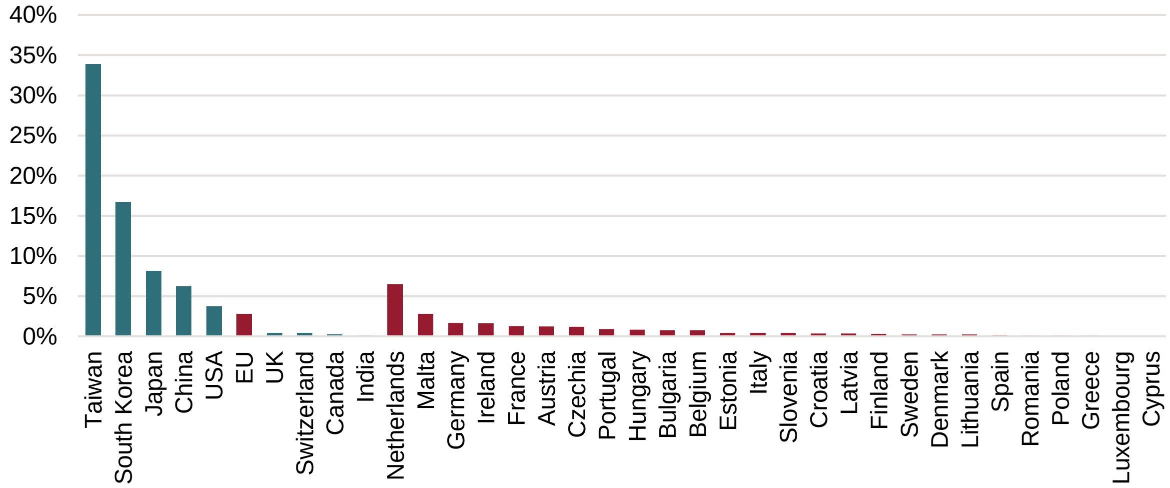
Source: Crunchbase

Figure Global exports market share for advanced semiconductors



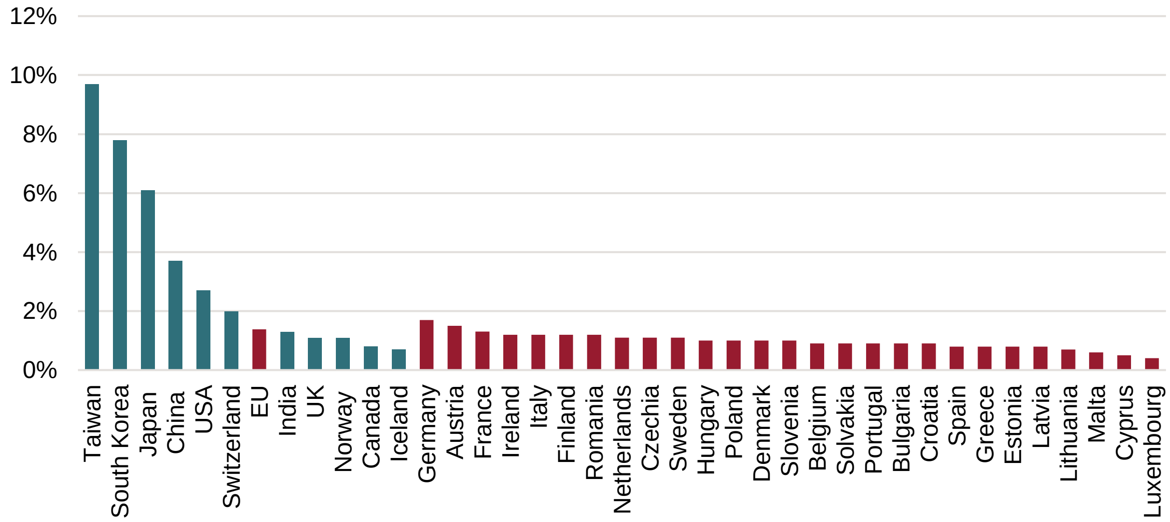
Source: Comtrade

Figure Exports share as a share of country exports for advanced semiconductors



Source: Comtrade, OECD

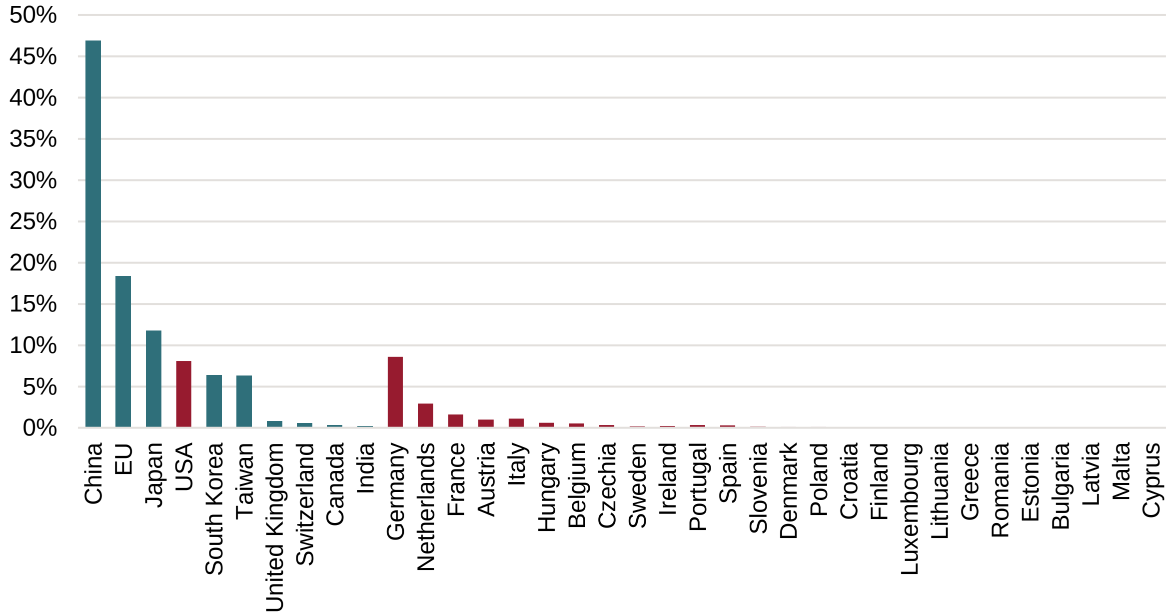
Figure Domestic value added embodied in foreign exports as a share of gross exports for advanced semiconductors



Source: OECD

Note: The data for this indicator is only available up to one decimal point e.g. 0.1%, 0.2%, 0.3%...

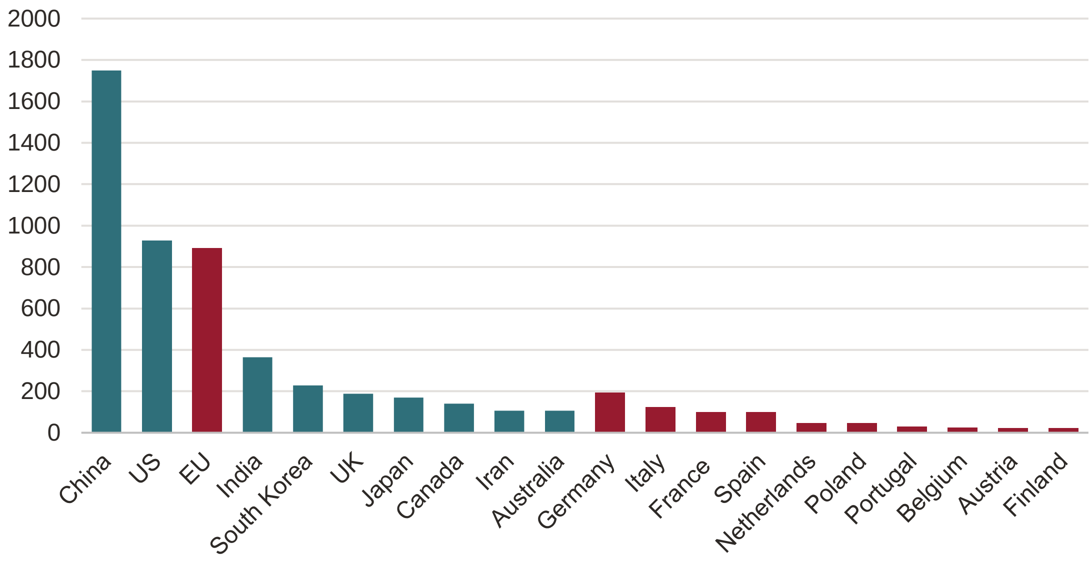
Figure **Global intermediate goods exports market share for advanced semiconductors**



Source: OECD

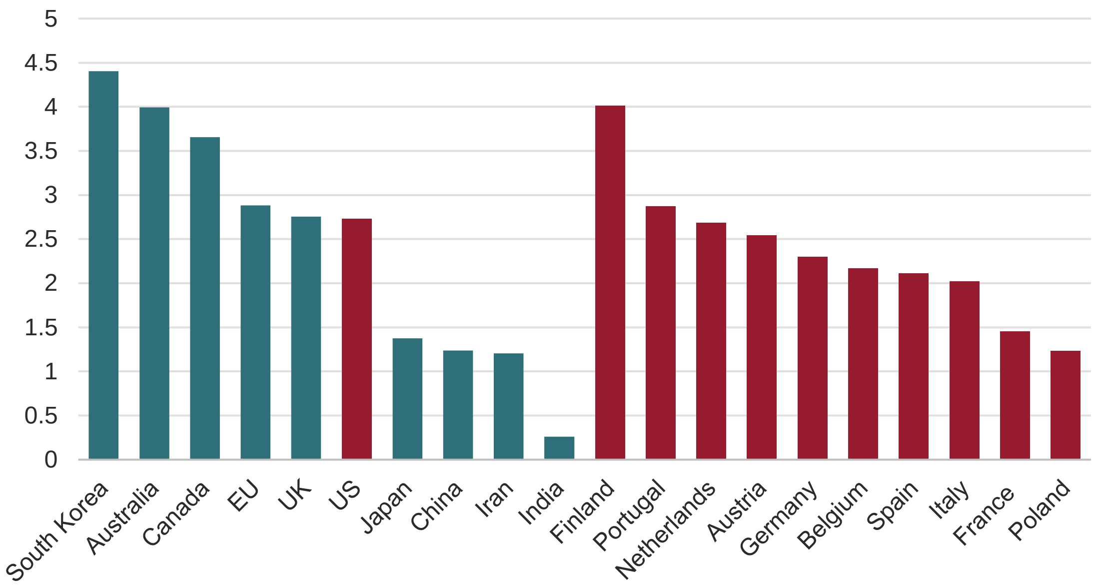
Artificial Intelligence

Figure Number of publications for AI



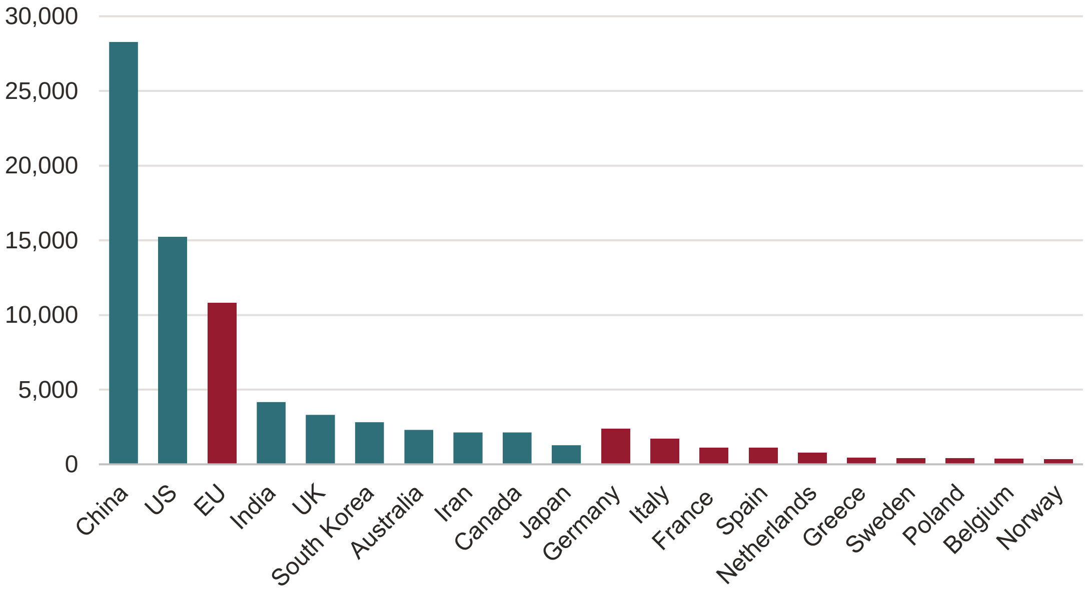
Source: ASPI

Figure Number of publications per million people for AI



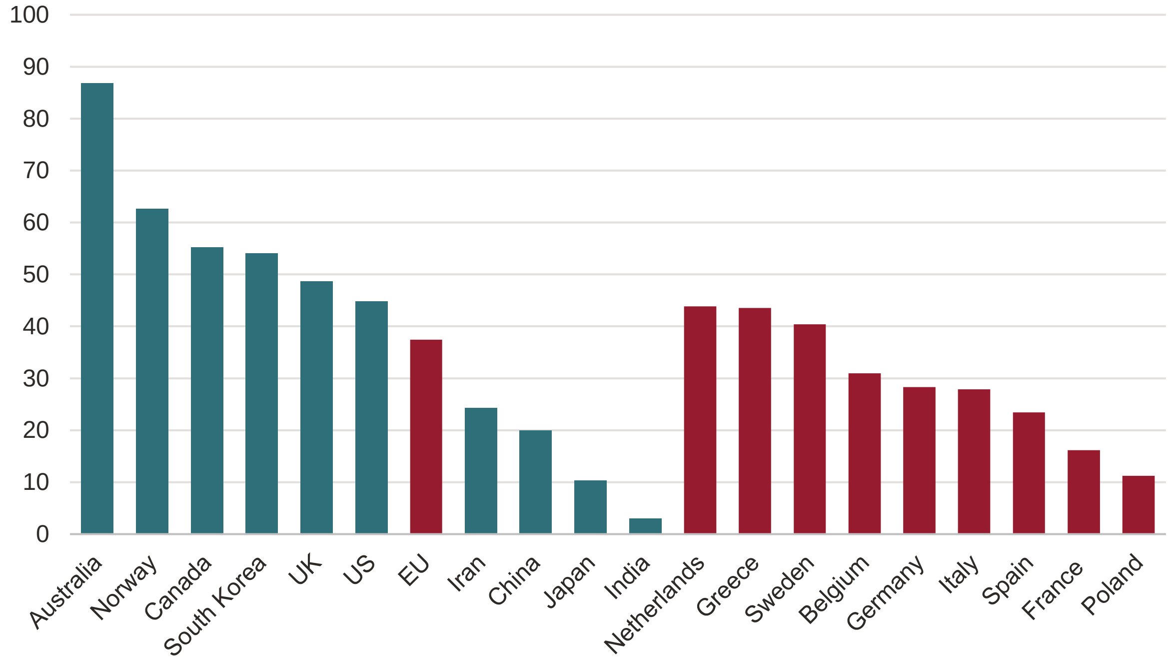
Source: ASPI

Figure Number of leading publications for AI



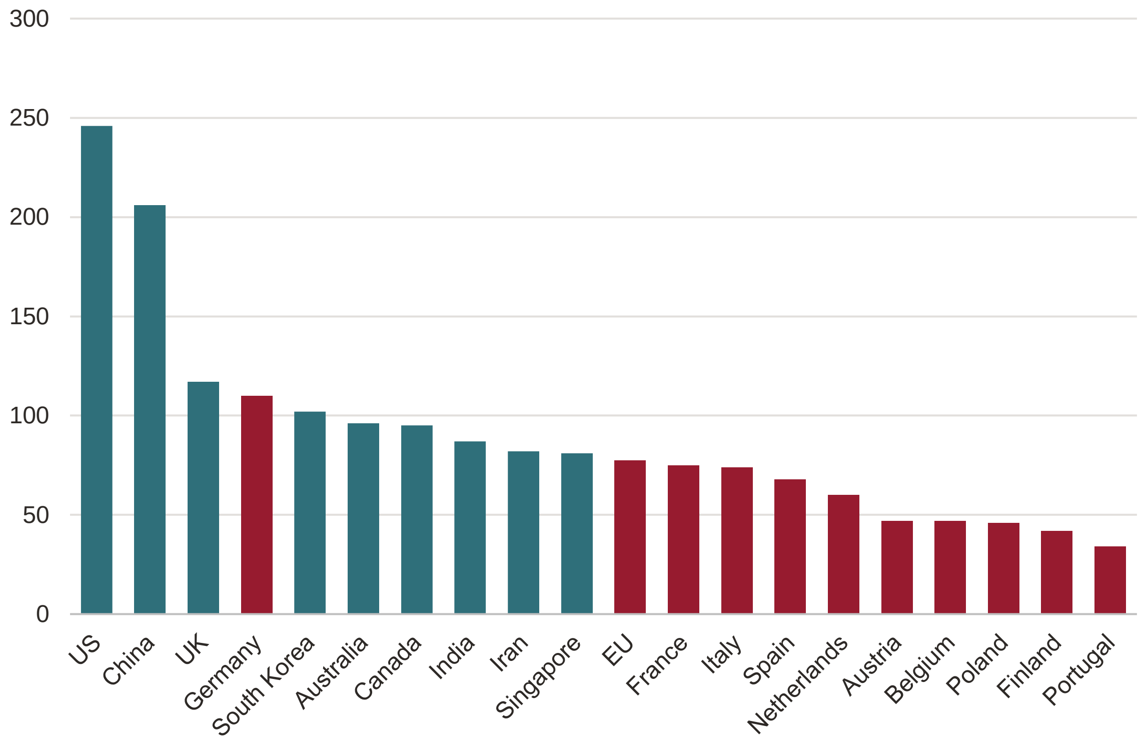
Source: ASPI

Figure Number of leading publications per million people for AI



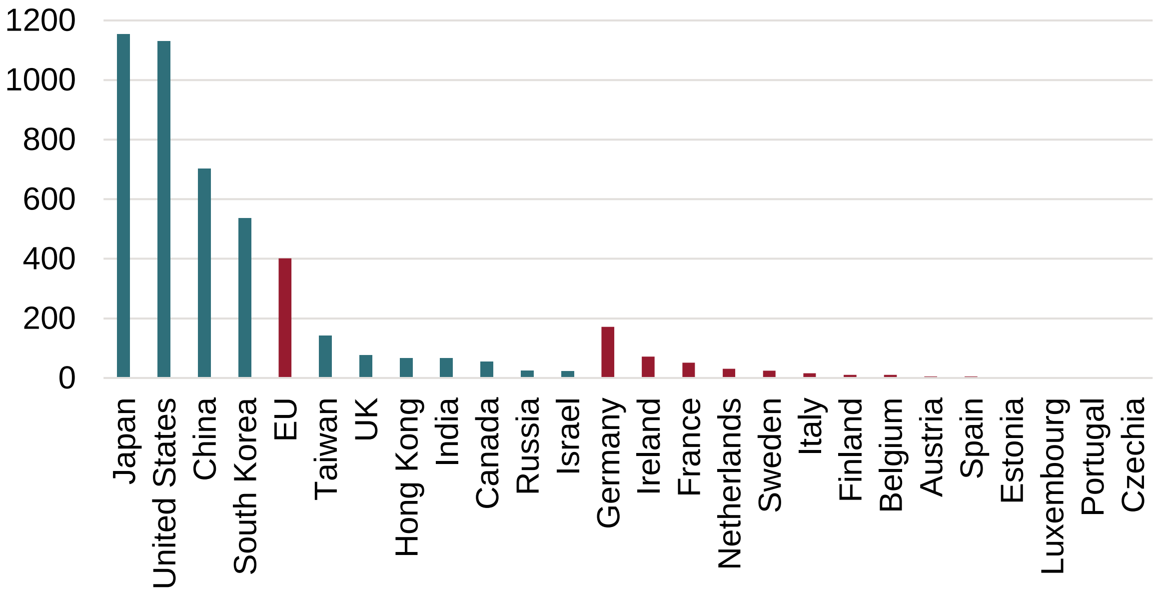
Source: ASPI

Figure H-index for AI



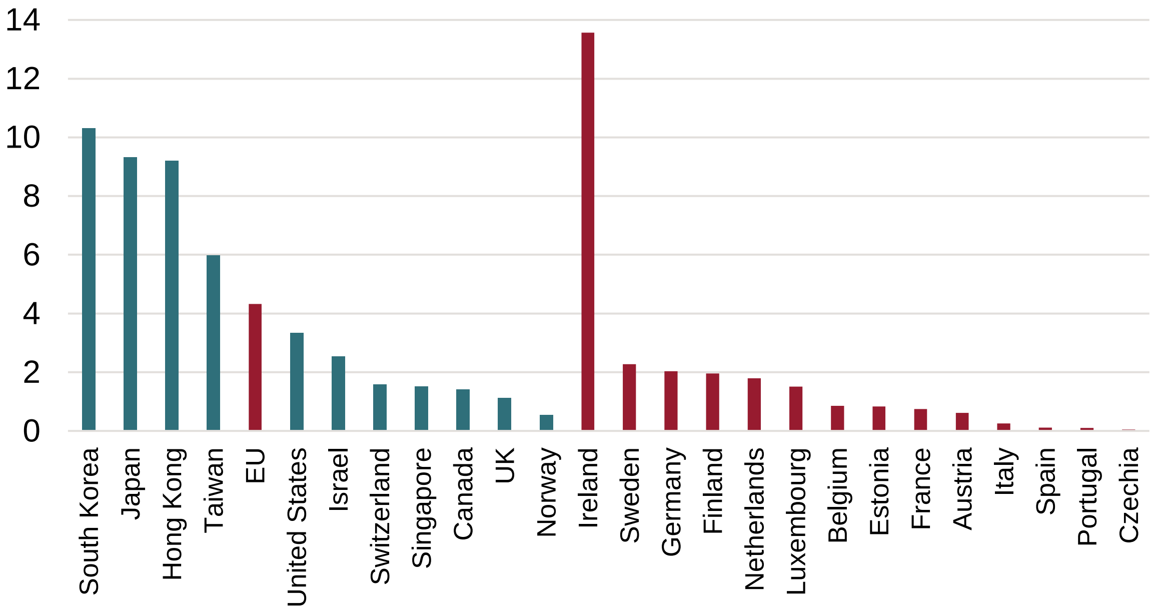
Source: ASPI

Figure Number of patents filed for AI



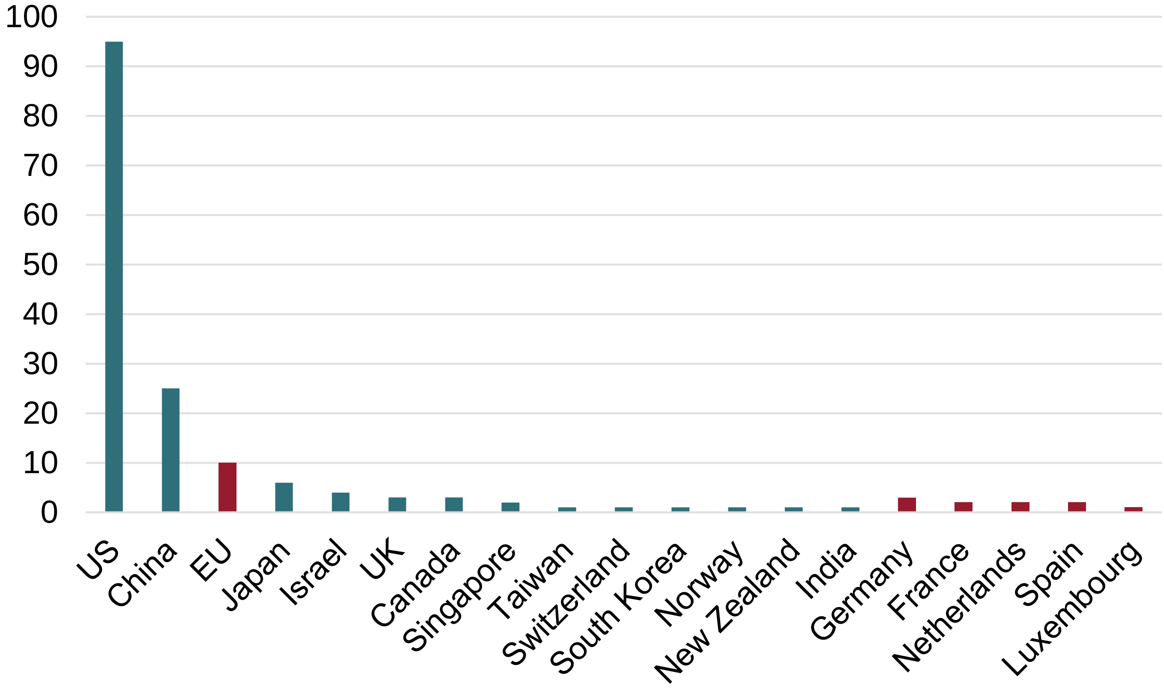
Source: OECD

Figure Number of patents filed per million people for AI



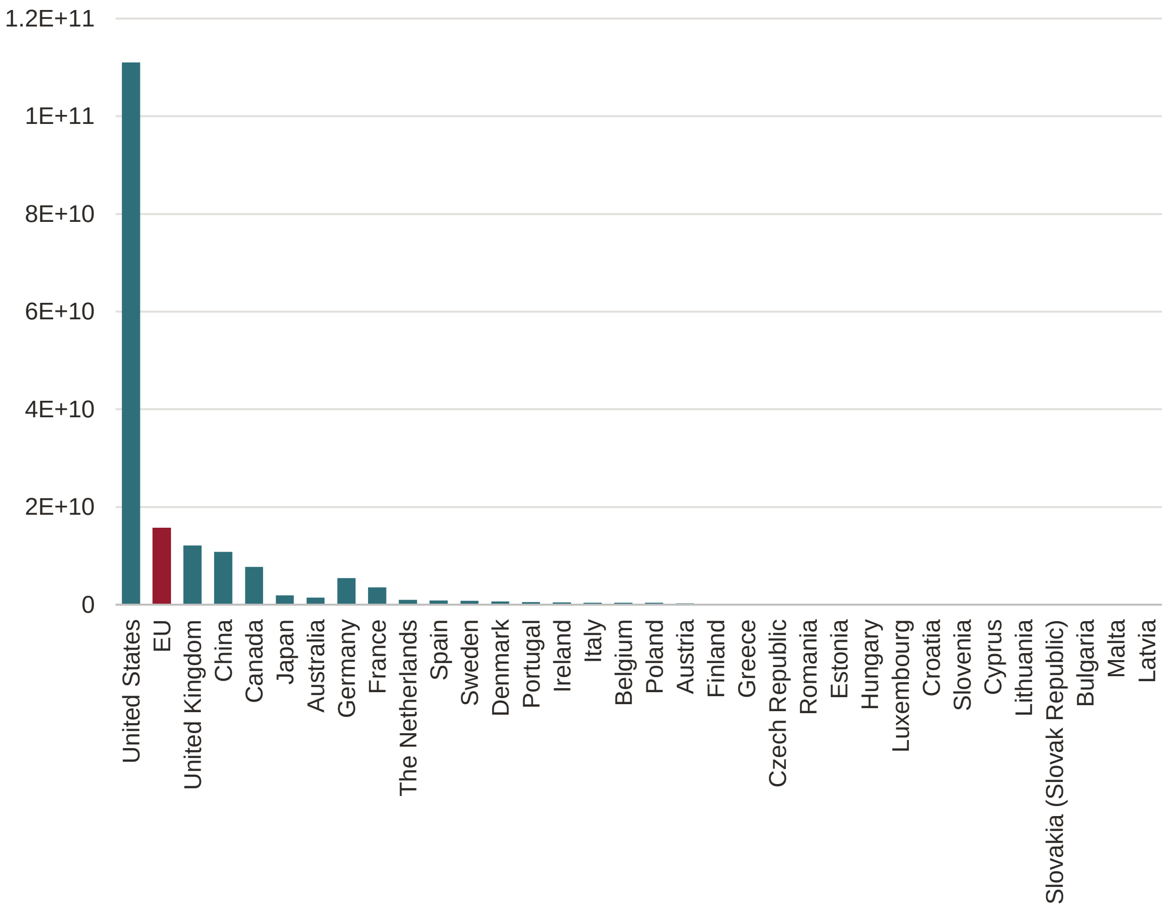
Source: OECD

Figure Count of leading global R&D businesses for AI



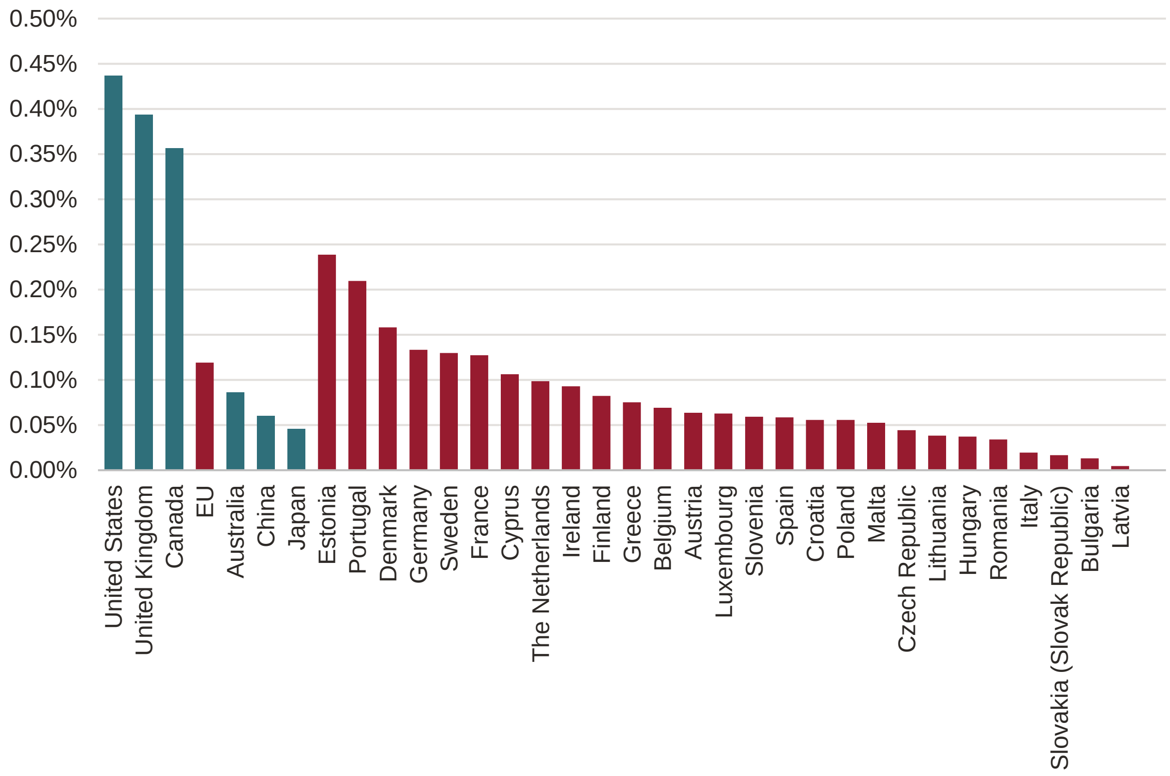
Source: European Innovation Scoreboard

Figure Value of start-up and scale-up funding for AI (USD)



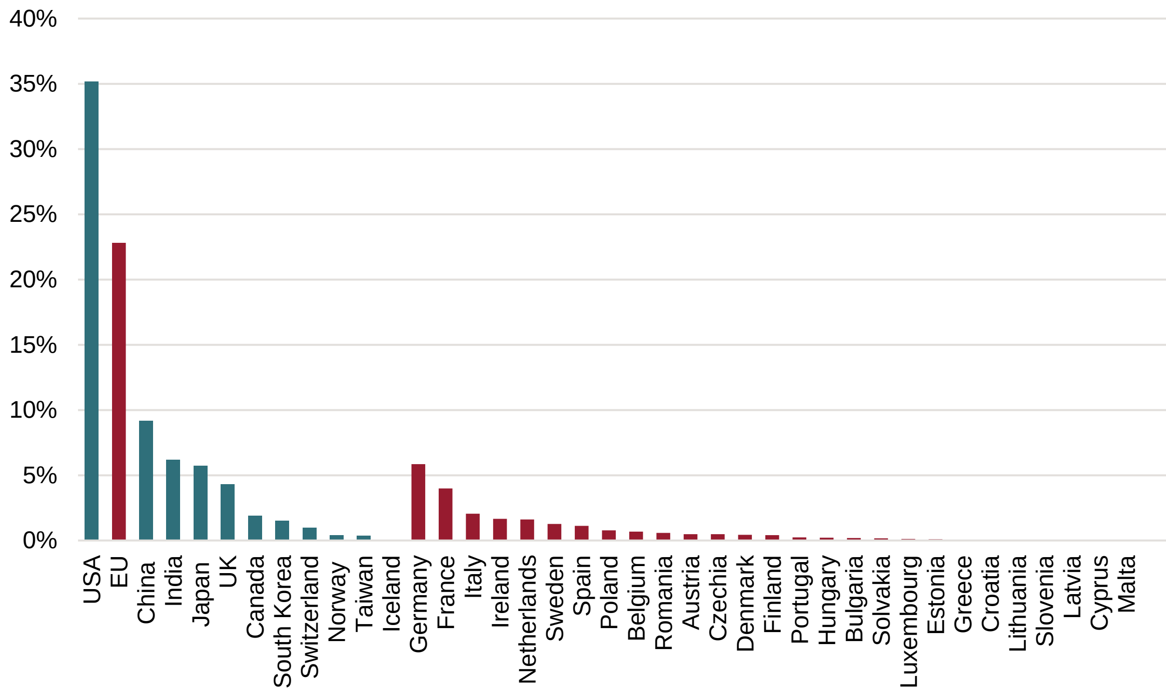
Source: Crunchbase

Figure Value of start-up and scale-up funding over GDP for AI



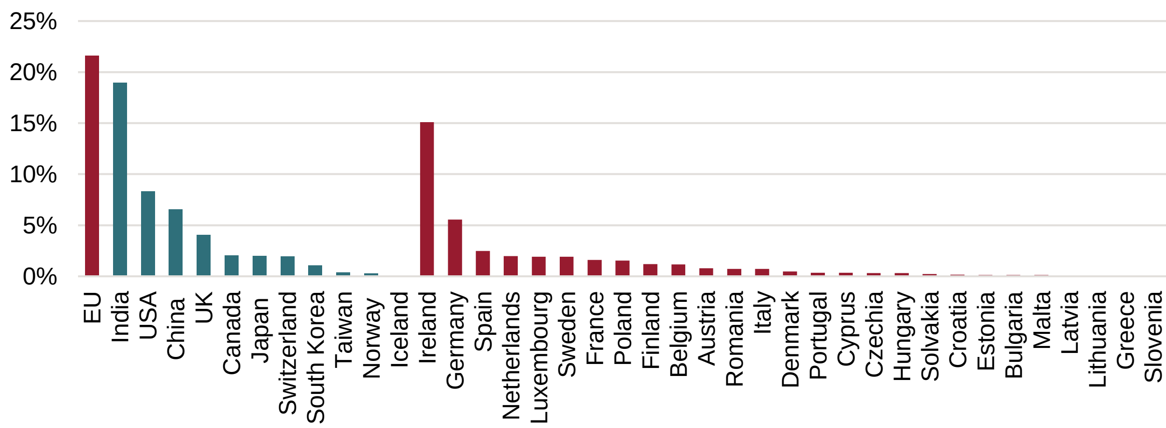
Source: Crunchbase

Figure Market share of global value added for Artificial Intelligence



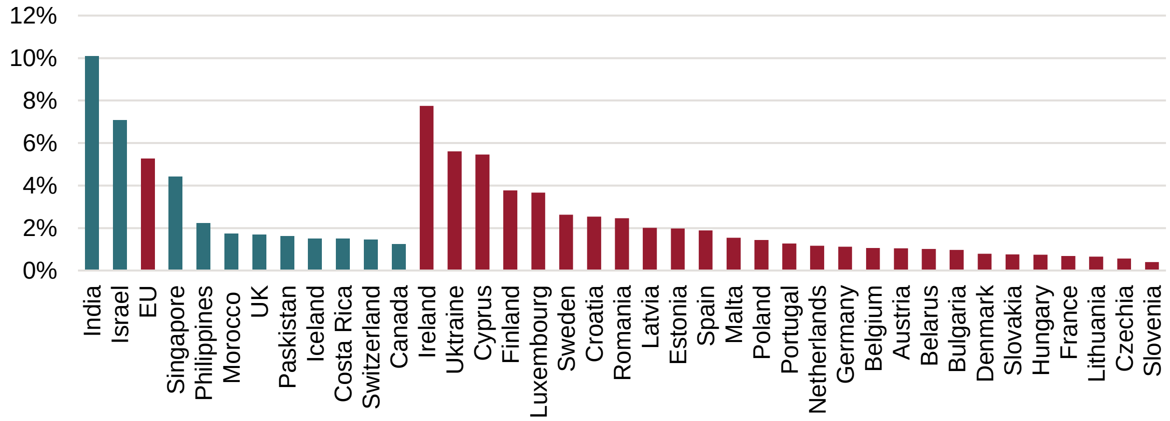
Source: OECD

Figure Global exports market share for Artificial Intelligence



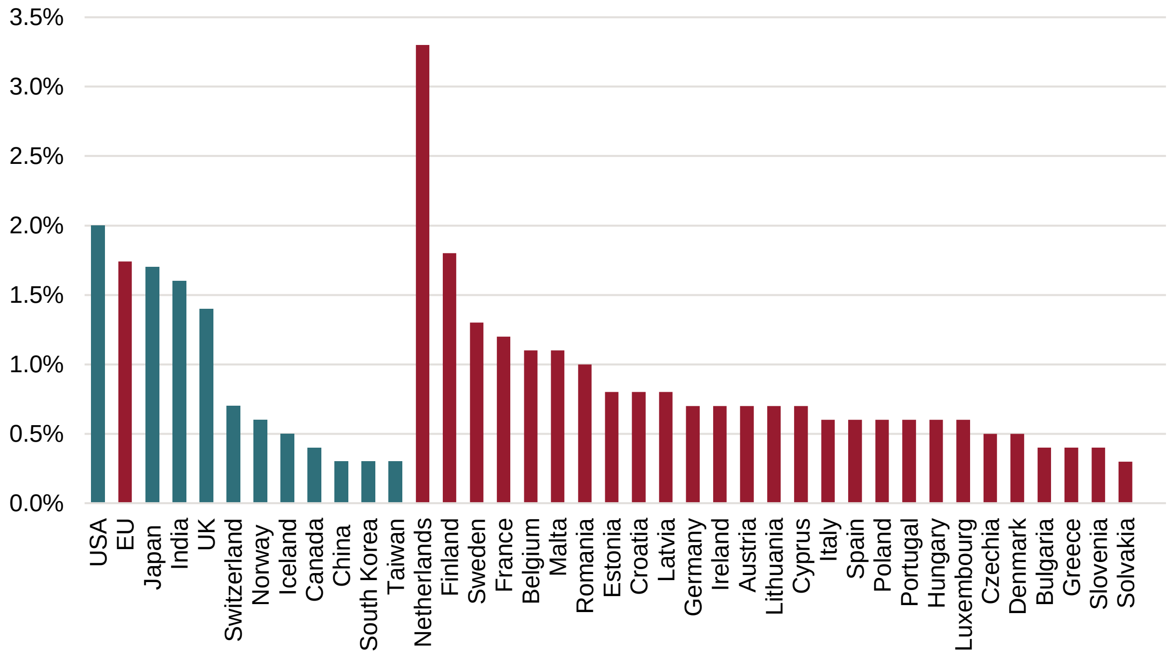
Source: OECD

Figure Exports share as a share of country exports for Artificial Intelligence



Source: OECD

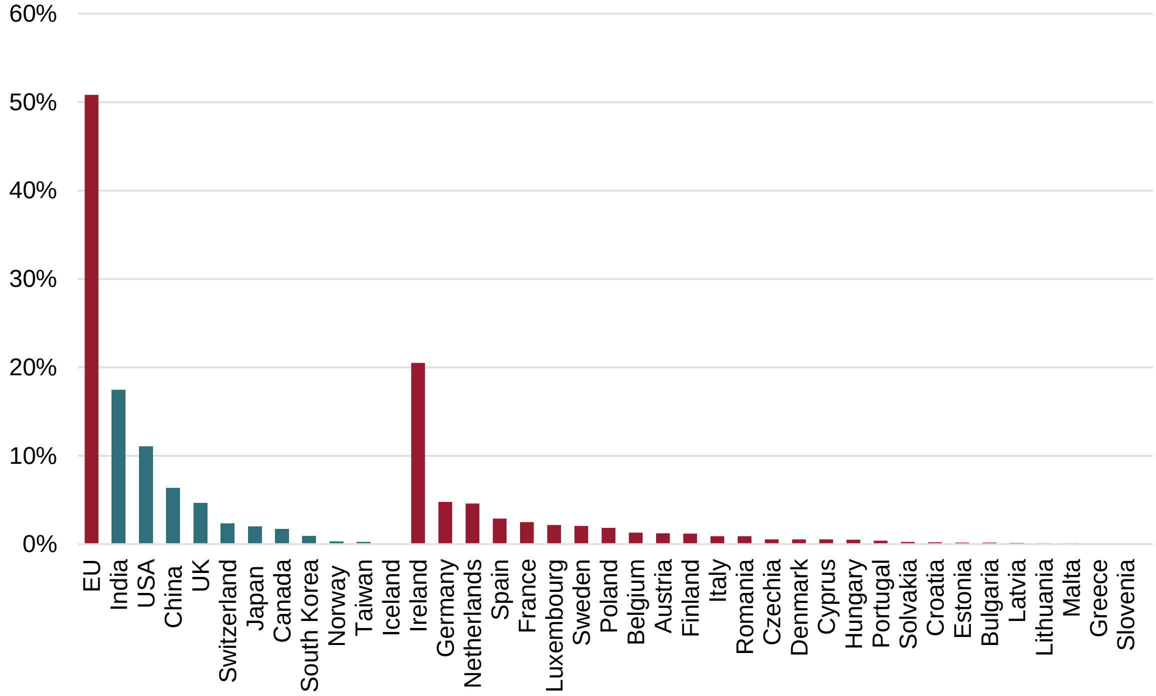
Figure Domestic value added embodied in foreign exports as a share of gross exports for Artificial Intelligence



Source: OECD

Note: The data for this indicator is only available up to one decimal point e.g. 0.1%, 0.2%, 0.3%...

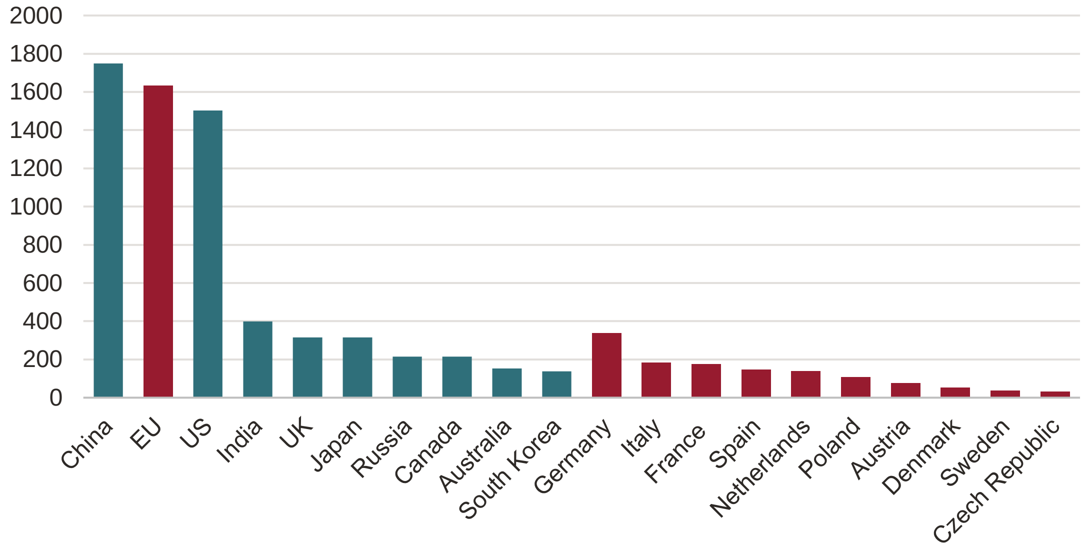
Figure Global Intermediate goods exports market share for Artificial Intelligence



Source: OECD

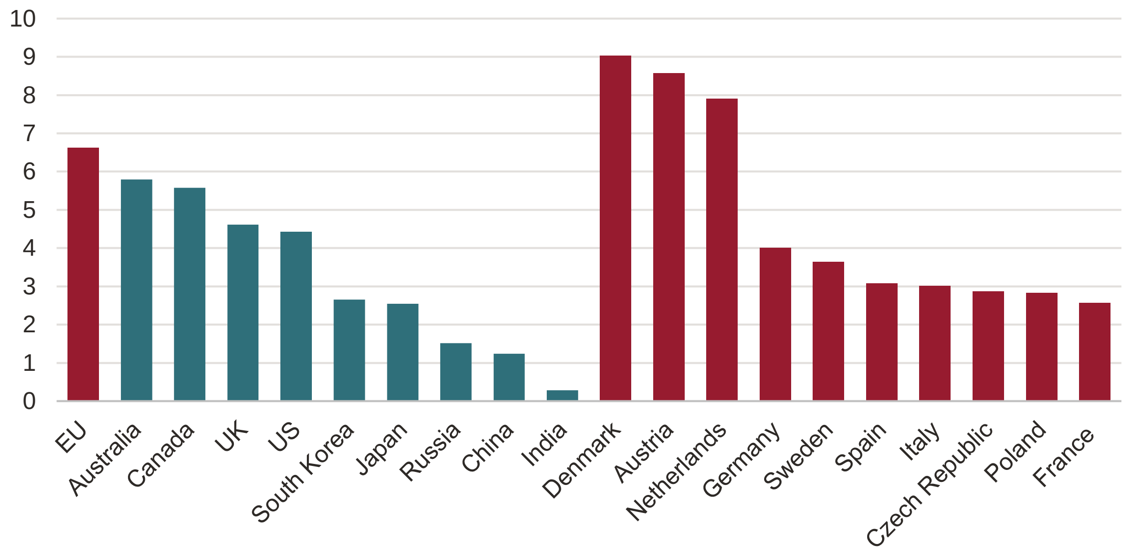
Quantum computing

Figure Number of publications for Quantum computing



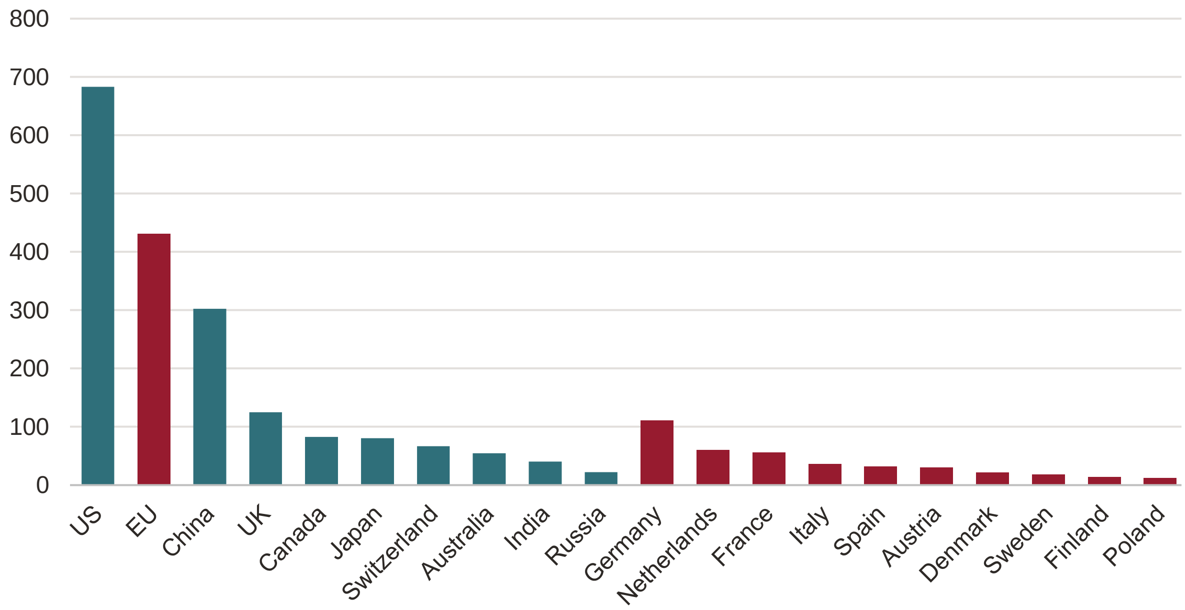
Source: ASPI

Figure Number of publications per million people for Quantum computing



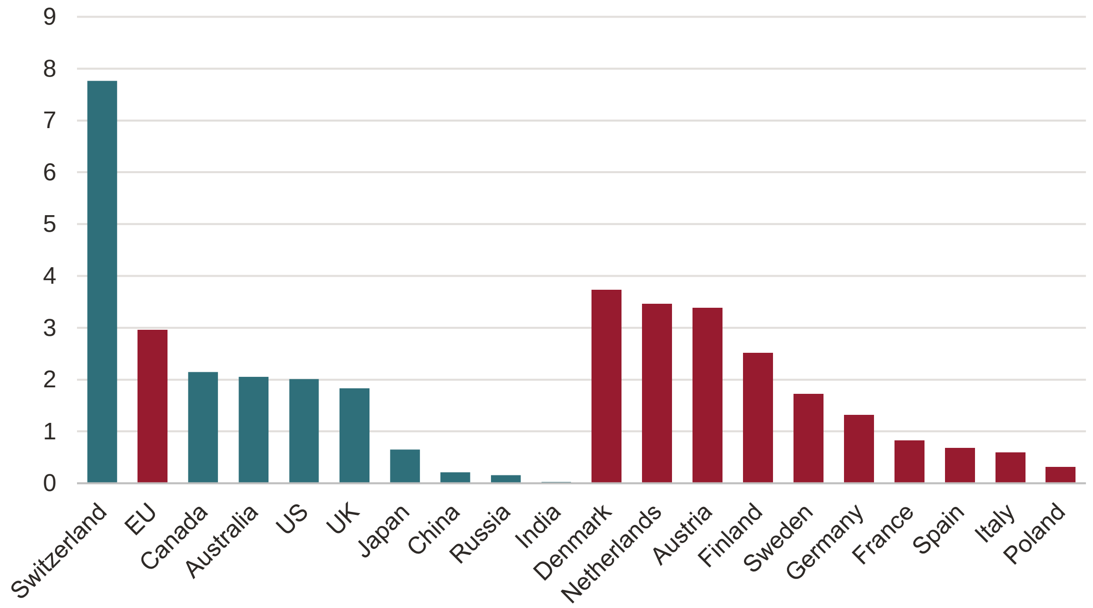
Source: ASPI

Figure Number of leading publications for quantum computing



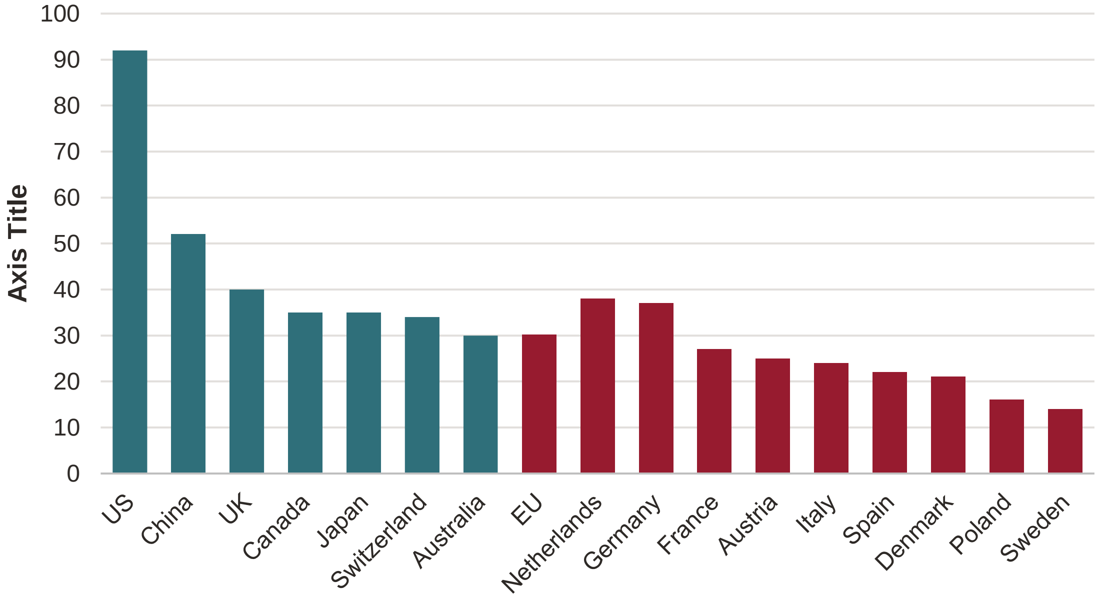
Source: ASPI

Figure **Number of leading publications per million people for quantum computing**



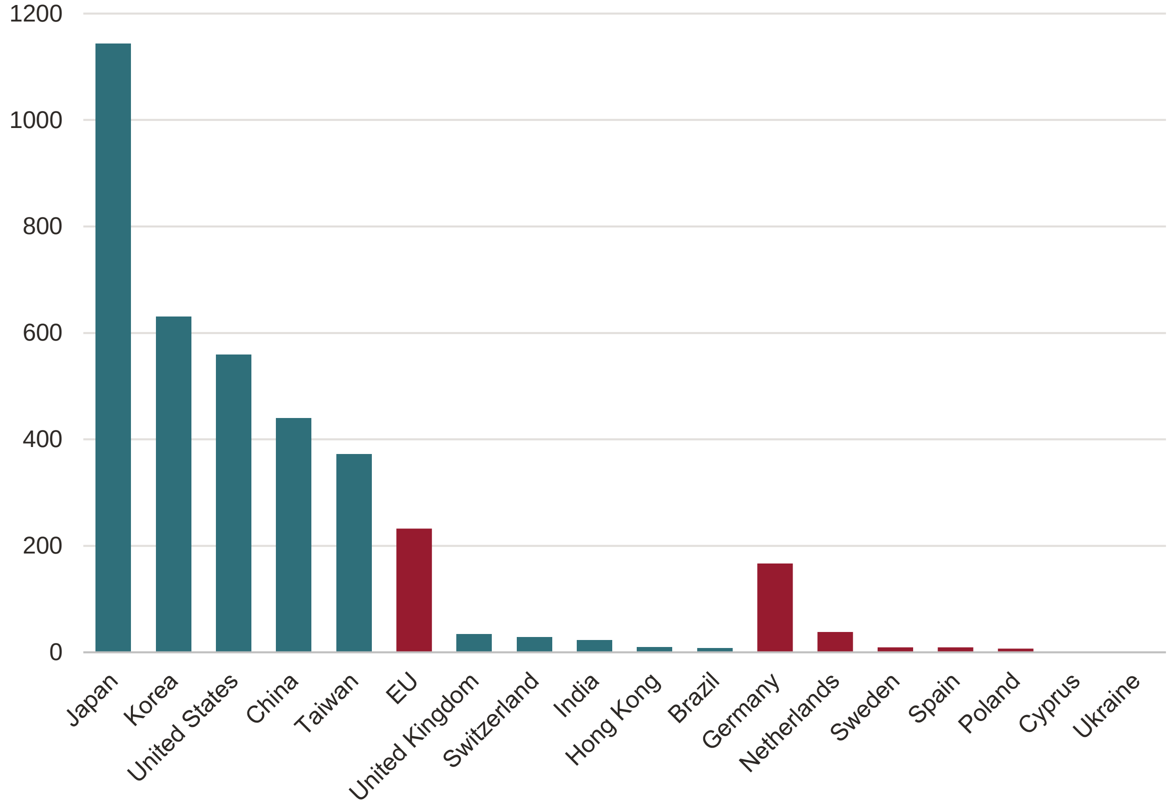
Source: ASPI

Figure H-index for Quantum computing



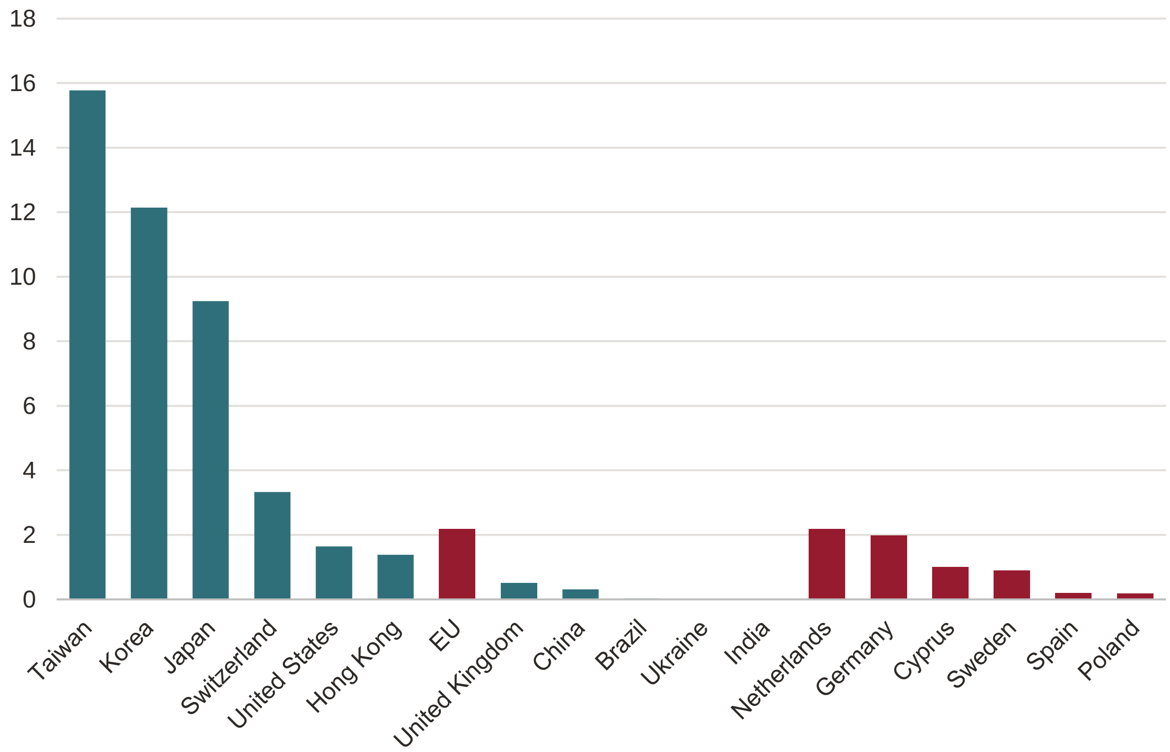
Source: ASPI

Figure Number of patents filed for Quantum computing



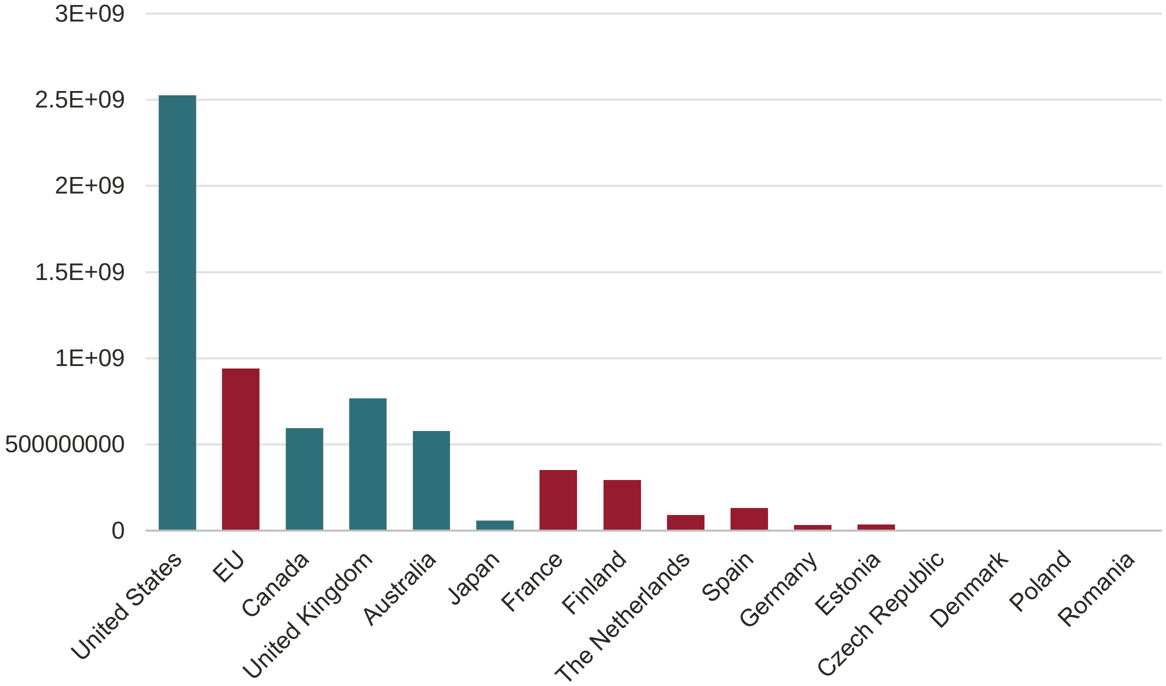
Source: OECD

Figure Number of patents filed per million people for Quantum computing



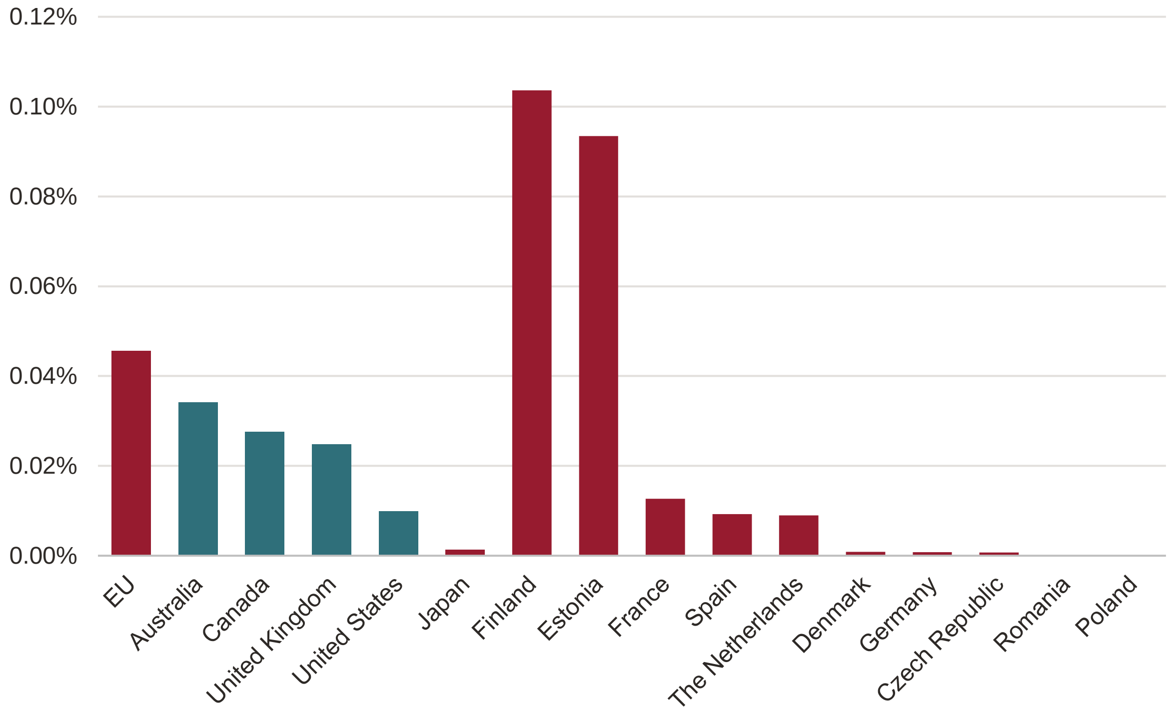
Source: OECD

Figure Value of start-up and scale-up funding for Quantum computing (USD)



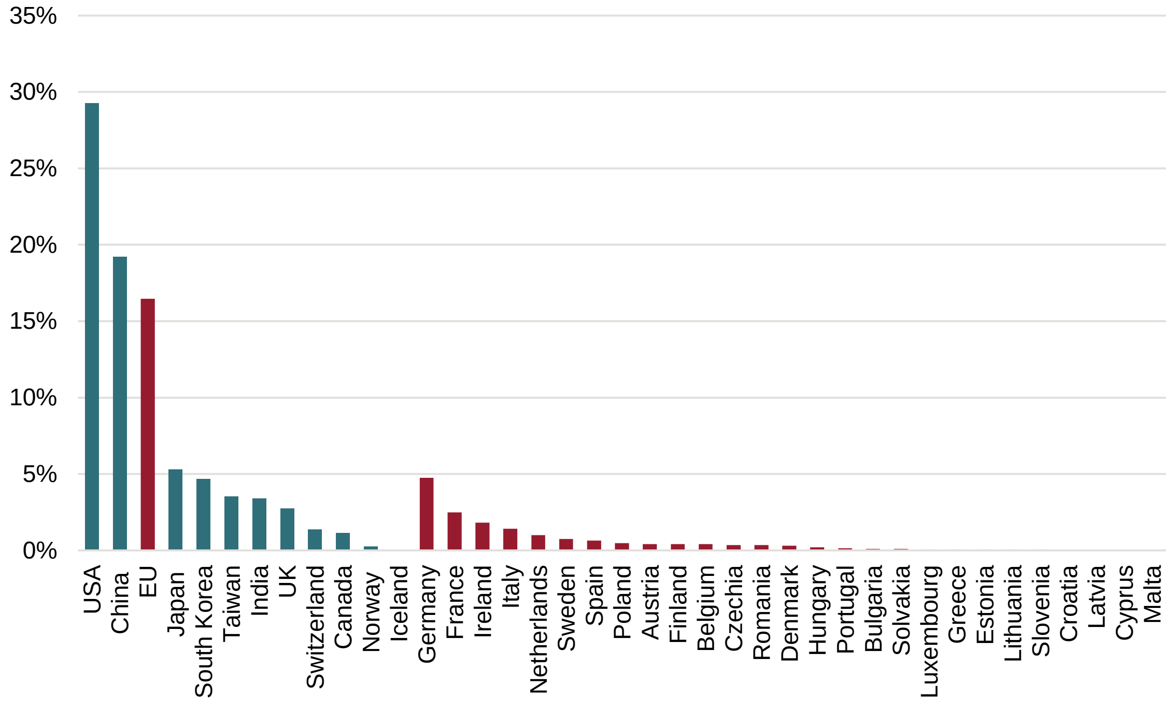
Source: Crunchbase

Figure Value of start-up and scale-up funding over GDP for Quantum computing



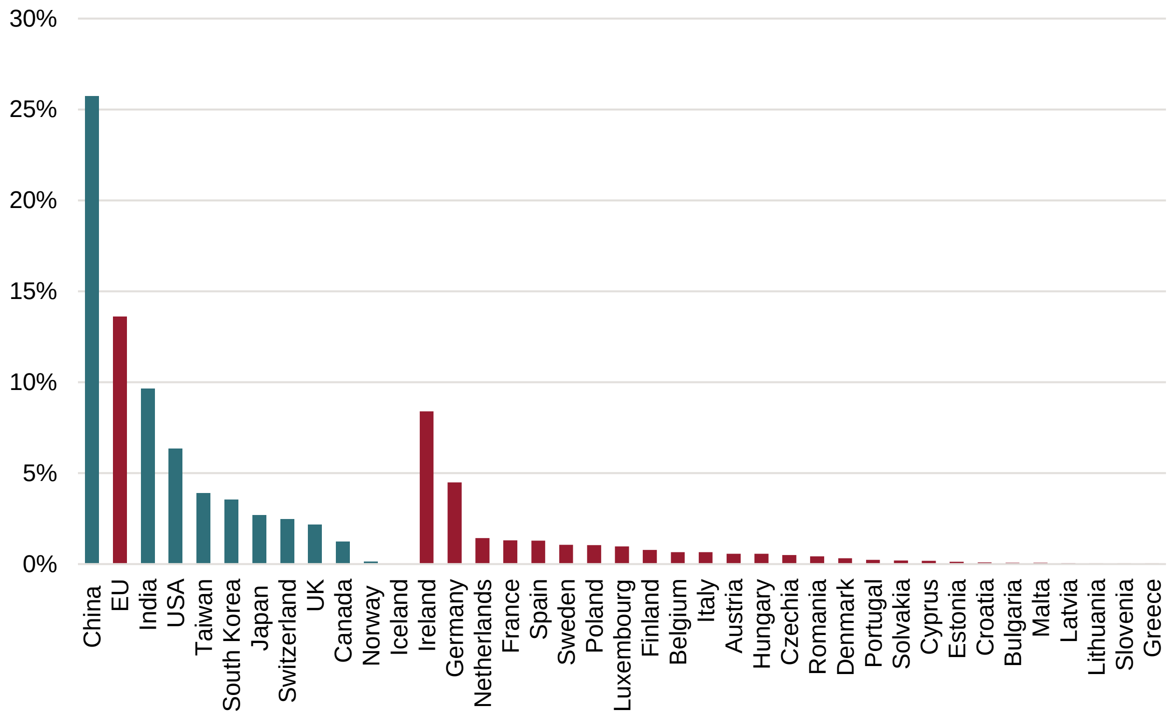
Source: Crunchbase

Figure Market share of global value addedfor Quantum computing



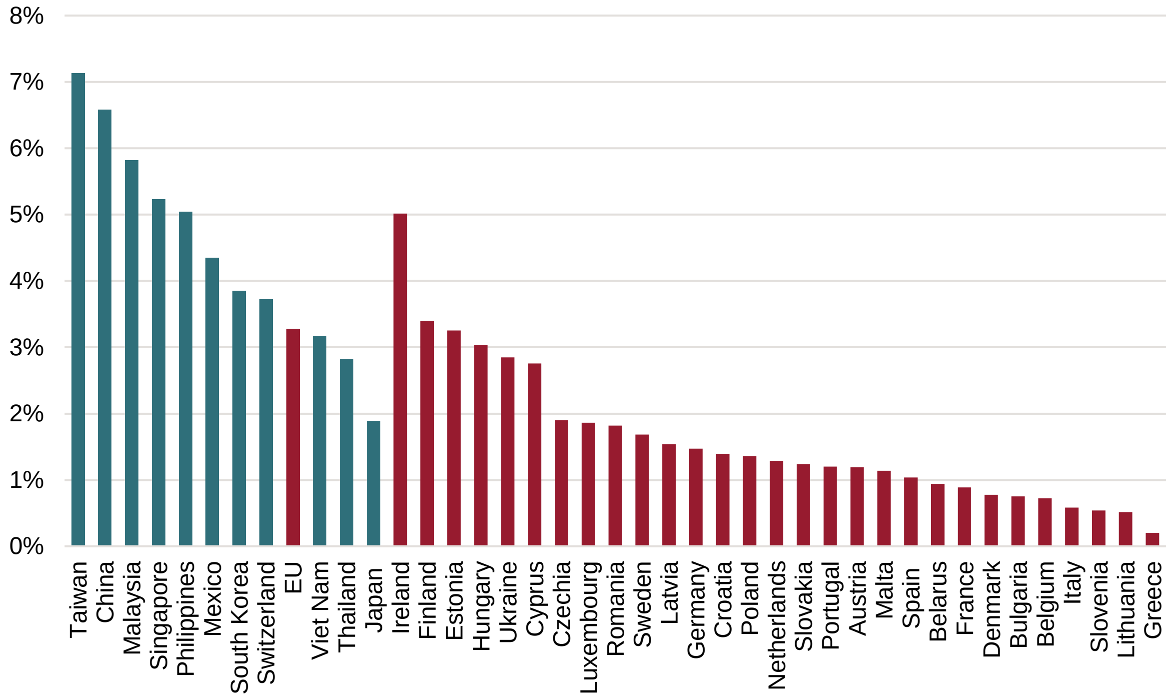
Source: OECD

Figure Global exports market share for Quantum computing



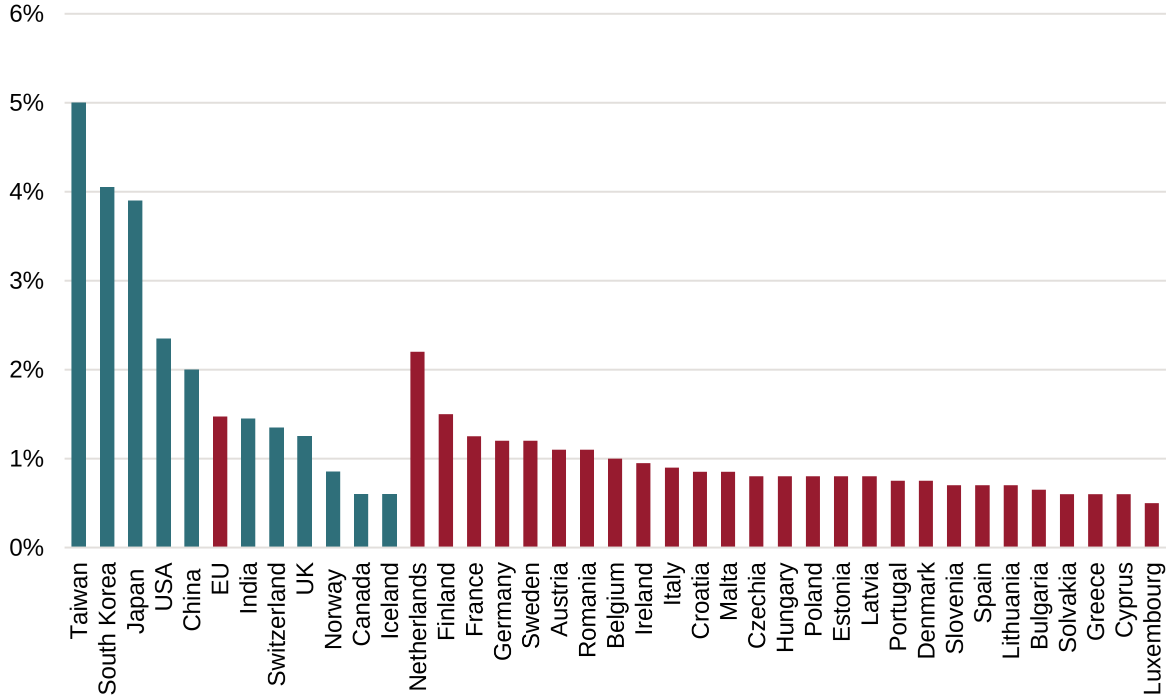
Source: OECD

Figure Exports share as a share of country exports for Quantum computing



Source: OECD

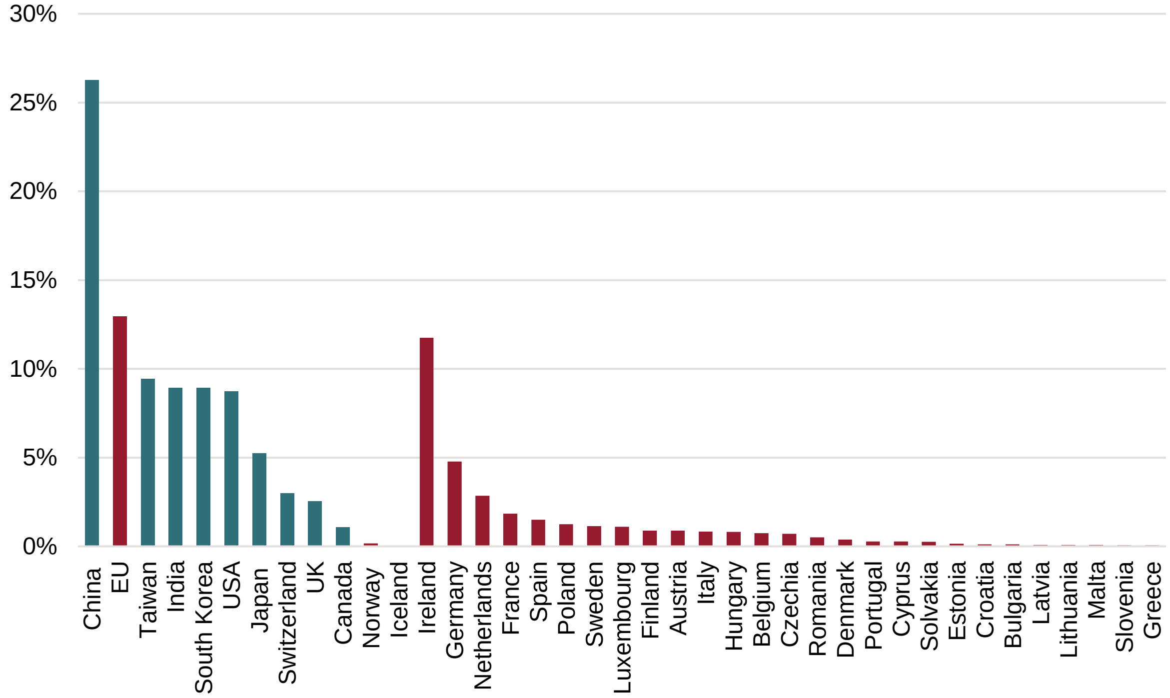
Figure Domestic value added embodied in foreign exports as a share of gross exports for Quantum computing



Source: OECD

Note: The data for this indicator is only available up to one decimal point e.g. 0.1%, 0.2%, 0.3%...

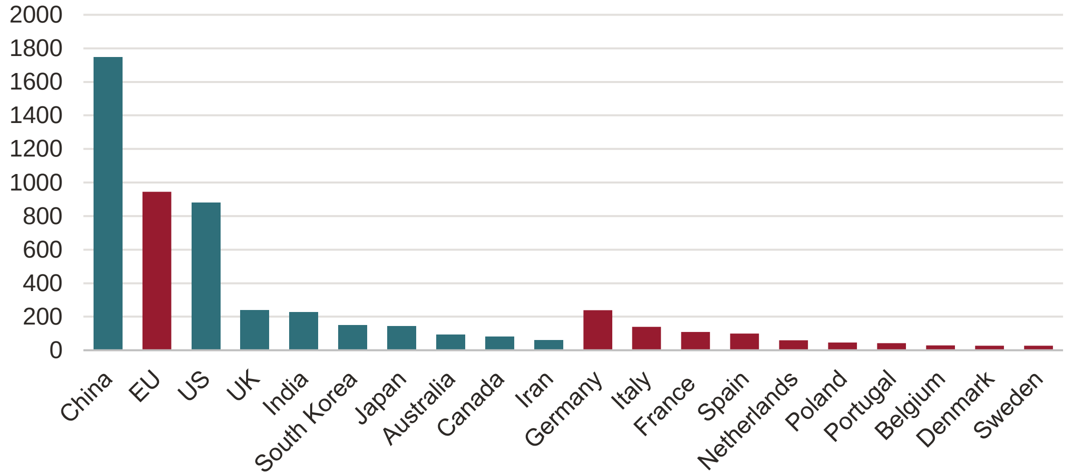
Figure Global intermediate goods exports market share for Quantum computing



Source: OECD

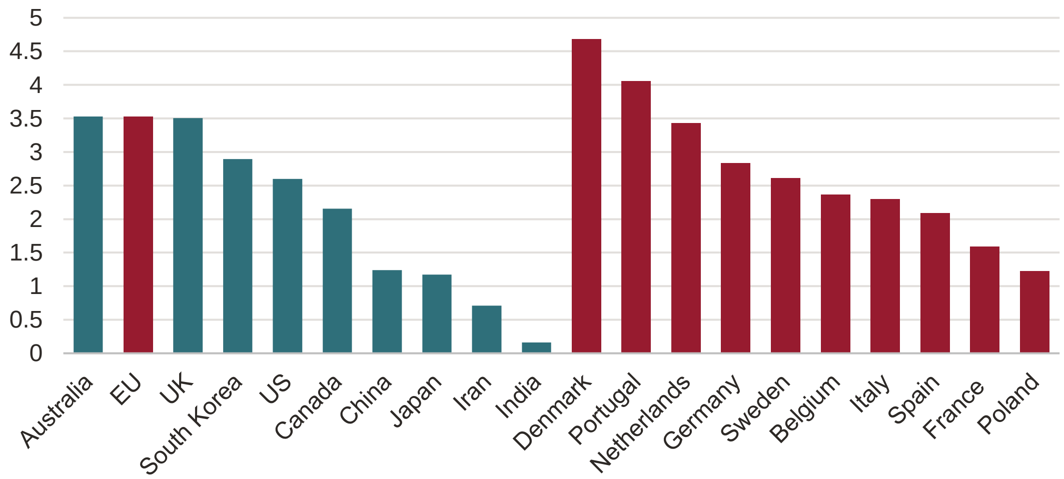
Biotechnologies

Figure Number of publications for biotechnologies



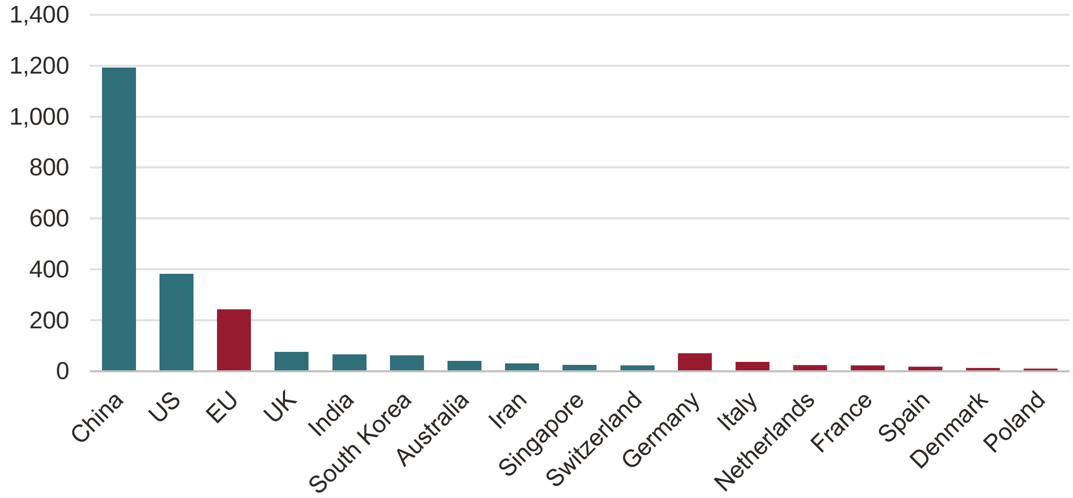
Source: ASPI

Figure Number of publications per million people for biotechnologies



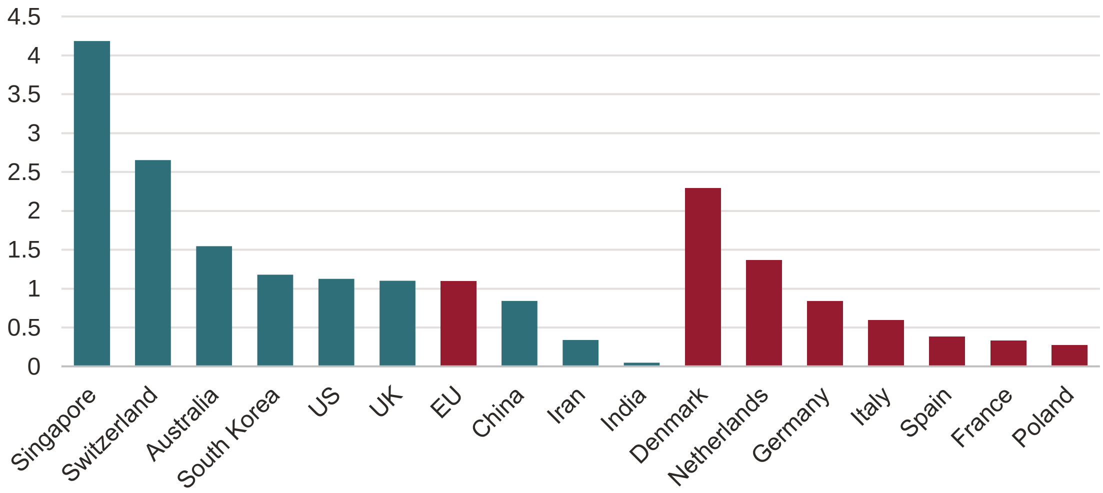
Source: ASPI

Figure Number of leading publications for biotechnologies



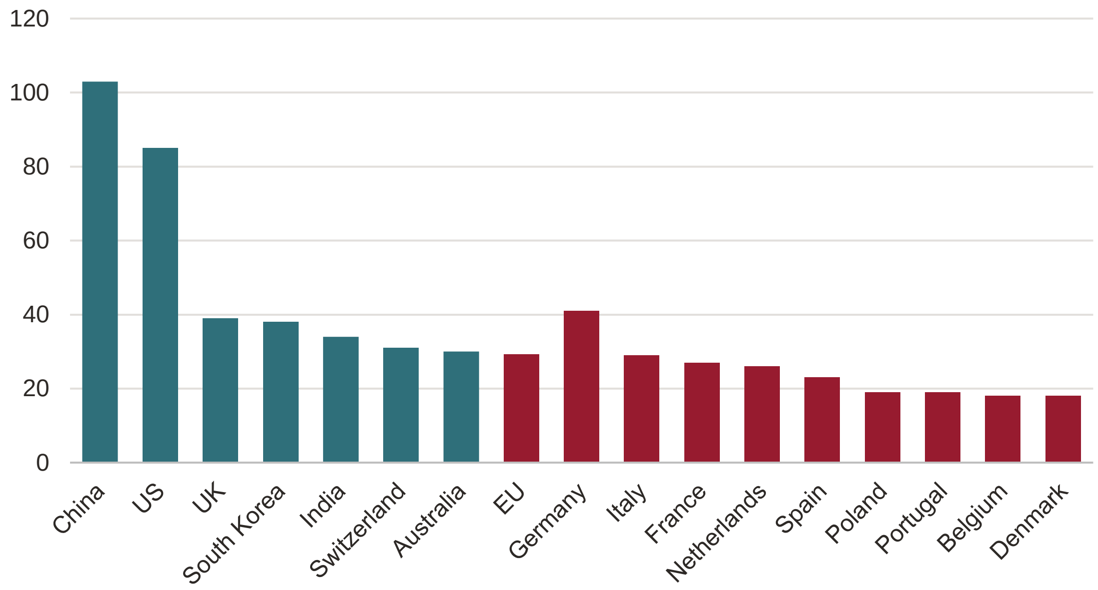
Source: ASPI

Figure Number of leading publications per million people for biotechnologies



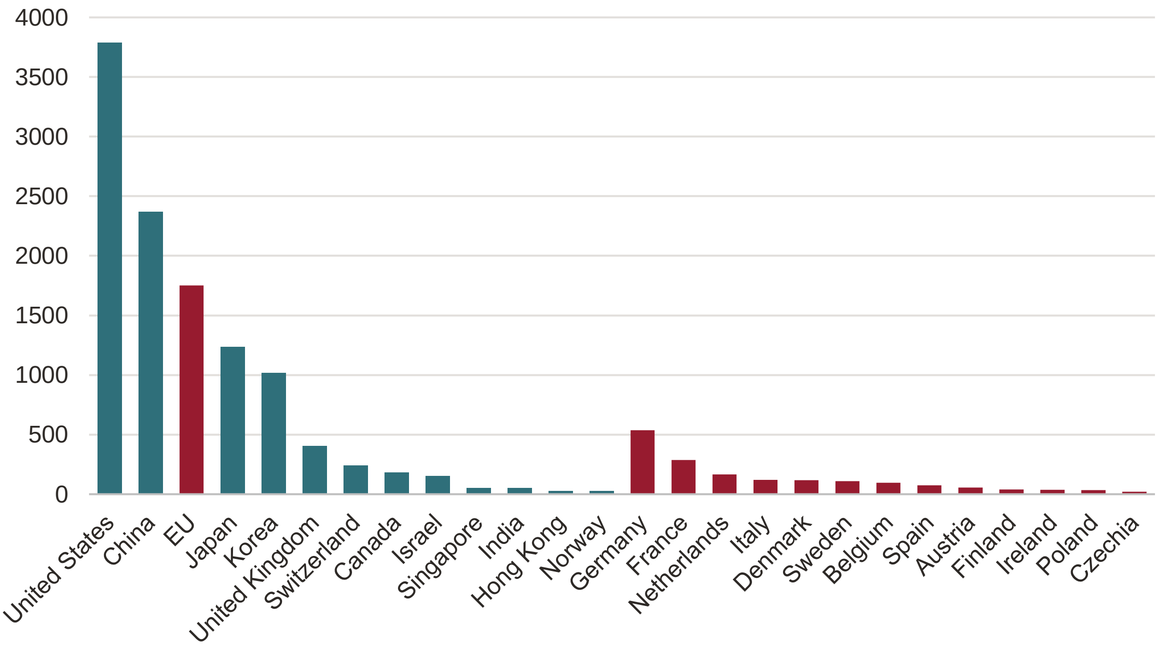
Source: ASPI

Figure H-index for biotechnologies



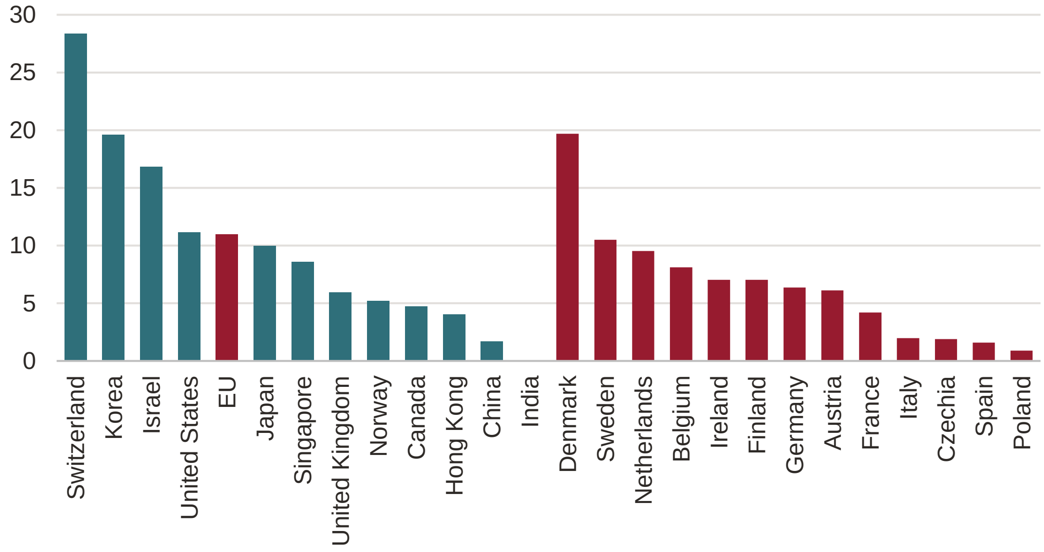
Source: ASPI

Figure Number of patents filed for biotechnologies



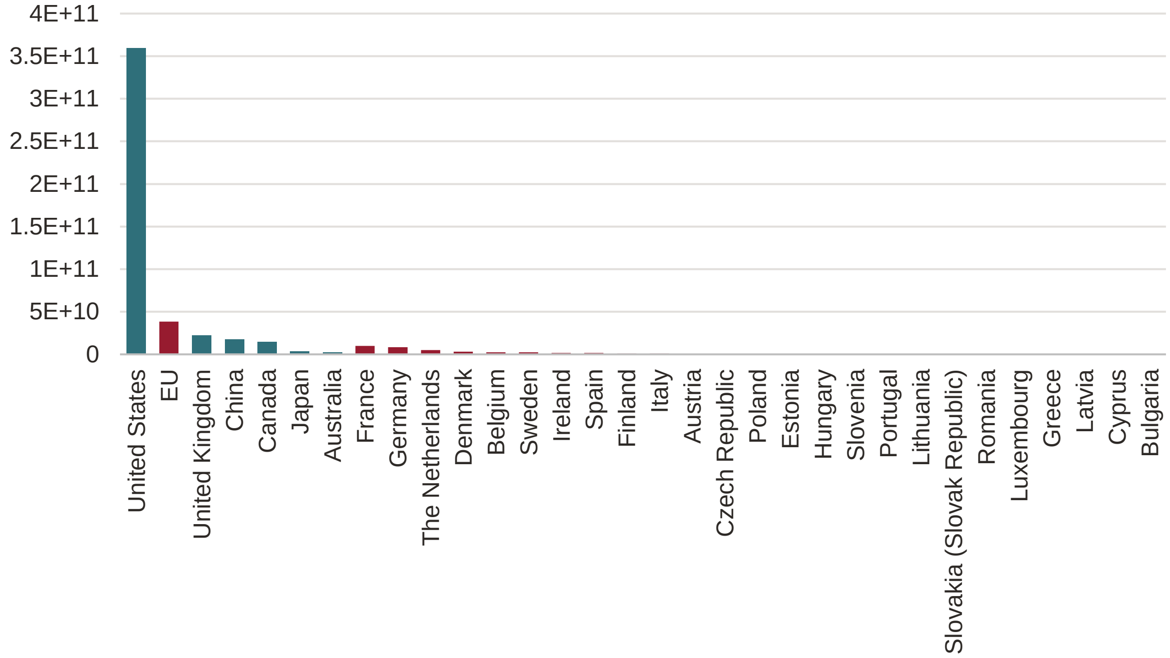
Source: OECD

Figure Number of patents filed per million people for biotechnologies



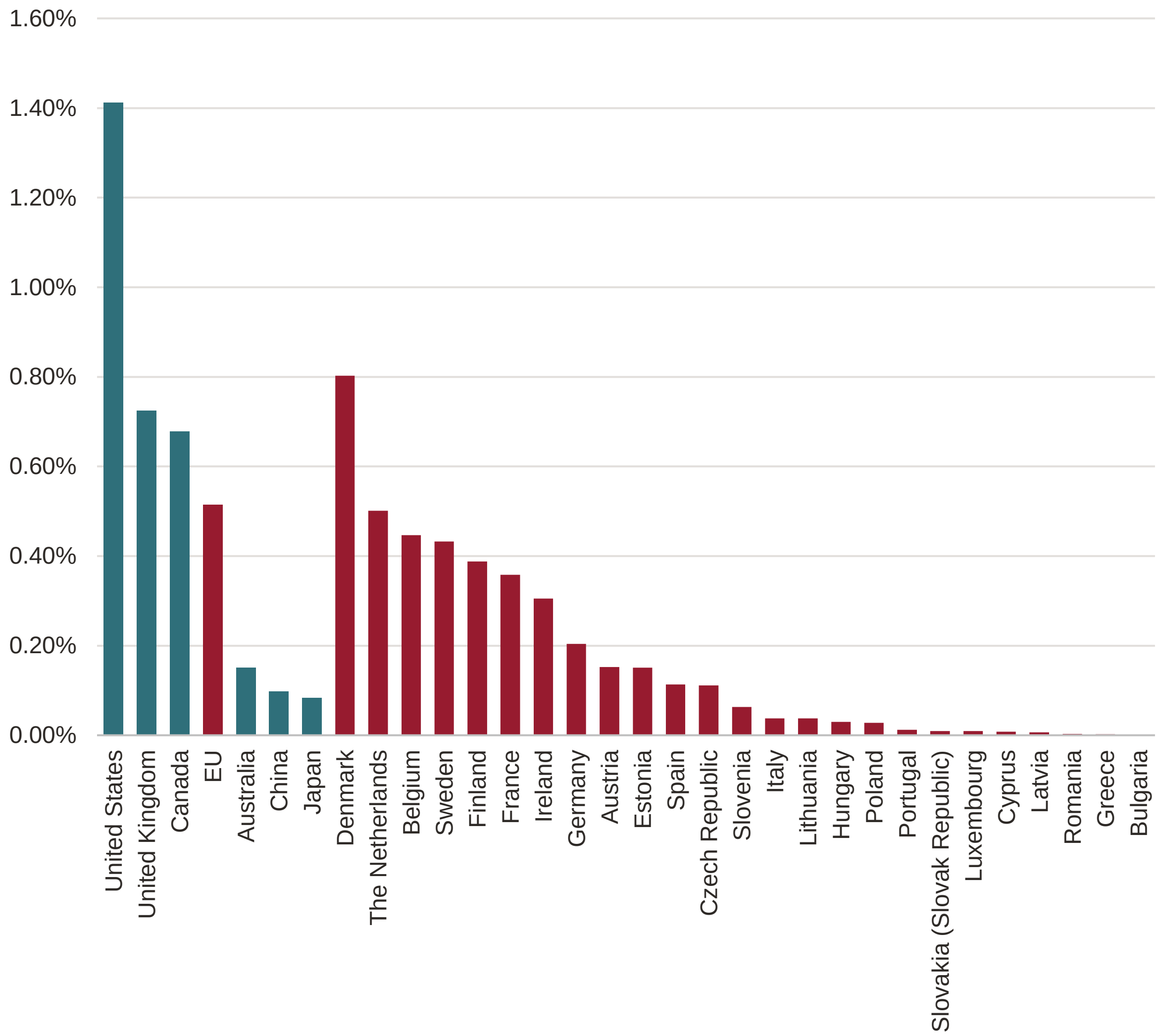
Source: OECD

Figure Value of start-up and scale-up funding for biotechnologies (USD)



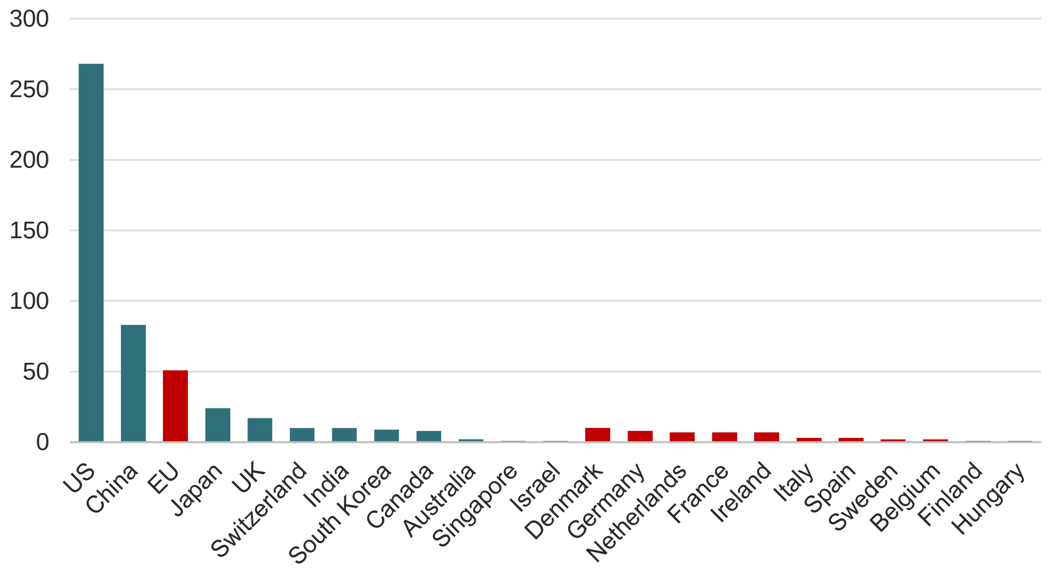
Source: Crunchbase

Figure Value of start-up and scale-up funding for biotechnologies over GDP



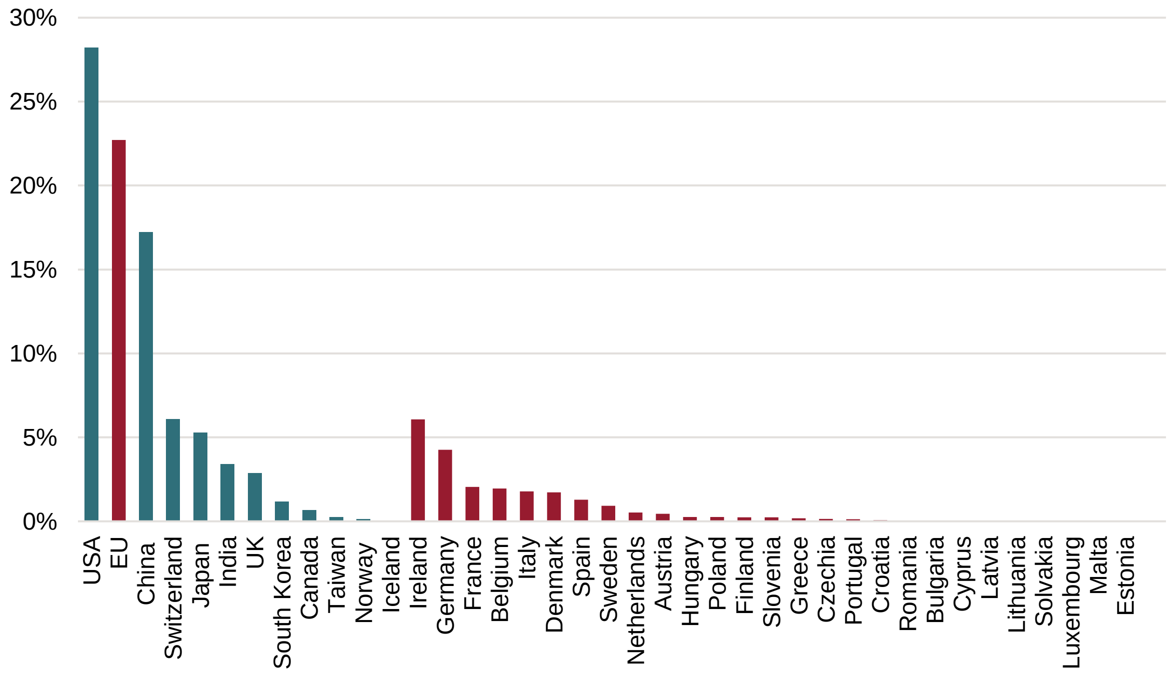
Source: Crunchbase

Figure Count of global leading R&D businesses for Biotechnologies



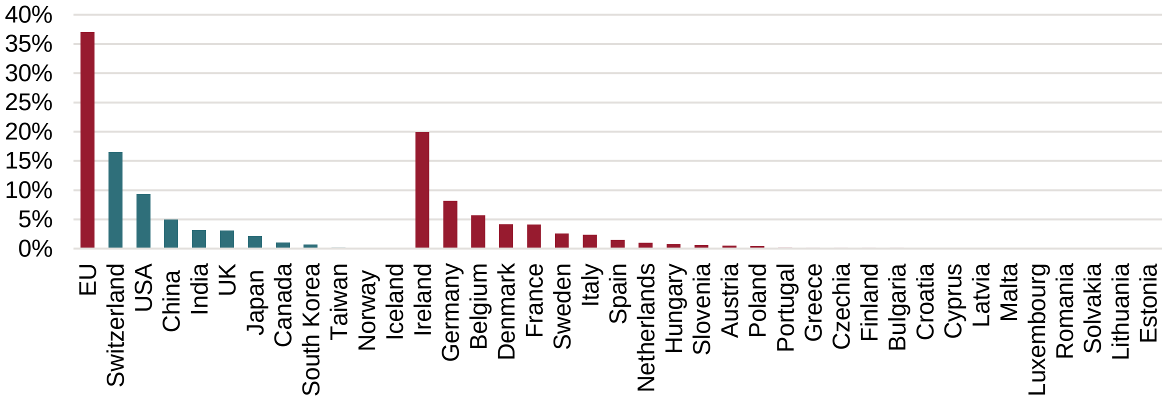
Source: EU Innovation Scoreboard

Figure 8 Market share of global value added for Biotechnologies



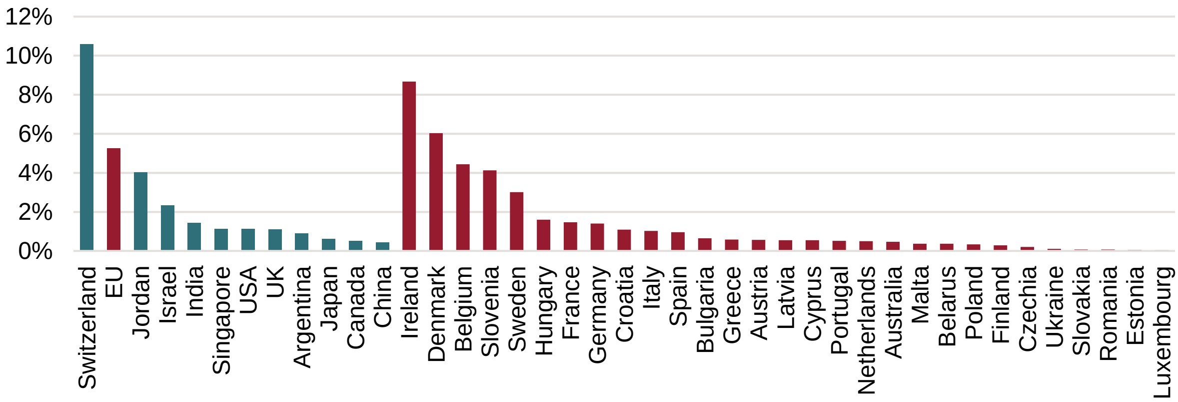
Source: OECD

Figure 9 Global exports market share for Biotechnologies



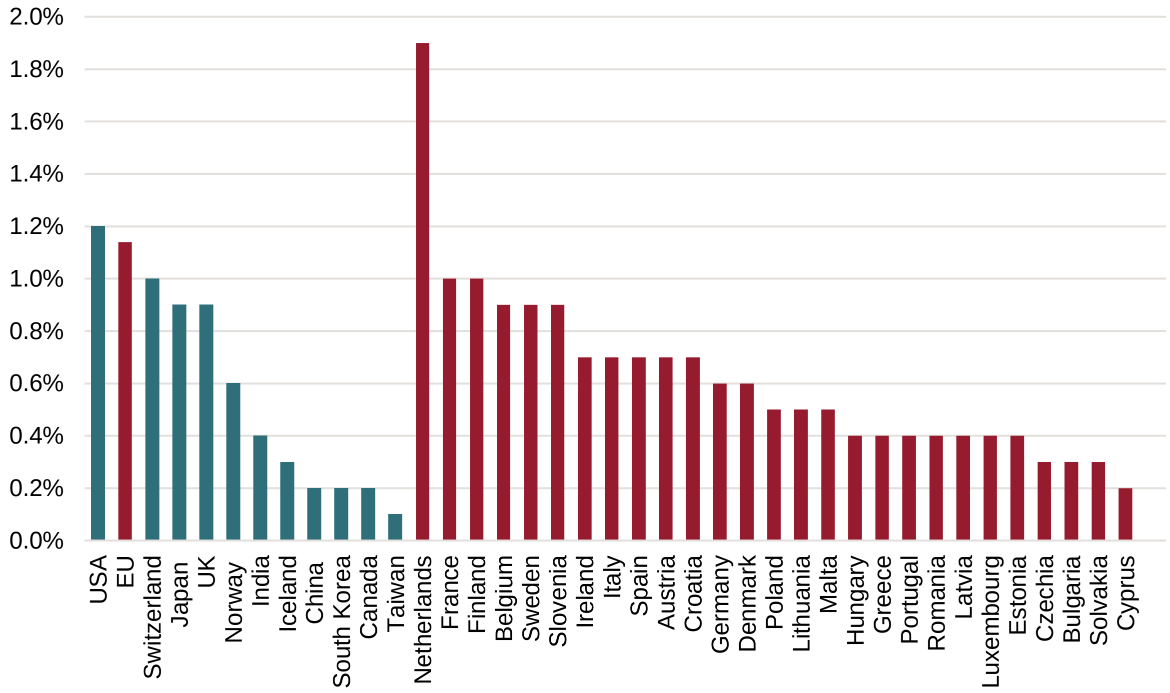
Source: OECD

Figure 10 Exports share as a share of country exports for Biotechnologies



Source: OECD

Figure 11 Domestic value added embodied in foreign exports as a share of gross exports for Biotechnologies

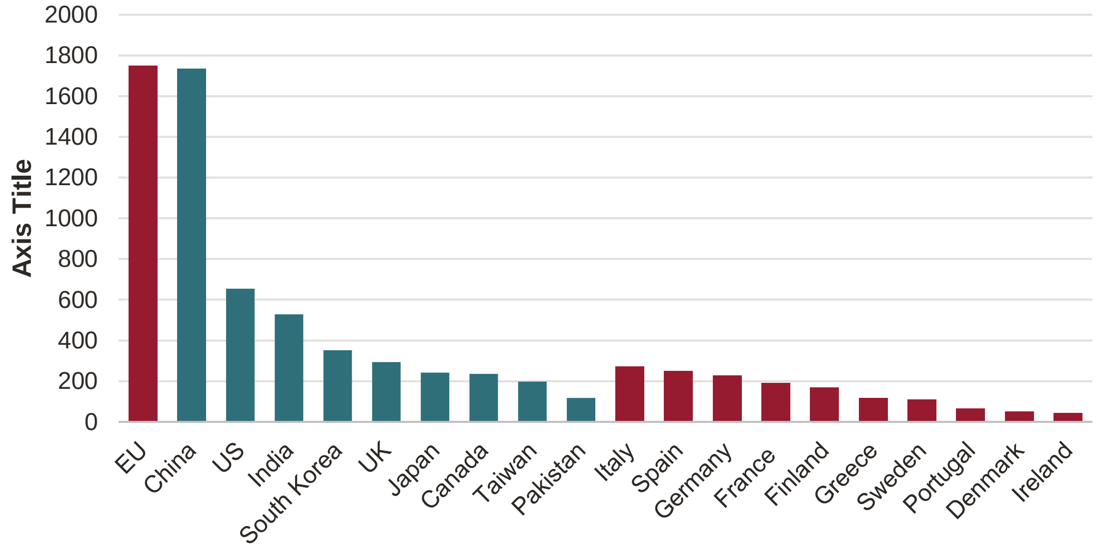


Source: OECD

Note: The data for this indicator is only available up to one decimal point e.g. 0.1%, 0.2%, 0.3%...

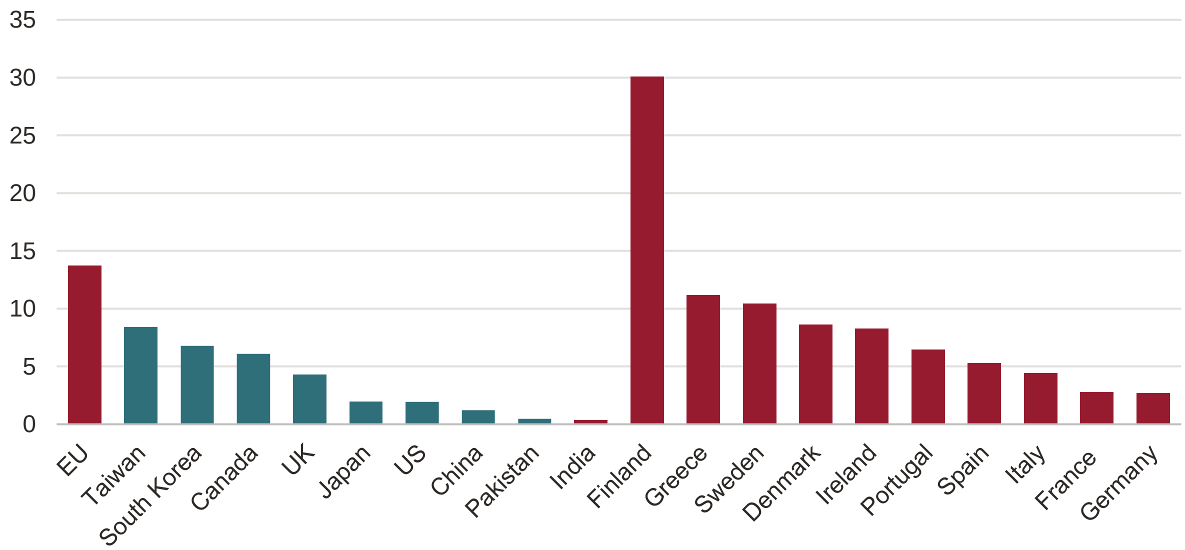
Advanced connectivity

Figure 12 Number of publications for advanced connectivity



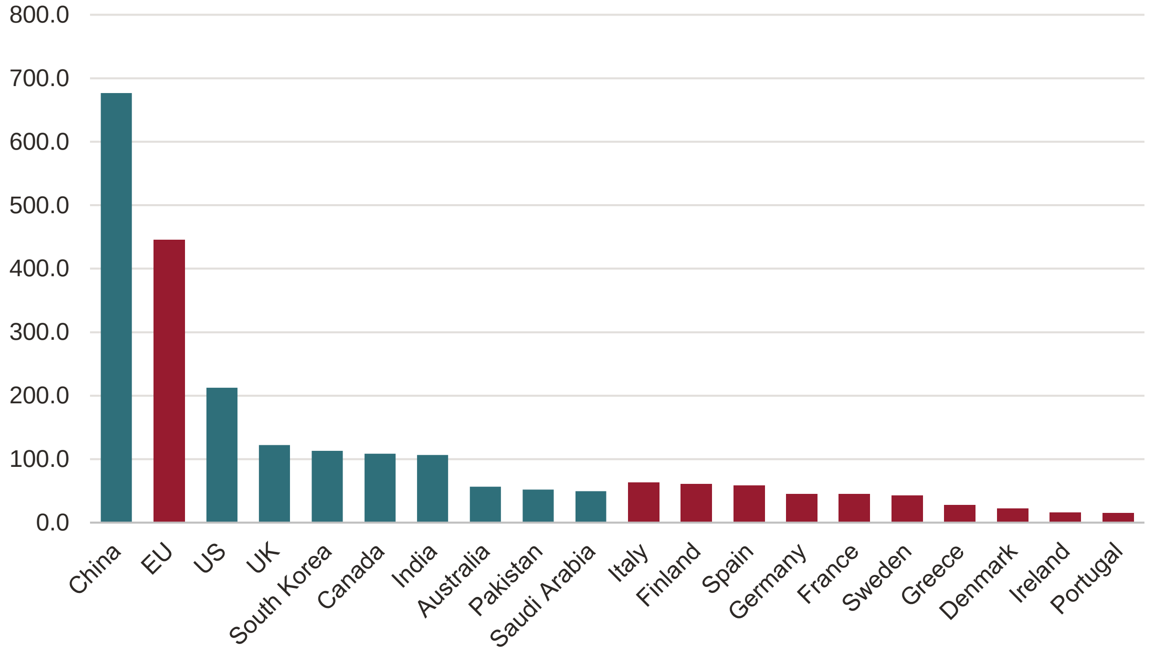
Source: ASPI

Figure 13 Number of publications per million people for advanced connectivity



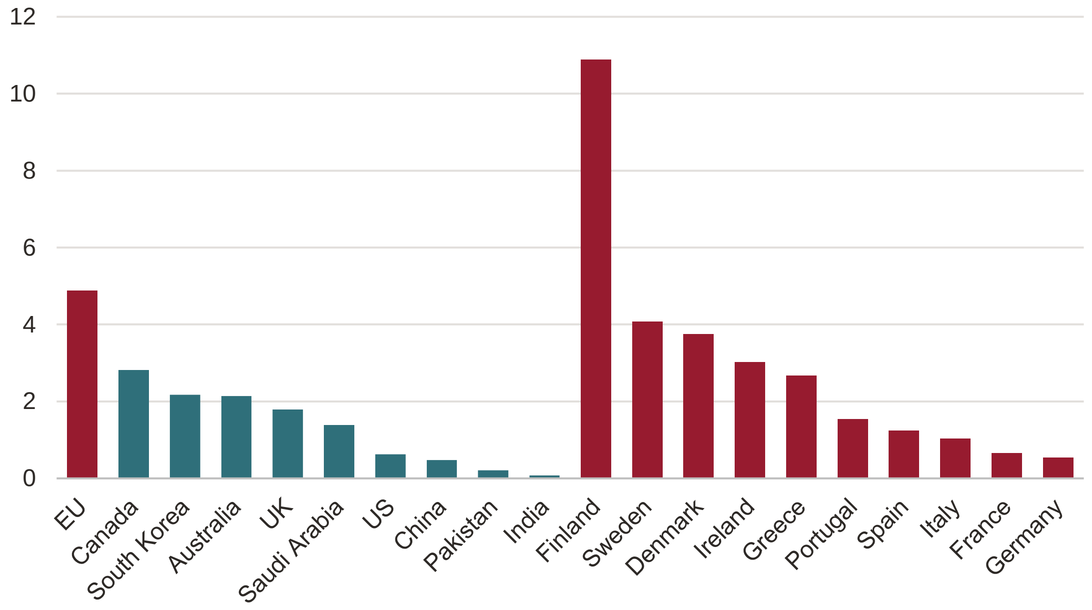
Source: ASPI

Figure 14 Number of leading publications for advanced connectivity



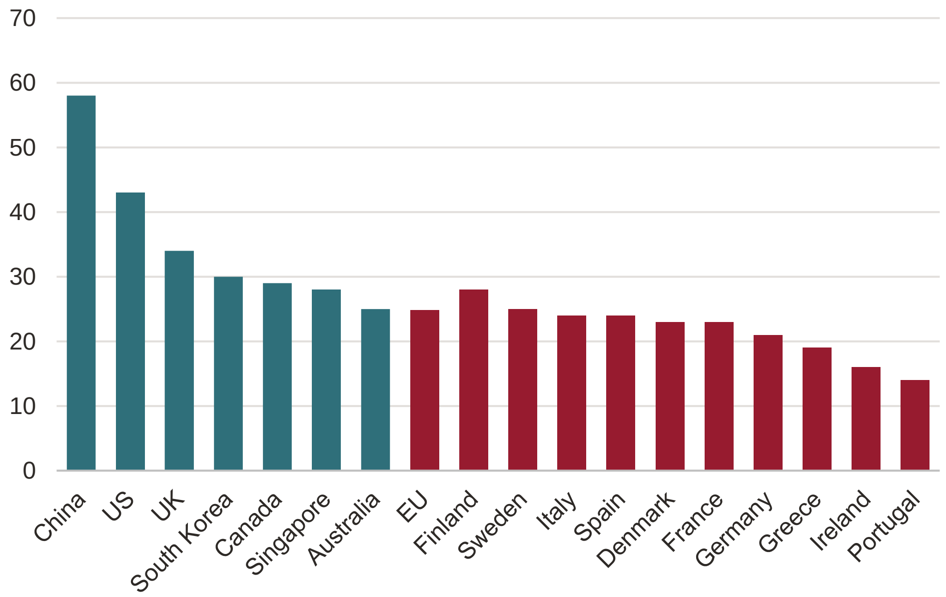
Source: ASPI

Figure 15 Number of leading publications per million people for advanced computing



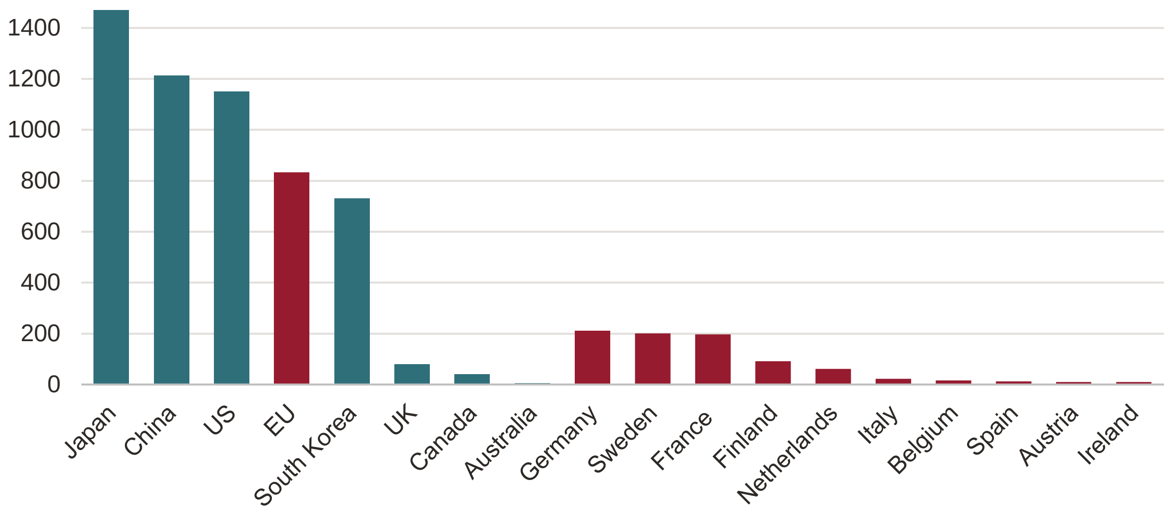
Source: ASPI

Figure 9316 H-index for advanced connectivity



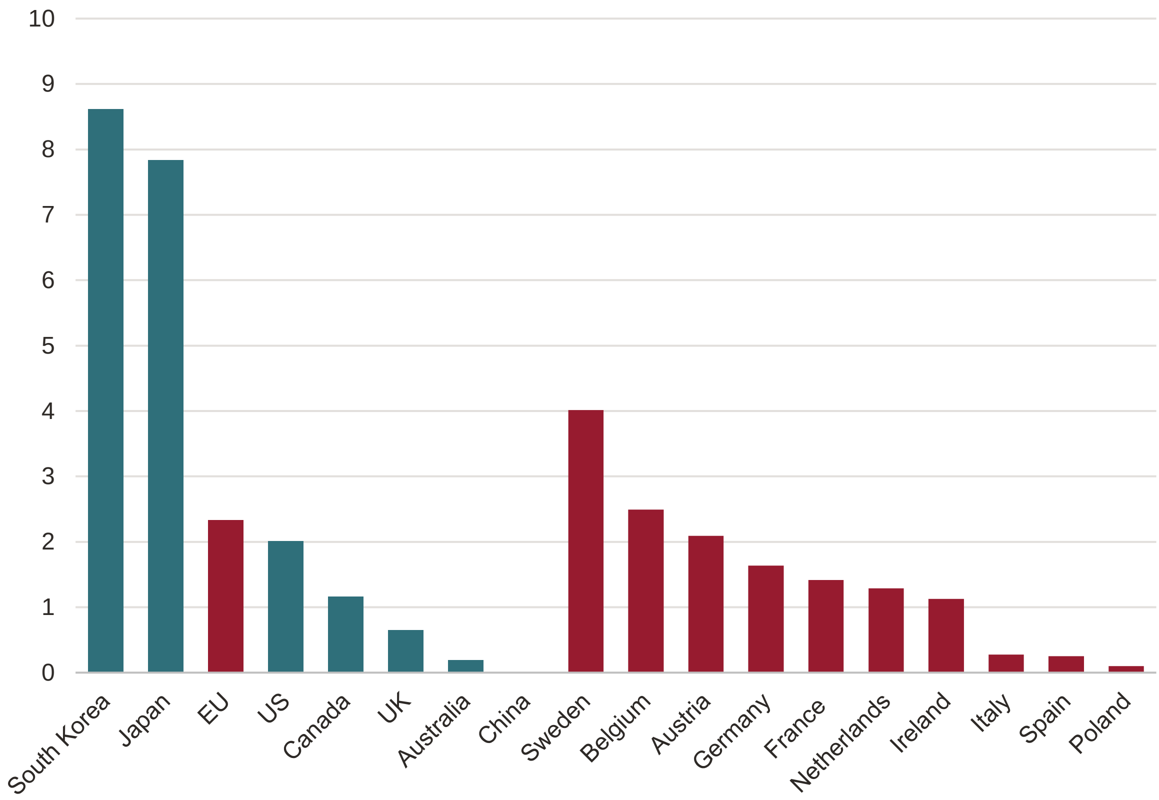
Source: ASPI

Figure 17 Number of patents filed for advanced connectivity



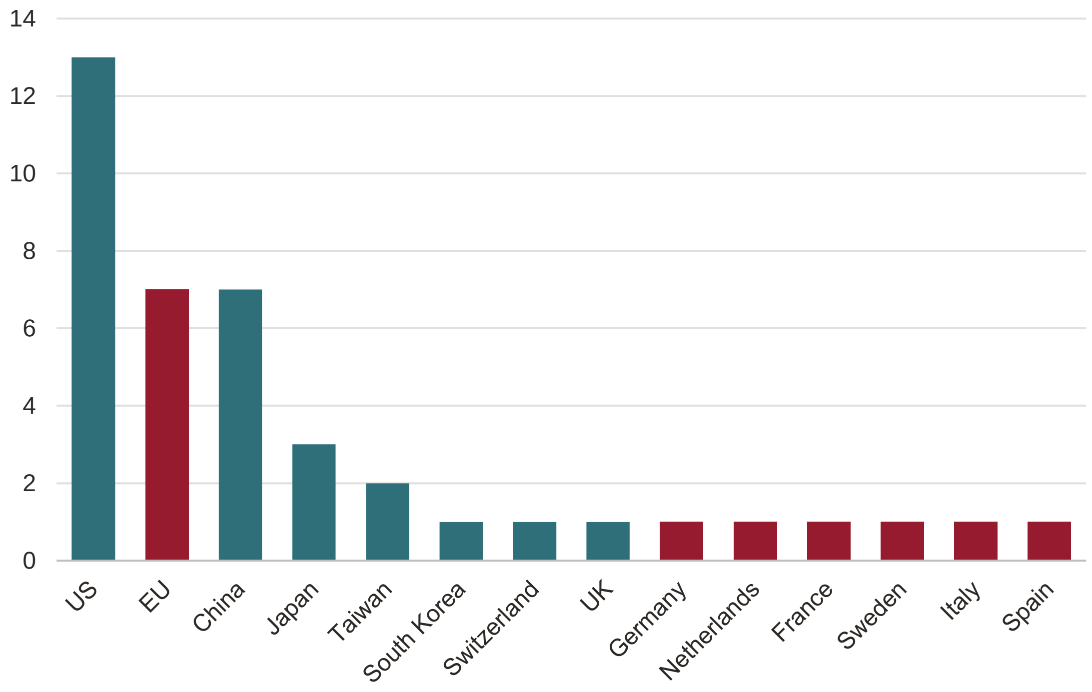
Source: OECD

Figure 18 Number of patents filed per million people for advanced connectivity



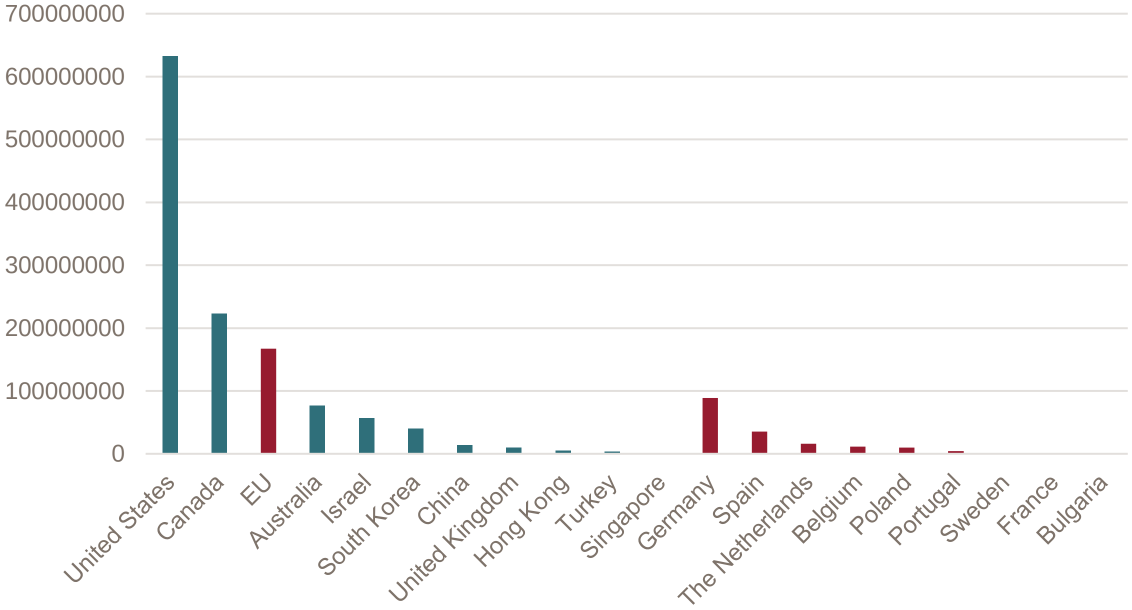
Source: OECD

Figure Count of global leading R&D businesses for advanced connectivity



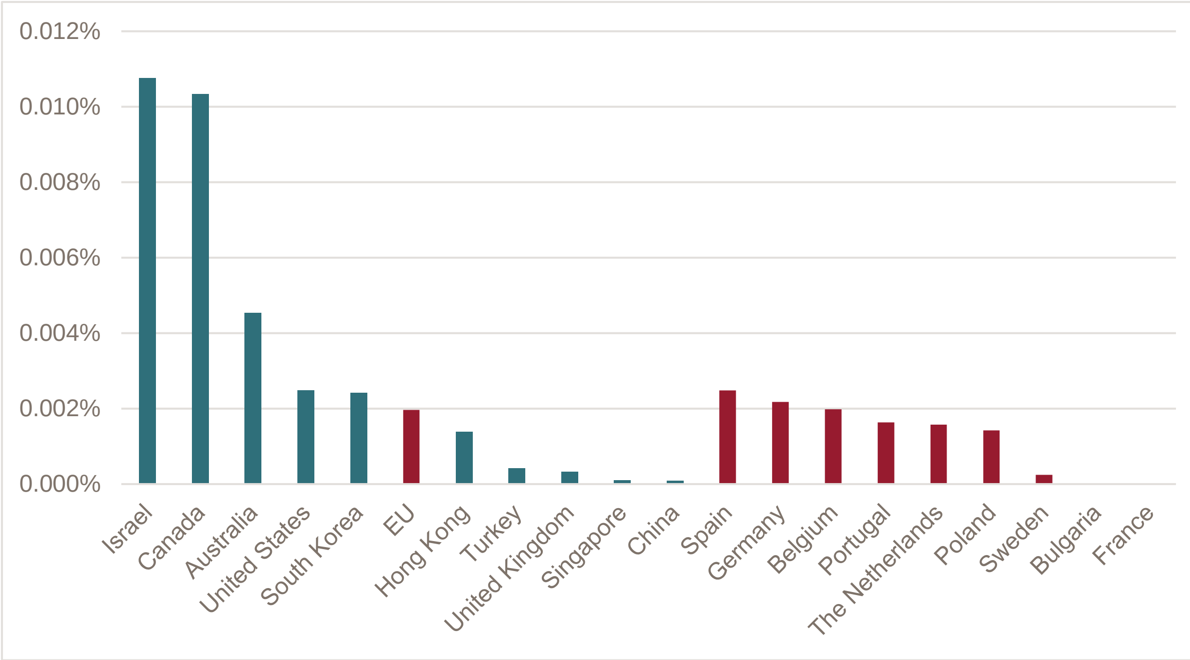
Source: European Innovation Scoreboard

Figure 19 Value of start-up and scale-up funding for advanced connectivity (USD)



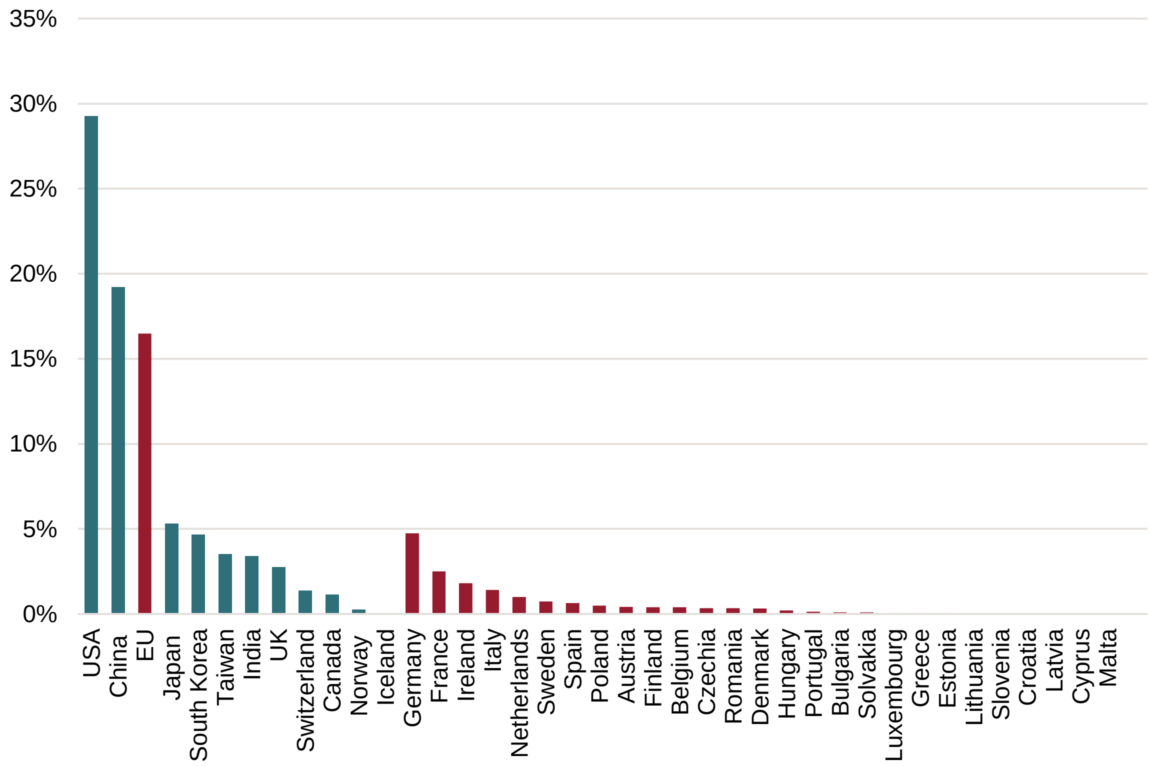
Source: Crunchbase

Figure 20 Value of start-up and scale-up funding over GDP for advanced connectivity



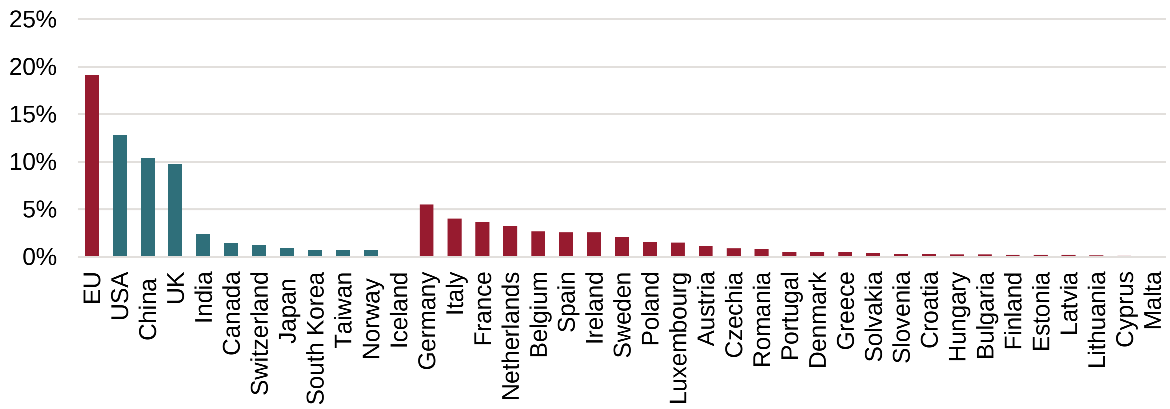
Source: Crunchbase

Figure 21 Market share of global value added for Advanced connectivity



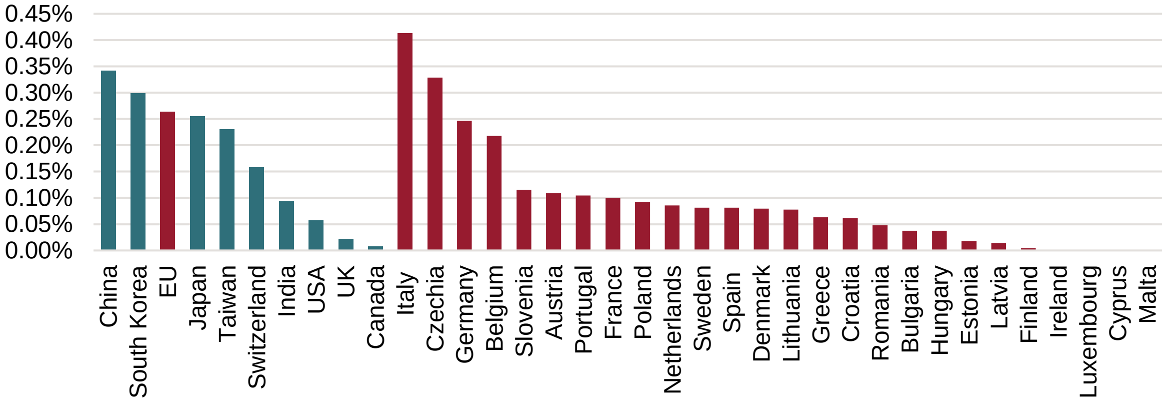
Source: OECD

Figure 22 Global exports market share for Advanced connectivity



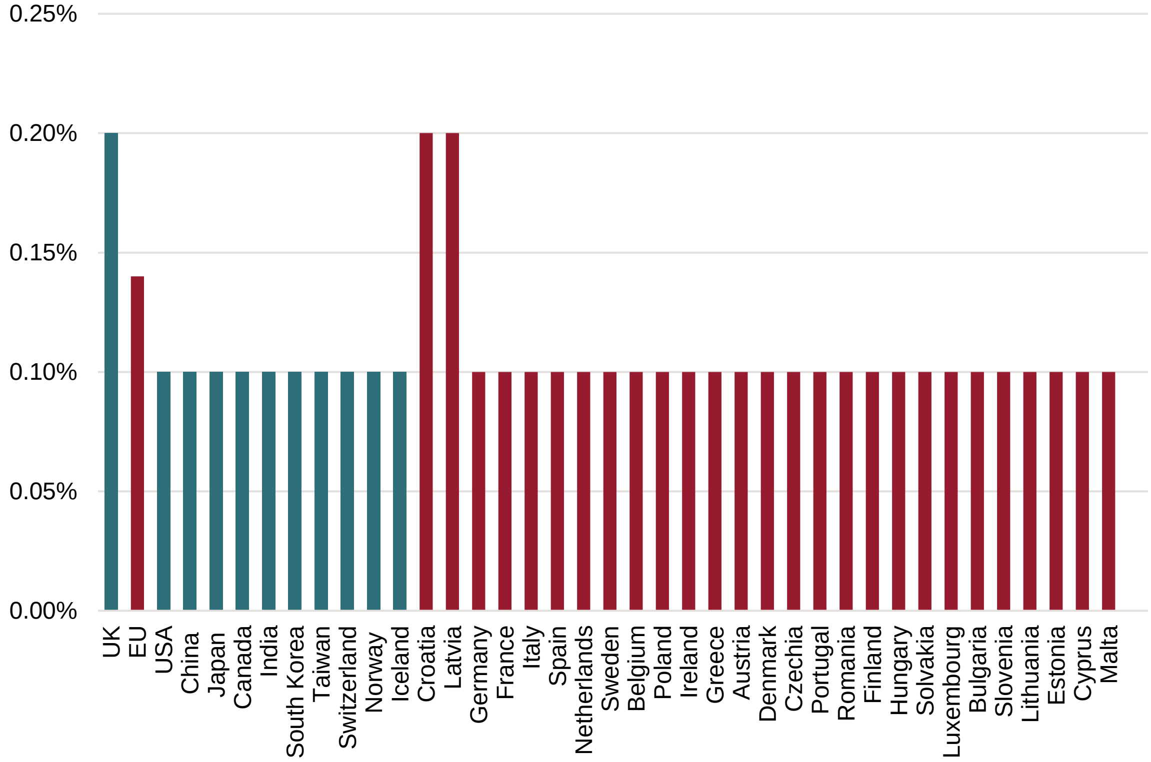
Source: OECD

Figure 23 Exports share as a share of country exports for Advanced connectivity



Source: OECD

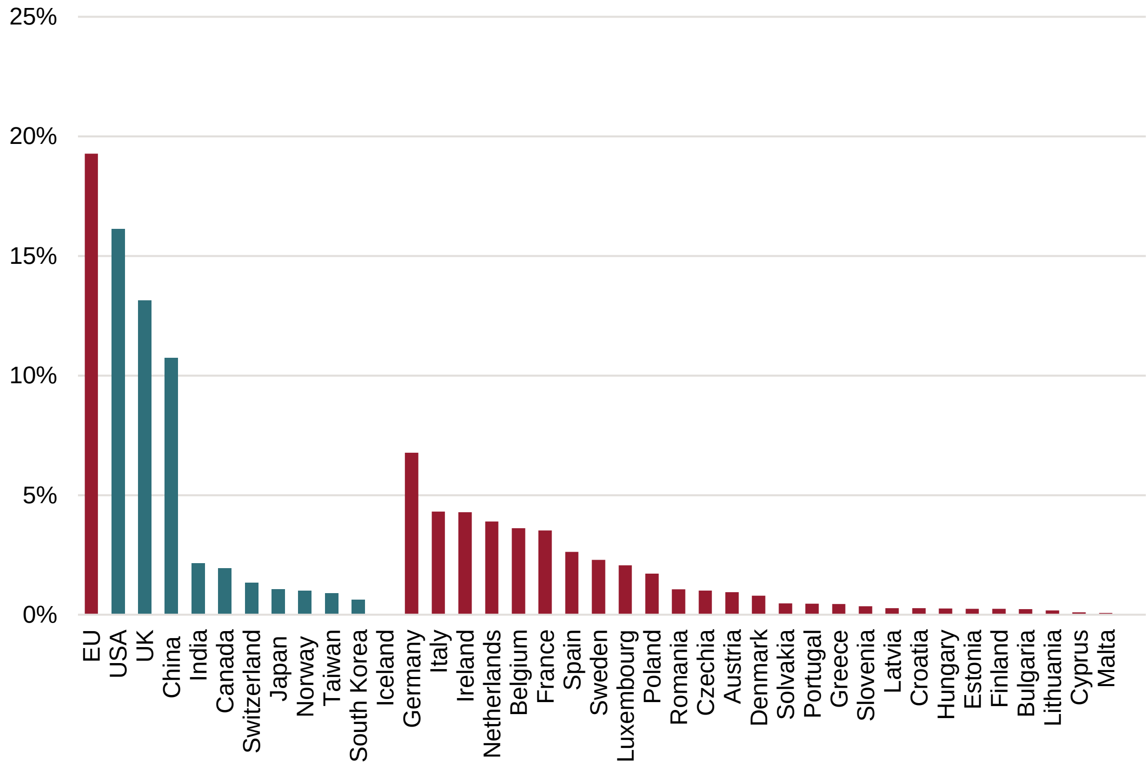
Figure 24 Domestic value added embodied in foreign exports as a share of gross exports for Advanced connectivity



Source: OECD

Note: The data for this indicator is only available up to one decimal point e.g. 0.1%, 0.2%, 0.3%...

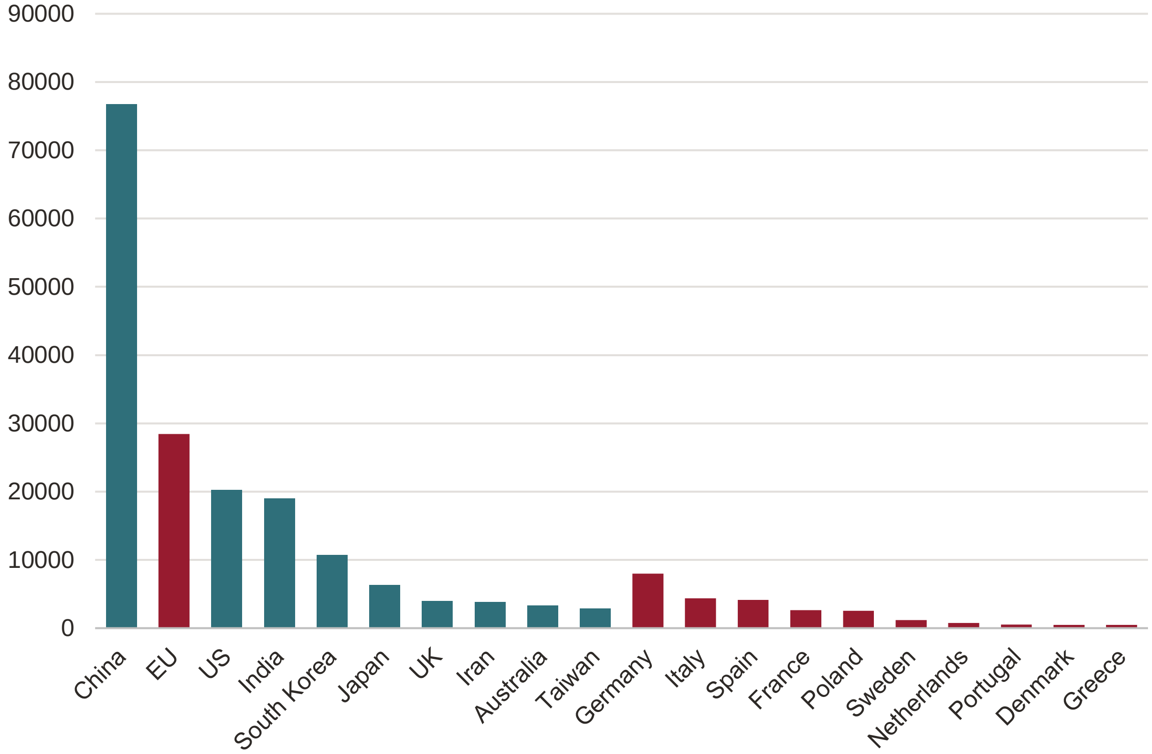
Figure 25 Global intermediate goods exports market share for Advanced connectivity



Source: OECD

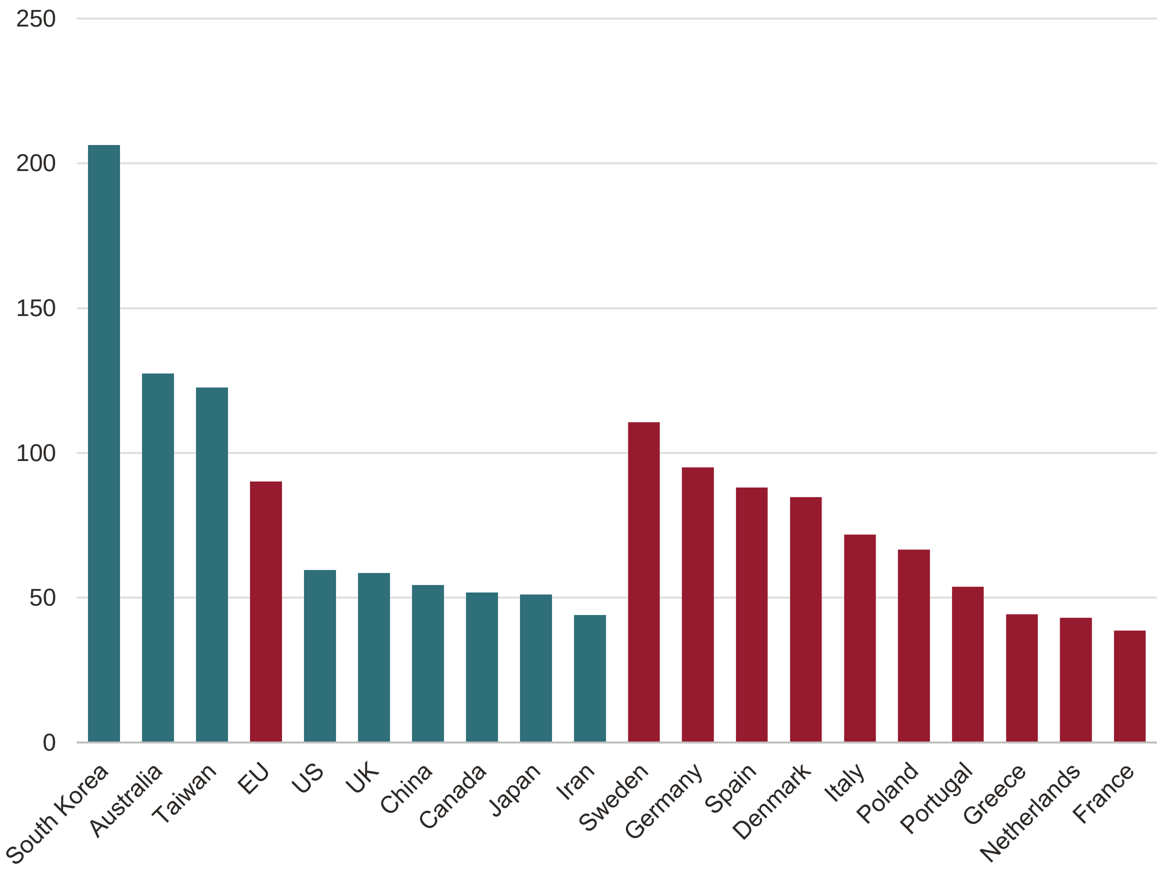
Energy technologies

Figure 26 Number of publications for energy technologies



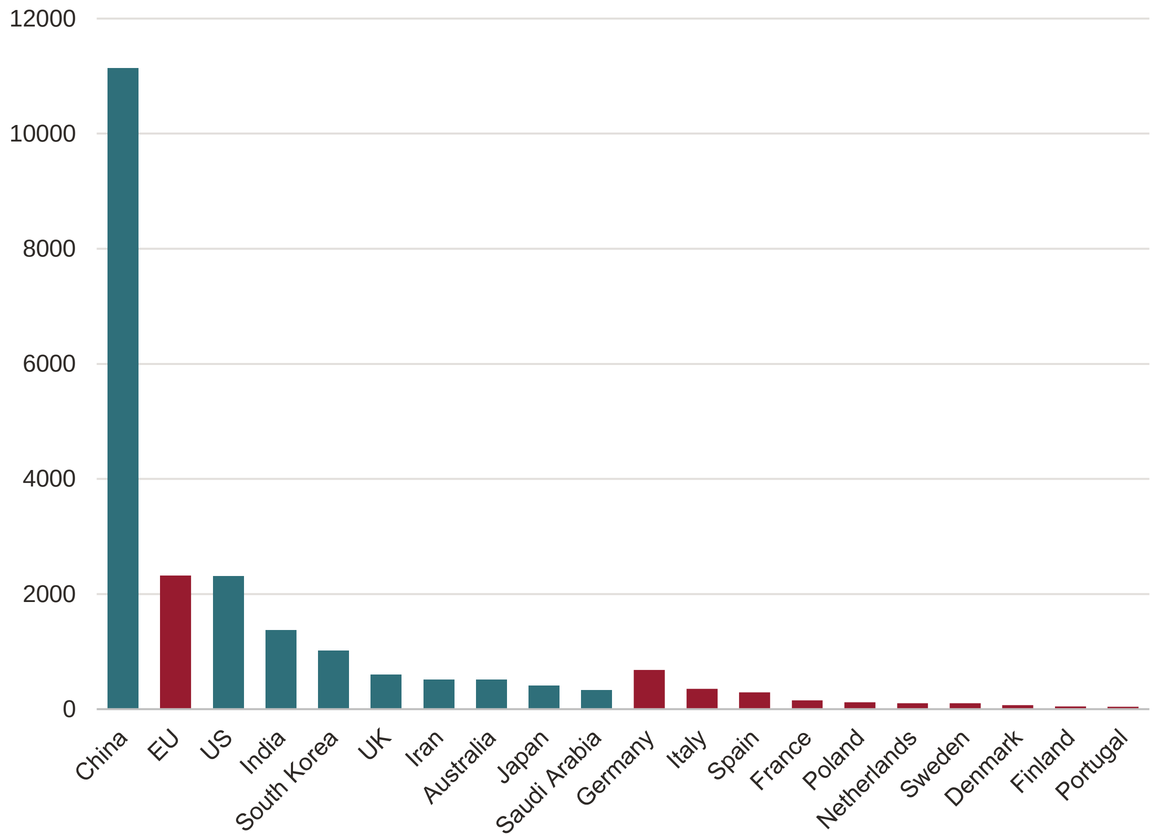
Source: ASPI

Figure 27 Number of publications per million people for energy technologies



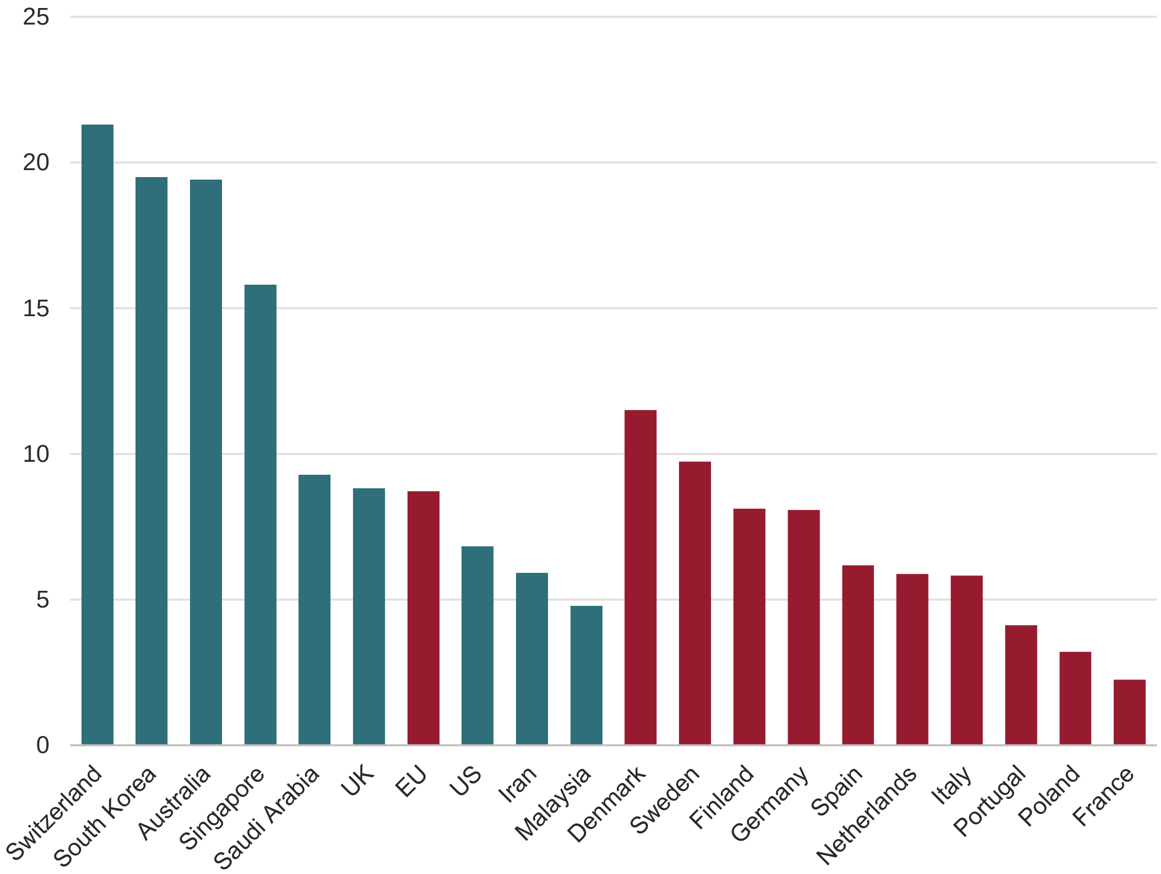
Source: ASPI

Figure 28 Number of leading publications for energy technologies



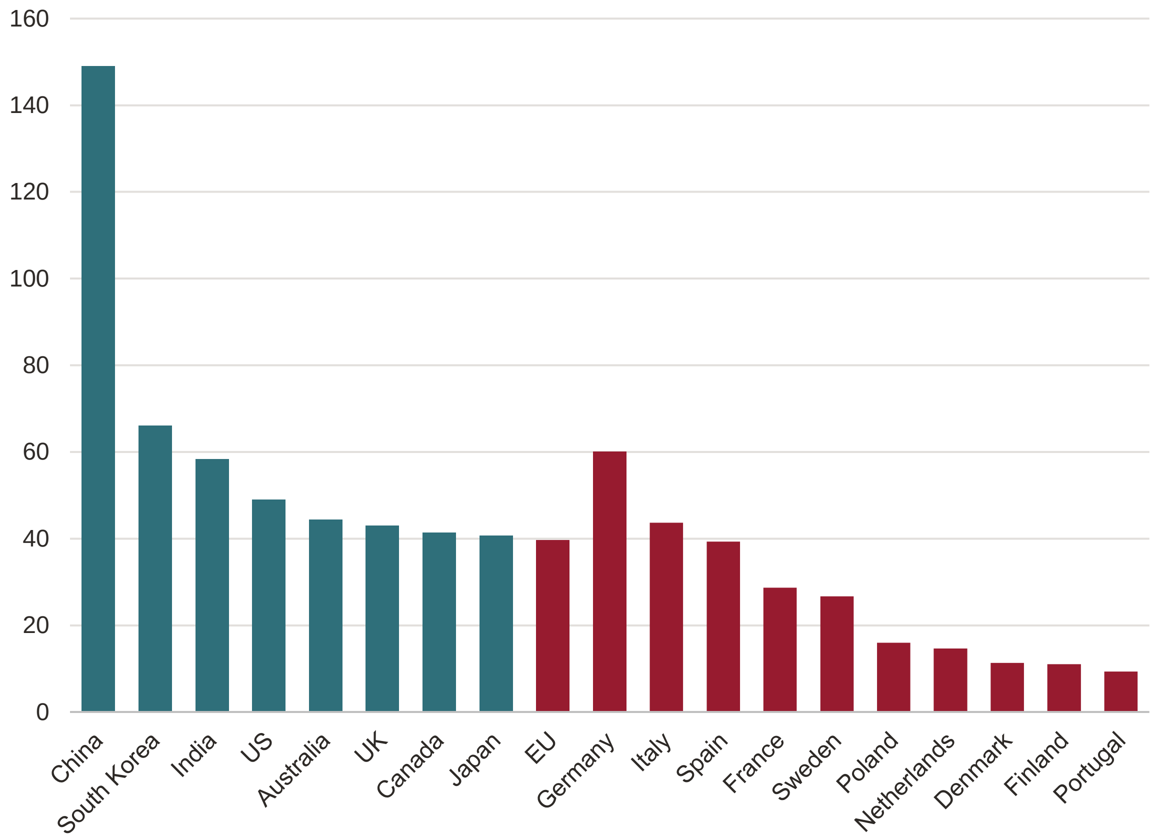
Source: ASPI

Figure 29 Number of leading publications per million people for energy technologies



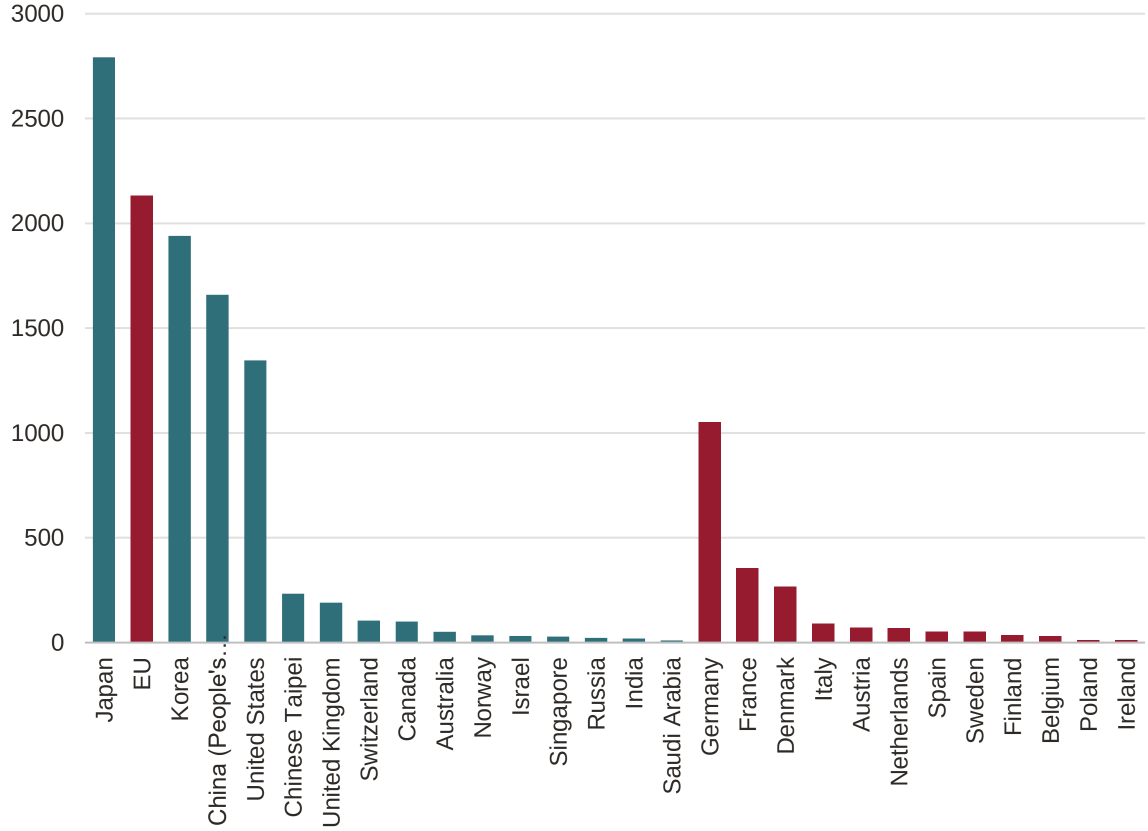
Source: ASPI

Figure 30 H-index for energy technologies



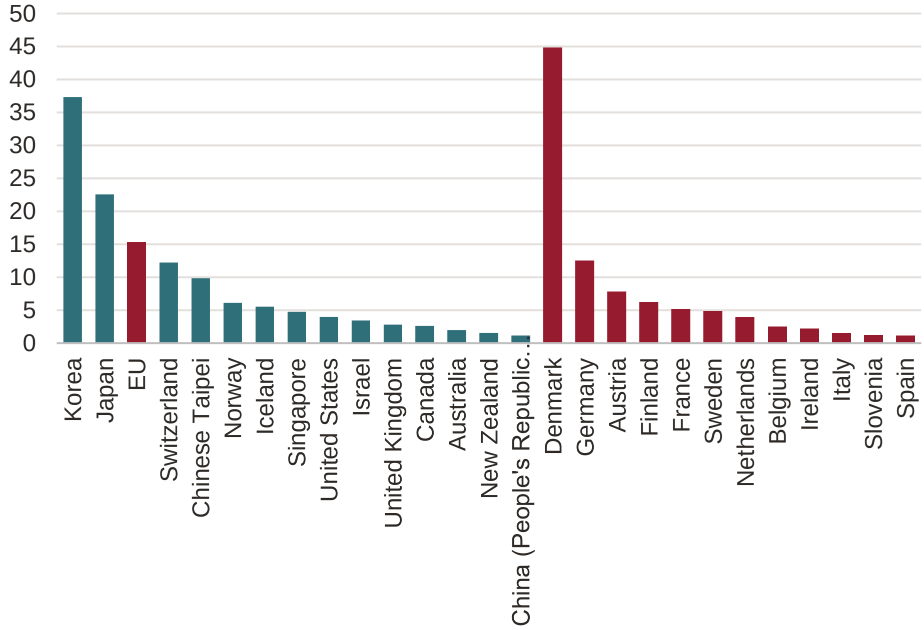
Source: ASPI

Figure 31 Number of patents filed for energy technologies



Source: OECD

Figure 32 Number of patents filed per million people for energy technologies



Source: OECD

Figure 33 Value of start-up and scale-up funding for energy technologies (USD)

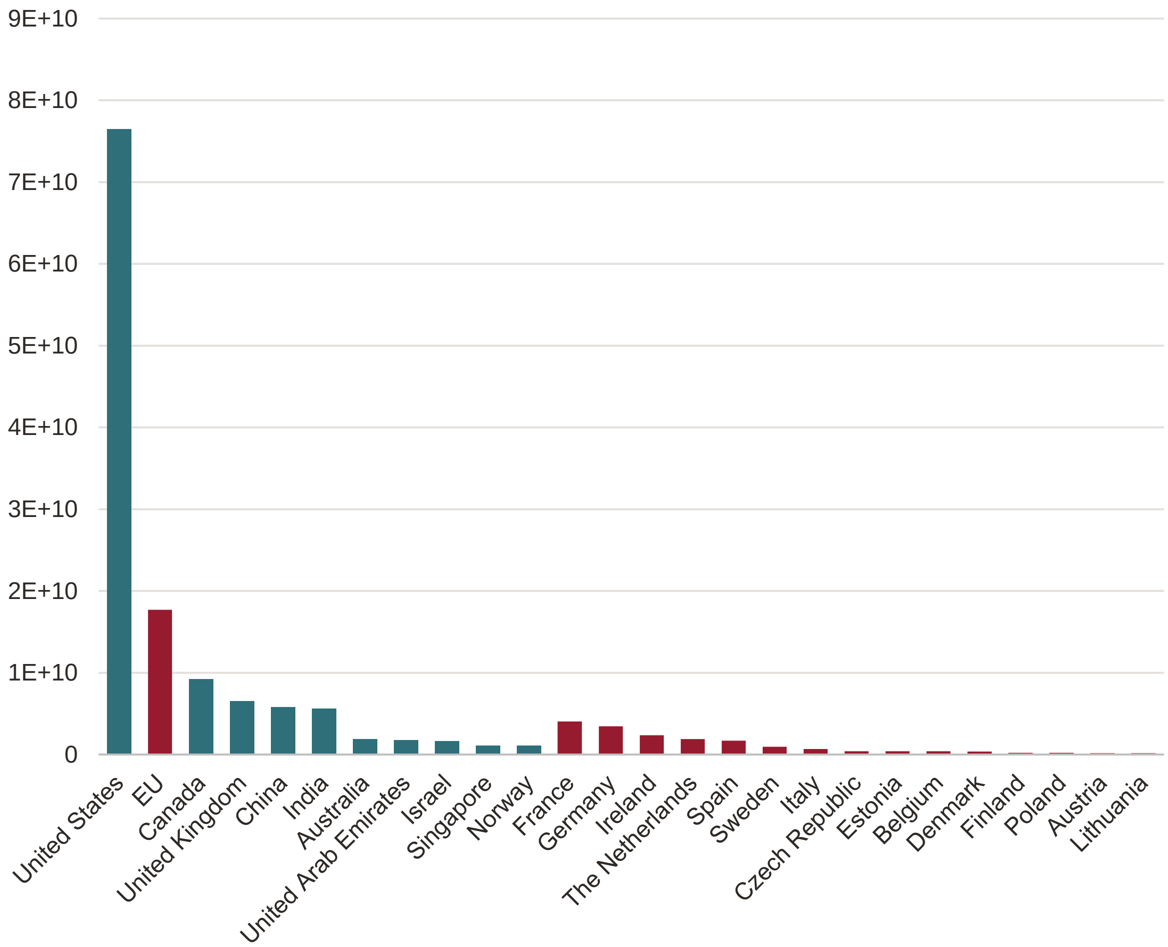
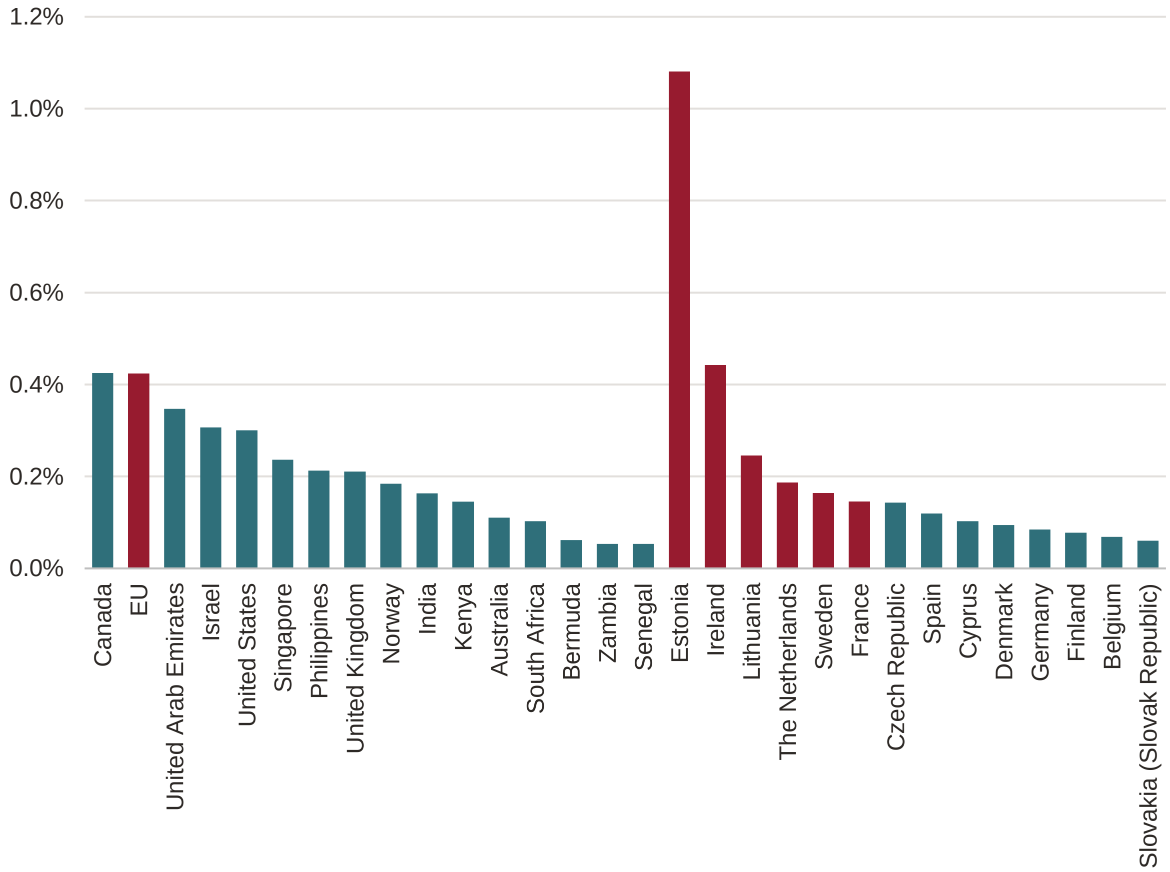
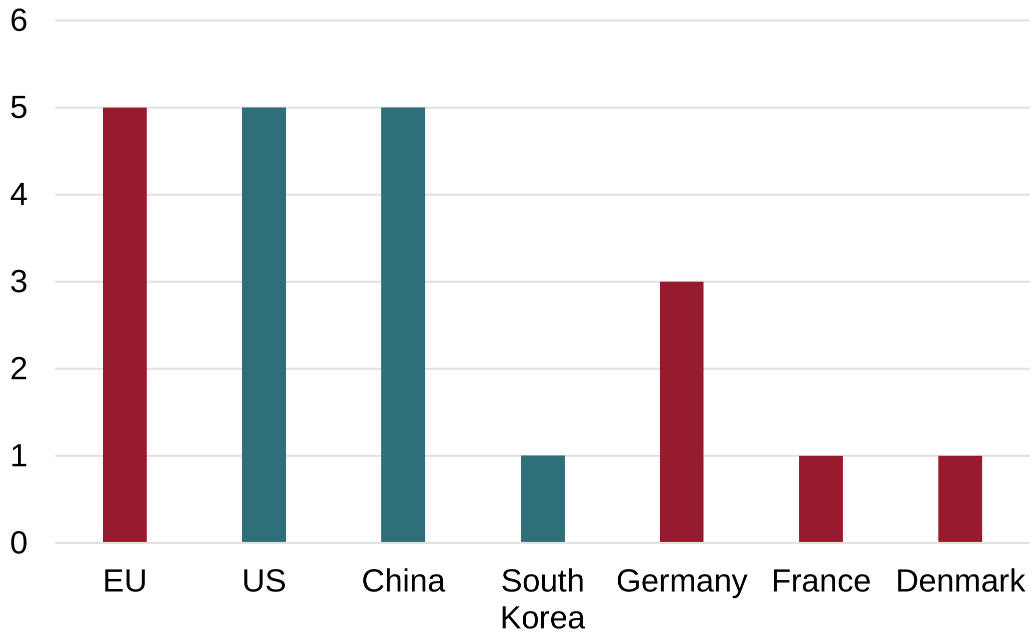


Figure 34 Value of start-up and scale-up funding over GDP for energy technologies



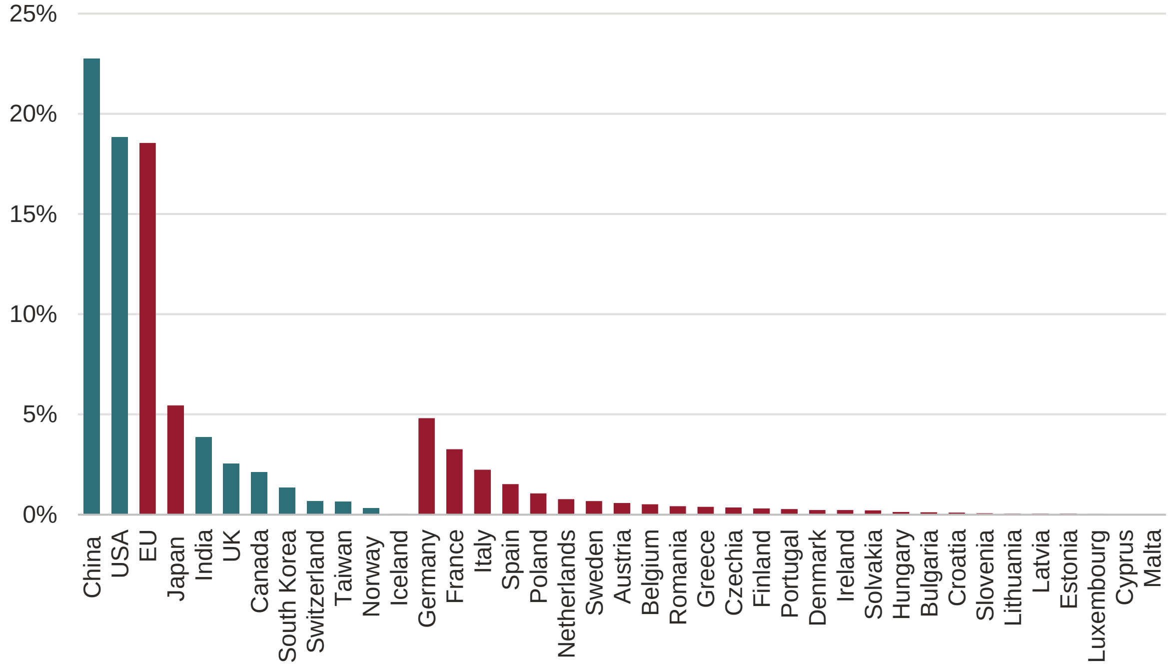
Source: Crunchbase

Figure 35 Count of global leading R&D businesses in energy technologies



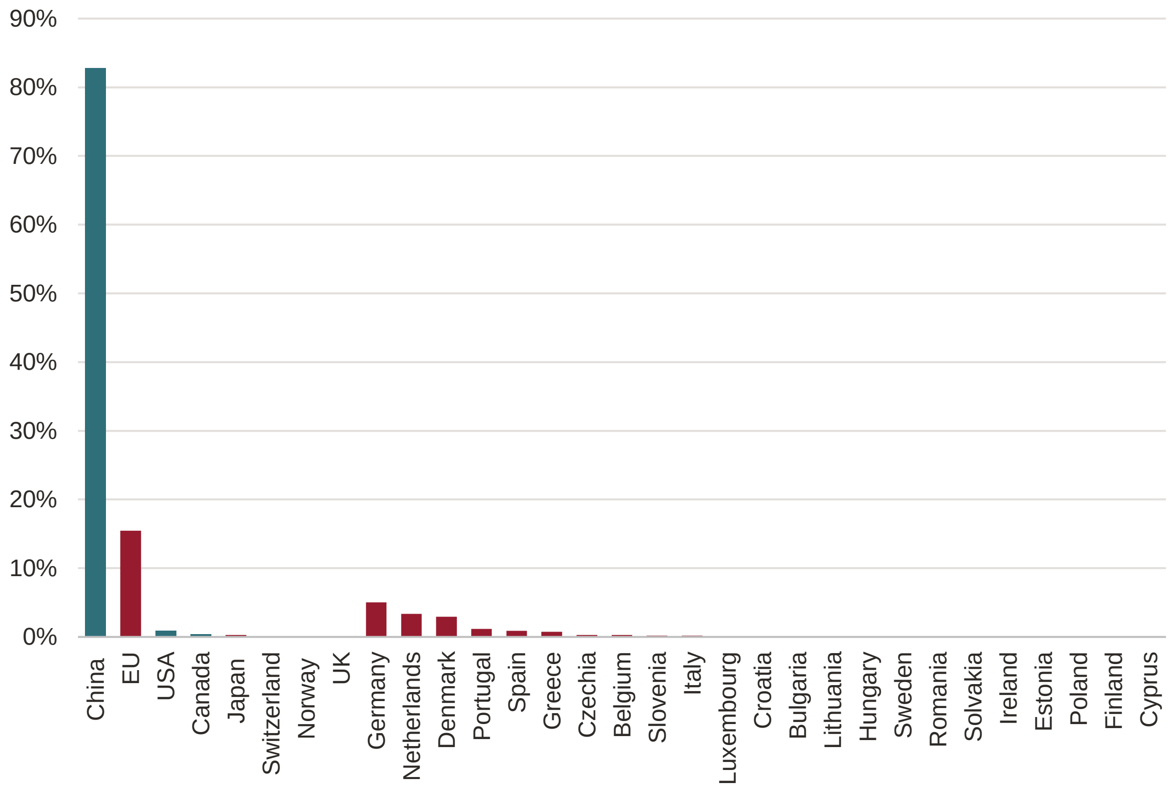
Source: EU Innovation Scoreboard

Figure 36 Market share of global value added for energy technologies



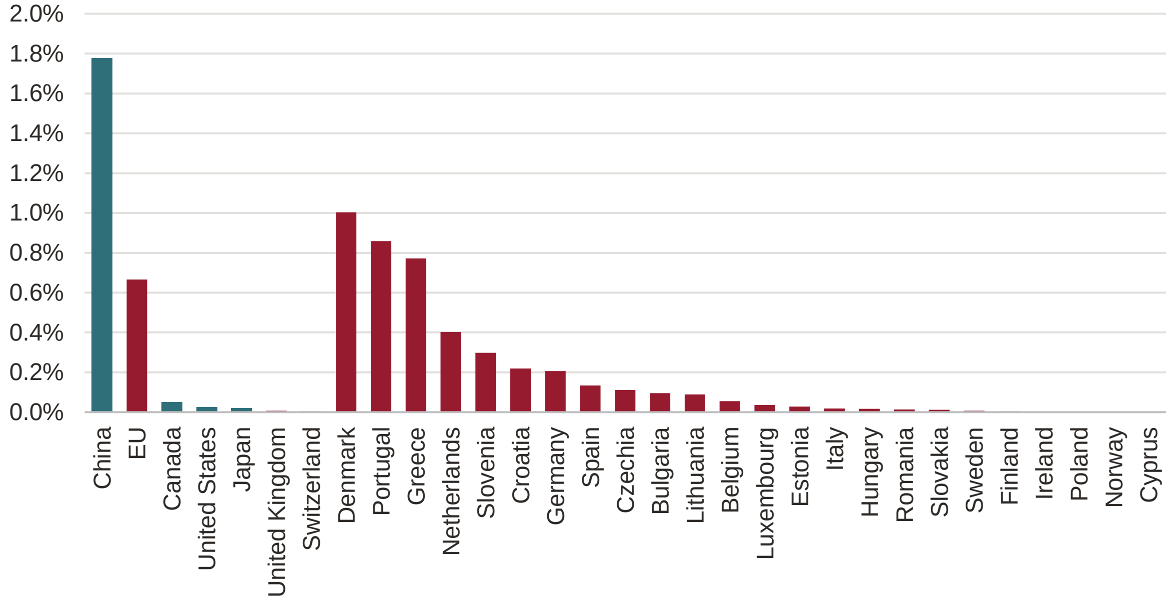
Source: OECD

Figure 37 Global exports market share for energy technologies



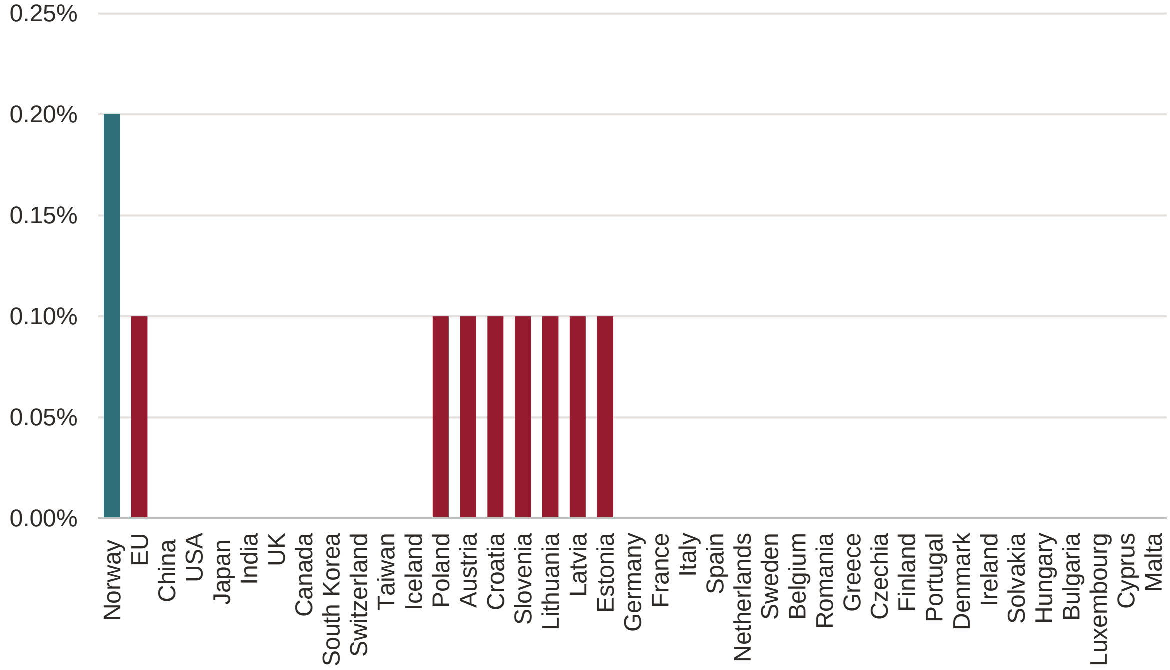
Source: European Innovation Scoreboard

Figure 38 Exports share as a share of country exports for energy technologies



Source: OECD

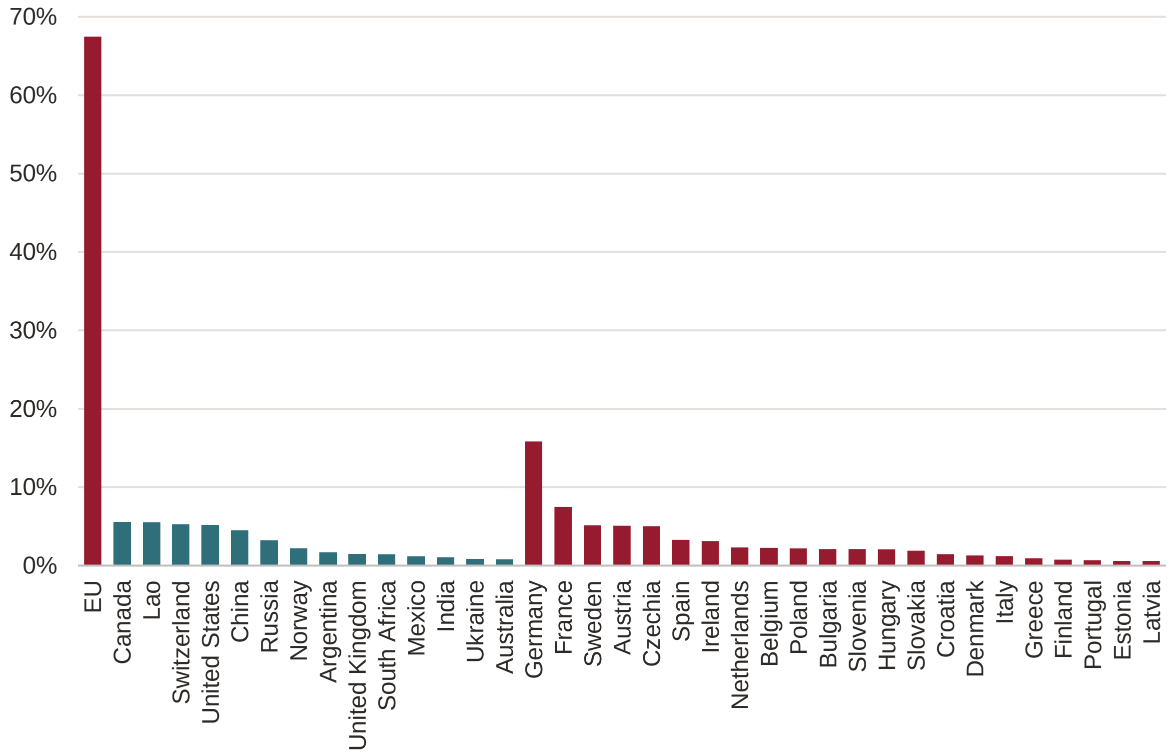
Figure 39 Domestic value added in foreign exports as a share of gross exports for energy technologies



Source: OECD

Note: The data for this indicator is only available up to one decimal point e.g. 0.1%, 0.2%, 0.3%...

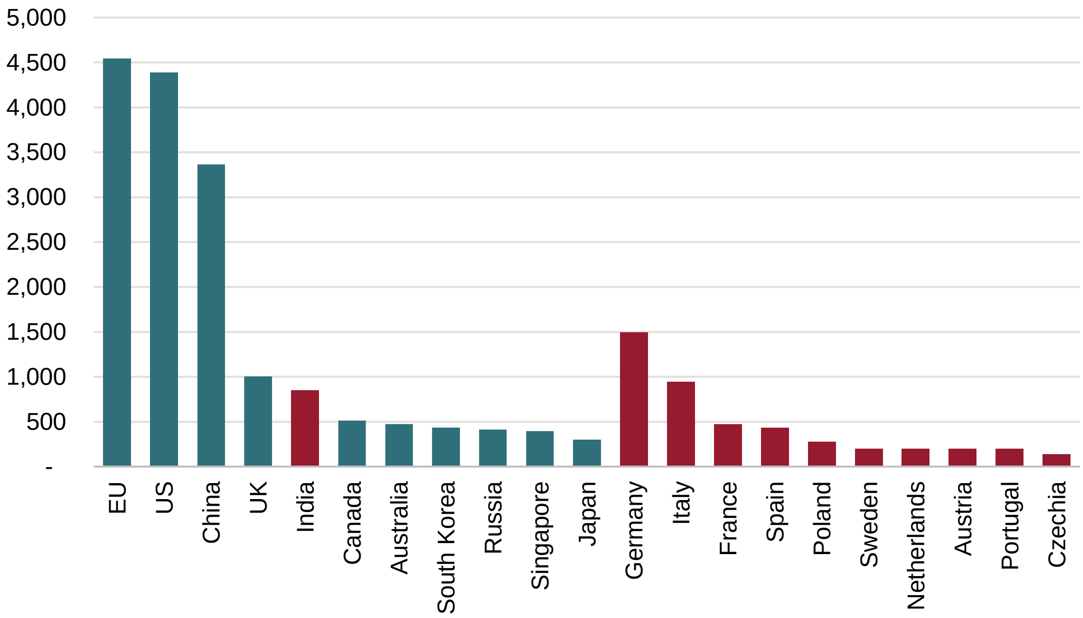
Figure 40 Global intermediate goods exports market share for energy technologies



Source: OECD

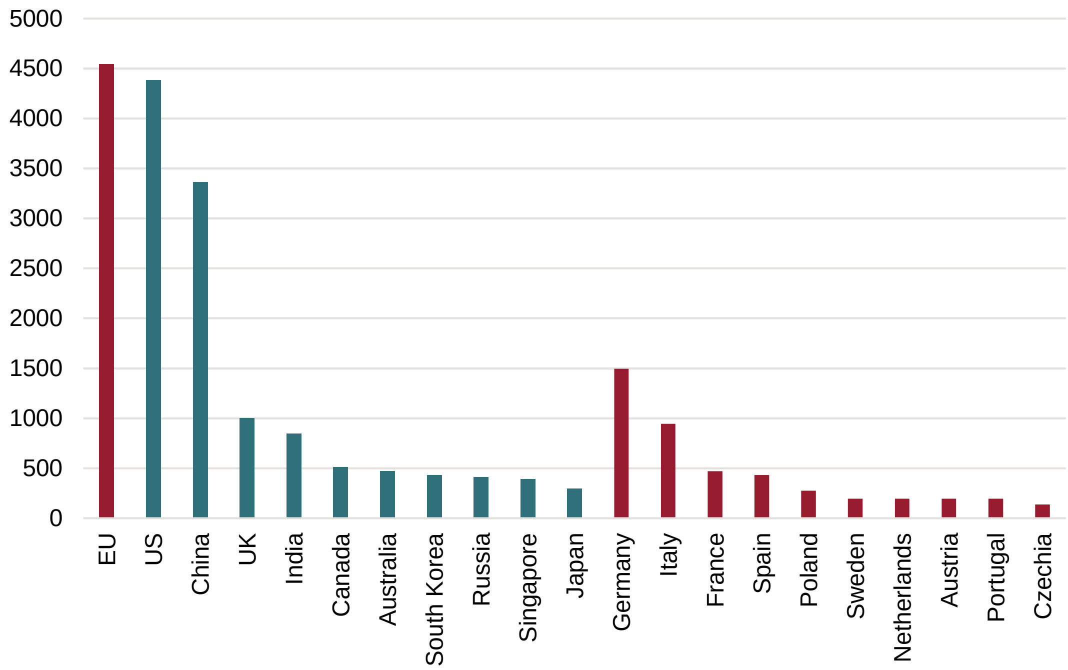
Additive manufacturing

Figure 41 Number of publications for additive manufacturing



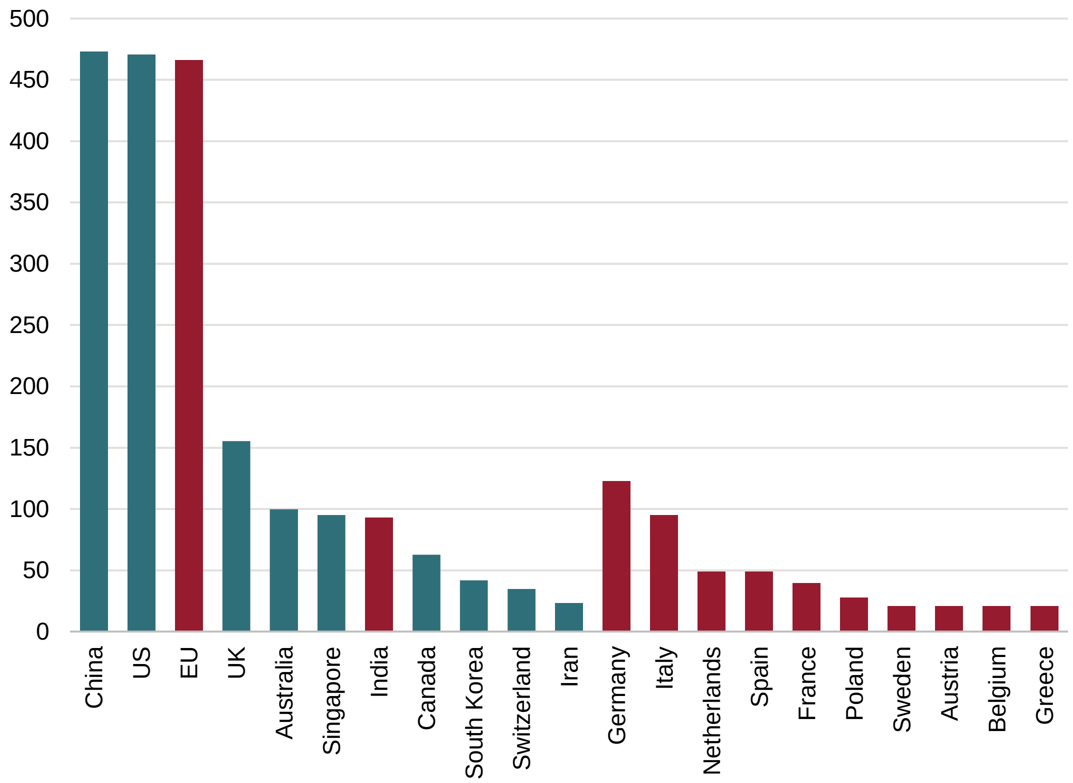
Source: ASPI

Figure 42 Number of publications per million people for additive manufacturing



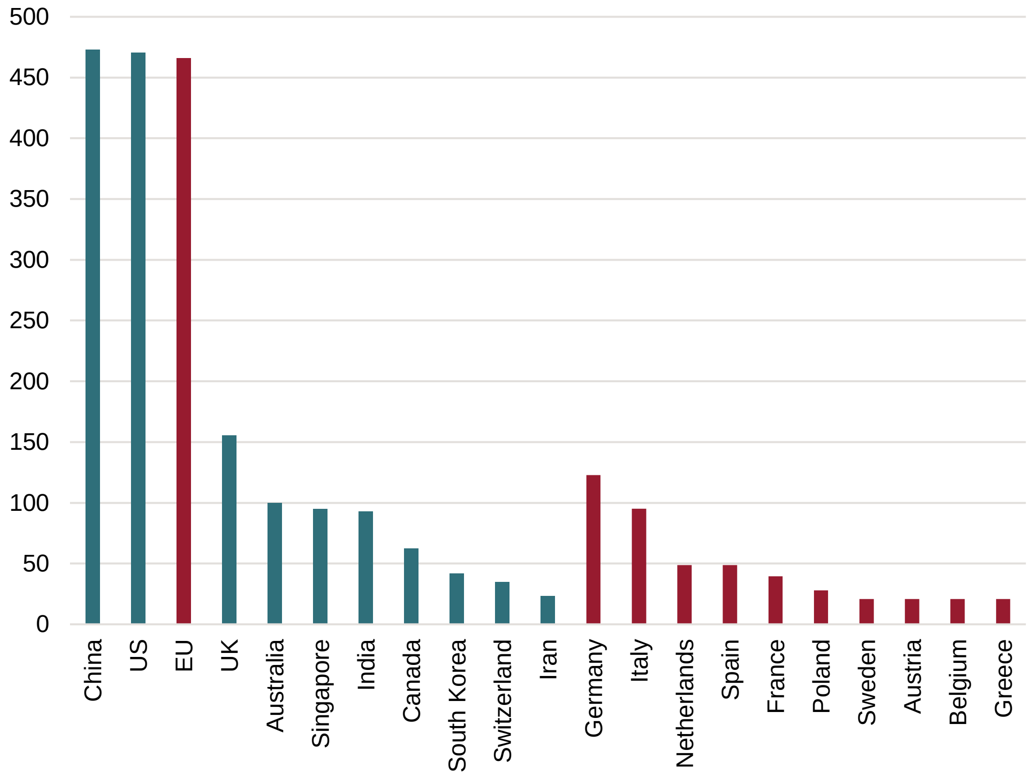
Source: ASPI

Figure 43 Number of leading publications for additive manufacturing



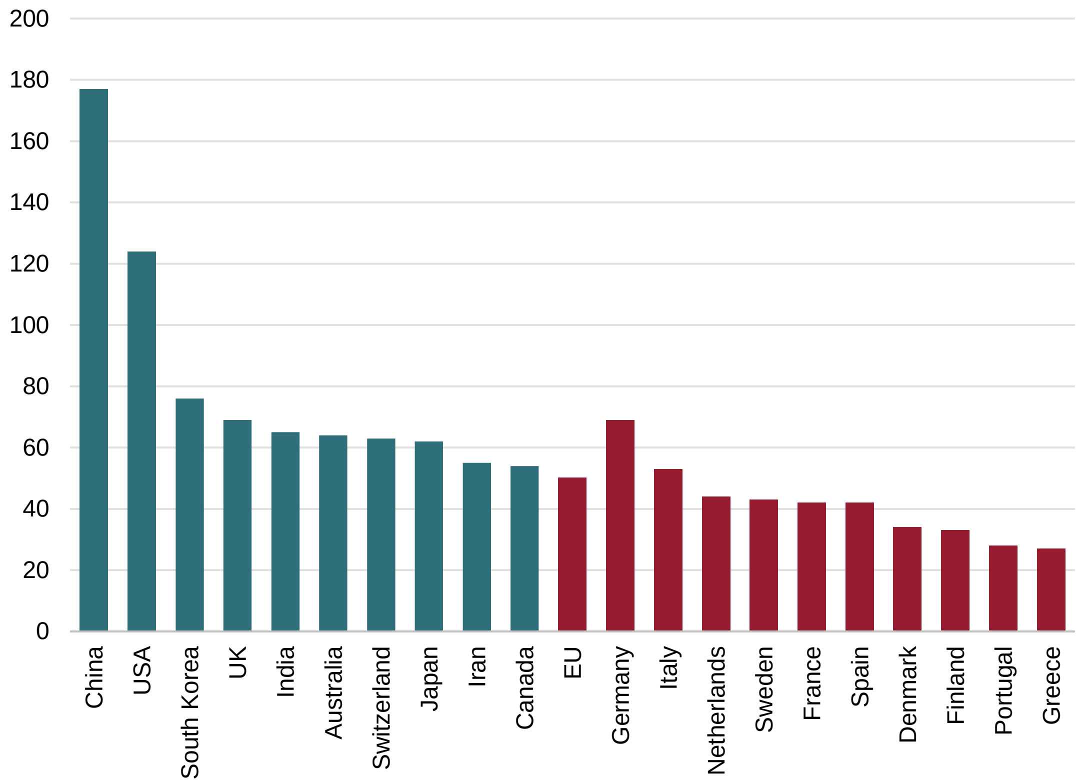
Source: ASPI

Figure 44 Number of leading publications per million people for additive manufacturing



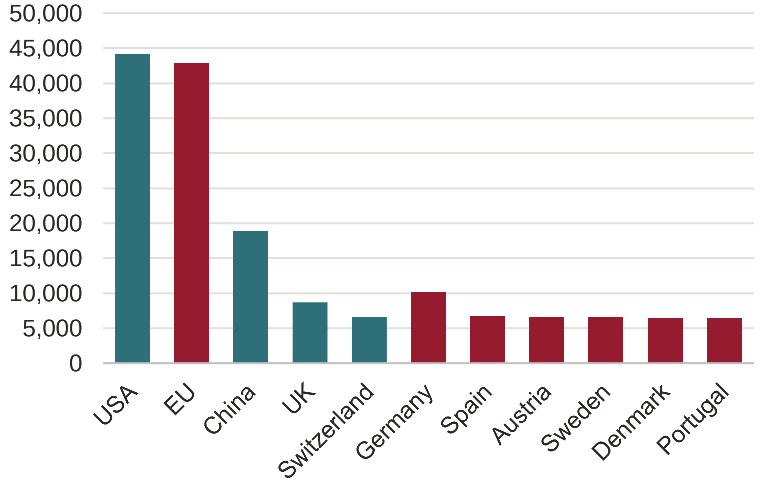
Source: ASPI

Figure 45 H-index for additive manufacturing



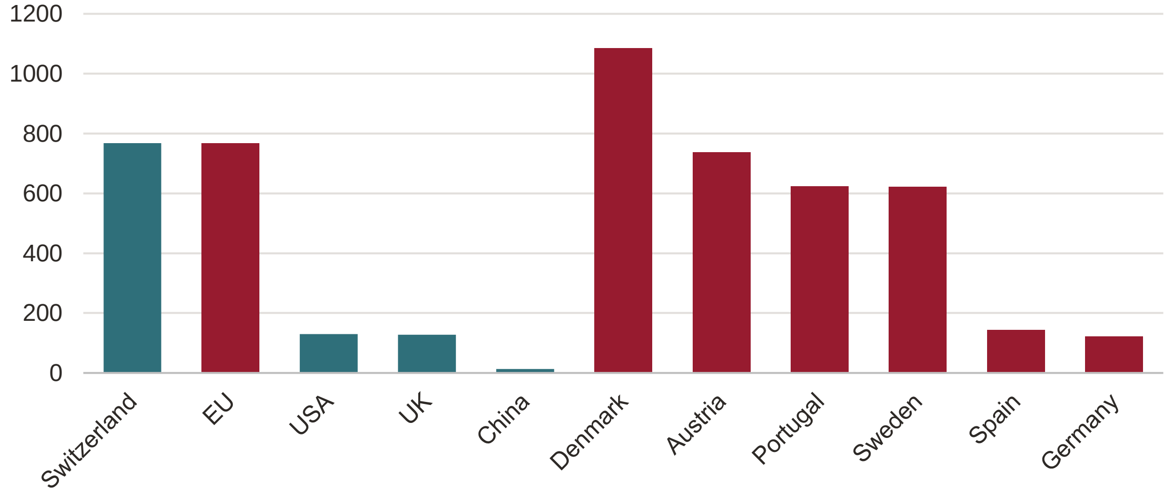
Source: ASPI

Figure 46 Number of patents filed for additive manufacturing



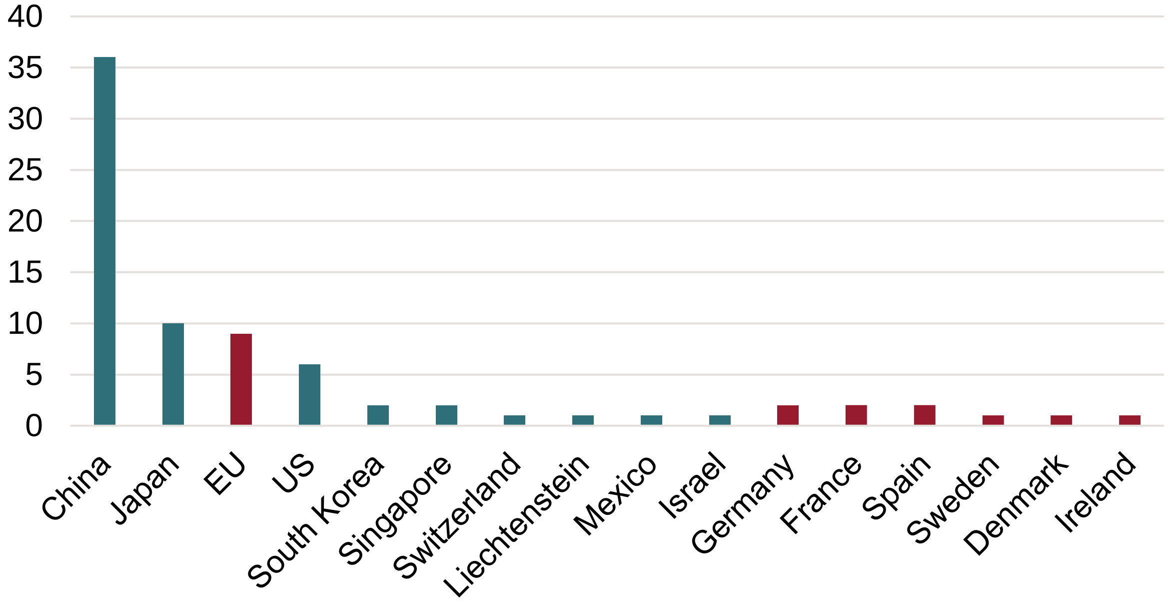
Source: iam-media.com

Figure 47 Number of patents filed per million people for additive manufacturing



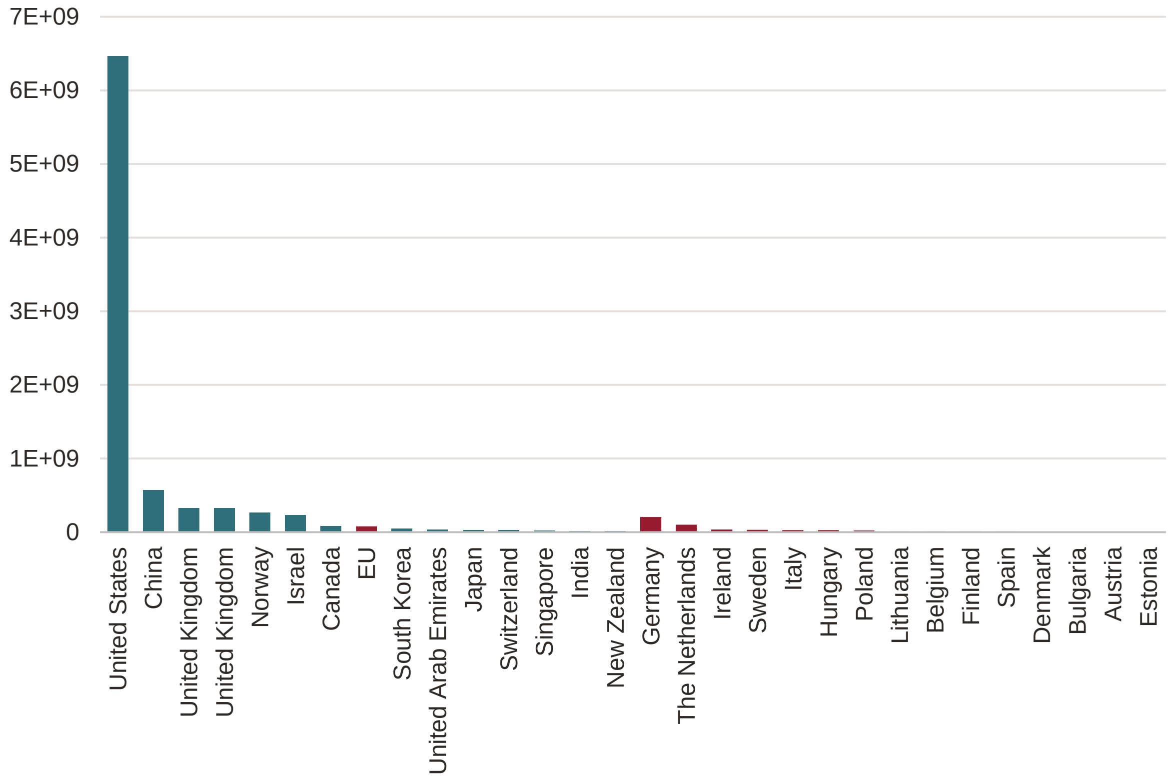
Source: iam-media.com

Figure Count of global leading R&D businesses in additive manufacturing



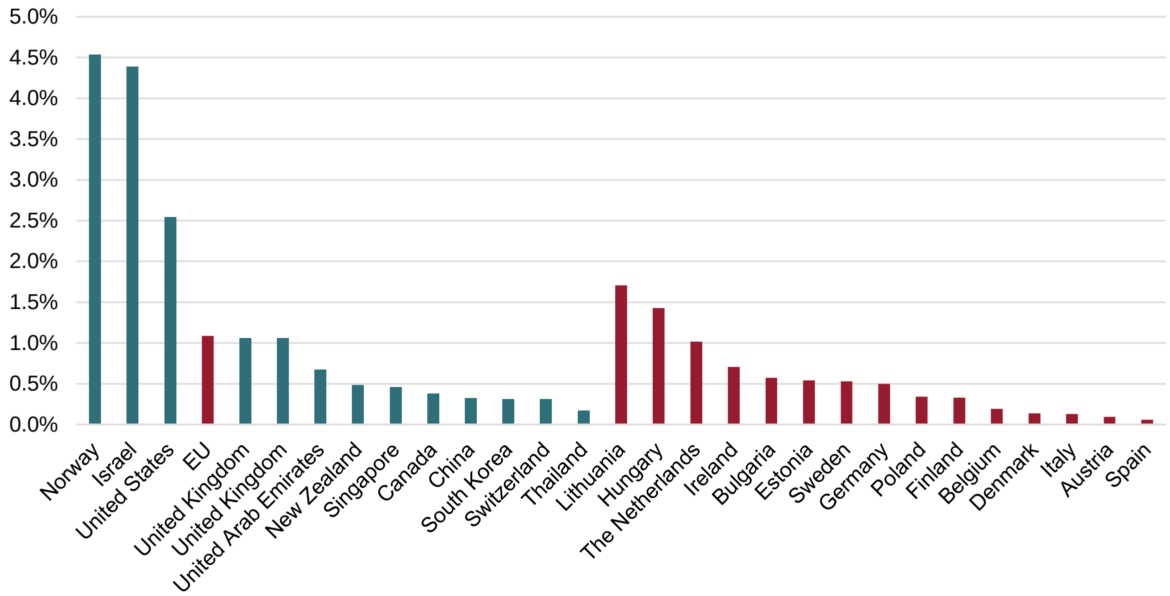
Source: European innovation Scoreboard

Figure 48 Value of start-up and scale-up funding for additive manufacturing (USD)



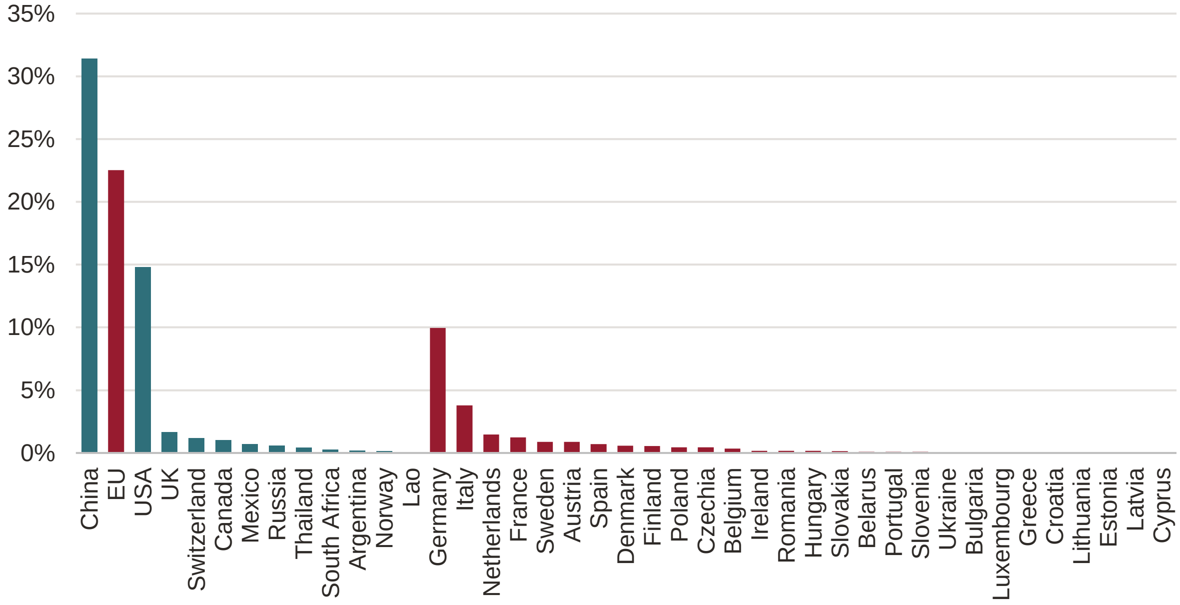
Source: Crunchbase

Figure 49 Value of start-up and scale-up funding over GDP for additive manufacturing



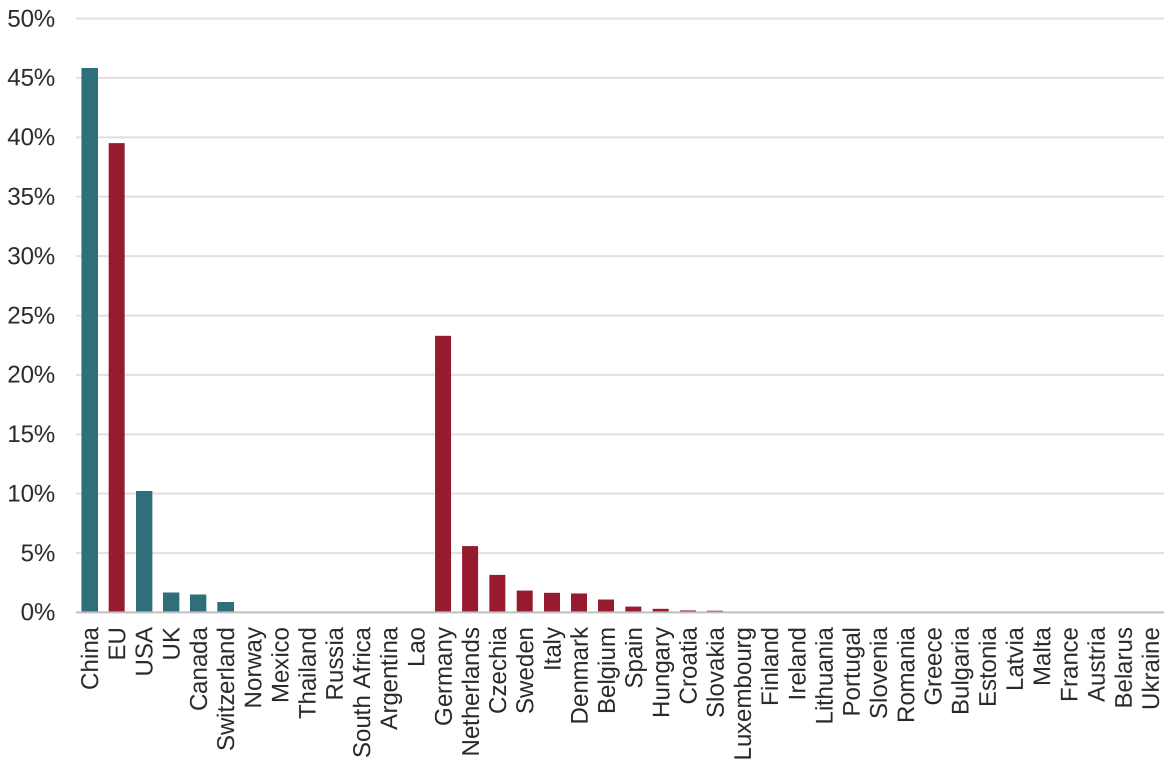
Source: Crunchbase

Figure 12950 Market share of global value added for additive manufacturing



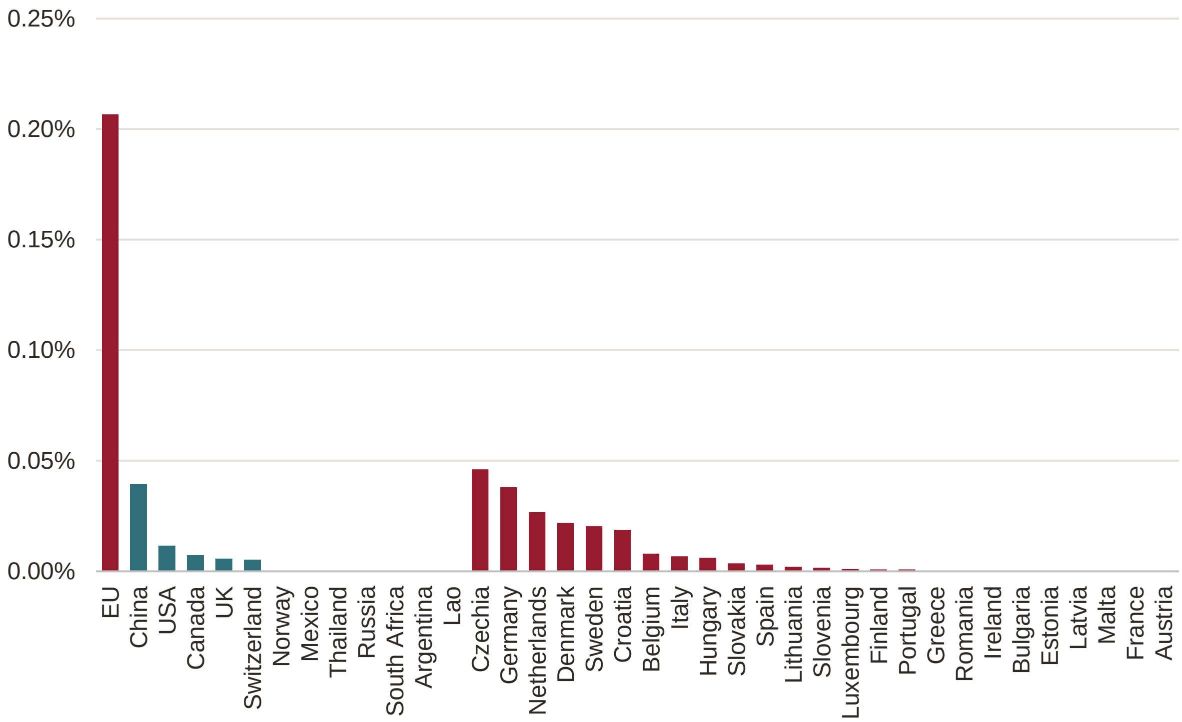
Source: OECD

Figure 51 Global exports market share for additive manufacturing



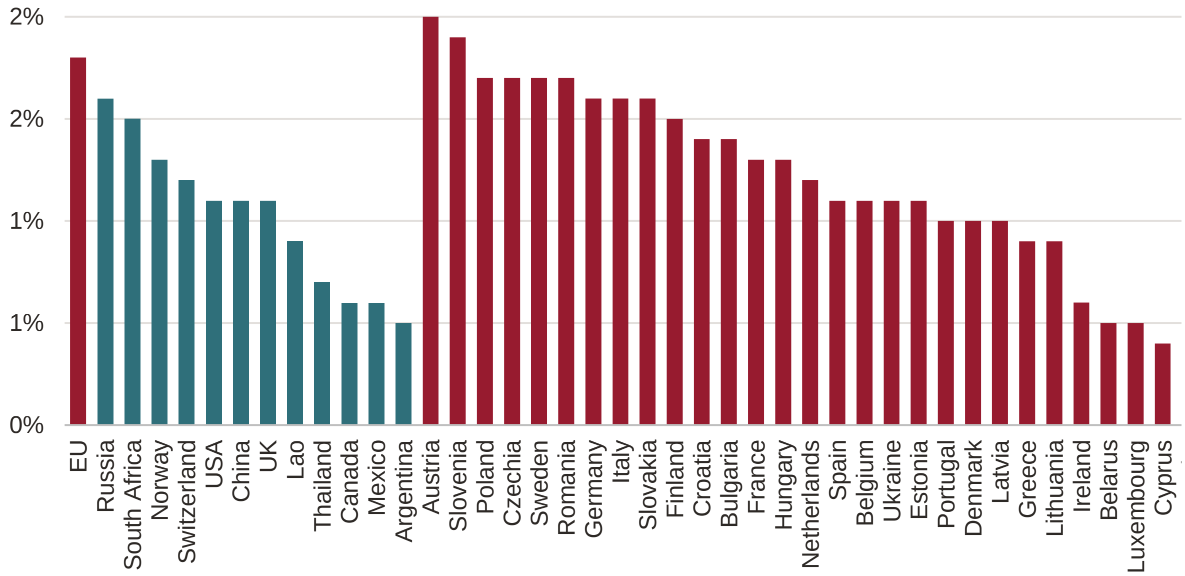
Source: OECD

Figure 52 Exports share as a share of country exports for additive manufacturing



Source: OECD

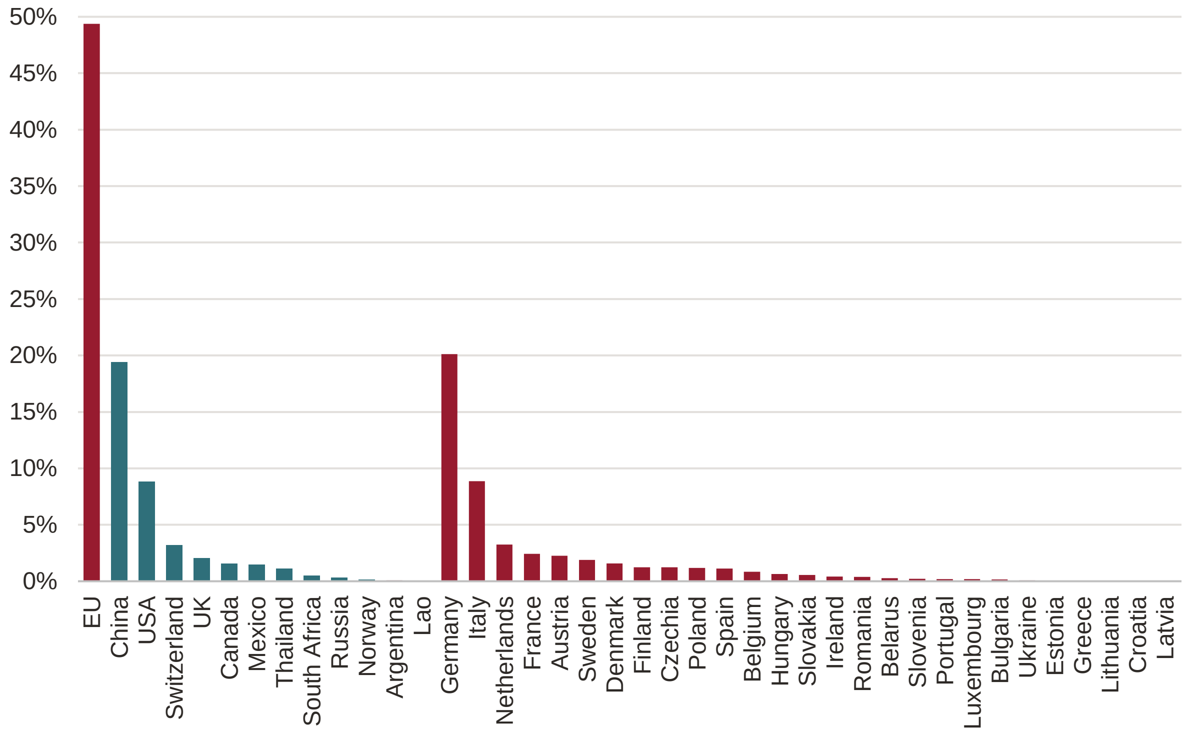
Figure 53 Domestic value added in foreign exports as a share of gross exports for additive manufacturing



Source: OECD

Note: The data for this indicator is only available up to one decimal point e.g. 0.1%, 0.2%, 0.3%...

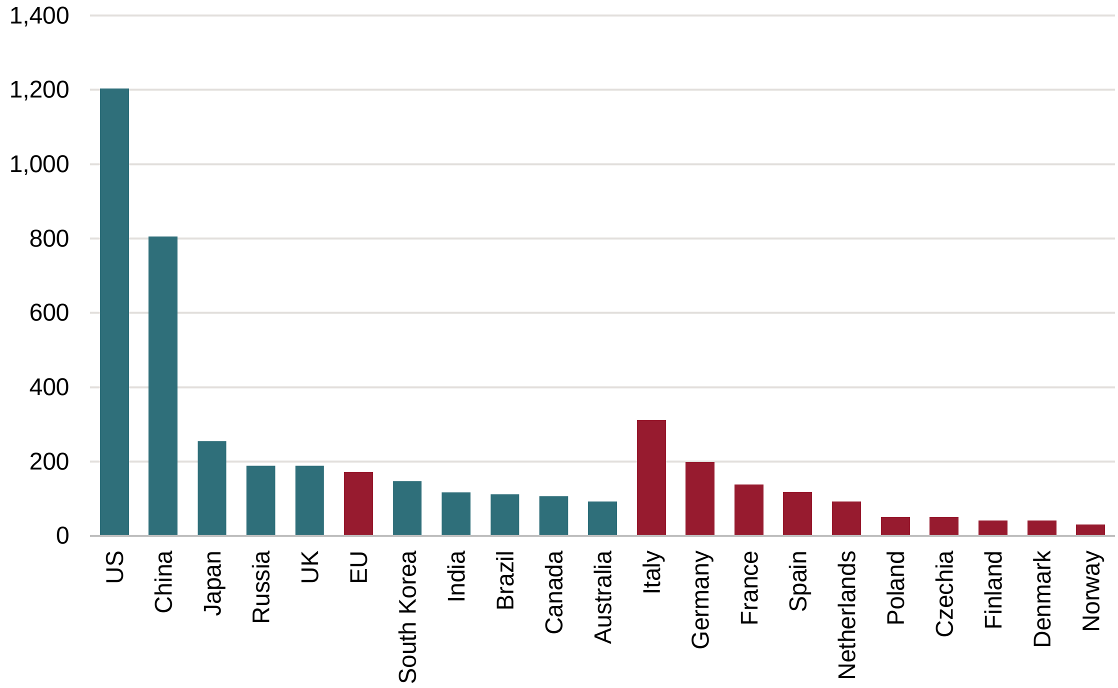
Figure 54 Global intermediate goods exports market share for additive manufacturing



Source: OECD

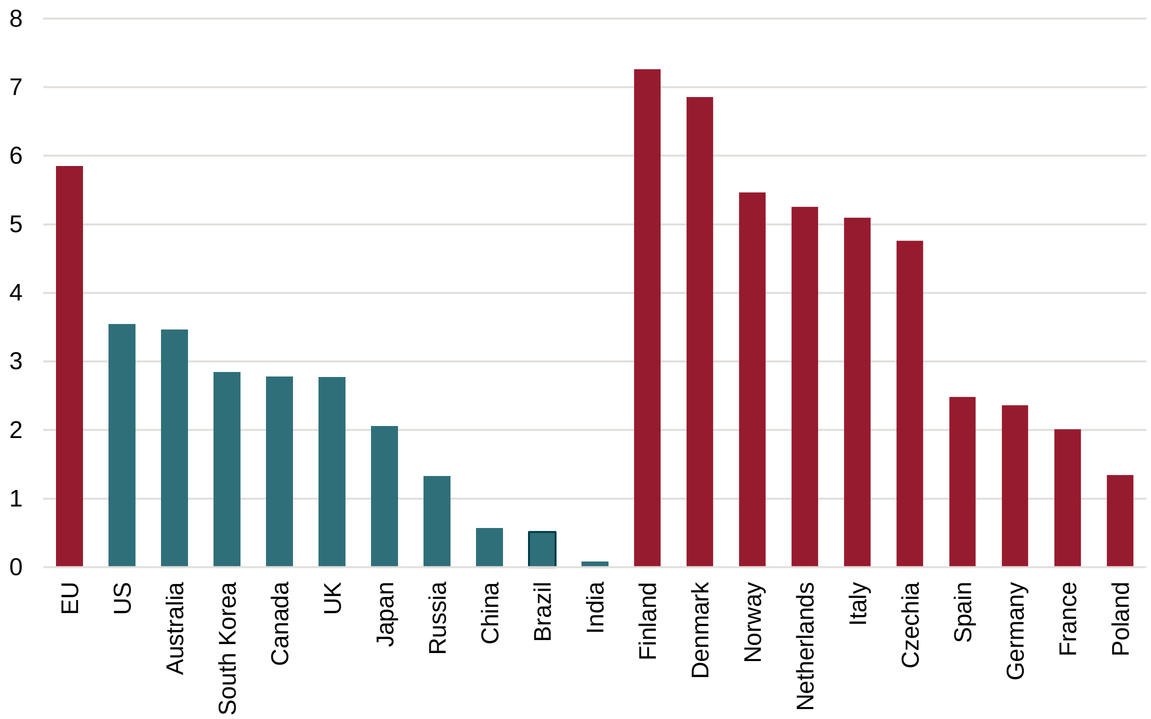
Space technologies

Figure 55 Number of publications for space technologies



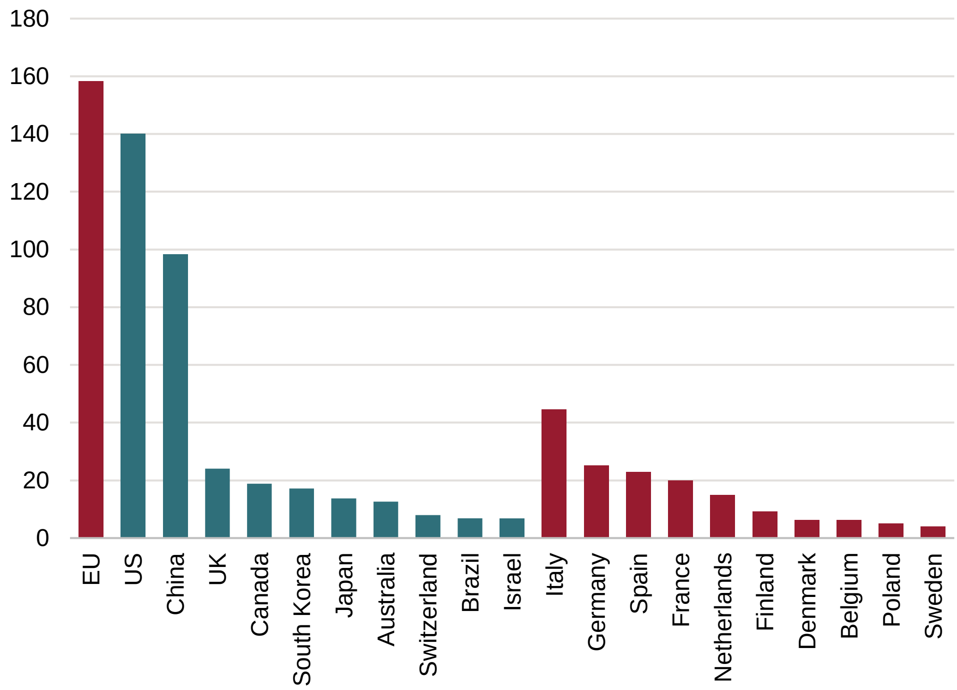
Source: ASPI

Figure 56 Number of publications per million people for space technologies



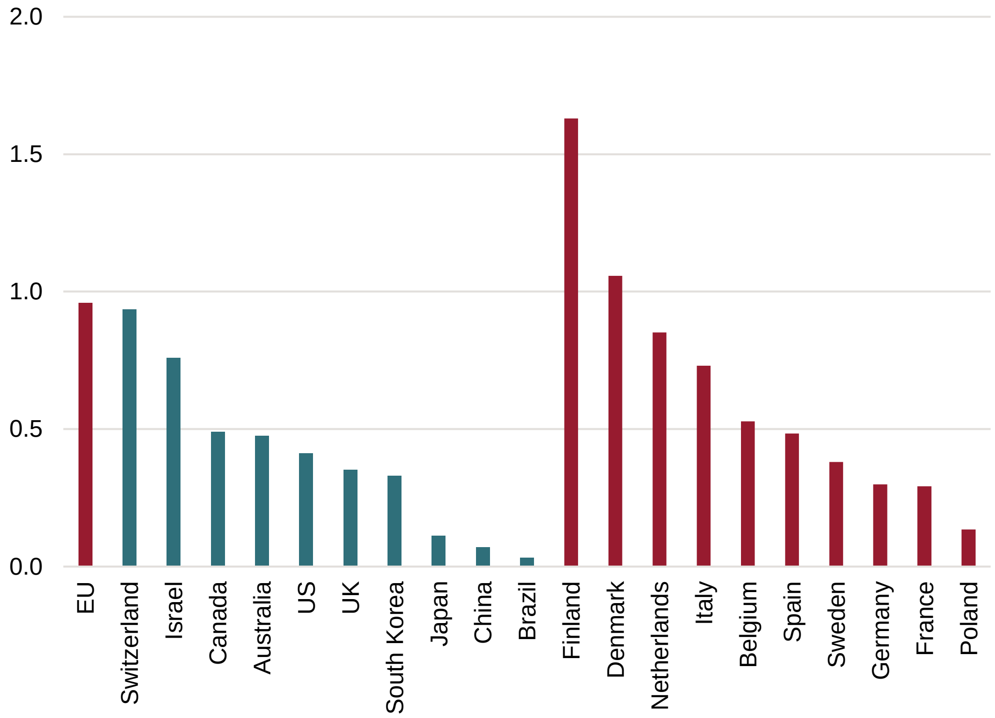
Source: ASPI

Figure Number of leading publications for space technologies



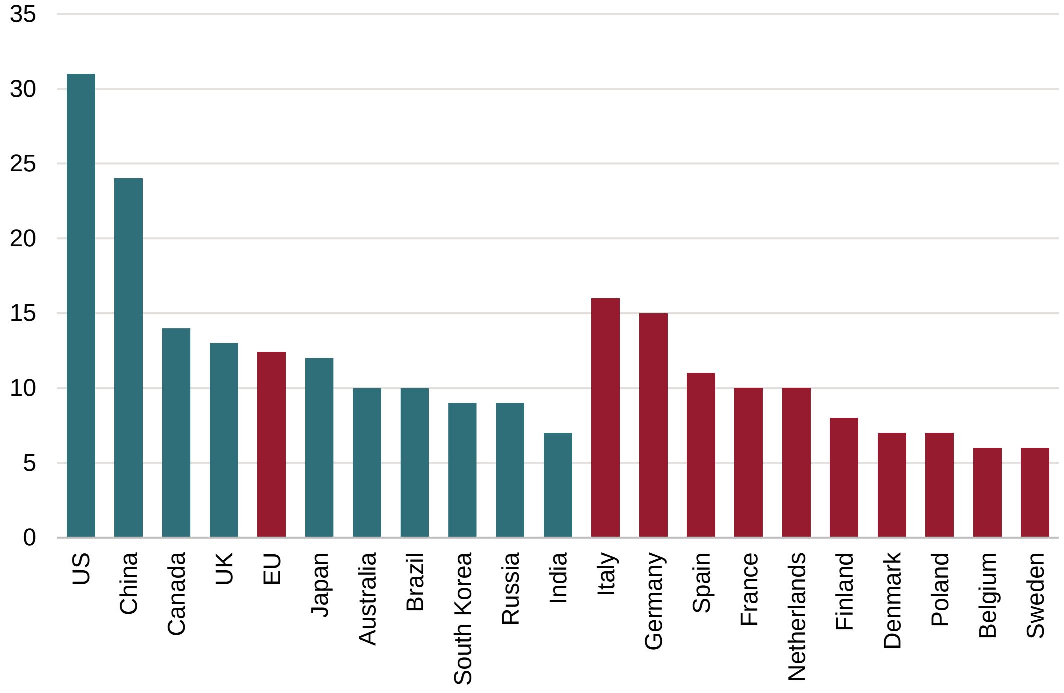
Source: ASPI

Figure Number of leading publications per million people for space technologies



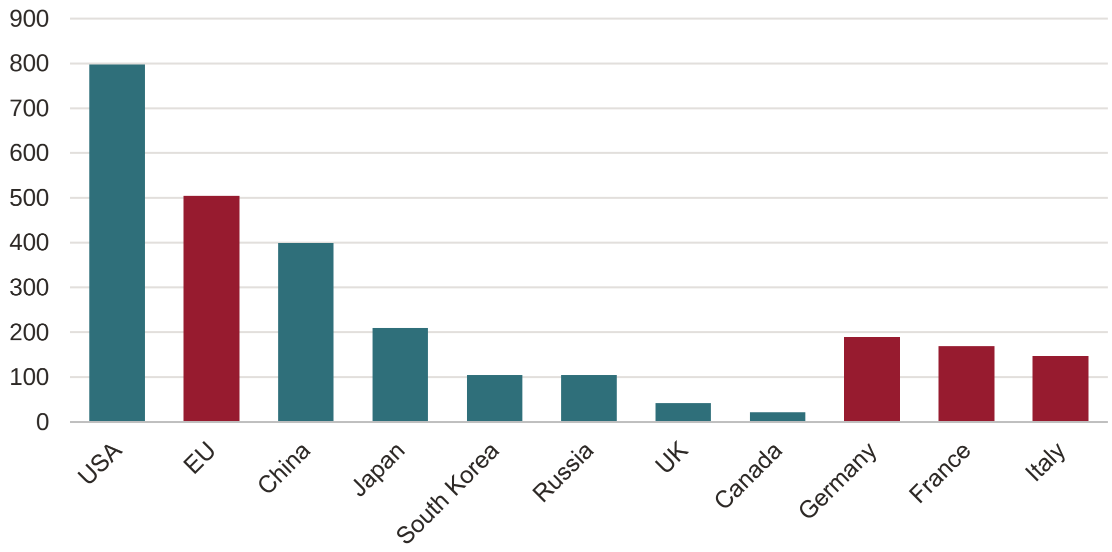
Source: ASPI

Figure 57 H-index for space technologies



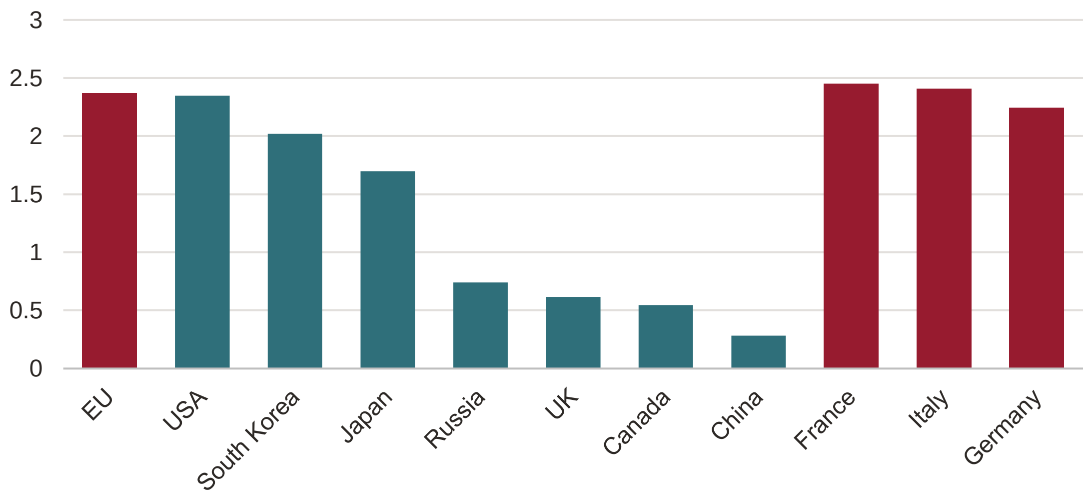
Source: ASPI

Figure 58 Number of patents filed for space technologies



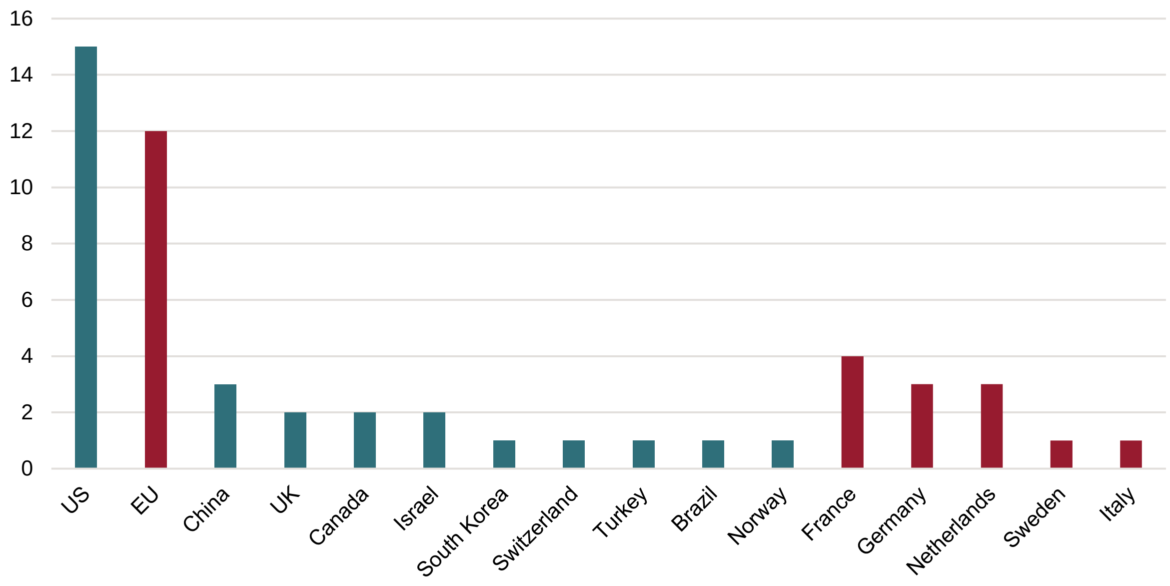
Source: D Young & Co

Figure 59 Number of patents filed per million people for space technologies



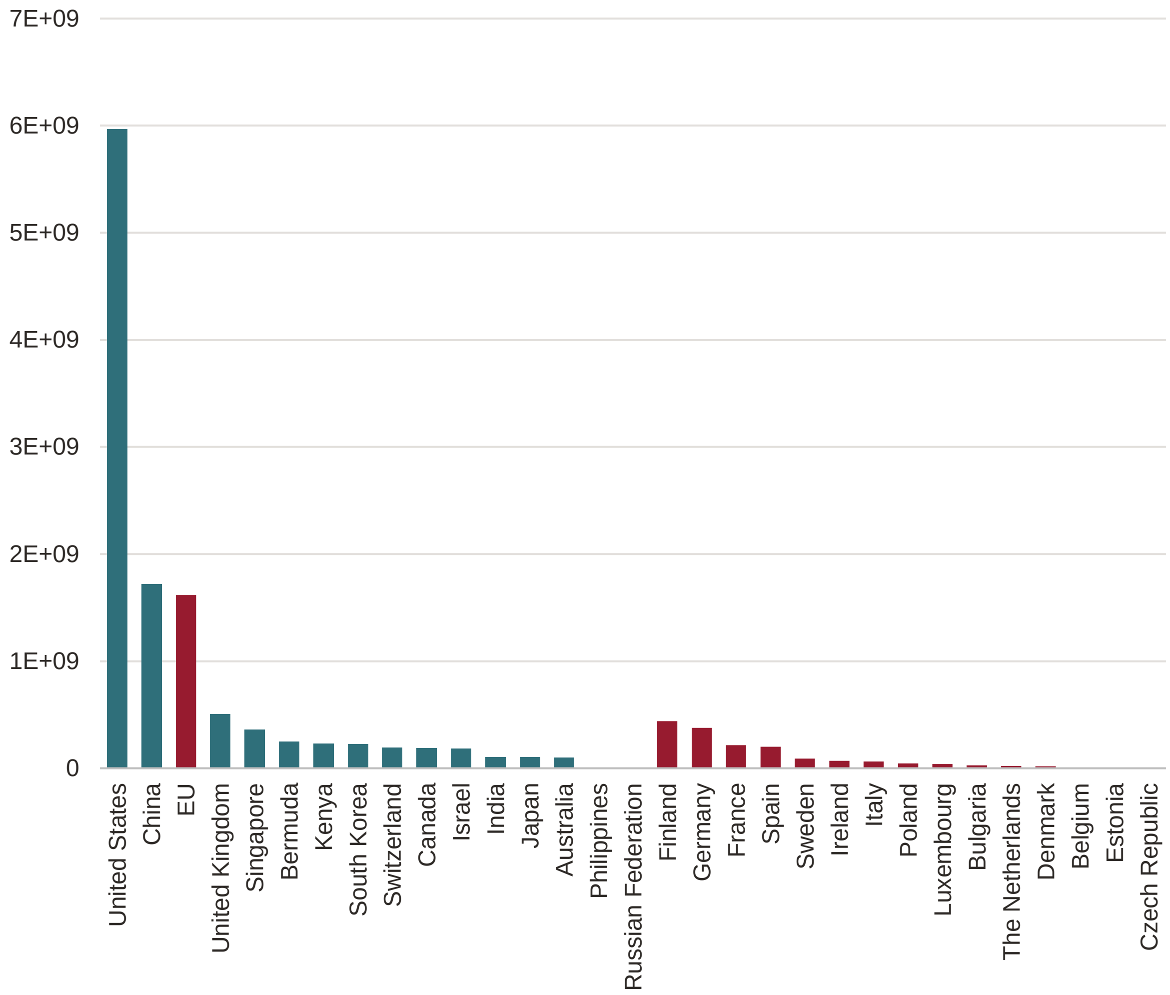
Source: D Young & Co

Figure 60 Count of global leading R&D businesses in space technologies



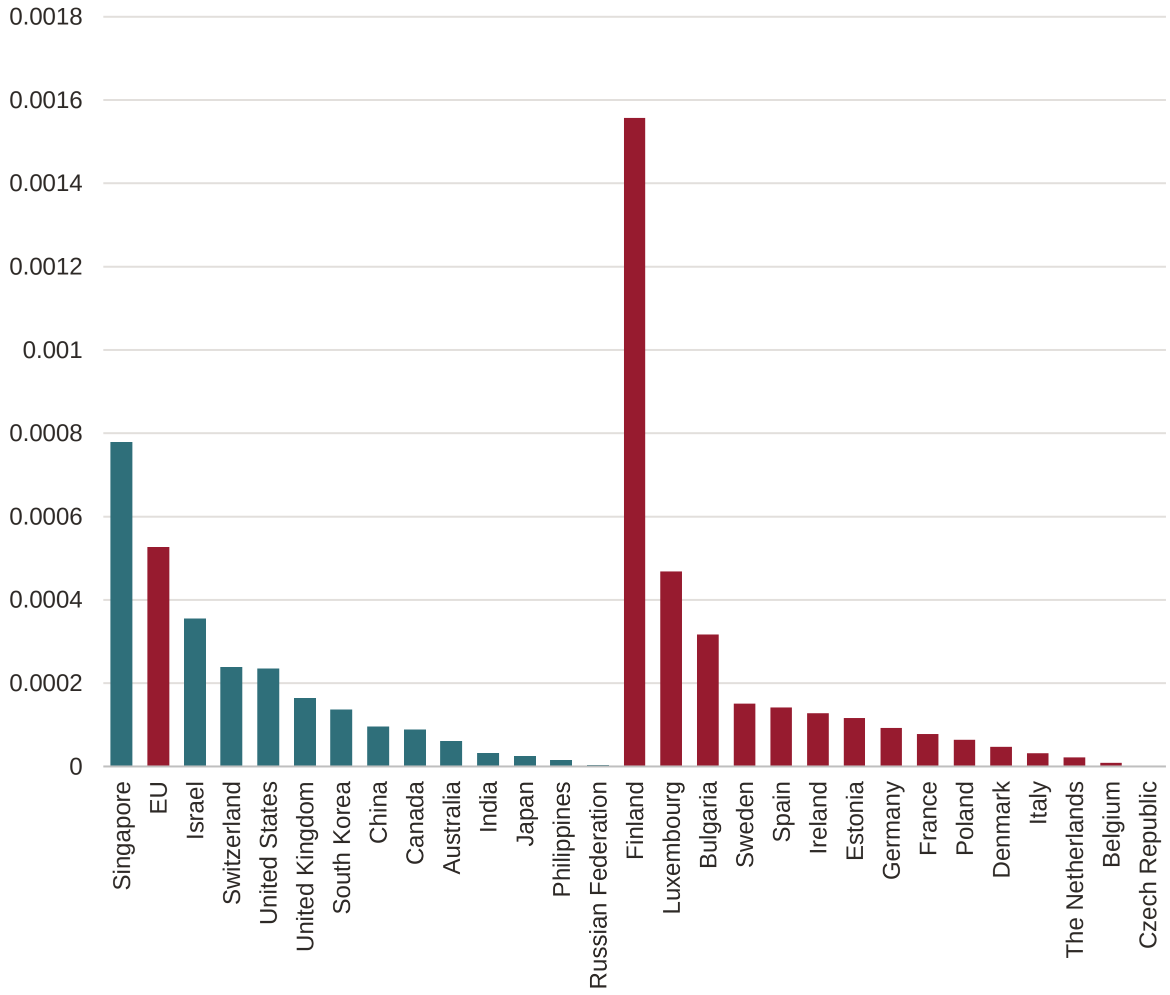
Source: European Innovation Scoreboard

Figure61 Value of start-up and scale-up funding for space technologies (USD)



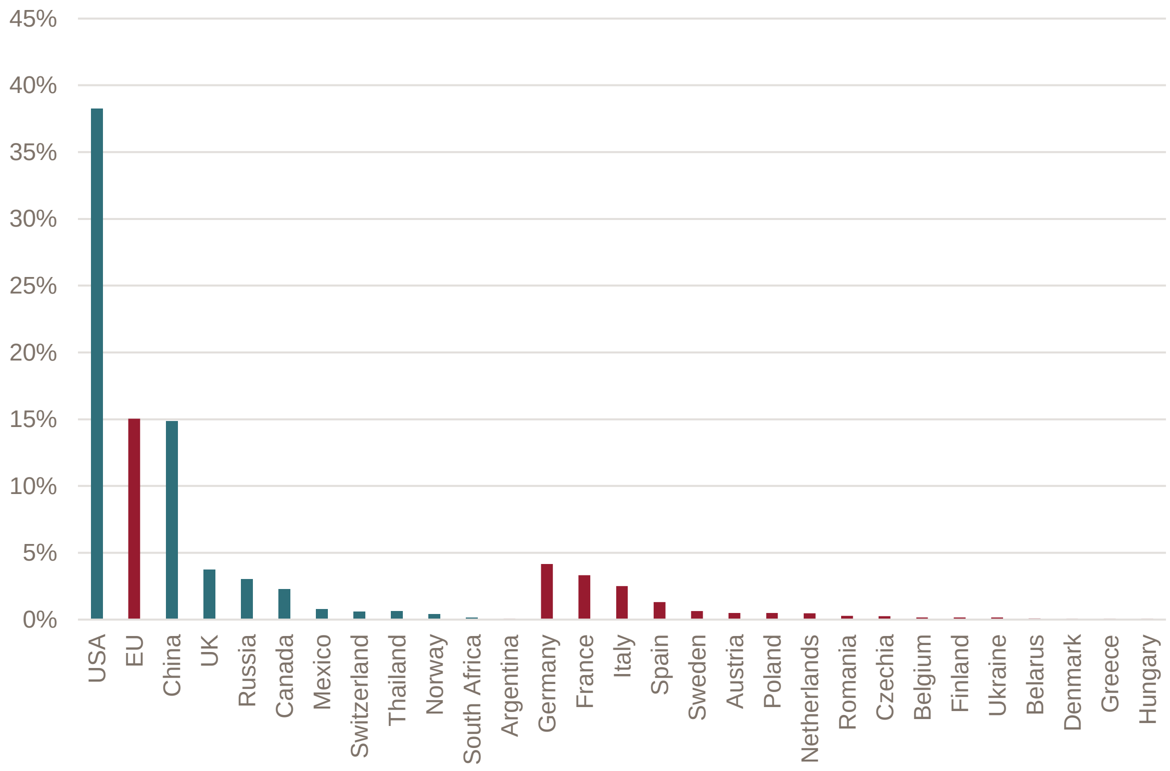
Source: Crunchbase

Figure62 Value of start-up and scale-up funding over GDP for space technologies



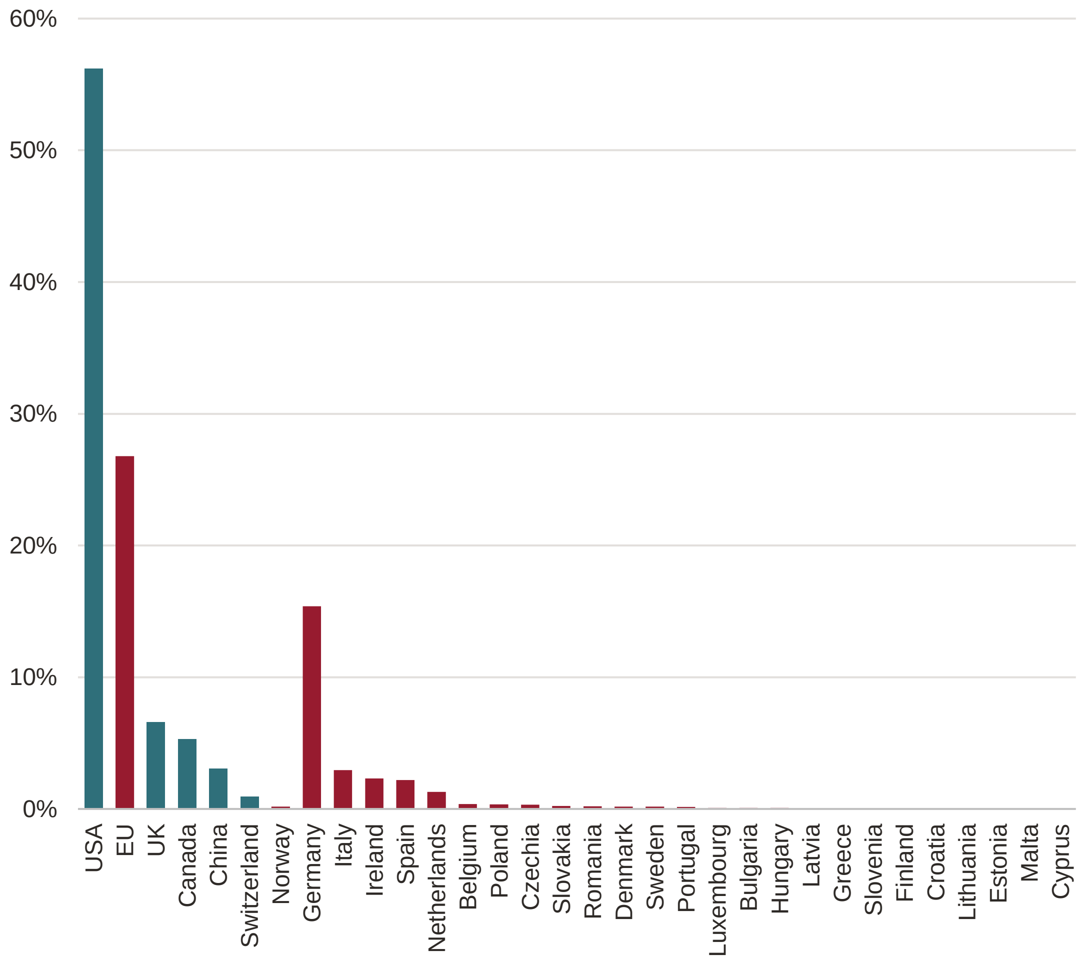
Source: Crunchbase

Figure63 Market share of global value added for space technologies



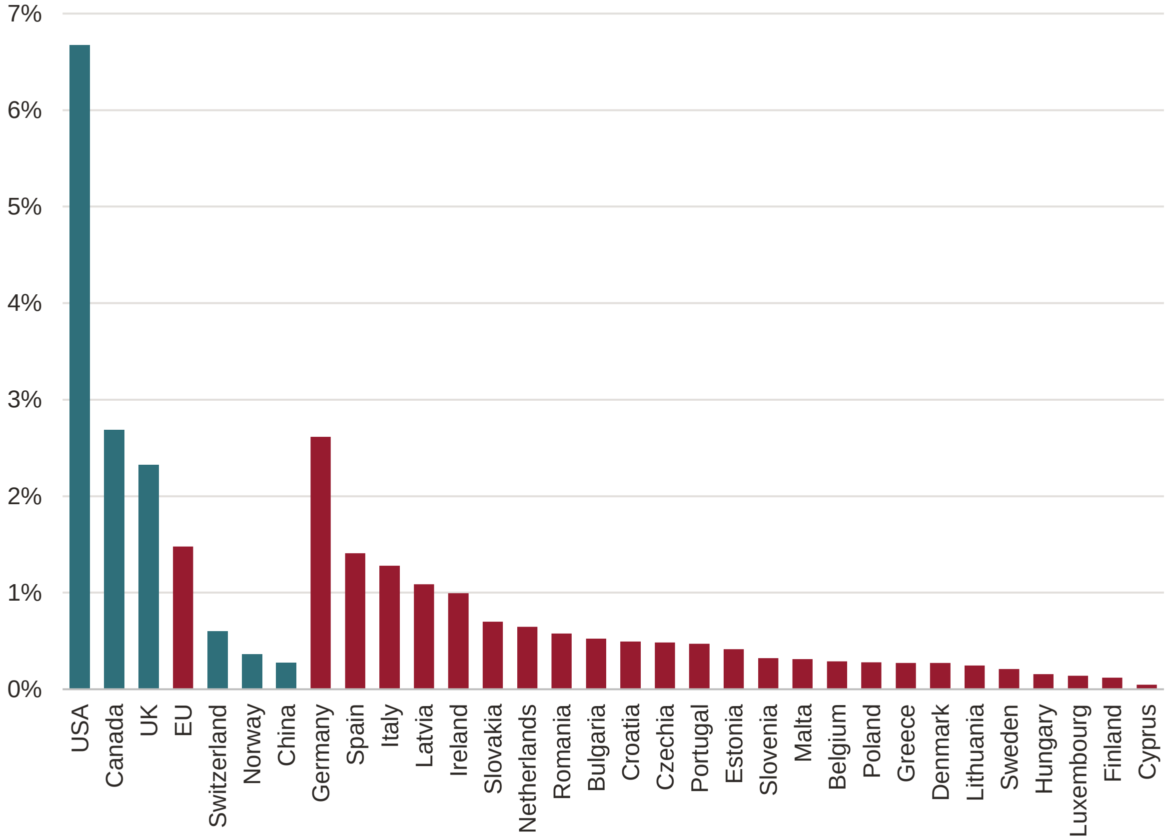
Source: OECD

Figure64 Global exports market share for space technologies



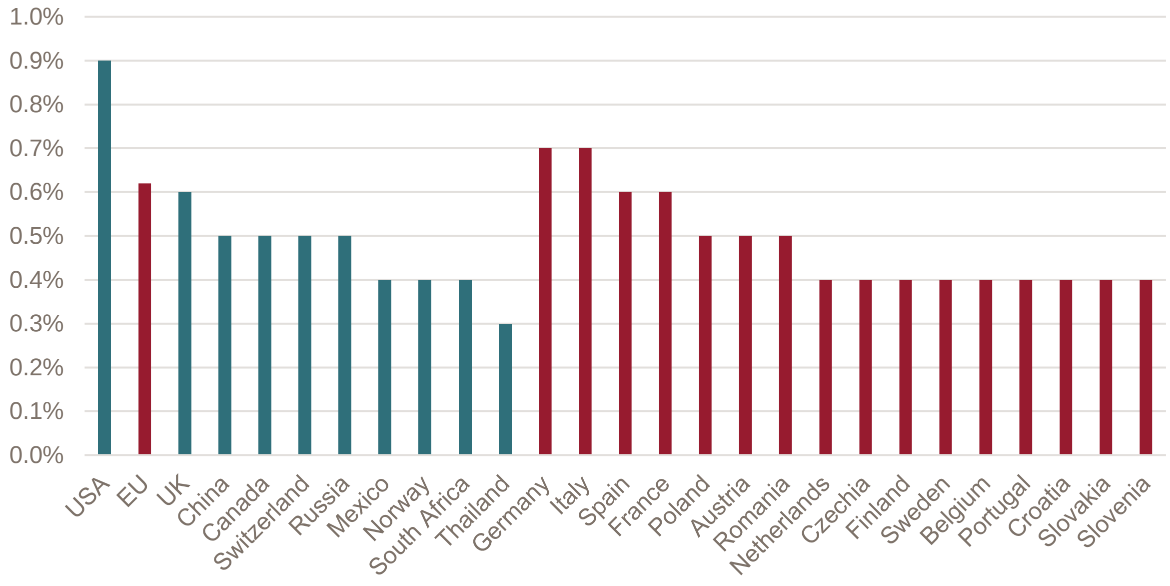
Source: OECD

Figure65 Exports share as a share of country exports for space technologies



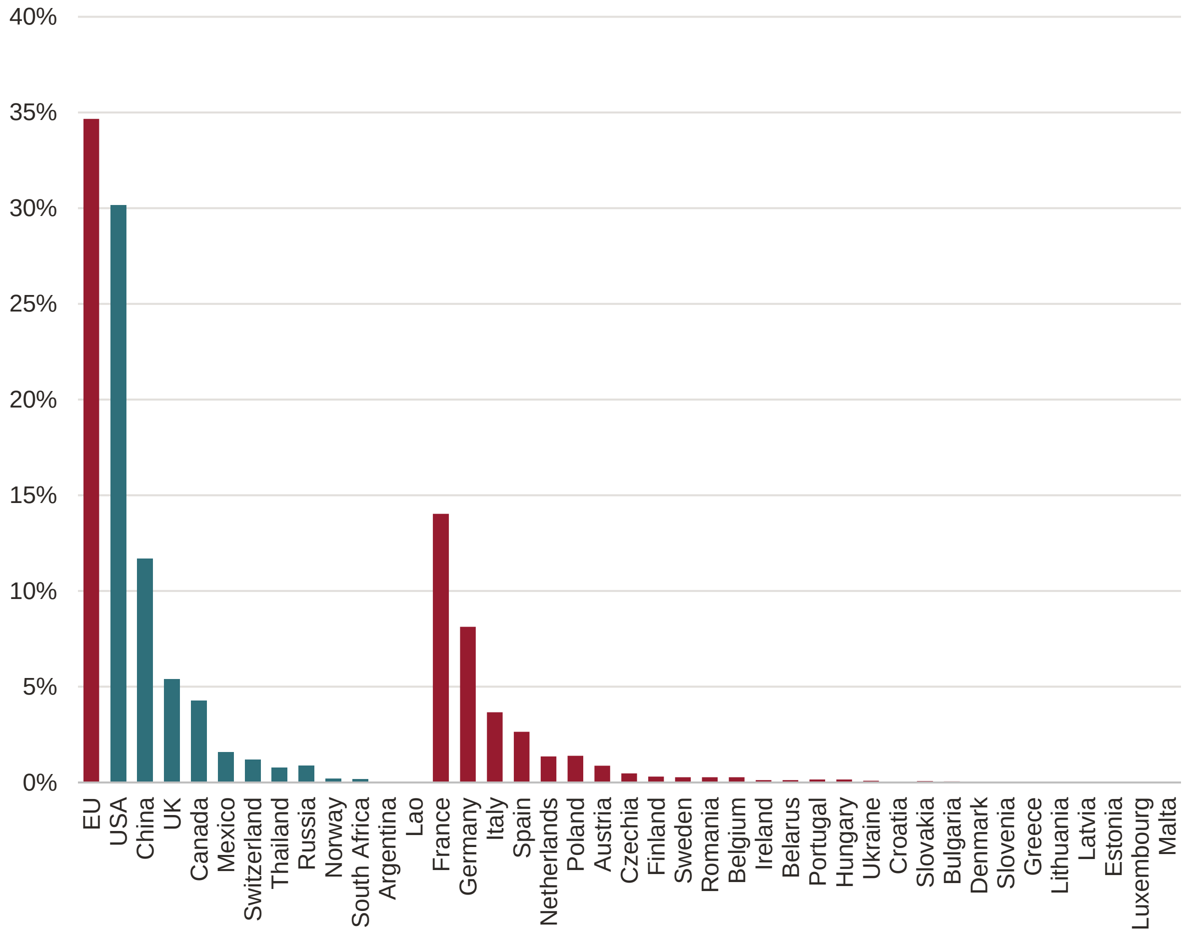
Source: OECD

Figure66 Domestic value added embodied in foreign exports as a share of gross exports for space technologies



Source: OECD

Figure67 Global intermediate goods exports market share for space technologies



Source: OECD

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