Department for Business & Trade

Analysis

The changing value and structure of the UK manufacturing sector

A project for the Department for Business and Trade (DBT) – Final Report

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About this report

This report is the final output of “The changing value and structure of the UK manufacturing sector” project, in which IfM Engage was commissioned by the Department for Business and Trade (DBT) through the Futures Procurement Framework. This project is part of DBT’s efforts to improve the understanding of the advanced manufacturing sector and support the department’s ongoing monitoring and evaluation work.

Contributors

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Executive Summary

This study contributes to the Department for Business and Trade's (DBT) ongoing efforts to strengthen the evidence base on the evolving value and structure of the UK manufacturing sector.

The study addresses four key policy questions:

1. How can we measure the direct and indirect value of manufacturing in the economy?
2. What is the changing role of services in manufacturing, and how does the UK compare internationally?
3. How can we define and quantify advanced manufacturing?
4. How can we define and identify emerging sectors within advanced manufacturing?

To address these questions, the study focuses on the UK context while drawing on international evidence and practices. It offers a set of definitions, analytical frameworks, and methodological approaches derived from academic literature and global policy experience. Quantitative estimations are provided through the use of these methodologies. Although a complete analysis is not part of this study, the findings emphasise the significance and usefulness of the proposed methods. Policy implications derived from the findings of this study are also discussed.

Measuring the direct and indirect value of manufacturing

The study introduces an updated methodology for measuring the value of the UK manufacturing value chain, which includes both the direct value of the manufacturing sector, as typically defined in statistical classifications and the broader set of manufacturing-related activities.

Based on the methodology presented in this study, it is estimated that the manufacturing value chain contributed £331 billion to the economy and supported 4.3 million full-time equivalent jobs in 2022. These figures represent approximately 15% of national value added and 14% employment in the UK, compared with 9.1% value added and 7.1% employment when considering direct values only.

Compared with other advanced economies, the UK recorded the lowest value added from the broader manufacturing value chain in 2019, accounting for just 15% of national value added. In contrast, Germany recorded 33%, followed by Switzerland at 29%, with both France and the United States at 19%.

The UK also experienced the sharpest decrease during the period analysed, falling from 23.6% in 1999 to 15.1% in 2019. In contrast, Switzerland observed the smallest reduction, from 30.7% to 28.8%.

Manufacturing value added gross multipliers are lower in the UK than in comparator countries, implying that the UK's relatively modest contribution from manufacturing reflects both a smaller industrial base and weaker value chain linkages, both within manufacturing and between manufacturing and other sectors of the economy. In other words, compared with other advanced economies, the UK manufacturing sector sources less, as a proportion of its value added, from other domestic industries, including manufacturing itself.

This study finds no evidence of a potential undercount in the UK's manufacturing sector when compared to other countries. In the UK, the sector's relatively lower contribution to the national economy compared to other advanced economies is attributed to both a smaller manufacturing base and weaker linkages with other sectors as well as within manufacturing.

The analysis in this study has several limitations, including the aggregation of manufacturing industries with varying patterns and trends, the exclusion of foreign inputs, and the inability to capture shifts in manufacturing firms' business models toward services.

The role of services within manufacturing

This study also assesses the role of services in modern manufacturing production processes and business models, comparing the United Kingdom's experience with that of selected countries, namely France, Germany, Switzerland, and the United States.

Manufacturing has always depended on services; however, in recent decades, this dependency has intensified due to outsourcing, offshoring, and the rise of global value chains, prompting firms to incorporate services into their core operations products.

Although not always consistently defined in the literature, servicification and servitization are key concepts that describe the growing role of services in modern manufacturing:

- Servicification means that "the manufacturing sector is increasingly relying on services, whether as inputs, as activities within firms or as output sold bundled with goods" (Miroudot and Cadestin, 2017).[1]
- Servitization describes "a firm-level practice regarding the increased offering of fuller market packages or 'bundles' of customer-focused combinations of goods, services, support, self-service, and knowledge in order to add value to core product offerings" (Vandermerwe and Rada, 1988).[2]

[1] Miroudot and Cadestin (2017). "Services in Global Value Chains: from Inputs to Value-Creating Activities

[2] Vandermerwe and Rada (1988). "Servitization of business: Adding value by adding services". European management journal, 6(4), 314-324.

A quantification of the level of servicification of UK manufacturing is provided using OECD Input-Output data as well as OECD Trade in Value-Added data:

- In 2019, business services contributed 33% of total manufacturing value added in the UK, a level comparable to France, Germany, Switzerland, and the United States.
- Between 2015 and 2019, the level of servicification in UK manufacturing remained stable, similar to trends in comparator countries.
- Key UK manufacturing sectors, such as pharmaceuticals, automotive, and aerospace, rely more on professional services than their counterparts in comparator countries
- In 2019, service inputs represented 23.6% of the value needed to produce a unit of manufacturing output in the UK, similar to comparator countries.
- Between 2006 and 2019, the use of service inputs in manufacturing increased across the UK and comparator countries.
- Domestically supplied service inputs constitute the largest share of total service inputs in manufacturing.

Measuring servitization is challenging and relies on case studies and surveys; the evidence regarding its impact varies based on service type, firm capabilities, firm size, and industry.

Defining and quantifying advanced manufacturing

This study suggests defining advanced manufacturing as a *set of activities aimed at producing products or integrated product-service solutions that are hard to replicate or substitute due to their use of innovative technologies, methods, or materials*.

These innovative technologies, methods, and materials typically draw on specialised knowledge from the physical, biological, and computer sciences and often require a highly qualified workforce as well as access to collaborative knowledge networks.

Advanced manufacturing is understood as applicable to both existing products and, more significantly, to new high-value products enabled by emerging technologies. It is positioned as a key driver of competitiveness in high-value, innovation-intensive environments and as a foundation for national industrial leadership in an increasingly technology-driven global economy.

Based on this conceptualisation, the study also proposes definitions of advanced manufacturing processes, firms, value chains, and sectors to support more targeted analysis and policy development.

The review of international practices reveals four main approaches commonly used to define and measure advanced manufacturing: (1) R&D intensity, (2) employee qualifications, (3) matching expert-selected technologies or products with existing industrial classifications, and (4) expert evaluations of individual firms

To illustrate how advanced manufacturing sectors might be identified and quantified in the UK, the study applies a selection of data-driven proxies guided by international practices. This is not intended as a comprehensive methodology but rather a practical example of how selected indicators can be used to inform policy and analysis. The initial focus is on the sector level, using data classified by Standard Industrial Classification (SIC) codes.

While this sectoral approach is useful for highlighting priority areas for policy attention, it does have some limitations. Sectors often include a mix of advanced and non-advanced firms, making it difficult to fully capture differences in technological capability and strategic focus.

To overcome these limitations, the report advocates for a shift toward firm-level approaches, which provide greater granularity and can more accurately identify firms that exhibit the characteristics of advanced manufacturing—thereby enabling more targeted and effective policy interventions.

Defining and identifying emerging sectors in advanced manufacturing

The study defines advanced manufacturing emerging sectors as "new or evolving industrial systems that use innovative manufacturing technologies, methods, and materials to produce high-value products or integrated product-service solutions that are hard to replicate or substitute."

These sectors may involve innovative methods for producing existing products or, particularly, new high-value products made possible by emerging technologies. They typically emerge in response to technological and scientific breakthroughs, shifts in market demand, and changes in regulations, institutions, or policies. They are usually in early, fluid stages of development, characterised by high uncertainty and transformation potential.

An analytical process for identifying emerging sectors in advanced manufacturing is proposed. It begins by examining three key drivers of emergence- technology development, demand growth, and regulatory, institutional, or policy shifts- each analysed across several proxies, generating a list of emerging areas, including technologies, products, and sub-sectors, based on foresight, expert input, and trends analysis.

In the synthesis step, these emerging areas are analysed to identify the intersections between the three key drivers: technology, market dynamics, and policy influences. The sectors that are shaped by all three factors are highlighted as potential emerging sectors that are likely to gain relevance. However, it’s important to note the key limitations of this analysis, including issues related to data availability, classification challenges, and the natural uncertainties surrounding emerging trends.

Several domains-such as advanced materials, additive manufacturing, biological manufacturing, AI and digital technologies, and advanced robotics-appear across multiple dimensions, indicating high growth potential and strategic significance for the UK. However, being recognised as an area of opportunity is a necessary, though not sufficient, condition; further validation and targeted policy assessment are required.

The final step of the process involves applying criteria for prioritising policies. This includes considering how well the policies align with the national industrial strategy, their proximity to existing domestic capabilities, their importance for national security, their overall economic impact, and the necessity for new regulations or standards. This approach ensures that the emerging sectors identified are not just feasible but also strategically significant and deserving of priority in policy actions.

Policy implications

This report presents evidence-based insights to inform current and future policymaking on the value and structure of UK manufacturing. The findings address how manufacturing's contribution is measured, the evolving role of services, and the definition of advanced manufacturing.

The following policy implications are derived from these findings, with the aim of supporting more targeted, future-focused industrial strategies.

Policy implication 1: The decline of UK manufacturing goes beyond statistical undercounting and should be recognised as a barrier to the country's long-term economic growth. It demands a detailed, sector-by-sector analysis to inform more effective industrial strategy.

While it is likely that manufacturing's contribution is underestimated across many economies due to changes in production organisation and the adoption of new business models, our analysis suggests that the UK's manufacturing sector remains smaller even when accounting for its indirect economic contribution across the full value chain. More concerningly, the UK has experienced the sharpest decline in the share of manufacturing within the value chain over the past two decades among the countries analysed, signalling not only a loss in productive capacity but also a weakening of the broader industrial ecosystem.

Given manufacturing's above-average productivity (both in absolute terms and in growth rates), the sector's relatively small role in the UK economy represents a constraint on the country's long-term economic growth potential. Overlooking the impact of manufacturing's decline runs counter to the UK's national policy goals and risks undermining the broader economic landscape, including innovation capacity, export performance, and economic resilience.

There is a clear need for a more granular understanding of the drivers behind the decline of UK manufacturing, analysed sector by sector, to inform future industrial strategies and support more effective growth-oriented policy interventions.

Policy Implication 2: A modern industrial strategy should recognise that manufacturing and services are deeply interconnected – the strength of one depends on the performance of the other.

A modern industrial strategy requires an up-to-date understanding of how industries operate today and the key factors that shape their competitiveness. The analysis of servicification in UK manufacturing presented in this study highlights the growing importance of services in enhancing the value and competitiveness of manufacturing. As services play a critical role throughout the manufacturing value chain – from design, testing and R&D to after-sales digital services – the traditional divide between manufacturing and services is increasingly obsolete. For industrial strategy to be effective, key services must be treated as integral to advanced manufacturing plans, and likewise, manufacturing must be considered within broader service-sector strategies. There is the need to emphasise that a decline in UK manufacturing would also reduce the demand for high-value-added services. For example, if a pharmaceutical manufacturing firm downsizes its operations, the need for specialised testing and research services would also decrease.

Rather than engaging in a false dichotomy between manufacturing and services, policymakers should focus on the data and evidence that show how these sectors mutually reinforce each other, contributing to capital investment, productivity growth, and job creation. This integrated perspective is especially relevant for the UK's advanced manufacturing sectors. While the overall level of servicification in UK manufacturing is broadly comparable to other advanced economies, certain sectors such as pharmaceuticals, automotive, and aerospace show a greater reliance on professional services than their counterparts in other countries. This reinforces the need for industrial strategy to reflect the real structure of modern production systems, where value is co-created across both manufacturing and service activities.

Policy Implication 3: UK industrial strategy should prioritise support for firms developing and deploying advanced, hard-to-replicate production processes – regardless of sector – by investing in enabling technologies, skills, and infrastructure that enhance process innovation and global competitiveness.

A key message from this report is that advanced manufacturing is best defined not only by the type of product being made, but by the sophistication of the processes used to make it. This process-oriented perspective allows for recognition that even so-called "low-tech" products can be produced using highly advanced methods, depending on the production systems, technologies, and organisational capabilities employed.

From a policy standpoint, advanced manufacturing should be seen as a strategic approach to building competitiveness, enabling firms to create products, processes, and solutions that are difficult to replicate or substitute, and thereby sustain advantage in a high-cost location like the UK. While sector-level metrics remain useful for identifying broad areas of opportunity, they can mask important differences across firms within the same sector. Sectors often contain a mix of firms with vastly different levels of technological capability and innovation maturity. As such, effective industrial strategy should combine sector-level insight with more granular, firm-level analysis to pinpoint where truly advanced manufacturing is occurring, and where policy intervention can deliver the greatest returns.

Policy implication 4: Industrial strategy should be underpinned by a dynamic monitoring system that continuously tracks technological, market, and regulatory shifts, enabling more adaptive and responsive support for emerging sectors, rather than relying on fixed indicators.

Emerging sectors, including those in advanced manufacturing, are typically in early and fluid stages of development, marked by high uncertainty and transformative potential. This report proposes a framework for identifying such sectors by examining three key drivers of emergence: technology development, demand growth, and regulatory or policy shifts. By using proxy indicators across these drivers, the analysis generates a "long list" of technologies, products, and sub-sectors showing early signs of disruption. Areas where signals converge across all three drivers are especially relevant for prioritisation. In this study, fields such as advanced materials, additive manufacturing, biological manufacturing, AI and digital technologies, and advanced robotics emerged as particularly promising for the UK manufacturing landscape.

However, it is important to recognise that the landscape of emerging sectors is dynamic. The results of this type of analysis are likely to evolve over time as new technologies emerge, market conditions shift, and policy priorities change. As such, the identification of emerging sectors should not be treated as a one-off exercise. Instead, it requires a continuous and iterative process, embedded within broader systems for science, innovation, and industrial policy intelligence. Regularly updating the evidence base, updating proxies, and refining methodologies will be essential to ensure that industrial strategy remains responsive, forward-looking, and aligned with emerging opportunities.

Policy Implication 5: Recognising growth potential is important, but it alone cannot dictate which emerging sectors deserve strategic support. Policymakers must evaluate additional factors to effectively allocate resources and focus attention on emerging sectors that truly warrant investment.

From a policy perspective, not all emerging sectors require government intervention. Sectors may become strategically relevant or 'attractive' when their anticipated growth potential, demand pull, or disruptive impact is perceived to present a meaningful opportunity for national economic or technological advancement. However, the mere presence of growth potential is not sufficient to justify prioritisation. Further validation and targeted policy assessment are essential to ensure that public support is directed to sectors that are not only promising but also strategically viable and nationally significant.

The UK may currently lead in certain technologies, but this does not guarantee the capabilities or institutional readiness needed to scale them into robust, competitive sectors. This includes evaluating how well emerging sectors align with the national industrial strategy, their proximity to existing domestic capabilities, and the availability of innovation infrastructure such as universities, R&D centres, testbeds, or clusters that can support scaling and experimentation. Additional considerations include the sector’s importance to national security, particularly its role in defence, critical supply chains, or systemic resilience; its cross-cutting economic impact, including potential spillovers across industries; and the need for new regulation or standards, especially where novel technologies or business models require updates to existing policy, safety, or compliance frameworks.

Introduction

The aim of this study is to contribute to the Department for Business and Trade's (DBT) efforts to update the evidence base on the changing value and structure of the UK manufacturing sector. Focusing on the UK, and drawing upon international experience, the study focuses on the following key areas: the appropriateness of current manufacturing statistical metrics; the role of services within manufacturing processes, and manufacturing firms' business models; defining and quantifying advanced manufacturing; and defining and quantifying emerging sectors.

Official statistics show that the economic contribution of manufacturing has declined in the UK and across other industrialised economies. Between 1998 and 2023, the contribution of manufacturing to UK GDP declined from 14.4% to 9.1%.[3] Across Organisation for Economic Co-operation and Development (OECD) countries, manufacturing value added as a share of GDP declined, on average, from 17.7% to 13.2% between 1998 and 2021.[4] The last 2 decades have seen a shift in the global manufacturing production from West to East, where China captured global value-added shares from other countries, particularly Europe and North America. China's share of global manufacturing value added increased from 6.4% to 31% between 2000 and 2022.[5]

Previous studies conducted by the Institute for Manufacturing (IfM), University of Cambridge, for DBT have shown that manufacturing has gone through several changes related to production processes and adopting new business models. And despite the decreasing contribution of the sector to the national GDP, as seen in official statistics, manufacturing is still vital to the UK economy. The IfM *Manufacturing Metrics Review Report* (2016) argues that modern manufacturing encompasses activities related to research and development (R&D), design, distribution and services, as well as physical production. This broader approach to understanding modern manufacturing has raised questions about the suitability of official statistics to measure manufacturing.[6] On the other hand, the IfM's *Inside the black box of manufacturing* report (2020) highlights the importance of knowledge and capabilities embedded in service sectors for the competitiveness of manufacturing. These services, especially technical and professional services, require deep knowledge and sophisticated capabilities related to the manufacturing activities they support.[7]

Manufacturing has also gained more attention from policymakers around the world as a fundamental engine of economic growth. In the UK the *Industrial Strategy Green*

[3] ONS (2024). GDP output approach – low-level aggregates, UK.

[4] World Bank (2024). World Development Indicator database.

[5] Cambridge Industrial Innovation Policy (2025). *UK Innovation Report 2025*.

[6] Manufacturing Metrics Expert Group (2016). Manufacturing Metrics Review report. A report prepared for the UK Department for Business, Innovation and Skills.

[7] Hauge J and O'Sullivan E. (2020). *Inside the black box of manufacturing*. A report prepared for the UK Department for Business, Energy and Industrial Strategy.

Paper (released in 2024) identifies advanced manufacturing as one of the country's key growth-driving sectors, alongside clean energy Industries, creative industries, defence, digital and technologies, financial services, life sciences, and professional and business services.[8]

Against this backdrop, and building on existing evidence, this study enhances the understanding of the value and structure of UK manufacturing, providing quantitative estimations, definitions, frameworks and methodologies drawn from academic research and international policy practices.

The rest of this report is structured as follows:

- Section 1 builds on the IfM's 2016 Manufacturing Metrics Review Report and introduces an updated methodology for measuring the direct and indirect value of manufacturing in the UK from a value-chain perspective, comparing it with 4 other advanced economies – France, Germany, Switzerland and the United States (USA).
- Section 2 assesses the role of services in modern manufacturing production processes and business models, focusing on 2 key concepts: servicification – a higher use of services required to produce a specific manufacturing product; and servitisation – a firm-level strategy to offer final customers a bundle of services and products to increase the value of a core product offering.
- Section 3 defines advanced manufacturing and designs a methodology to measure advanced manufacturing in relation to the UK.
- Section 4 defines emerging sectors and identifies key metrics to assess the relevance of emerging sectors for UK manufacturing.

[8] UK Government (2024). Invest 2035: The UK's Modern Industrial Strategy.

1. Measuring the UK manufacturing value chain

Key messages

- The report introduces an updated methodology for measuring the value of the manufacturing value chain, which includes both the direct value of the manufacturing sector, as defined in statistical classifications, and the broader set of manufacturing-related activities.
- We estimate that the manufacturing value chain contributed £331 billion to the economy and supported 4.3 million full-time equivalent jobs in 2022. These figures represent approximately 15% of national value added and 14% employment in the UK, compared with 9.1% value added and 7.1% employment when considering direct values only.
- Compared with other advanced economies, the UK recorded the lowest value added from the broader manufacturing value chain in 2019, accounting for just 15% of national value added. In contrast, Germany recorded 33%, followed by Switzerland at 29%, and France and the USA at 19%.
- The UK also experienced the sharpest decrease during the period analysed, falling from 23.6% in 1999 to 15.1% in 2019. In contrast, Switzerland saw the smallest reduction, going from 30.7% to 28.8%.
- Manufacturing value-added gross multipliers are lower in the UK than comparator countries. This suggests the UK has weaker inter-sectoral and intra-manufacturing links relative to comparator countries.
- We find no evidence of a potential undercount in the UK's manufacturing sector compared to other nations. However, the sector's lower contribution to the national economy, relative to other advanced economies, is explained by both a smaller manufacturing base and weaker links with other sectors and within manufacturing.
- This analysis has some limitations, including the grouping of manufacturing industries with different patterns and trends, the exclusion of foreign inputs, and the inability to capture shifts in manufacturing firms' business models towards services. These issues are explored further in Section 2.

1.1. Introduction

Over the past 2 decades, UK manufacturing has experienced a declining share of employment and value added relative to the broader economy, a trend shared by other advanced economies. However, previous studies suggest that this contribution may be underestimated as a result of changes in organising production processes and adopting new business models.[9]

Building on the 2016 *Manufacturing Metrics Review Report*,[10] we introduce an updated methodology for measuring the direct and indirect value of manufacturing from a value-chain perspective. This approach uses input–output analytical tables (IOTs) from the Office for National Statistics (ONS) for the years 2017, 2019, 2021 and 2022. The analysis is complemented by an international comparison with France, Germany, Switzerland and the USA for 1999, 2012 and 2019, using harmonised IOTs published by the OECD.

Key questions addressed in this section include:

- How to measure the direct and indirect value of manufacturing?
- How does the multiplier in UK manufacturing compare internationally?
- Do current measurements undercount the UK's manufacturing sector compared to other nations?
- Has outsourcing led to an unfairly diminished view of the UK's industrial strength?

1.2. The direct value of manufacturing

This sub-section analyses the direct value of manufacturing within the UK economy, highlighting its contributions to value added, employment, trade, and research and development. The manufacturing sector, defined as Section C of the UK Standard Industrial Classification (SIC) of economic activities, contributes significantly to the UK economy:

- £216.8 billion of value added in 2023, accounting for 9.1% of the UK economy
- 2.6 million jobs in 2023, representing 7.1% of total employment
- 89% of the UK's goods exports, totalling £350.3 billion in 2023
- Nearly half of the UK's business expenditure on research and development (BERD), amounting to £24 billion in 2023 (Table 1.1)

[9] Hauge, J. and O'Sullivan, E. (2019). *Inside the black box of manufacturing: Conceptualising and counting manufacturing in the economy*. Report prepared for the UK Department for Business, Energy and Industrial Strategy.

[10] Department for Business, Innovation and Skills (2018). *Manufacturing Metrics Review Report*. A paper by the Manufacturing Expert Group.

Leading manufacturing industries, based on their contributions to value added, employment, BERD and exports, include:

- **value added** (share of manufacturing value added in brackets) – food products (12.2%), basic pharmaceutical products (9.3%), fabricated metal products (8.9%), motor vehicles, trailers and semi-trailers (9.0%) and machinery and equipment (7.9%)
- **employment** (share of manufacturing employment in brackets) – food products (16.3%), fabricated metal products (11.5%), machinery and equipment (7.0%), rubber and plastic products (6.1%) and motor vehicles, trailers and semi-trailers (5.5%)
- **BERD** (share of manufacturing BERD in brackets) – basic pharmaceutical products (36.2%), motor vehicles, trailers and semi-trailers (20.5%), other transport equipment (9.6%), computer, electronic and optical products (9.5%) and machinery and equipment (5.8%)
- **exports** (share of manufacturing exports of goods in brackets) – motor vehicles, trailers and semi-trailers (13%), other transport equipment (13%), machinery and equipment (11.5%), basic metals (9.9%) and chemicals and chemical products (9.2%)

Table 1.1 Direct value of manufacturing

Industry	Value added, 2023 (£ billion)	Employment, 2023 (thousands)	Value added per employee, 2023 (£ million)	BERD, 2023 (£ million)	Goods exports, 2023 (£ billion)
Manufacture of food products	26.4	423.3	62.4	791	14.7
Manufacture of beverages and tobacco	9.5	54.0	176.8		11.6
Manufacture of textiles	3.3	58.0	56.3	56	2.5
Manufacture of wearing apparel	2.2	30.8	71.4		4.1
Manufacture of leather and related products	0.4	6.8	52.1		1.7
Manufacture of wood and wood and cork products	4.2	94.8	44.6	111	0.7
Manufacture of paper and paper products	3.9	50.0	78.4		2.4
Printing and reproduction of recorded media	4.3	77.8	55.4		0.0
Manufacture of coke and refined petroleum products	2.1	10.5	195.9	292	12.8
Manufacture of chemicals and chemical products	10.9	104.0	105.1	967	32.1
Manufacture of basic pharmaceutical products	20.1	50.8	397.0	8,681	26.3
Manufacture of rubber and plastic products	7.8	157.0	49.8	173	8.5
Manufacture of other non-metallic mineral products	6.8	92.8	73.3	110	2.8
Manufacture of basic metals	5.0	73.8	67.6	205	34.8
Manufacture of fabricated metal products	19.2	299.3	64.3	505	8.8
Manufacture of computer, electronic and optical products	14.6	132.8	110.3	2,277	29.1
Manufacture of electrical equipment	5.9	77.3	76.8	817	14.0
Manufacture of machinery and equipment n.e.c.	17.2	181.0	95.2	1,400	40.2
Manufacture of motor vehicles, trailers and semi-trailers	19.5	142.3	137.3	4,910	45.4
Manufacture of other transport equipment	13.8	136.3	101.0	2,309	45.4

Manufacture of furniture	4.2	84.0	49.5	391	1.7
Other manufacturing	5.3	108.5	49.2		10.5
Repair and installation of machinery and equipment	10.0	147.8	67.5	n.a.	n.a.
Total manufacturing	216.8	2,593.0	83.6	23,995	350.3
Share manufacturing in total economy	9.1%	7.2%	1.27	48.0%	89.0%
Total economy	**2,378.5**	**36,242.0**	**65.6**	**49,973**	**393.5**

Note: n.a. = not available or not applicable.

Source: ONS (2024). GDP output approach, low level aggregates; ONS (2024). UK; JOBS03 Employee Jobs by Industry (not seasonally adjusted); ONS (2024). JOBS04 Self-employment Jobs by Industry (not seasonally adjusted); ONS (2024). UK Trade in goods by Classification of Product by Activity, time series data set, Quarterly and Annual up to and including 2024 Q2; ONS (2024). Business enterprise research and development (R&D), UK: 2023.

1.3. Manufacturing value chain

Building on the 2016 *Manufacturing Metrics Review Report*, we have updated the methodology to measure the direct and indirect value of manufacturing from a value-chain perspective. This approach incorporates international best practices,[11] aligns with the latest methods adopted by the Office for National Statistics (ONS) for compiling IOTs and related metrics, and accounts for data availability in other countries to enable international comparisons. The data sources and main steps followed are outlined below:

- **Industry-by-industry input-output analytical tables.** ONS IOTs (105 industries) are used to calculate value-added and full-time equivalent (FTE) employment multipliers.
- **Aggregation of manufacturing purchases.** Domestic purchases from and of manufacturing industries (SIC codes C10 to C33) are aggregated to derive multipliers.
- **Estimation of FTE coefficients.** FTE coefficients (£ per FTE) are estimated using ONS data "FTE employment multipliers and effects".
- **Computation of indirect value.** The indirect value of manufacturing is calculated using these multipliers and distributed across sectors based on manufacturing's intermediate consumption for all industries outside SIC codes C10 to C33. This means we exclude the indirect effect on manufacturing, and multipliers can be understood as "net" multipliers. This approach is particularly relevant when combining figures of direct and indirect effects outside the context of IOTs.[12] However, this does not mean that standard output multipliers involve double counting, as the issue of double counting emerges from its application outside the context of IOTs.[13]
- **Indirect FTE distribution.** Indirect FTE is allocated based on manufacturing's intermediate consumption and variations in labour intensity across industries, measured as FTE/£ of output.
- **Sector classification.** Sectors are classified into the following groups:
    - engineering and R&D (SIC 71, 72)
    - materials and infrastructure (SIC 1 to 9, 35, 41 to 43)
    - resource management (SIC 36 to 39)
    - manufacturing (SIC 10 to 33)

[11] See, for example, NIST (2023). *Annual Report on the U.S. Manufacturing Economy: 2023*; Morris and Thomas (2020). *Measuring Manufacturing's Significance in the USA*; Tang et al. (2022). *Input servitization, global value chain, and carbon mitigation: An input-output perspective of global manufacturing industry*; Stehrer et al. (2015). *The Relation between Industry and Services in Terms of Productivity and Value Creation*.

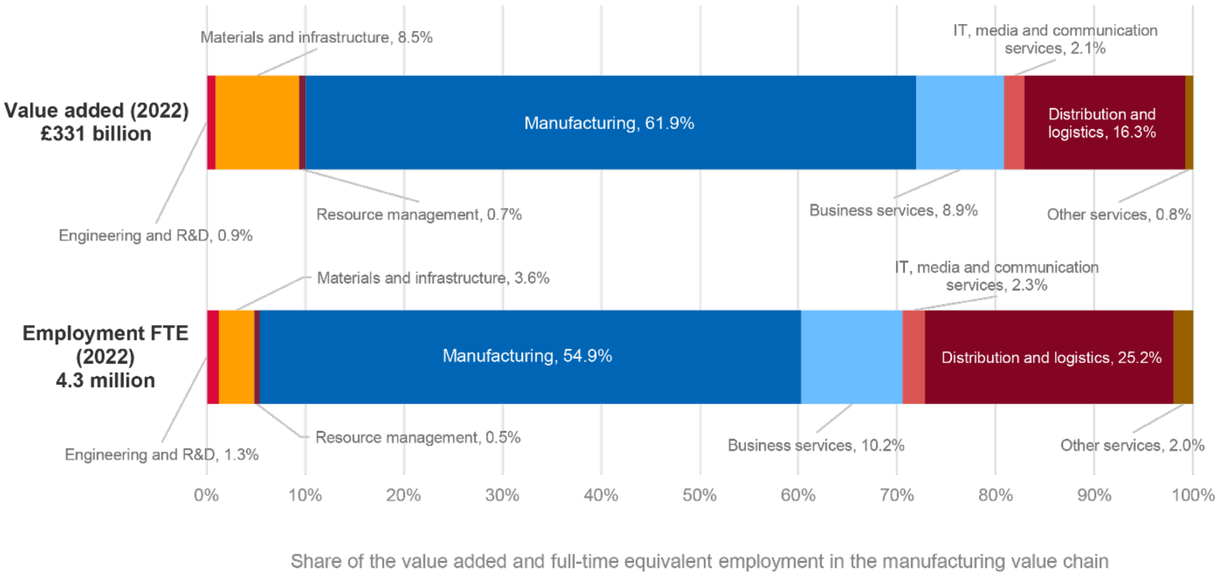
[12] Oosterhaven, J. and Stelder, D. (2002). Net Multipliers Avoid Exaggerating Impacts: With A Bi–Regional Illustration for the Dutch Transportation Sector. *Journal of Regional Science*, 42: 533–543. https://doi.org/10.1111/1467-9787.00270

[13] Sancho, F. (2013). Some conceptual difficulties regarding "net" multipliers. *The Annals of Regional Science,* **51**: 537–552. https://doi.org/10.1007/s00168-012-0542-0

- business services (SIC 64 to 70, 73 to 74, 77 to 82)
- IT, media and communication services (SIC 58 to 63)
- distribution and logistics (SIC 45 to 53)
- other services (SIC 55, 56, 75, 84 to 97)

Following this updated methodology, we find that manufacturing contributed £331 billion to the UK economy and supported 4.3 million FTE jobs in 2022.[14] These figures represent approximately 15% of UK value added and employment during the respective reference years, compared to the 9.1% value added and 7.1% employment direct values discussed in Section 3.2. Across the value chain, distribution and logistics, business services, and materials and infrastructure are the main contributors to value added and employment beyond direct manufacturing activities (Figure 1.1).

Figure 1.1 Direct and indirect value of manufacturing in the UK



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on ONS IOTs, industry by industry, 2022; and 2022 FTE employment multipliers and effects.

We also calculated the value of the manufacturing value chain for 2021, 2019 and 2017, the earliest years for which comparable industry-by-industry IOTs were published by the ONS (Table 1.2). Between 2017 and 2019, the net multiplier type I effect of manufacturing value added (excluding indirect effect on manufacturing) declined from 1.68 to 1.55, and the gross multiplier (including indirect effect on manufacturing) went from 2.16 to 1.86. This indicates a reduction in manufacturing purchases from other sectors, particularly distribution and logistics services. In contrast, between 2021 and 2022, the manufacturing net multiplier effect increased from 1.58 to 1.62, and the gross multiplier went from 1.89 to 1.95. This growth was primarily driven by larger purchases of materials, infrastructure inputs, and distribution and logistics services. However, IOTs do not constitute a time series and are therefore not revised to reflect methodological improvements. Instead, they

[14] The most recent ONS data on employment multipliers is from 2020. However, because of the impact of the COVID-19 pandemic, the 2019 data offers a more accurate reflection of the UK economy.

adhere to the latest Blue Book guidance, which means they may not be fully comparable across different years. As a result, these figures cannot be directly compared with the 2016 *Manufacturing Metrics Review Report*. However, the analysis of harmonised IOTs published by the OECD offers insights into long-term trends.

Table 1.2 Value of manufacturing value chain, 2017, 2019, 2021 and 2022

Sector group	Value added (£, million)				Employment (FTE, million)			
	2017	2019	2021	2022	2017	2019	2021	2022
Design, engineering and R&D	3,407	3,143	2,959	3,007	0.05	0.07	0.06	0.05
Materials and infrastructure	23,291	19,019	22,876	28,045	0.19	0.17	0.16	0.16
Resource management	2,804	2,138	2,076	2,216	0.02	0.02	0.02	0.02
Manufacturing	188,483	194,895	197,604	204,851	2.58	2.58	2.31	2.38
Business services	31,910	26,227	28,018	29,381	0.49	0.43	0.47	0.44
IT, media and communication services	6,765	5,928	6,384	6,848	0.09	0.1	0.09	0.10
Distribution and logistics	57,427	47,551	48,823	53,849	1.1	1.08	1.02	1.09
Other services	3,940	3,197	2,643	2,764	0.1	0.1	0.09	0.09
Total (excluding the indirect effect on manufacturing)	318,026	302,097	311,383	330,961	4.64	4.54	4.23	4.33
Type I net multiplier (excluding the indirect effect on manufacturing)	1.69	1.55	1.58	1.62	1.8	1.76	1.83	1.82
Total (including the indirect effect on manufacturing)	406,365	362,609	372,942	400,320	5.39	5.19	4.83	4.97
Type I gross multiplier (including the indirect effect on manufacturing)	2.16	1.86	1.89	1.95	2.09	2.02	2.09	2.09

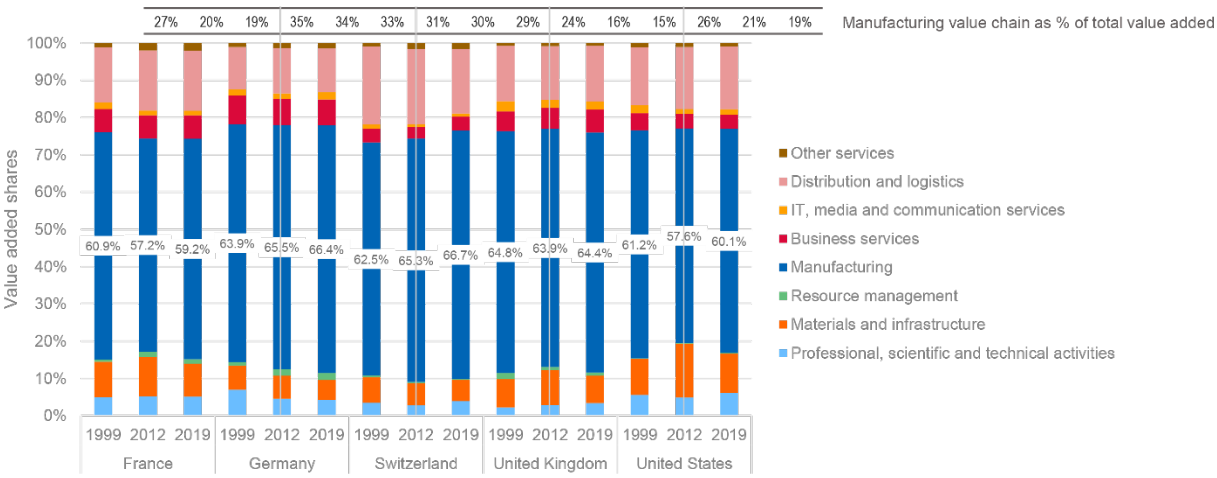
Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on ONS IOTs, industry by industry, 2017, 2019, 2021 and 2022; and 2022 FTE employment multipliers and effects.

Using the harmonised OECD input–output tables, we did a similar value-added analysis for France, Germany, Switzerland, the United Kingdom (UK) and the United States (USA) for the years 1999, 2012 and 2019. We adjusted sectoral groupings to account for data availability, as outlined below:

- professional, scientific and technical activities (M)
- materials and infrastructure (A01 to A03, B05 to B09, D, F)
- resource management (E)
- manufacturing (C10 to C33)
- business services (K, L, N)
- IT, media and communication services (I, J)
- distribution and logistics (G, H)
- other services (O, P, Q, R, S, T)

In 2019 the UK recorded the lowest value added from the broader manufacturing value chain among the countries analysed, accounting for just 15% of national value added. In contrast, Germany recorded 33%, followed by Switzerland at 29%, and France and the USA at 19% (Figure 1.2).

Figure 1.2 Manufacturing value chain in selected countries: value added, 1999, 2012 and 2019



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on OECD (2023). IOTs for 1999, 2012 and 2019.

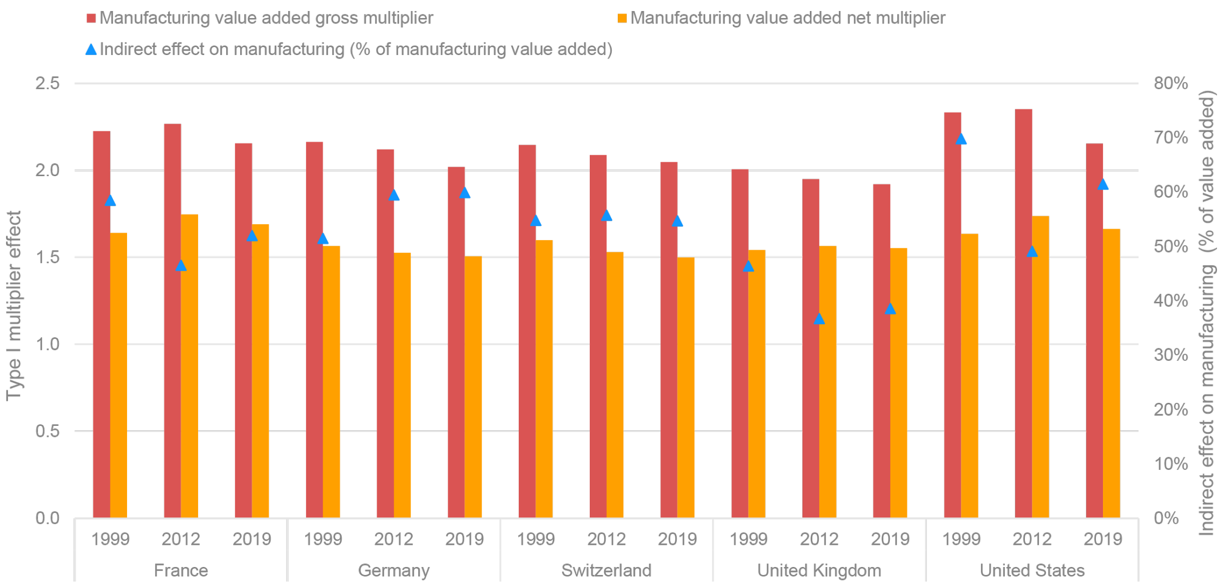
A closer look at the manufacturing value chain and its evolution between 1999 and 2019 reveals 6 key findings (Figure 1.2):

- **Decline in manufacturing value-chain contributions, particularly in the UK.** The contribution of manufacturing value chains to national economies fell between 1999 and 2019. Among the countries analysed, the UK experienced the sharpest decrease, falling from 23.6% to 15.1%. In contrast, Switzerland saw the smallest reduction, from 30.7% to 28.8%. The UK also recorded the lowest shares in both 1999 and 2019 and the lowest manufacturing value-added multipliers.

- **Shifts in manufacturing value-added shares.** Between 1999 and 2019, Germany and Switzerland saw increases in the share of manufacturing value added within their broader value chains. In Germany this share rose from 63.9% to 66.4%, while in Switzerland it increased from 62.5% to 66.7%. Conversely, France, the UK and the USA experienced slight reductions, ranging from 0.5 to 1.8 percentage points, in the share of manufacturing value added in their broader value chains. However, all countries saw a reversal of this trend between 2012 and 2019, with the largest increase occurring in the USA, where manufacturing shares rose from 57.6% to 60.1%.
- **Distribution and logistics and materials and infrastructure emerged as the largest contributors to manufacturing value chains.** Distribution and logistics made particularly large contributions in Switzerland, the USA, and France, primarily through wholesale and retail trade. Meanwhile, materials and infrastructure had the most substantial contributions in the USA, France and the UK, primarily through agriculture (in all 3 countries) and mining and quarrying (in the USA).
- **The UK experienced an increase in the participation of professional, scientific and technical activities and business services.** Among the economies analysed, the UK experienced the largest increase in professional, scientific and technical activities, rising from 2.3% in 1999 to 3.4% in 2019. Despite this growth, the UK still had the lowest participation from this sector compared to the other countries. Similarly, business services in the UK grew from 5.3% in 1999 to 6.2% in 2019, a level comparable to France and Germany, and higher than Switzerland and the USA.
- **The UK exhibited the highest participation of IT, media and communication services.** By 2019, this sector had contributed 2.2% to the UK's manufacturing value chain, exceeding the shares seen in the other countries. However, except for Germany, all economies saw a decline in the participation of this sector group between 1999 and 2019, with most of the decline occurring between 1999 and 2012.
- **Germany showed the highest participation in resource management activities.** Although this sector group, which includes activities such as waste management, represents a small proportion overall, Germany recorded both the largest share (1.9%) and the fastest growth, with its contribution expanding by one percentage point between 1999 and 2019.

As Figure 1.3 illustrates, manufacturing value-added gross multipliers are lower in the UK than in comparator countries, with the USA displaying the highest values. This indicates that the UK has weaker inter-sectoral and intra-manufacturing links relative to comparator countries. When the indirect effect on manufacturing is excluded, Switzerland and Germany display smaller net multipliers than the UK. This reflects the relatively modest indirect effect on manufacturing in the UK, once again highlighting the weak internal connections within its manufacturing sector compared to other countries.

Figure 1.3 Manufacturing value-added gross and net multipliers in selected countries, 1999, 2012 and 2019



Note: The indirect effect on manufacturing refers to the impact arising from the purchase of intermediate outputs by manufacturing industries from other manufacturing industries

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on OECD (2023). IOTs for 1999, 2012 and 2019.

Previous studies have warned that manufacturing's contribution to the UK and other advanced economies may have been underestimated. They suggest this undercounting primarily stems from scientific, technical and professional services closely linked to manufacturing.[15] We test this hypothesis by analysing manufacturers' purchases of professional, scientific and technical inputs, as well as purchases of manufacturing products by businesses in these service sectors. The rationale is that if the hypothesis holds, these purchases should account for a growing share of total domestic purchases over time.

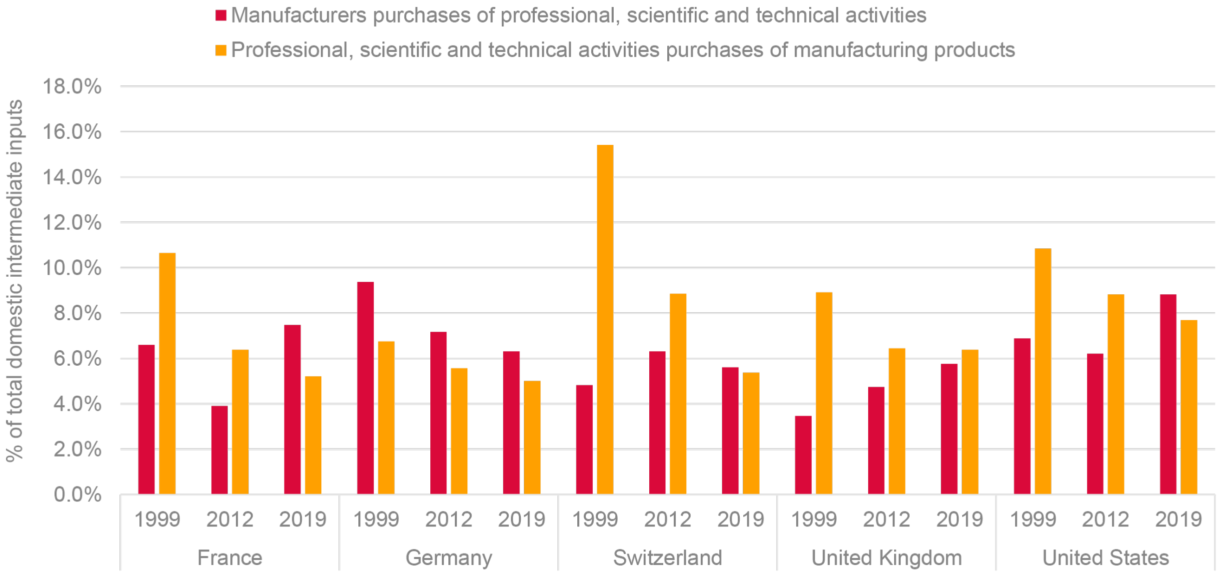
As Figure 1.4 illustrates, the UK has seen the largest increase in the share of professional, scientific and technical purchases made by manufacturers as a proportion of total domestic intermediate inputs. A similar trend, albeit at a slower pace, is seen in comparator countries, except for Germany, where the opposite pattern emerges. Additionally, a decline is seen across all examined countries in the share of manufacturing products purchased by businesses in professional, scientific and technical activities.

Therefore, this analysis does not provide enough evidence to confirm that manufacturing's value is underestimated as a result of stronger links with professional, scientific and technical activities. However, this analysis has some limitations, including the grouping of manufacturing industries with different patterns

[15] Hauge, J. and O'Sullivan, E. (2019). *Inside the black box of manufacturing: Conceptualising and counting manufacturing in the economy*. A report prepared for the UK Department for Business, Energy and Industrial Strategy.

and trends, the exclusion of foreign inputs, and the inability to capture shifts in manufacturing firms' business models towards services. These issues are explored further in Section 4.

Figure 1.4 Links between manufacturing and professional, scientific and technical in selected countries: value added, 1999, 2012 and 2019



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on OECD (2023). IOTs for 1999, 2012 and 2019.

1.4. Conclusions

The value-added gross multiplier of UK manufacturing is lower than in other advanced economies, whereas the net multiplier is slightly higher than in countries such as Germany and Switzerland. This suggests that UK manufacturing has weaker interconnections with other sectors and within its manufacturing industries than comparator countries.

Using harmonised OECD data, we find no evidence of a potential undercount in the UK's manufacturing sector compared to other nations. However, the sector's lower contribution to the national economy, relative to other advanced economies, is explained by both a smaller manufacturing base and weaker links with other sectors and within manufacturing itself.

The contribution of the UK's manufacturing value added, relative to the broader manufacturing value chain, went from 64.8% in 1999 to 64.4% in 2019, according to OECD data, and from 59.3% in 2017 to 61.9% in 2022, according to ONS data. This does not indicate a significant impact of domestic outsourcing on UK manufacturing.

A closer examination of specific service activities – such as professional, scientific and technical services, and IT, media and communication services – offers some evidence of increasing outsourcing. However, this rise remains below the levels seen in France, Germany, Switzerland, and the USA for professional, scientific and technical services, and only slightly above for IT, media and communication services.

However, this analysis has some limitations, including the grouping of manufacturing industries with different patterns and trends, the exclusion of foreign inputs, and the inability to capture shifts in manufacturing firms’ business models towards services.

2. Assessing the contribution of services in modern manufacturing

Key messages

- This section assesses the role of services in modern manufacturing production processes and business models, comparing the experience of the UK with selected countries, namely France, Germany, Switzerland and the USA.
- Manufacturing has always relied on services, but in recent decades this reliance has grown because of outsourcing, offshoring and the emergence of global value chains, leading firms to integrate services into their core products.
- Although not always consistently defined in the literature, servicification and servitisation are key concepts that describe the growing role of services in modern manufacturing:
    - Servicification means that “the manufacturing sector is increasingly relying on services, whether as inputs, as activities within firms or as output sold bundled with goods” (Miroudot and Cadestin, 2017).
    - Servitisation describes “a firm-level practice regarding the increased offering of fuller market packages or ‘bundles’ of customer-focused combinations of goods, services, support, self-service, and knowledge in order to add value to core product offerings” (Vandermerwe and Rada, 1988).
- A quantification of the level of servicification of UK manufacturing is provided using OECD input–output data and OECD Trade in Value Added (TiVA) data:
    - In 2019 business services contributed 33% of total manufacturing value added in the UK, a level comparable to France, Germany, Switzerland, and the USA.
    - Between 2015 and 2019, the level of servicification in UK manufacturing remained stable, similar to trends in comparator countries.
    - Key UK manufacturing sectors, such as pharmaceuticals, automotive and aerospace, rely more on professional services than their counterparts in comparator countries.
    - In 2019 service inputs represented 23.6% of the value needed to produce a unit of manufacturing output in the UK, similar to comparator countries.
    - Between 2006 and 2019, the use of service inputs in manufacturing increased across the UK and comparator countries.

- Domestically supplied service inputs make up the largest share of total service inputs in manufacturing.
- Measuring servitisation is challenging and, based on case studies and surveys, there is mixed evidence on its impact, depending on service type, firm capabilities, firm size and industry.
- The Rolls-Royce (RR) and General Electric (GE) servitisation strategies are outlined to show how manufacturing companies can move beyond selling physical products and generate higher value through service-based solutions.
- The analysis of this section underscores the vital role of services in manufacturing and the need to integrate them into manufacturing strategies.

2.1. Introduction

This section assesses the role of services in modern manufacturing production processes and business models, comparing the experience of the UK with selected countries, namely France, Germany, Switzerland, and the USA.

The use of services in manufacturing production has always been a reality, since R&D, transportation, production software and marketing services, among others, have complemented the production and delivery of final manufacturing goods. The IfM report *Inside the black box of manufacturing*, for example, highlights the importance of knowledge and capabilities embedded in service sectors for the competitiveness of manufacturing. Technical services (i.e. R&D, industrial design, analysis and testing) require deep knowledge and sophisticated capabilities related to the manufacturing activities they support. In addition, professional services (i.e. regulatory, intellectual property, investment and consultancy services) increasingly provide services tailored to manufacturing activities. Therefore, in modern economies a significant proportion of the value of manufactured goods depends on activities officially categorised as belonging to services.[16]

Before the emergence of global value chains (GVCs), however, most of those service activities were done “in-house” by manufacturing firms. From the 1970s onwards, firms started a process of de-verticalisation by outsourcing non-core and low-value-added activities to other firms, aiming to become more efficient – a process driven by information and communications technologies (ICT). In other words, with de-verticalisation processes, companies reduced their level of vertical integration, opting to outsource certain production stages or services to external suppliers. This approach allowed firms to focus on their core competencies while relying on specialised partners for other aspects of their operations. These changes are reflected in the increase in service value added in national statistics.[17] In addition to

[16] Hauge J. and O’Sullivan E. (2020). *Inside the black box of manufacturing*. A report prepared for the UK Department for Business, Energy and Industrial Strategy

[17] Baldwin, R. E., Forslid, R. and Ito, T. (2015). *Unveiling the evolving source of value added in exports*. Institute of Developing Economies.

the GVC element, over the past 2 decades the increase in digital production services and the higher use of Industry 4.0 technologies, such as industrial robotics, artificial intelligence (AI), 3D printing (3DP) and the internet of things (IoT), have contributed to an increase in the use of services by manufacturing firms. Outsourcing service activities and the increasing reliance on services for use in manufacturing processes further impacted manufacturing firms. Companies were forced to adapt their business models and strategies to increasing competition and the evolution of customer needs, ultimately extending their business models to offer final customers "bundles" of products and services.[18]

This section focuses on the role of services in modern manufacturing production processes and business models, assessing the importance of **servicification** – a higher use of services required to produce a specific manufacturing product; and **servitisation** – a firm-level strategy to offer final customers a bundle of services and products to increase the value of the core product offering.

The rest of this section will provide:

- a definition of key concepts, focusing on **servicification** and **servitisation**
- a quantitative assessment of **servicification**, comparing the UK with selected countries, namely France, Germany, Switzerland and the USA
- a case study and qualitative evidence about **servitisation** in the UK

2.2. Key definitions: tertiarisation, servicification and servitisation

The increased importance of services in manufacturing activities is indicated in the literature using concepts such as tertiarisation, servicification and servitisation. For the purposes of this study, **tertiarisation** is the overarching term indicating when an economy shifts from relying on primary and secondary sectors to the tertiary sector – including all types of service, from hairdressers, hotels and restaurants to ICT, software and R&D services. It is associated with an increasing contribution of services to domestic value added and national employment.[19] On the other hand, **servicification** and **servitisation** are 2 concepts that refer to the increasing role of services within manufacturing production processes and manufacturing firms' business models (Figure 2.1).

[18] Gaiardelli P. et al. (2014). A classification model for product-service offerings. Cambridge Service Alliance, University of Cambridge.

[19] The analysis of tertiarisation is outside the scope of this study. For a review of tertiarisation in advanced economies, see, among others, Wölfl A. (2005). The Service Economy in OECD Countries. *OECD Science, Technology and Industry Working Papers 2005/3.*

Figure 2.1 Key definitions: tertiarisation, servicification and servitisation

Tertiarisation

The generalised structural shift of an economy from primary (i.e. agriculture, mining and quarrying) and secondary (i.e. manufacturing, construction) sectors to service activities, associated with an increasing contribution of services to domestic value added and employment (Wölfl, 2005)

Servicification

"Manufacturing sector is increasingly relying on services, whether as inputs, as activities within firms or as output sold bundled with goods" (Miroudot and Cadestin, 2017)

Servitisation

"A firm-level practice regarding the increased offering of fuller market packages or 'bundles' of customer-focused combinations of goods, services, support, self-service, and knowledge in order to add value to core product offerings" (Vandermerwe and Rada, 1988)

Source: Wölfl A. (2005). The Service Economy in OECD Countries. *OECD Science, Technology and Industry Working Papers 2005/3*; Miroudot and Cadestin (2017). Services in Global Value Chains: from Inputs to Value-Creating Activities. *OECD Trade Policy Papers*, No. 197; Vandermerwe and Rada (1988). Servitization of business: Adding value by adding services. *European Management Journal*, 6(4): 314–324.

Servicification and **servitisation** are often used interchangeably, and the boundaries between them are blurry. The academic and grey literature, however, has identified important differences.[20]

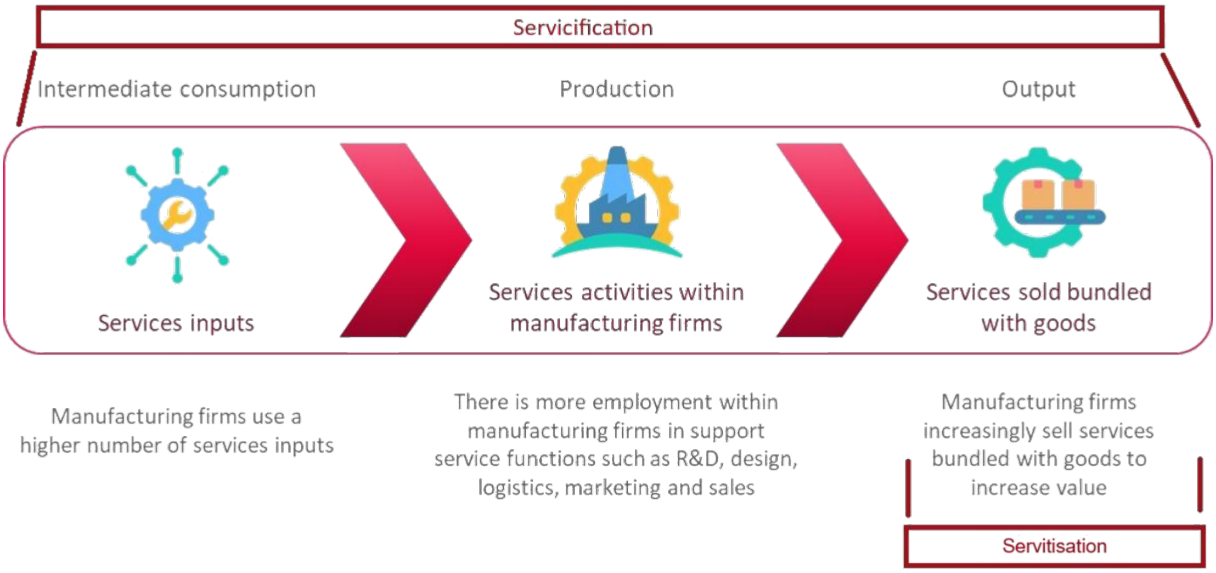
From a broader perspective, servicification includes servitisation. In this respect, "***the servicification of manufacturing means that the manufacturing sector is increasingly relying on services, whether as inputs, as activities within firms or as output sold bundled with goods***"[21] (Figure 2.2). On the other hand, servitisation only refers to "***a firm-level practice regarding the increased offering of fuller market packages or 'bundles' of customer-focused combinations of goods, services, support, self-service, and knowledge in order to add value to core product offerings***".[22]

[20] Refer to Appendix 1 for a list of selected publications on servicification and servitisation.

[21] Miroudot and Cadestin (2017). Services in Global Value Chains: from Inputs to Value-Creating Activities. *OECD Trade Policy Papers*, 197.

[22] Vandermerwe and Rada (1988). Servitization of business: Adding value by adding services. *European Management Journal*, 6(4): 314–324.

Figure 2.2 Servicification of the manufacturing sector



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on Miroudot and Cadestin (2017). Services in Global Value Chains: from Inputs to Value-Creating Activities. *OECD Trade Policy Papers*, 197.

From a value-chain perspective, servicification refers to a higher use of services needed to produce a specific product. In the case of **servicification**, final manufacturing products ***cannot*** be put in the market without the use of services. On the other hand, servitisation refers to higher services that can be bundled to an existing product at the end of the value chain. Or it can refer to services that are foundational to firms' operations as enablers of parts of the value chain, including accounting, recruitment, office maintenance and security services. In the case of **servitisation**, final manufacturing products ***can*** exist without services.

Servicification can be further detailed based on the following features:

- **A higher use of domestic and foreign services by manufacturing companies to produce goods.**[23] Companies started outsourcing and offshoring tasks once conducted entirely within their own business. Core activities were still performed in-house, while less critical activities were outsourced to domestic or foreign companies. As a result, manufacturing firms are now ***buying*** more services as inputs for their business processes, including production.
- **An increase in services activities within manufacturing firms.** This trend is the result of (i) a shift from internal to external provision of services in manufacturing firms[24] and (ii) the increasing importance of services for the production process and the entire value chain. The first aspect relates to a firm-level reorganisation of activities that followed de-verticalisation and contributed to

[23] Jones, R. W. and Kierzkowski, H. (2018). The role of services in production and international trade: A theoretical framework. *World Scientific Book Chapters*, 233–253.

[24] Baldwin, R. E., Forslid, R. and Ito, T. (2015). *Unveiling the evolving source of value added in exports*. Institute of Developing Economies.

some "mechanical" shifts.[25] Activities (from R&D and design to marketing, HR, transportation and logistics) once conducted inside the firm have been outsourced. Even with no changes in the product/production process, the mere counting of activities results in a higher role of services not accounted for when activities were done "in-house". The second element relates to the increasing need for service-related employees, given the higher coordination required with the outsourced activities and the increased use of services along the value chain. This element directly relates to manufacturing firms ***producing*** more services. Other changes that can relate to both mechanical shifts and the evolution of activities and goods are the relative price effects (since manufacturing over time became cheaper relative to services) and the recomposition of activities, which relate to changes in the nature of the final product.

Servitisation can also be detailed as related to:

- **A higher contribution of services to product sales** because of firms **selling more services** bundled with their manufactured goods. This indicates a shift in manufacturing firms' business models with the aim of increasing the value of their manufacturing goods by adding services. In other words, to be more competitive and meet new customers' needs, manufacturing firms are extending their traditional manufacturing business to service business. The results of this process are "business models that have evolved from a 'pure product' orientation toward an integrated product–service system (PSS)",[26] where PSS is "a system of products, services, supporting networks and infrastructures that are designed to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models".[27] Servitization has been classified across multiple dimensions that refer to very different types of service, such as product-attached services, operations services on own products and vendor-independent operations services.[28] The dimensions of servitisation can be further differentiated between extension (additional services), infusion (integrated service components) and orientation (service-focused strategies).[29] In other words, when companies implement a servitisation strategy, services become an integral part of a product offering and may include, for example, repair and maintenance service added to a device, or maintenance, repair and overhaul (MRO) services in the aerospace sector.[30] Another important form of servitisation

[25] Hauge, J. and O'Sullivan, E. (2019). *Inside the black box of manufacturing: Conceptualising and counting manufacturing in the economy*. A report prepared for the UK Department for Business, Energy and Industrial Strategy.

[26] Gaiardelli P. et al. (2014).

[27] Mont O. K. (2002). Clarifying the concept of product–service system. *Journal of Cleaner Production*, 10(3).

[28] Raddats, C. and Kowalkowski, C. (2014). A Reconceptualization of Manufacturers' Service Strategies. *Journal of Business-to-Business Marketing*, 21(1): 19–34.

[29] Calabrese, A., Levialdi Ghiron, N., Tiburzi, L., Baines, T. and Ziaee Bigdeli, A. (2019). The measurement of degree of servitization: literature review and recommendations. *Production Planning & Control*, 30(13): 1118–1135.

[30] Aircraft maintenance, repair and overhaul (MRO) services refer to "both scheduled maintenances to keep the aircraft airworthy on an ongoing basis as well as unscheduled or unplanned maintenance due to damage,

is implementing services with outcomes focused on the capabilities delivered by a product's performance.[31] For example, RR's service contracts to maintain engines (i.e. this is the outcome "to achieve") are paid based on how many hours the engine is in the air, which requires more coordination between the provider and the customer.[32]

In conclusion, industrialised economies are following a structural shift, moving from agriculture and manufacturing sectors to the service sector. This structural shift is associated with an increasing contribution of services to domestic value added and national employment (i.e. tertiarisation). Within such a structural shift, the manufacturing sector is increasingly relying on service as inputs and product sales, a process mainly associated with outsourcing and offshoring, as well as the emergence of GVCs (i.e. servicification). In this context manufacturing firms are implementing business strategies aimed at expanding their offerings by integrating services with their core products (i.e. servitisation).

2.3. Quantifying the servicification of manufacturing

2.3.1. Methodological note

There is no established methodology to assess the level of servicification in the manufacturing sector, partly because of the lack of comparable data across countries.[33] For this study, the level of servicification in manufacturing is measured as the purchase of service inputs by the manufacturing sector. The OECD input-output data set is used to ensure data comparability across countries, together with the OECD TiVA database.[34]

Manufacturing (and services) have been defined in the literature in several ways.[35] The analysis presented in this study is based on the statistical definitions of manufacturing and services, as per the UN's International Standard Industrial Classification of all Economic Activities (ISIC Rev. 4):

- Manufacturing involves all the activities included within Section C, as defined in ISIC Rev. 4: "the physical or chemical transformation of materials, substances, or components into new products, although this cannot be used as the single universal criterion for defining manufacturing. The materials, substances, or components transformed are raw materials that are products of agriculture,

component and engine failures, mandatory modifications, and upgrades to the cabin interior, systems and other components"; BIS (2016). UK Aerospace Maintenance, Repair, Overhaul and Logistics Industry Analysis. BIS Research paper number 275.

[31] Baines, T., Ziaee Bigdeli, A., Bustinza, O. F., Shi, V. G., Baldwin, J. and Ridgway, K. (2017). Servitization: revisiting the state-of-the-art and research priorities. *International Journal of Operations & Production Management*, 37(2): 256–278.

[32] Refer to Rolls-Royce's case study in Section 2.4.

[33] Nordwal, A. (2016). *The servicification of EU manufacturing–Building competitiveness in the internal market*. National Board of Trade Sweden.

[34] OECD (2023). National Input-Output Tables (IOTs), 2023 edition; OECD (2023). Trade in Value Added (TiVA) database.

[35] Hauge J and O'Sullivan E. (2020).

forestry, fishing, mining or quarrying as well as products of other manufacturing activities. Substantial alteration, renovation or reconstruction of goods is generally considered to be manufacturing."

- Services cover all the activities included from Section G to Section U of ISIC Rev. 4, involving activities spanning accommodation, transport, information and communication services, financial services, professional and scientific service, education and defence.

The analysis conducted in this study focuses on service activities called "**services of the business economy**" listed in Table 2.1 with the corresponding statistical codes.

Table 2.1 Services of the business economy: statistical definition

ISIC Rev. 4 Section	Description
G	Wholesale and retail trade; repair of motor vehicles
H49	Land transport and transport via pipelines
H50	Water transport
H51	Air transport
H52	Warehousing and support activities for transportation
H53	Postal and courier activities
I	Accommodation and food service activities
J58 to 60	Publishing, audiovisual and broadcasting activities
J61	Telecommunications
J62 to 63	Computer programming, consultancy and information services
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support services

Source: As per the UN's International Standard Industrial Classification of all Economic Activities (ISIC Rev. 4).

Based on Table 2.1, **knowledge-intensive business services (KIBS)** are the "professional, scientific and technical activities, administrative and support services" (Section M in the statistical classification) and "computer programming, consultancy and information services" (Section J62 to 63 in the statistical classification).

The level of servicification of the UK is compared with selected countries, namely France, Germany, Switzerland and the USA. Table 2.2 reports the contribution of manufacturing value added to GDP and manufacturing employment to total employment in each of the selected economies.

Table 2.2 Manufacturing contribution in the UK and selected countries, 2022

	UK	France	Germany	Switzerland	USA
Manufacturing value added (% of GDP)	8.1%	9.5%	18.3%	18.4%	10.5%*
Manufacturing employment (% of total employment)	8.9%	11.1%	19.0%	12.3%	9.9%

Note: *for the US, Manufacturing value added data refer to 2021

Source: World Bank (2024). World Development Indicators database; ILOSTAT (2024). Employment by sex and economic activity.

2.3.2. Quantifying servicification: value-added approach

Methodological attempts to quantify the servicification of manufacturing are relatively new. They include measuring service value added as a share of total manufacturing value added and assessing whether it has changed over time. Most of those attempts have focused on international trade, using OECD TiVA indicators.[36]

For example, analysis conducted by the World Bank shows that service exports as a share of total global exports has remained around 20% since the 1980s, but the contribution of services to value-added exports has increased worldwide, rising from under 30% in 1980 to over 40% in 2009. This increase in services as a share of value-added trade was driven by services embodied in exports, although differences exist across countries and among industries.[37]

International trade data is useful when assessing the competitiveness of national products and services in international markets. However, trade data does not offer the full picture when it comes to value-added trends in all the components of the final demand, namely consumption, investment, government spending and net exports. Given the scope of this report, the UK manufacturing sector, our analysis uses an indicator made available by the OECD that measures the value added in final demand. The OECD TiVA indicator "origin of value added in final demand" reveals "how the value of final demand of goods and services consumed within a country is an accumulation of value generated by many industries in many countries".[38] In other words, the indicator estimates value added for final demand in a country sector (i.e. UK manufacturing) broken down by the value added generated by other industries in domestic and foreign countries.[39]

Figure 2.3 shows the level of servicification measured as business service value added as a share of total manufacturing value added, comparing the UK with selected countries. Based on this measure, in 2019 the level of servicification of UK

[36] Mercer-Blackman, V. and Ablaza, C (2018). The servicification of manufacturing in Asia: Redefining the sources of labor productivity. *ADBI Working Paper Series*, 902.

[37] Heuser, C. and Mattoo, A. (2017). Services trade and global value chains. In World Bank, IDE-JETRO, OECD, UIBE, and WTO (eds), Measuring and Analyzing the Impact of GVCs on Economic Development.

[38] OECD (2023). Trade in Value Added (TiVA) 2023 edition: Origin of value added in final demand

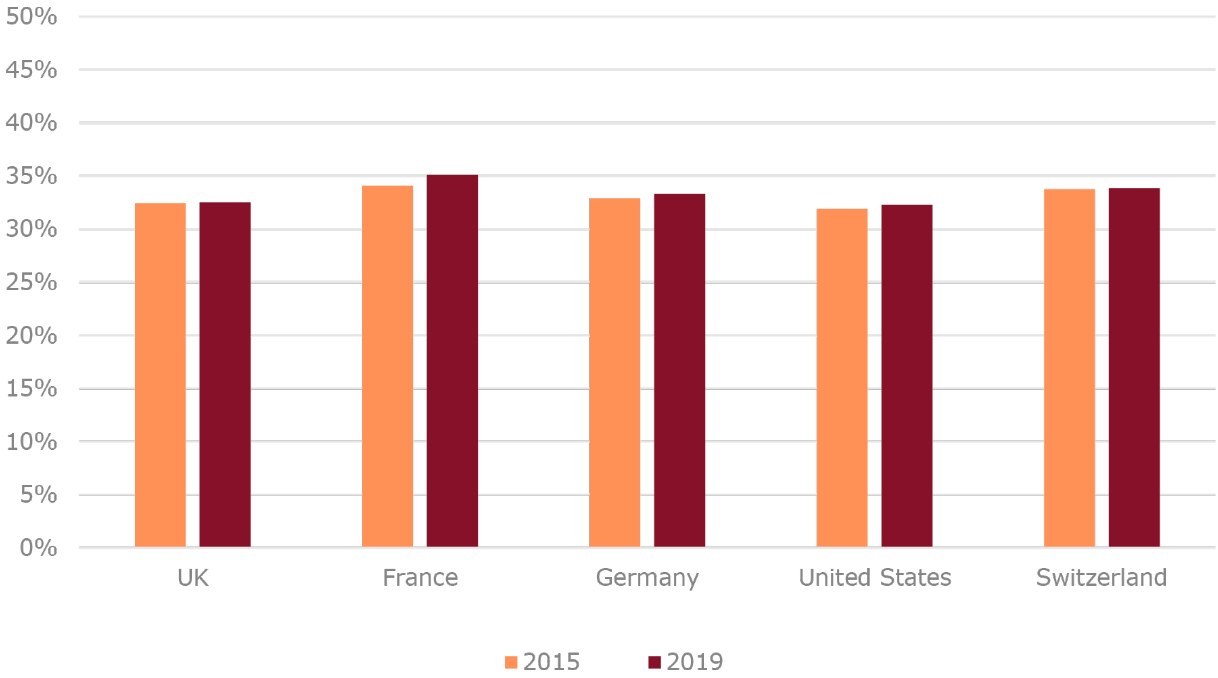
[39] Ibid.

manufacturing is estimated at 33%. In other words, 33% of the value added in UK manufacturing comes from the accumulation of value added generated by business services, domestically and internationally.

Based on data shown in Figure 2.3:

- **The level of servicification in UK manufacturing is similar to that of comparator countries in both 2015 and 2019.**
- **Across the UK and comparator countries, the level of servicification in manufacturing does not change substantially between 2015 and 2019.**

Figure 2.3 Business economy service value added as a share of total manufacturing value added – selected countries, 2015 and 2019 (%)



Note: Business economy services are defined as Section G to Section N of ISIC Rev. 4 statistical classification.

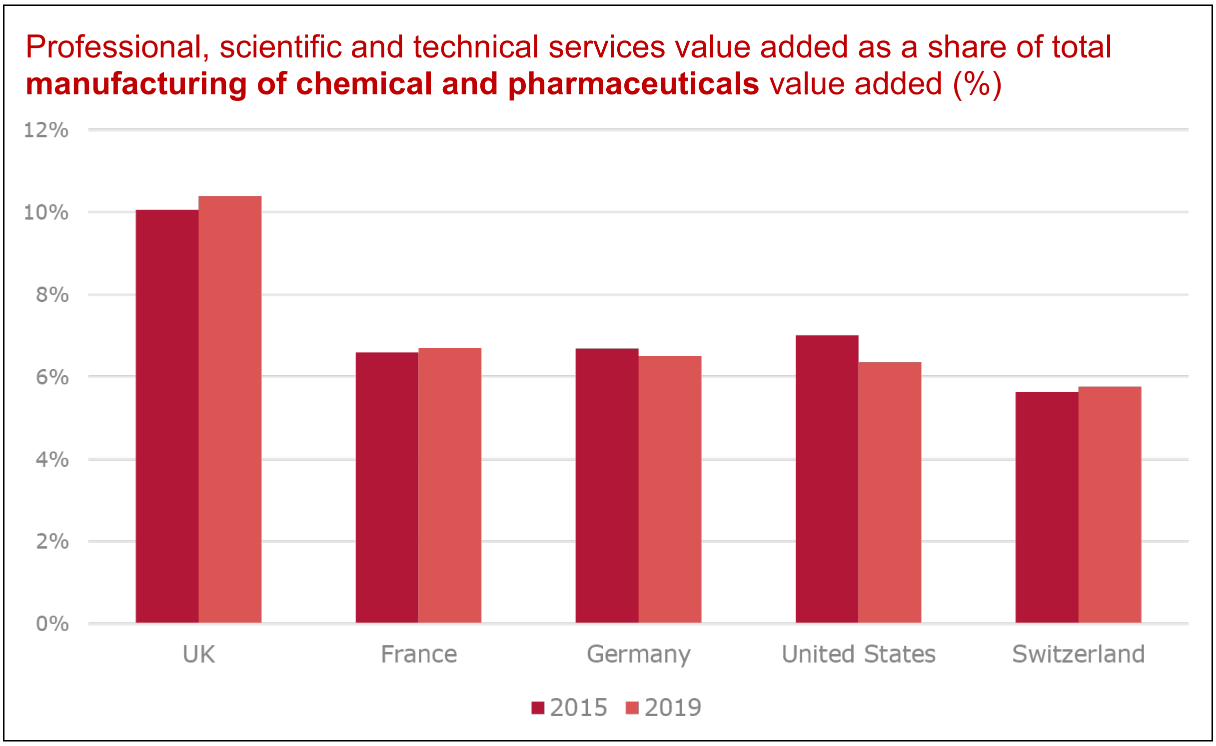
Source: OECD (2023). Trade in Value Added (TiVA) 2023 edition: Origin of value added in final demand.

Figure 2.3 provides an aggregated measure of the servicification of the whole manufacturing sector. However, it is possible to further disaggregate the analysis and assess the level of servicification of UK manufacturing compared to selected countries by focusing on KIBS and selected sectors, including pharmaceutical, automotive and other transport equipment (including aerospace).

KIBS such as "professional, scientific and technical" services include activities that are fundamental to modern manufacturing processes, such as R&D, architectural and engineering activities, specialised scientific and technical activities, legal, accountancy and marketing activities. On the other hand, pharmaceuticals, automotive and other transport equipment (including aerospace) play a vital role in

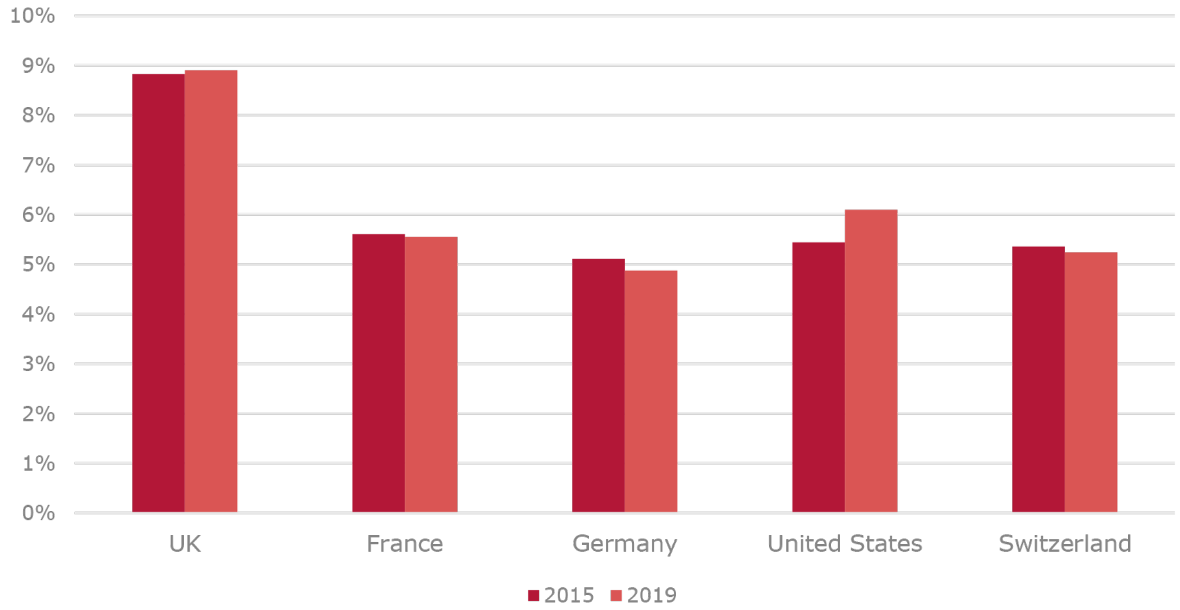
UK manufacturing, accounting for 23% of manufacturing value added in 2023.[40] Figure 2.4 shows the "professional, scientific and technical" services value added as a share of manufacturing value added in selected sectors, comparing the UK with other countries.

Figure 2.4 Professional, scientific and technical services value added as a share of total manufacturing value added – selected countries and sectors, 2015 and 2019 (%)

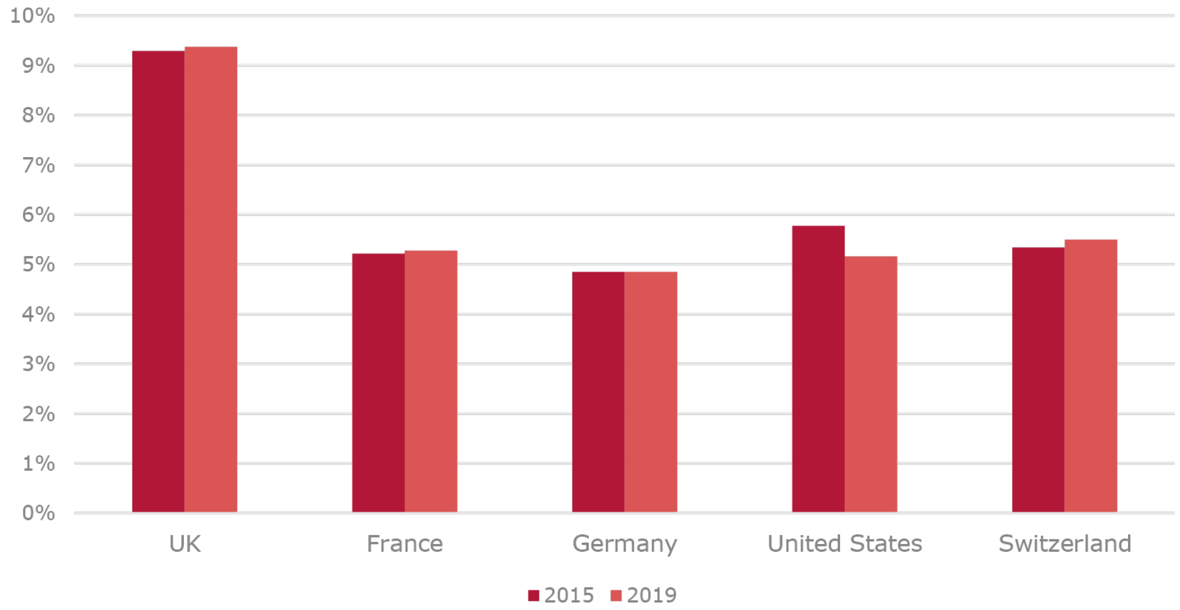


[40] Cambridge Industrial Innovation Policy (2025). The UK Manufacturing Dashboard.

Professional, scientific and technical services value added as a share of total **manufacturing of motor vehicles** value added (%)



Professional, scientific and technical services value added as a share of total **manufacturing of other transport (aerospace)** value added (%)



Note: Professional, scientific and technical services are defined as Section M of ISIC Rev. 4 statistical classification.

Source: OECD (2023). Trade in Value Added (TiVA) 2023 edition: Origin of value added in final demand.

The data in Figure 2.4 shows that key sectors of UK manufacturing, such as pharmaceuticals, automotive and aerospace, rely more on professional services than those in comparator countries. For example, in 2019, 9.4% of the value added in UK motor-vehicle manufacturing came from professional services, compared to 5.3% in

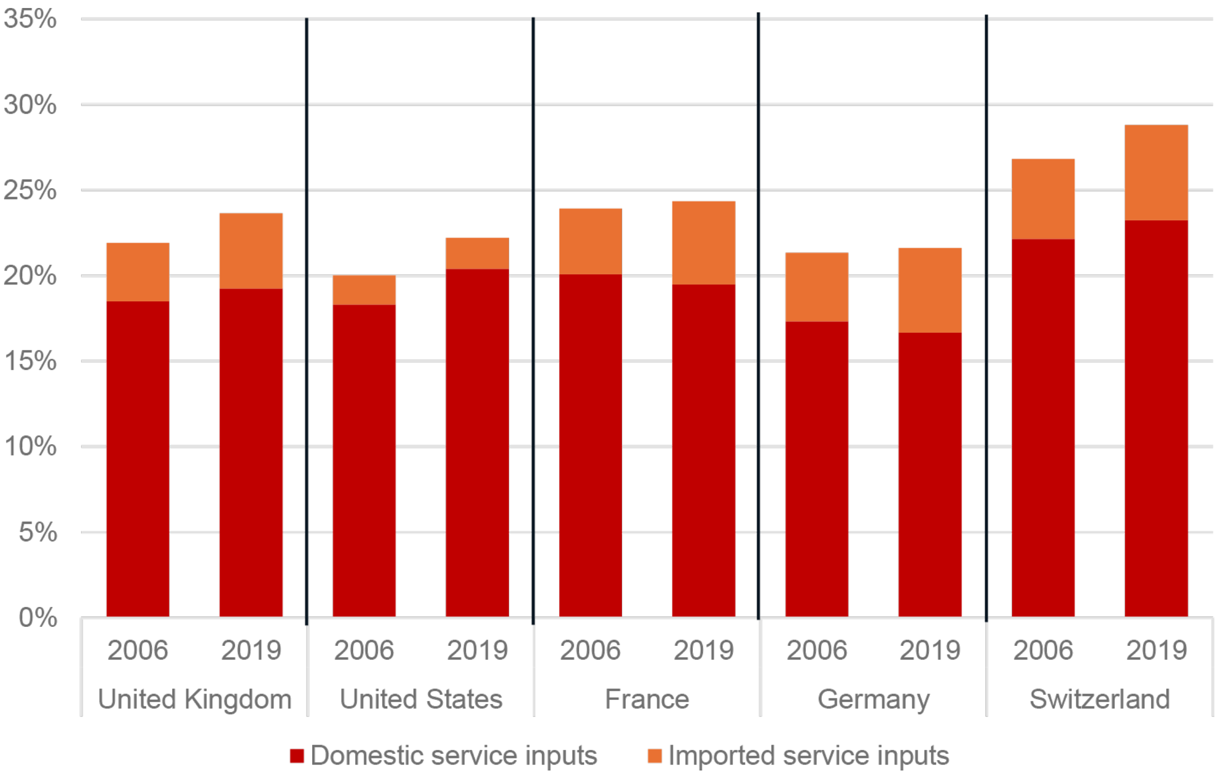
France and 4.8% in Germany. In other words, **the use of professional, scientific and technical services in selected UK manufacturing sectors is higher than in comparator countries, which suggests a higher level of servicification in those sectors**.

2.3.3. Quantifying servicification: output approach

The servicification of manufacturing can also be quantified by measuring the purchased service inputs in manufacturing and the extent to which service inputs have increased in total manufacturing output.[41] The "output approach" and the "value-added approach" analysed in the previous section should be read together to better understand the importance of value-adding services in manufacturing.

Figure 2.5 shows the level of service inputs into manufacturing output, comparing the UK with selected countries in 2006 and 2019.

Figure 2.5 Share of service inputs in manufacturing output – selected countries, 2006 and 2019 (%)



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on OECD (2023). National Input-Output Tables (IOTs), 2023 edition.

Figure 2.5 shows the following:

- In 2019 service inputs accounted for 23.6% of the value needed to produce a unit of manufacturing output in the UK, a level similar to that of comparator countries.

[41] Wolfmayr, Y. (2008). Service Inputs and Competitiveness of Manufacturing Exports of OECD Countries. Austrian Institute of Economic Research WIFO.

Therefore, **the servicification of UK manufacturing is comparable to these countries**.

- The level of manufacturing servicification increased in both the UK and comparator countries between 2006 and 2019, based on service inputs analysis.
- In both the UK and comparator countries, domestically supplied service inputs make up the largest share of total service inputs used in manufacturing.

2.4. Assessing the servitisation of manufacturing

2.4.1. Methodological challenges in measuring manufacturing servitisation

Manufacturing servitisation refers to companies' business strategies. Therefore, measuring the level of servitisation across the manufacturing sector, and the impact of such business strategies on firms' performance and competitiveness, is complex (Box 2.1). Empirical studies use diverse methodologies such as case studies and quantitative analyses and rely on surveys where firms describe their businesses, including whether they are engaged in servitisation activities.

Nonetheless, previous analyses show that in the UK 78% of manufacturing firms developed servitisation business models in 2020.[42] On the other hand, almost 75% of French manufacturing firms provided services that were extra to their core product in 2017, although the extent of firms' engagement with servitisation varies across manufacturing sub-sectors.[43]

Regarding the impact of servitisation on business performance, the evidence is mixed. Some studies suggest that firms adopting servitisation strategies often experience improved financial performance.[44] On the other hand, other analyses of servitisation highlighted that while it can lead to improved financial outcomes, the positive impact of a servitisation strategy relies on factors such as the nature of the services offered, the firm's capabilities, the industry in which firms operate[45] and firm size.[46]

[42] The Manufacturer (2020). Annual Manufacturing Report 2020.

[43] Crozet M. and Milet E. (2017). Should everybody be in services? The effect of servitization on manufacturing firm performance. *Journal of Economic and Management Strategies.*

[44] Baines (2013). Servitization of the manufacturing firm: Exploring the operations practices and technologies that deliver advanced services. *International Journal of Operations & Production Management.*

[45] Raddats et al. (2019). Servitization: A contemporary thematic review of four major research streams. *Industrial Marketing Management*, 83.

[46] Neely (2009). Exploring the financial consequences of the servitization of manufacturing. *Operations Management Research.*

Box 2.1 Methodological challenges in measuring manufacturing servitisation

Financial reporting gap. A major barrier in servitisation measurement is the lack of standardised financial reporting on service revenue. Many firms bundle product and service revenue together in financial statements, making it difficult to assess servitisation intensity. The issue is exacerbated by hidden servitisation, where firms provide supplementary services, such as AI maintenance or remote diagnostics, that do not generate direct revenue but contribute significantly to servitisation strategies. The absence of distinct service revenue breakdowns creates an incomplete picture of servitisation's financial and strategic significance.

Sectoral heterogeneity. Industries exhibit intrinsic differences in servitisation models, making cross-sectoral and country measurements challenging. In aerospace and defence, maintenance services are offered through long-term and performance-based contracts, such as RR's Power by the Hour (PBH) model. However, in pharmaceuticals, it revolves around regulatory-driven patient services and intellectual property management. The automotive sector relies on leasing and software-driven services, whereas in consumer electronics, services are often bundled as value-added features rather than standalone revenue streams.

Market structures further influence servitisation measurement. In oligopolistic industries, such as aerospace and telecommunications, firms generate significant revenue from premium services, making financial indicators more reliable. In contrast, highly competitive sectors, such as consumer electronics, often provide services as a value-added component rather than a primary revenue driver, making revenue-based indicators inadequate for measuring servitisation. These variations emphasise the need for alternative measurement approaches tailored to different market structures.

Inadequacy of industry classification systems. Existing industry classification systems further hinder accurate measurement. The Standard Industry Classification (SIC) system, widely used for economic analysis, does not capture the complexity of servitisation. The system assigns firms to a single category based on primary revenue-generating activities, leading to misclassification of hybrid business models. For instance, industrial manufacturers expanding to equipment-as-a-service models are still classified under traditional manufacturing, despite their business focus on service provision.

International inconsistencies in classification frameworks, such as NAICS in North America, ISIC under the United Nations and NACE in Europe, further complicate cross-country servitisation analysis. The absence of explicit service revenue breakdowns within these classifications limits the ability to effectively track servitisation trends, making policy interventions less data-driven and targeted.

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on the review of the literature presented in Appendix 1.

2.4.2. Case study: Rolls-Royce and General Electric servitisation

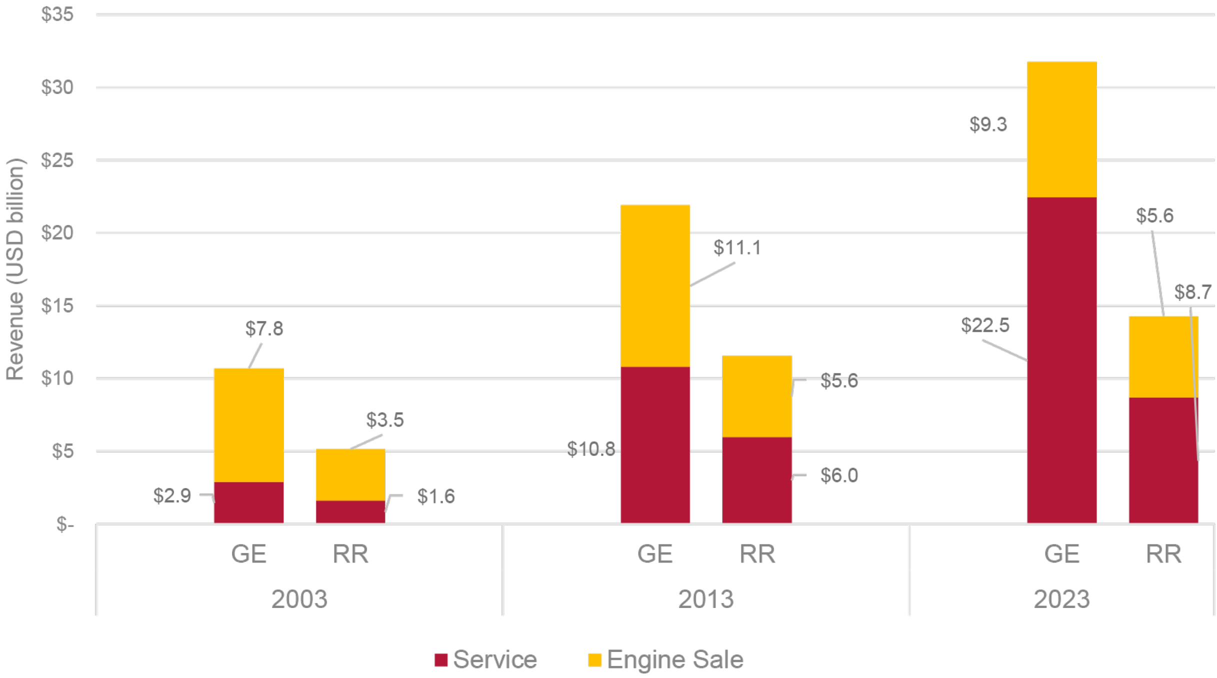
The following case study offers an overview of how servitisation can evolve and play a different role within similar companies acting in the same sectors and segments of the value chain.

Servitisation of the aerospace sector dates back to the 1970s with RR's introduction of the PBH model, which initiated a new business model from selling aircraft engines to providing integrated service packages. Under this model, customers paid based on flying hours, transferring maintenance risks to the manufacturers. Prior to PBH, engine manufacturers relied on time-and-materials contracts, with airlines or third-party providers managing maintenance and repairs.

From the 1990s, original equipment manufacturers (OEMs) and airlines increasingly embraced long-term, fixed-price maintenance agreements. These agreements allowed airlines to streamline operations by outsourcing engine maintenance, which reduces operational complexity and minimises uncertainty about the availability of parts and costs. For OEMs, the technological advancements that improved engine reliability and extended life cycles challenged traditional revenue models that relied on spare parts' sales. Recognising the critical importance of customer support in sustaining and expanding their business, OEMs entered the MRO market.

In 1997 RR launched TotalCare, a programme offering customised aftermarket services for wide-body engines, with costs calculated based on flight hours. This marked the start of incorporating long-term service agreements into its business strategy. GE Aerospace introduced similar fixed-payment service offerings such as Maintenance Cost Per Hour (MCPH) and On-Point Solutions. Both companies have since heavily invested in building their service capabilities and adopted service-centric business models. Over the past 2 decades, RR and GE Aerospace have expanded their service operations through reorganisation, acquisitions and joint ventures. For example, between 2003 and 2023, the share of engine service revenue as a percentage of total aviation-related revenue (i.e. services plus engines) for GE and RR increased from 27% to 71%, and 32% to 61%, respectively (Figure 2.6). While RR pioneered the servitisation model, GE gained a competitive edge by capturing a larger share of service revenue since the 2010s.

Figure 2.6 Rolls-Royce (RR) and General Electric (GE): aviation-related revenue coming from services and engines, 2003-2023



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on Rolls-Royce. Annual report 2003, 2013, 2023. London: Rolls-Royce plc; General Electric Company. 2003, 2013, 2023 annual report.

RR's and GE's respective servitisation strategies are shaped by several factors, including the size of their installed base, the diversity of their product portfolios, and their partnership decisions:

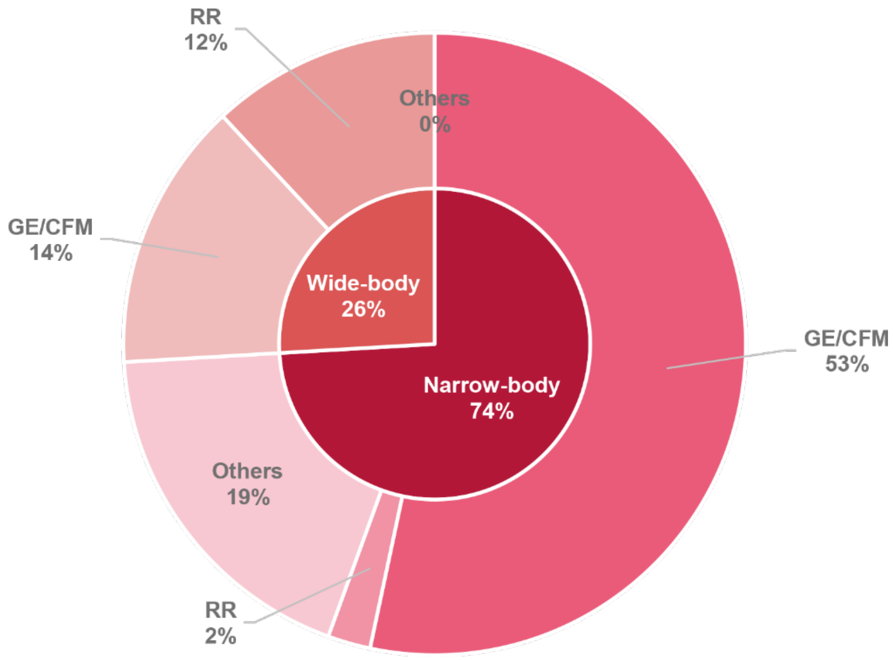
- GE's larger installed base allows it to achieve economies of scale and reduce operational costs.[47] This scale advantage strengthens its ability to offer competitive service pricing while maintaining profitability.
- GE benefits from a diversified product portfolio, including narrow-body, wide-body, regional jets and military aircraft. This broad scope provides access to a wider customer base and multiple revenue streams. In contrast, RR's focus on wide-body engines narrows its service potential[48] and market share (Figure 2.7).
- Partnership choices influence the development of complementary capabilities and differentiated service offerings. For instance, GE's main MRO joint venture, CFM International, has secured its dominance in the narrow-body segment through the widely used CFM56 and LEAP engines. By comparison, RR's MRO joint ventures, including Singapore Aero Engine Services Private Ltd (SAESL),

[47] GE Aerospace manages more than 44,000 commercial engines and 26,000 military engines, while RR has 4,860 large engines for wide-body aircraft and 6,500 engines for business aviation.

[48] As of February 2023, GE held 53% and 14% of the in-service narrow- and wide-body engine market, respectively. RR held 2% and 12% of the in-service narrow- and wide-body engine market, respectively.

HAESL in Hong Kong, and N3 in Germany, mainly focus on its Trent and Pearl engine families.

Figure 2.7 Rolls-Royce (RR) and General Electric-CFM International (GE/CFM): market share of in-service engine types, February 2023



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on Rolls-Royce. Annual report 2003, 2013, 2023. London: Rolls-Royce plc; General Electric Company. 2003, 2013, 2023 annual report.

The case of Rolls-Royce and General Electric's servitisation strategies outline how manufacturing companies can move beyond selling physical products and generate higher value through service-based solutions. Such strategies have benefited the companies in terms of recurring revenue – instead of relying on one-time engine sales, firms can secure long-term contracts for engine maintenance and performance-based services – and profit margins as long as selling services generates consistent cash flow compared to cyclical product sales. For final customers, on the other hand, airlines face lower upfront costs for engine purchases and pay only for the use of those engines (PBH model). This means they have predictable maintenance expenses.

2.5. Conclusions

This section has examined the role of services in modern manufacturing production processes and business models. It has compared the UK with France, Germany, Switzerland and the USA and focused on 2 key concepts: servicification – the increasing reliance of manufacturing firms on services, associated with outsourcing and offshoring practice, as well as the emergence of GVCs; and servitisation – a firm-level strategy where manufacturers integrate services into their core product offering, adding value for customers.

Quantitative estimates of the level of servicification of manufacturing showed that while the UK's level of servicification is comparable to other advanced economies, certain UK manufacturing sectors, including pharmaceuticals, automotive and aerospace, rely more on professional services. This underscores the growing importance of services in enhancing the competitiveness and value of UK manufacturing. The case study of RR's and GE's servitisation strategies outline how servitisation can evolve and play a different role within similar companies acting in the same sectors and segments of the value chain, financially benefiting both companies and final customers.

The analysis presented in this section highlights the crucial role and complementarity of services in manufacturing. If manufacturing depends on services along the manufacturing value chain, it is essential to incorporate key services into manufacturing strategies.

3. Defining and quantifying advanced manufacturing

Key messages

- This section defines advanced manufacturing as a *set of activities aimed at producing products or integrated product–service solutions that are hard to replicate or substitute because of their use of innovative technologies, methods or materials*.
- These innovative technologies, methods and materials typically draw on specialised knowledge from the physical, biological and computer sciences, and often require a highly qualified workforce, as well as access to collaborative knowledge networks.
- Advanced manufacturing is understood as applicable to both existing products and, significantly, new high-value products enabled by emerging technologies. It is positioned as a key driver of competitiveness in high-value, innovation-intensive environments, and as a foundation for national industrial leadership in an increasingly technology-driven global economy.
- Based on this conceptualisation, the report also proposes definitions of advanced manufacturing processes, firms, value chains and sectors to support more targeted analysis and policy development.
- The review of the international practice reveals 4 main approaches commonly used to define and measure advanced manufacturing: (1) R&D intensity, (2) employee qualification, (3) matching expert-selected technologies or products with existing industrial classifications, and (4) expert evaluations of individual firms.
- To illustrate how advanced manufacturing sectors might be identified and quantified in the UK, the report applies a selection of data-driven proxies guided by international practice. This is not intended to be a comprehensive methodology, but rather a practical example of how certain indicators can be used to inform policy and analysis. The initial focus is on the sector level, using data classified by SIC codes.
- While this sectoral approach is useful for highlighting priority areas for policy attention, it has limitations. Sectors often include a mix of advanced and non-advanced firms, making it difficult to capture differences in technological capability and strategic focus.
- To overcome these limitations, the report argues for a shift towards firm-level approaches, which offer greater granularity and can more accurately identify firms that embody the characteristics of advanced manufacturing – allowing for more targeted and effective policy interventions.

3.1. Introduction

This section defines advanced manufacturing and related terms, drawing on a review of the academic and policy literature. It then examines how different countries and institutions have approached quantifying advanced manufacturing and sets out a recommended approach for the UK context.

In recent years there has been increasing recognition that high-wage economies such as the UK face structural challenges in competing internationally in cost-driven and labour-intensive manufacturing – often referred to as “traditional” manufacturing. In this context, “advanced” manufacturing has gained prominence as a strategic concept, representing the types of manufacturing activity that can still be competitive and value-generating in high-cost environments.

Despite its growing policy relevance, advanced manufacturing remains somewhat contested and ambiguously defined. In the UK it is identified as one of the 8 strategic priorities in the 2024 *Industrial Strategy Green Paper*.[49] However, the green paper acknowledges the conceptual uncertainties surrounding advanced manufacturing and calls for further analytical work to delineate the specific subsectors and capabilities that fall within its scope.

There is, therefore, a clear need for more precise conceptualisation of advanced manufacturing to inform industrial strategy, enable effective benchmarking and guide policymaking. We hope that the analysis presented in this section supports this effort by clarifying key terms, reviewing international practices and proposing approaches suited to the UK context.

3.2. A review of the definitions of advanced manufacturing

Many definitions of advanced manufacturing exist, and, unsurprisingly, they vary across countries, institutions and contexts. Some emphasise applying specific technologies in manufacturing, others highlight the intensity of R&D, and others focus on the types of product typically associated with advanced manufacturing.

As summarised in Table 3.1, we compare definitions drawn from academic and policy literature along 3 key dimensions. First, we consider **how manufacturing is conceptualised (perspective)** – whether it is framed as a process, a set of activities, a system or a practice. Second, we identify **what makes manufacturing “advanced” (characteristics)**, focusing on distinctive features such as integrating digital technologies, new materials, automation or combining production with services. Third, we examine **why advanced manufacturing is considered desirable (purpose)**, highlighting the strategic purposes commonly associated with it, such as enhancing competitiveness, enabling innovation or supporting national capabilities. This comparative analysis provides the foundation for developing a more comprehensive and precise definition of advanced manufacturing.

[49] DBT (2024). Invest 2035: the UK’s modern industrial strategy.

Table 3.1 Comparative overview of advanced manufacturing definitions

Source	How manufacturing is conceptualised (perspective)	What makes manufacturing "advanced" (characteristics)	Why is advanced manufacturing desirable (purpose)
DBT (2023)	Manufacturing as production processes	Integration of advanced science into manufacturing	Helps manufacturers create products that meet future technological demands Enables national leadership on the twin transitions of net zero and digitalisation
PCAST (2011)	Manufacturing as a family of activities	Use and coordination of information, automation, computation, software, sensing and networking, use of cutting-edge materials and emerging capabilities enabled by science	Creates new ways to manufacture existing products and to manufacture new products emerging from new technologies Revitalises national leadership in manufacturing and supports economic productivity and ongoing knowledge production and innovation in the country
De Weck et al. (2014)	Manufacturing as a creation process	Coupling of production with services; use of custom-designed and recycled materials; use of ultra-efficient processes	Creates integrated solutions
CSIRO (2016)	Manufacturing as a set of offerings, systems and processes	Rapid adoption of technologies	Centres manufacturing on value addition across entire supply chains
Next Generation Manufacturing Canada (n.d.)	Manufacturing as the production of finished goods	Use of new digital, materials and production technologies	Allows innovation and making things faster, cleaner and better than before
TWI (n.d.)	Manufacturing as a practice	Incorporating cutting-edge advancements, such as artificial intelligence and composite materials	Improves competitiveness within the manufacturing sector

Source: see appendix 2

Key aspects of the definitions included in Table 3.1 are discussed next. A full set of definitions reviewed for this section can be found in Appendix 2.

UK Department for Business and Trade (2023)

> "Production processes that integrate advanced science and technology, including digital and automation, to manufacturing. These processes use R&D, innovation, our extensive knowledge network, and our highly skilled population. This helps UK manufacturers create products that are meeting future technological demands and enables the UK to lead on the twin transitions of net zero and digitalisation."[50]

The definition provided by the UK DBT frames advanced manufacturing as a **process** characterised by 2 main features. First, it involves the use or integration of advanced science and technology, through R&D, innovation, knowledge networks and a highly skilled workforce. Second, the aim is to make products that meet future technological demands, particularly those related to net zero and digitalisation.

However, the definition is slightly ambiguous regarding whether both characteristics must be present for a process to qualify as advanced manufacturing. Specifically, it is unclear whether it includes processes that use state-of-the-art science and technology to produce existing, traditional products, or whether it encompasses making products that meet future technological needs using conventional processes. This lack of clarity limits its operational usefulness for policy and industrial strategy.

US President's Council of Advisors on Science and Technology (PCAST) (2011)

> "The family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/ or (b) make use of cutting edge materials and emerging capabilities enabled by the physical / biological sciences, e.g. nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies."[51]

This definition considers advanced manufacturing as a "**family of activities**". These activities, first, depend on the use and coordination of information, with a strong emphasis on **digital technologies**, including computation, software and networking. Second, they use **state-of-the-art materials and emerging scientific capabilities**, with specific reference to fields such as **nanotechnology, chemistry and biology**. Importantly, the definition encompasses both **applying advanced processes to the production of existing products** and **developing entirely new products**.

[50] DBT (2023). Advanced manufacturing plan.

[51] PCAST (2011). Report to the President on ensuring American leadership in advanced manufacturing.

De Weck et al. (2014)

> "Advanced manufacturing is the creation of integrated solutions that require the production of physical artifacts coupled with valued-added services and software, while exploiting custom-designed and recycled materials and using ultra-efficient processes."[52]

This definition considers advanced manufacturing as being characterised by **integrating physical production with services**. It defines advanced manufacturing as a creation process with 3 core features: producing integrated solutions that combine physical artefacts, services and software; using custom-designed and recycled materials; and applying ultra-efficient processes.

While the definition is valuable in highlighting the importance of integrating services and software with physical products, it is also relatively narrow in scope. By requiring all 3 features to be present, it excludes manufacturing activities that, for example, focus on advanced physical production without incorporating services or recycled materials. Additionally, the concept of "ultra-efficient processes" is left undefined.

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2016)

> "This report defines advanced manufacturing as the set of technology based offerings, systems and processes that will be used to transition the current manufacturing sector into one that is centred on adding value across entire supply chains. Advanced manufacturers are companies that rapidly create or adopt these technologies… Advanced manufacturing can be applied equally to traditional manufacturing industries and those that are being continually discovered through the expansion and evolution of the sector. For example, an expansion of the current supply chain into product disposal or re-use would see a range of advanced manufacturing products, systems and products be heavily utilised."[53]

This definition sees advanced manufacturing as **a set of technology-based offerings, systems and processes**. The main distinctive characteristic of these things is that they **add value across entire supply chains** – that is, they can be applied to R&D, production, after-sale services and end-of-life management of products. Similarly, advanced manufacturers can be found performing activities from the initial R&D stage through to after-sales services and, increasingly, end-of-life management.

While the definition is somewhat unclear in many aspects (e.g. what is meant by "adding value" and the "set of offerings, systems, and processes" is not fully described), it underscores the importance of the manufacturing supply chain, and not only the companies doing the physical production stages.

[52] De Weck et al. (2014). Trends in advanced manufacturing technology innovation.

[53] CSIRO (2016). Advanced manufacturing – a roadmap for unlocking future growth opportunities for Australia.

Next Generation Manufacturing Canada (n.d.)

> "Manufacturing is about adding value to raw materials and components to produce finished goods for customers. Advanced manufacturing uses new digital, materials, and production technologies to innovate and make things faster, cleaner, safer, and better than before. It is at the heart of a value-creating network of researchers, tech companies, and of course manufacturers creating value for customers through products as well as data-based services. Advanced manufacturing can be found in all sectors of industry, but is the most advanced in fields like automotive and aerospace, medical technologies and biomanufacturing, robotics and automation, electronics, textiles, and processing industries."[54]

This definition emphasises the use of digital, materials and production technologies as key enablers of innovation and improved manufacturing performance. It frames **advanced manufacturing** not as a discrete sector but as an activity embedded within a broader **value-creating network**, including researchers, technology firms and manufacturers. A particularly important contribution of this definition is its recognition that advanced manufacturing **cuts across all sectors of industry**. Rather than constituting a single sector, **advanced manufacturing spans multiple industries**, with a particularly strong presence in sectors such as **automotive, aerospace, medical technologies and electronics**.

TWI (n.d.)

> "Advanced manufacturing is the practice of using innovative technologies and methods to improve and enhance competitiveness within the manufacturing sector. By incorporating cutting-edge advancements, such as artificial intelligence and composite materials, we can optimise every aspect of the value chain – from product conception to end-of-life considerations."[55]

This definition frames advanced manufacturing not just as a process or activity but also as a **practice**. Following this conception, advanced manufacturing practices can be implemented in any kind of firm within the manufacturing sector, and even in activities within firms. It emphasises using **innovative technologies and methods** as the core feature of these practices, with the objective of enhancing **competitiveness**. This makes it one of the few definitions that directly link advanced manufacturing to market performance, clearly suggesting that being "advanced" is not only about improving how things are made but also about doing so more effectively *than competitors*. The definition positions advanced manufacturing as a strategic tool for achieving a competitive edge, highlighting not just capability but also purpose.

[54] Next Generation Manufacturing Canada (n.d.) How is advanced manufacturing different from manufacturing?

[55] TWI (n.d.) What is advanced manufacturing? (A complete guide).

This definition also acknowledges the **value-chain** dimension of manufacturing and references the importance of **materials**, though it remains broad in how competitiveness is achieved – through process improvements, product innovation or integrated solutions.

Summary

In summary, the above definitions highlight different aspects of advanced manufacturing that could be considered in a comprehensive definition of advanced manufacturing, as follows.

Perspective

- **Focus on processes rather than products.** A recurring insight is that advanced manufacturing should be defined not by the nature of the products being made but by the **sophistication of the processes** used to make them. This allows for the possibility that even traditionally "low-tech" products can be produced using advanced manufacturing techniques, depending on how the production is organised and executed.

Characteristics

- **Innovative and sophisticated technologies, methods and materials.** Advanced manufacturing is consistently associated with the use of technologies, methods and materials that are innovative, sophisticated, cutting-edge and/or science-based. Examples frequently cited include automation, artificial intelligence, additive manufacturing and advanced materials such as composites. Some definitions also emphasise the scientific foundations underpinning these innovations, particularly in fields such as nanotechnology, chemistry, biology and the physical and biological sciences more broadly.

- **Skilled workforce and knowledge networks.** Most definitions highlight the critical role of human capital – including a highly skilled workforce and access to knowledge networks. The ability to adopt, adapt and scale advanced manufacturing technologies depends on specialised skills and collaborative ecosystems involving manufacturing workers.

- **Manufacturing value chains.** Another important aspect emphasised is the need to encompass other important segments of the manufacturing value chain that enable manufacturing activities to be advanced. This includes, for example, manufacturing-oriented R&D, product development, support services, after-sales services and end-of-life processes.

- **Integrating services and manufacturing.** Closely related to the value-chain perspective is the increasing integration between manufacturing and services, especially software-enabled services.

Purpose

- **Competitiveness orientation.** Finally, a notable feature in some definitions is an explicit focus on competitiveness. In other words, advanced manufacturing is framed as a strategic approach to creating products, processes and solutions that are hard to replicate or **substitute**, offering firms a pathway to sustained competitive advantage in high-cost and globalised markets.

3.3. A proposed definition of advanced manufacturing and related concepts

3.3.1. Proposed definition of advanced manufacturing

Building on the analysis presented in the previous section, the following definition of advanced manufacturing is suggested:

Advanced manufacturing

Advanced manufacturing is a set of activities aimed at making products or integrated product–service solutions that are hard to replicate or substitute because of their use of innovative technologies, methods or materials. These innovative technologies, methods and materials typically draw on specialised knowledge from the physical, biological and computer sciences, often requiring a highly qualified workforce and access to collaborative knowledge networks.

Advanced manufacturing can be applied to producing existing products or, especially, new high-value products enabled by emerging technologies. What makes advanced manufacturing hard to replicate or substitute may be the use and coordination of innovative production technologies (e.g. tools, metrology, sensing, automation), sophisticated support activities embedded in the production process (e.g. data analytics, diagnostics, quality control) or the techno-organisational structure required by complex production systems (e.g. new product development workflows, specialised skills and training, customer demand management systems).

As such, advanced manufacturing is a key driver of competitiveness in high-value, innovation-intensive environments, and a foundation for national industrial leadership in an increasingly technology-driven global economy.

An elaboration of this suggested definition is provided below:

- **Perspective.** Our suggested definition views advanced manufacturing as a **set of activities** aimed at making products or integrated product–service solutions. Central to this definition is the emphasis on physical production processes, which reflects the core, tangible nature of manufacturing. While the primary output is physical products, these can be offered together with services, reflecting the increasing integration of digital and service elements in modern manufacturing. We consider providing such related services – including design, diagnostics, data analytics and post-sales support – to be an integral part of the set of activities that define advanced manufacturing.
- **Characteristics.** In our suggested definition, advanced manufacturing is characterised by using innovative technologies, methods and materials. We use the word “innovative” instead of similar terms (cutting-edge, state-of-the-art, advanced, ultra-efficient, and so on) intentionally. By using this term, we wish to

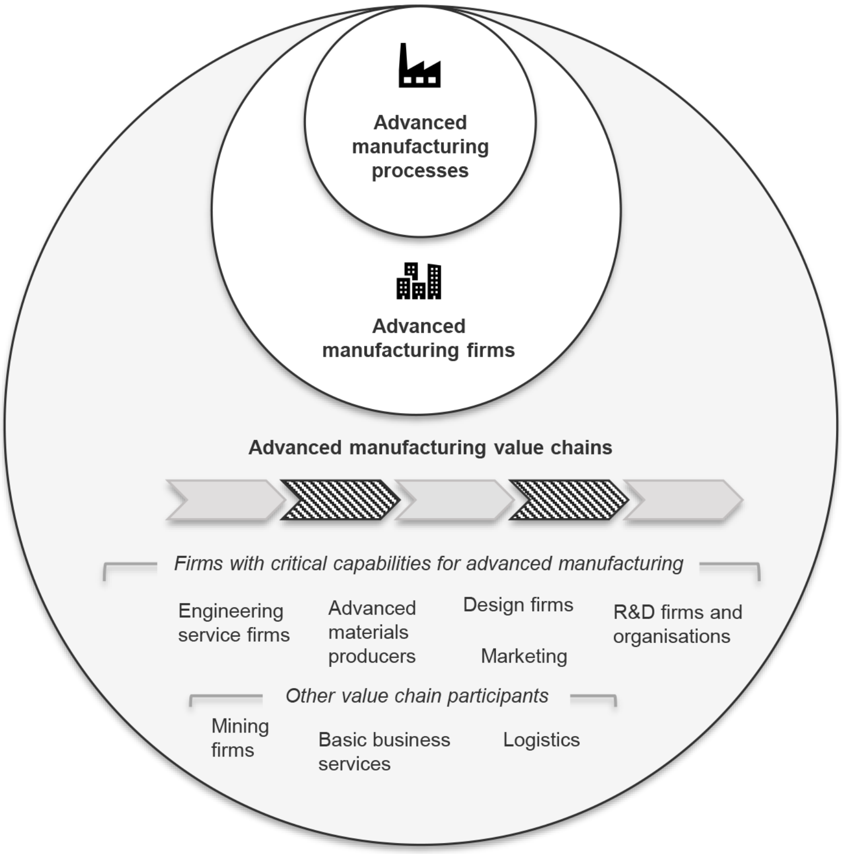
leverage the notion of innovation as inventions that have market value. We also refer to innovative technologies, methods and materials. Arguably, a broad definition of “technology” could also encompass methods and materials. To avoid doubt, however, we make it clear that these are not limited to the physical products used in production but also include the intangible methods that underpin production. We also highlight the importance of materials as a different category because of their role in product performance. We therefore mention it separately.

- **Purpose.** Our definition frames advanced manufacturing as a set of activities that are hard to replicate or substitute. This is a key distinguishing aspect of our definition. Instead of using the commonly used “new”, “better”, “improved” or “enhanced”, we emphasise competition and state clearly that the goal of advanced manufacturing is to be hard to replicate or substitute by competitors. In other words, to generate competitive advantage for manufacturing companies, it is not enough to use innovative technologies, methods and materials if it does not benefit the market. A fundamental goal of advanced manufacturing is to obtain a competitive edge, which leads to market value that can be sustained over time.

3.3.2. Related concepts: advanced manufacturing firms, value chains and sectors

Building on the definition above, definitions related to advanced manufacturing are proposed. Figure 3.1 provides represents the relationship between these definitions.

Figure 3.1 Levels of the proposed definitions related to advanced manufacturing



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge.

- **Advanced manufacturing processes.** Advanced manufacturing processes create novel materials and components with superior properties and performance, enhancing the precision, efficiency and capabilities of traditional manufacturing processes.[56] These processes go beyond traditional equipment by incorporating advanced technologies and capabilities such as automation, robotics, sensing and real-time data analytics. They draw on specialised knowledge from fields like materials science, biotechnology, computer science and nanotechnology, and are often key to enabling the creation of products or integrated product–service solutions that are difficult to replicate or substitute using conventional methods. Beyond technological sophistication, advanced manufacturing processes are typically embedded in organisational systems that include functions such as design, quality assurance, diagnostics and demand forecasting. They rely on highly skilled talent, interdisciplinary collaboration and access to knowledge networks, making them central to the operations of advanced manufacturing firms and value chains.
- **Advanced manufacturing firms.** Advanced manufacturing firms are manufacturing enterprises that place advanced manufacturing at the core of their

[56] This definition is taken from National Institute of Standards and Technology (NIST) (2024). Advanced Manufacturing.

business strategies and operational routines. With this definition, it is not enough for a firm to have a single production line or isolated unit using advanced technologies. Rather, advanced manufacturing must be central to the firm's operations, with the majority of its activities grounded in the use of innovative technologies, methods and materials. Importantly, this definition excludes firms whose competitive advantage is primarily derived from non-technological factors, such as locational advantages, regulatory environments or preferential policies. While such firms may be competitive, they cannot be classified as advanced manufacturing firms.

- **Advanced manufacturing sectors.** Advanced manufacturing sectors are defined as manufacturing sectors in which a significant proportion of value added is generated by advanced manufacturing firms. This approach shifts the focus from product types or industry labels to the nature of the firms operating within the sector. By interpreting sectors through the lens of firm characteristics, this definition recognises that advanced manufacturing is not confined to specific product categories. Instead, it is about the intensity of technological and organisational sophistication that firms in the sector bring to their production and innovation activities.
- **Advanced manufacturing value chains.** Advanced manufacturing value chains refer to the networks of firms and organisations that carry out functions critical to enabling and sustaining advanced manufacturing activities. These functions may include R&D, industrial design, manufacturing engineering services, advanced materials processing and other complementary capabilities. Defining these value chains is essential, as they represent the most appropriate unit of analysis for industrial strategy. Importantly, value chains cut across sector boundaries. The competitiveness of individual advanced manufacturing firms often depends on the broader ecosystem in which they are embedded. This perspective aligns with the concept of industrial commons,[57] which emphasises the importance of co-located capabilities in fostering innovation and long-term industrial competitiveness.

Box 3.1 presents a set of questions and answers designed to clarify the distinctions between the definitions outlined above.

[57] Pisano and Shih (2012). Producing Prosperity: Why America Needs a Manufacturing Renaissance.

Box 3.1 Questions and answers to clarify our definition of advanced manufacturing and related concepts

Is the microchip design company ARM an advanced manufacturing firm?

No. It is not a manufacturing firm, so it is not an advanced manufacturing firm according to our definition (our definition clearly states advanced manufacturing firms need to be manufacturing firms). However, it is part of advanced manufacturing value chains, as it supports the advanced production done by manufacturing companies in the semiconductor value chain (e.g. the Taiwanese foundry TSMC).

Are the pharmaceutical research companies that developed the COVID-19 vaccine – but did not manufacture it – advanced manufacturing firms?

No. Although they developed high-tech products, they are not manufacturing firms, so they are not advanced manufacturing firms, according to our definition.

Is a firm that has 5 factories, only one of which is a “smart factory”, an advanced manufacturing firm?

No. This firm does not have advanced manufacturing at the core of its routines and strategies and thus is not an advanced manufacturing firm.

Is a packaging firm that uses traditional manufacturing processes and technologies to package a “high-tech product” an advanced manufacturing firm?

No. Despite being associated with a high-tech product, this firm does not have advanced manufacturing at the core of its routines and strategies, and thus is not an advanced manufacturing firm.

Is a food manufacturer that uses automated manufacturing processes and technologies to produce sandwiches an advanced manufacturing firm?

Yes. Despite producing an existing “low-tech” product, the firm has advanced manufacturing at the core of its routines and strategies, and is thus an advanced manufacturing firm.

Should we distinguish between advanced manufacturing firms and firms participating in advanced manufacturing value chains?

Yes. Both are important types of firm, but this distinction is important because there are fundamental differences between firms carrying out physical production and firms that support this production. Firms engaged in physical production face issues such as high capital costs for acquiring and maintaining production machinery and facilities, technical and organisational issues related to manufacturing scale-up (including hiring and managing large quantities of workers) and compliance with strict production-related regulations. Thus, these firms require different industrial strategy approaches than firms participating in advanced manufacturing value chains with no physical production activities.

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge.

3.4. Methods to identify and measure advanced manufacturing

The review of international practice reveals there are many ways to measure advanced manufacturing, reflecting different policy objectives, analytical frameworks and data constraints. These methods vary across several key dimensions, including the level of analysis (sector, product or firm level), the criteria used for identifying advanced manufacturing and the types of data used. In addition to definitions that explicitly refer to “advanced manufacturing”, we also consider closely related concepts such as “high-tech industries” and “knowledge-intensive industries”. These related classifications often serve similar policy purposes and offer useful proxies in the absence of a universally agreed definition of advanced manufacturing.

Table 3.2 summarises the main methodologies found in the literature and international practice. It identifies 4 main approaches used to define and measure advanced manufacturing: (1) R&D intensity, (2) employee qualification, (3) matching expert-selected technologies or products with existing industrial classifications, and (4) expert evaluations of individual firms.

Table 3.2 Summary of reviewed methods to identify and measure advanced manufacturing

Author	Criteria used	Main indicators used	Advanced manufacturing “label”	Measurement level
OECD	R&D intensity	R&D expenditure as a share of value added or output	High and medium to high R&D intensity industries	Sector level
Eurostat	R&D intensity	R&D expenditure as a share of value added or output	High-technology manufacturing	Sector level
Expert Commission for Research and	R&D intensity	R&D expenditure as a share of value added or output	R&D-intensive industrial and service sectors	Sector level

Innovation (Germany)				
National Bureau of Statistics (China)	R&D intensity	R&D expenditure as a share of value added or output	High-tech sectors (manufacturing)	Sector level
Eurostat	Employee qualification	Share of tertiary educated persons employed in the sectors	Knowledge-intensive activities (KIA)	Sector level
Bureau of Labor Statistics (US)	Employee qualification	Share of STEM occupations in the sectors	High-tech industry	Sector level
Expert Commission for Research and Innovation (Germany)	Mixed: labour qualification, R&D intensity and innovation indicators	Qualification of employees; expenditure on 6 types of knowledge capital (R&D, other innovation activities, software and databases, training, marketing, design)	Knowledge-intensive sectors	Sector level
Foreign Trade Division of the US Trade Bureau	Matching expert-selected products and technologies with existing industrial classifications	Expert-selected products and technologies	Advanced technology products (ATPs)	Product level
National Bureau of Statistics (China)	Matching expert-selected products and technologies with existing industrial classifications	Expert-selected products and technologies	Advanced manufacturing	Sector level
Office of the Leading Group for the Fifth National Economic Census of the State Council (China)	Matching expert-selected products and technologies with existing industrial classifications	Expert-selected products and technologies	Industrial strategic emerging sectors	Sector level
National Bureau of Statistics (China)	Expert evaluations of individual firms	Expert-selected products and technologies Turnover exceeds CNY20 million	Industrial strategic emerging sectors	Firm level
European Commission's Joint Research Centre (JRC) (EU)	Presence of expert-selected products and technologies in companies or patent descriptions	Search for advanced manufacturing-related terms on company descriptions and on patents, using text-search algorithm	Advanced manufacturing (ADMAN)	Firm level
Ministry of Science and Technology /	Expert evaluation of firms based on self-	Expert evaluation of firms based on self-	High-tech enterprises /	Firm level

Ministry of Finance / State Administration of Taxation (China)	reported information: company age, IPR, core business technologies, scientific and technical personnel, R&D expenditure, turnover from high-tech products, and so on	reported information: company age, IPR, core business technologies, scientific and technical personnel, R&D expenditure, turnover from high-tech products, and so on	advanced manufacturing	
INCIT's Smart Industry Readiness Index (SIRI)	Expert evaluation of firms based on 16 dimensions across 3 areas: processes, technologies and organisation	Expert evaluation of firms based on 16 dimensions across 3 areas: processes, technologies and organisation	Industry 4.0 / smart industry	Firm level
ISO 9000s certifications	Expert evaluation of firms based on 7 principles: customer focus, leadership, people involvement, process approach, continual improvement, factual approach to decision-making, and mutually beneficial supplier relations	Expert evaluation of firms based on 7 principles: customer focus, leadership, people involvement, process approach, continual improvement, factual approach to decision-making, and mutually beneficial supplier relations	ISO 9001 certified firms	Sector level

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge.

R&D intensity

A common sector-level approach to measuring advanced manufacturing is to calculate sectors' R&D intensity – that is, the R&D expenditure of organisations in the sector divided by the sector's value added, turnover or output. This is the approach used by organisations such as the OECD, Eurostat, the Expert Commission for Research and Innovation of Germany, and the National Bureau of Statistics of China.

For example, for the OECD, R&D intensity is calculated as the industry's business R&D expenditure divided by gross value added (GVA).[58] For OECD countries, GVA data mainly comes from the OECD's Structural Analysis (STAN) Database. For non-European economies, additional sources are also used to fill gaps. For the business R&D data (BERD) by industry, the Analytical Business Enterprise Research and Development (ANBERD) database is used. The industry list used is based on International Standard Industrial Classification (ISIC) Revision 4.

Share of qualified employees

Another approach is to measure the share of qualified persons employed in the sectors. For example, Eurostat's "knowledge-intensive activities" are identified by

[58] OECD (2016). OECD Taxonomy of Economic Activities Based on R&D Intensity.

calculating the share of tertiary educated persons employed in the sectors.[59] They use the EU–Labour Force Survey for the population aged 15 to 64, using annual average data. An activity is then classified as **knowledge-intensive** if the tertiary educated persons employed represent more than 33% of the total employment in that activity. The sectors are identified using the NACE Rev.1.1 industrial classification until the reference year 2008, and NACE Rev.2 starting with the reference year 2008.

The US Bureau of Labour Statistics, in turn, measures its "high-tech industry" by calculating the share of STEM occupations in the sectors.[60] To identify high-tech industries, they use data from the Occupational Employment Statistics survey and the Current Population Survey to determine the share of jobs in each industry held by STEM workers. These include various types of engineers, IT workers, scientists, post-secondary teachers and managers of these workers. Industries are identified as **high tech** if they have a share that is 2.5 times the national average (in their case, industries in which at least 14.5% of jobs were in STEM occupations). Then, industries are separated into 2 groups: **high-tech manufacturing industries**, a subset of the goods-producing industry; and **high-tech service industries**.

Matching expert-selected products and technologies with existing classifications

Another possible approach is to have experts identify a list of products and technologies related to advanced manufacturing, and then identify sectors (or products) in existing classifications that relate to those products and technologies of interest.

This is the approach taken by the Foreign Trade Division of the US Census Bureau to identify ATPs.[61] In their approach, first, **10 advanced technology fields** are identified: biotechnology, life sciences, opto-electronics, information and communications, electronics, flexible manufacturing, advanced materials, aerospace, weapons, and nuclear technology.

Then, the **commodity classification codes** (HS/HTS) used to report US merchandise trade are identified as "advanced technology" codes, if:[62]

1. the code contains products with technology from a recognised high-tech field (e.g. biotechnology)
2. these products represent leading-edge technology in that field
3. such products make up a significant part of all items covered in the selected classification code

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[59] Eurostat (2024). High-tech industry and knowledge-intensive services (htec).

[60] US Bureau of Labor Statistics (2016). The high-tech industry, what is it and why it matters to our economic future.

[61] US Census Bureau (n.d.). Advanced Technology Product (ATP) Code Descriptions.

[62] US Census Bureau (n.d.). International Trade Definitions.

Finally, the identification process of ATP codes is conducted **manually** by experienced analysts instructed to use their knowledge and judgement to determine whether or not a particular product contained significant amounts of these technologies, given that valuing the contribution of the advanced technologies to the product is not practical.[63]

A similar approach was adopted by the National Bureau of Statistics of China.[64] The National Development and Reform Commission of China compiled the first version of the **National Guidance Catalogue for Key Products and Services in Strategic Emerging Industries** in 2013 and published the updated version in 2016. The updated version lists nearly 4,000 detailed products and services relating to emerging industries. China's National Bureau of Statistics identified 9 strategic emerging industries in 2018, including:

1. new generation information technology industry
2. high-end equipment manufacturing industry
3. new materials industry
4. biotechnology industry
5. new energy vehicle industry
6. new energy industry
7. environmental industry
8. digital creative industry
9. related service industries

The 9 strategic emerging sectors were identified based on the perception of significant technological breakthroughs and major development demands – that is, sectors likely to play a crucial role in leading and driving overall and long-term economic and social development. After identifying these 9 emerging sectors, a correspondence list (at 4-digit level) between advanced manufacturing and China's national economic activities classification was developed.

Expert evaluation of individual firms

Another way to identify advanced manufacturing firms is through expert evaluations of individual firms. This can be done by analysing documents submitted by companies and by auditor visits to companies.

An example of this approach is the "high-tech enterprise" certification done by China's Ministry of Science and Technology, the Ministry of Finance and the State

[63] McGuckin, R. H., Iii, T. A. A., Herrick, P. E. and Norfolk, L. (1989). *Measuring the trade balance in advanced technology products,* 89–1.

[64] National Bureau of Statistics of China (2018). Notice of the National Bureau of Statistics on Issuing the Statistical Classification of New Industries, New Business Forms and New Business Models.

Administration of Taxation.[65] In this programme, firms can be classified as “high-tech enterprises” if they conform to certain criteria. If a manufacturing firm is certified as a “high-tech enterprise”, it is considered an “advanced manufacturing company”.

To be certified as a “high-tech enterprise”, an enterprise is evaluated by government experts on the following conditions:

1. The enterprise has been **registered** for not less than one year when applying for certification.
2. The enterprise shall own **intellectual property rights** of technologies that present core support to their key products (services) by such means as independent research and development, transfer, donation or merger in the past 3 years.
3. **The technologies** that show core support to their key products (services) shall fall within the scope, as prescribed in the ***High-tech Fields under the Key Support of the State***.
4. **The number of scientific and technical personnel** engaged in research and development, as well as relevant technology innovation activities, shall account for not less than 10% of the total number of employees of the enterprise for the current year.
5. **The proportion of its total research and development expenditure** to its total sales revenue in the past 3 fiscal years should comply with pre-established thresholds.
6. The proportion of the total research and development expenses **incurred within China** to the total research and development expenses shall not be less than 60%.
7. The enterprise's **revenue from high-tech products (services)** shall account for not less than 60% of its total revenue in the latest year.
8. The evaluation of innovative capacity of the enterprise shall satisfy the corresponding requirements.
9. No major safety accident, major quality accident or serious environmental violation of law occurs within one year before the enterprise applies for certification.

Interestingly, the Chinese government tracks the firms certified as “high-tech enterprises” (also “advanced manufacturing” and “industrial strategic emerging sectors”) and reports on their growth and other metrics. Also, firms that receive the certification can apply for government policies targeted specifically at them, such as a tax reduction.

[65] Ministry of Industry and Information Technology (2024) Notice of three departments on matters related to the preparation of the list of advanced manufacturing enterprises that enjoy the value-added tax additional deduction policy in 2024.

Another example of an approach that relies on expert evaluations of individual firms is the Smart Industry Readiness Index (SIRI) assessment.[66] This index was developed by the Singaporean Development Board in partnership with global testing, inspection, certification and training company TÜV SÜD. It is currently managed by the International Centre for Industrial Transformation (INCIT). Firms can acquire an assessment from the centre's experts, which covers 16 dimensions in 3 main areas (processes, technology and organisation).

Another approach that relies on expert evaluation of firms is the one adopted by the ISO 9001 – Quality Management Systems certification.[67] In the certification process, a 2-stage review is carried out by auditors, evaluating the company's quality management systems across 7 principles: customer focus, leadership, people involvement, process approach, continual improvement, factual approach to decision-making, and mutually beneficial supplier relations.

There are also sector-specific certifications of quality that could be explored to help assess whether firms attain the quality requirements of specific sectors. For example, in the aerospace sector quality assurance is key and companies are usually required to be certified by the AS/EN 9100 quality-management system series of standards.[68] Developed by the International Aerospace Quality Group (IAQG), AS/EN 9100 is based on ISO 9001. It provides international consistency and addresses the specific regulatory, safety and reliability requirements of the aerospace sector, including civil aviation, space and defence. These certifications would be a good proxy for advanced manufacturing in aerospace.

3.5. Identifying and measuring advanced manufacturing in the UK

3.5.1. Sector level

In this section we use proxies across the identified criteria to illustrate how advanced manufacturing sectors in the UK might be identified and quantified. This is not meant to be a comprehensive methodology, but rather a practical example of how selected proxies can be applied in practice. We focus on the sectoral level, making use of available data classified by SIC codes.

The process follows a series of indicative steps to identify and estimate the economic footprint of advanced manufacturing sectors in the UK:

- **Step 1** – identify relevant indicators related to innovation, skills and R&D intensity for which data is available, as per Table 3.3
- **Step 2** – calculate the value of these indicators for each manufacturing sector at the 2-digit level and identify manufacturing sectors above the whole manufacturing average for each indicator

[66] NCIT (n.d.) Smart Industry Readiness Index.

[67] ISO (2015) Quality management principles.

[68] BSI (n.d.) AS/EN 9100 - Aerospace Quality Management System Series.

- **Step 3** – classify as advanced manufacturing sectors those that are above average in at least 2 indicators

For step 1, according to our definition, advanced manufacturing is a set of activities that is hard to replicate or substitute because of the use of innovative technologies, methods and materials. Through the international review of measurement methodologies, it was found that there are 3 common sets of indicator used to assess the prevalence of these activities in sectors: **R&D intensity**, **worker qualification** (or skills) and **other innovation measures**. We use some proxies across these indicators, as summarised in Table 3.3.[69]

Table 3.3 Indicators used to identify and quantify advanced manufacturing using existing UK SIC codes

Criteria	Indicator	Data set
Innovation	Share of turnover in the sector carried out by broader innovator firms	UK Innovation Survey (UKIS) 2023
Skills (worker qualification)	Qualification Index Score	ONS Education by Industry data tables, England and Wales, August 2023
R&D intensity	Sector BERD / Sector GVA	ONS Business Expenditure on R&D (BERD) 2023 data set

- Sectoral R&D intensity is an established concept and is usually measured as the R&D expenditure of the businesses in a sector as a share of the sector's value added. We follow this approach commonly found in academic and policy studies.
- Worker qualification is often measured by the share of individuals with tertiary education (or above) working in a sector, by the share of individuals with STEM qualifications working in a sector, and others. We take a slightly different approach, taking advantage of a measurement provided by the ONS, called the Qualification Index Score.[70]
- Innovation measures are more varied and can include analysis of R&D expenditure, patents, publications, research activities, innovation surveys, and so on. We use the results of the UK Innovation Survey 2023, which asks firms about their innovation activities and outputs.[71] This was chosen because it provides definitions of innovation that are broad enough to encompass the different forms

[69] The other approaches identified require direct input from experts and are not considered for this initial analysis.

[70] ONS (2023). How qualified are the people in my industry? This score compares how qualified population groups are. The index score assigns every individual aged 16 years and over in the population a rank (1 to 4) based on their highest level of qualification, excluding those whose highest level of qualification is unknown. The index score is then the average rank of all individuals in that population. The theoretical maximum value for the index score is 4.00, indicating that 100% of individuals in a population have obtained Level 4 or above qualifications. The minimum value for the index score is 0.00, indicating that 100% of individuals in a population have obtained no qualifications.

[71] DBT (2024). UK Innovation Survey.

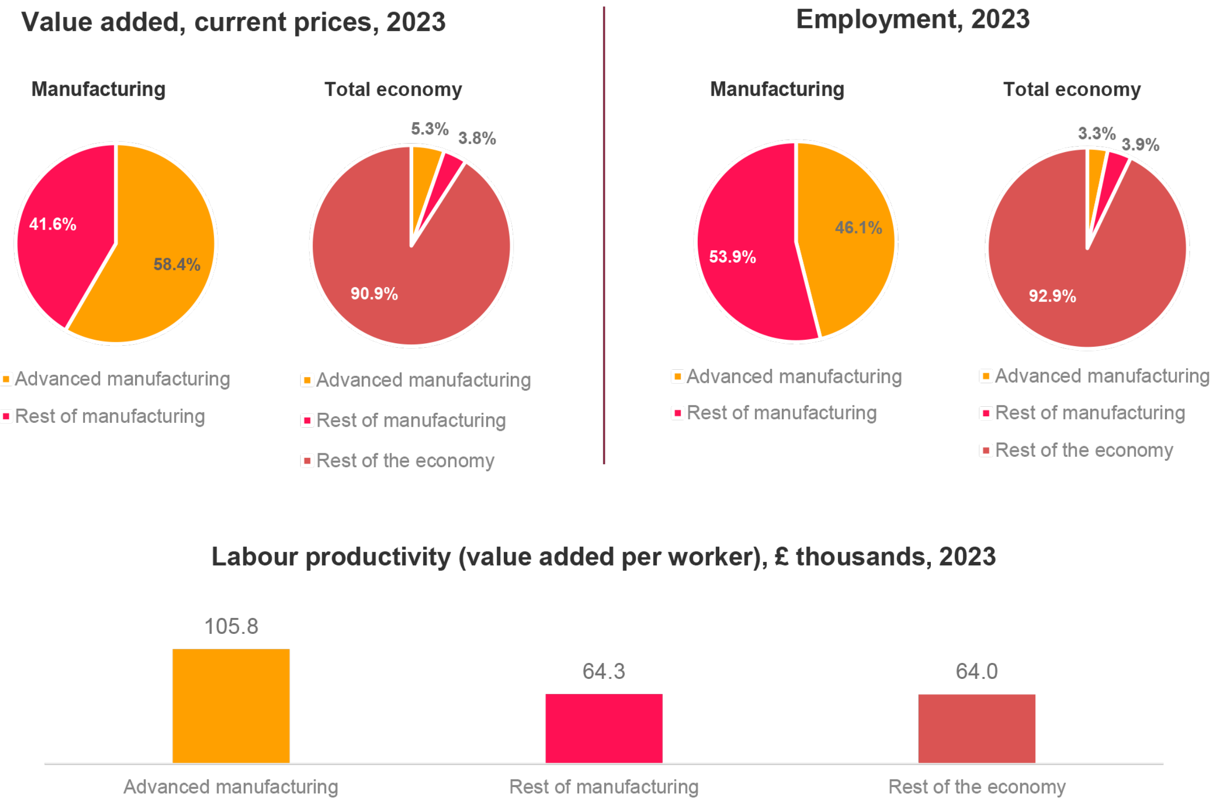
in which innovation occurs in different sectors, relying on firms' own assessment of their innovation activities.

- Appendix 3 summarises steps 2 and 3. We calculate the value of these indicators for each manufacturing sector at 2-digit level and identify manufacturing sectors above the whole manufacturing average for each indicator. We then classify as advanced manufacturing sectors those that are above average in at least 2 indicators. The list of advanced manufacturing sectors identified, using existing 2-digit SIC codes, is as follows:
    - 11: Manufacture of beverages
    - 19: Manufacture of coke and refined petroleum products
    - 20: Manufacture of chemicals and chemical products
    - 21: Manufacture of basic pharmaceutical products and pharmaceutical preparations[72]
    - 25: Manufacture of fabricated metal products, except machinery and equipment
    - 26: Manufacture of computer, electronic and optical products
    - 27: Manufacture of electrical equipment
    - 28: Manufacture of machinery and equipment, not elsewhere classified
    - 29: Manufacture of motor vehicles, trailers and semi-trailers
    - 30: Manufacture of other transport equipment
    - 32: Other manufacturing

Using this list of sectors, summary statistics of value added, employment and labour productivity are presented in **Figure 3.2**. In 2023 the aggregate of these industries represented 58.4% of UK manufacturing value added, and 5.3% of total UK value added. In terms of employment, it represented 46.1% of UK manufacturing employment and 3.3% of total UK employment. Finally, advanced manufacturing sectors have significantly higher labour productivity than the rest of UK manufacturing and the rest of the UK economy.

[72] The pharmaceuticals manufacturing sector did not officially meet the threshold for R&D intensity. However, previous analyses comparing R&D expenditure by SIC code and product group have shown that this sector's R&D expenditure is underestimated, because it is carried out mainly by R&D firms not classified as pharmaceuticals manufacturing. We therefore classified it as meeting the threshold for the R&D intensity indicator.

Figure 3.2 Value added, employment and labour productivity of advanced manufacturing compared to the rest of manufacturing and the total economy, 2023



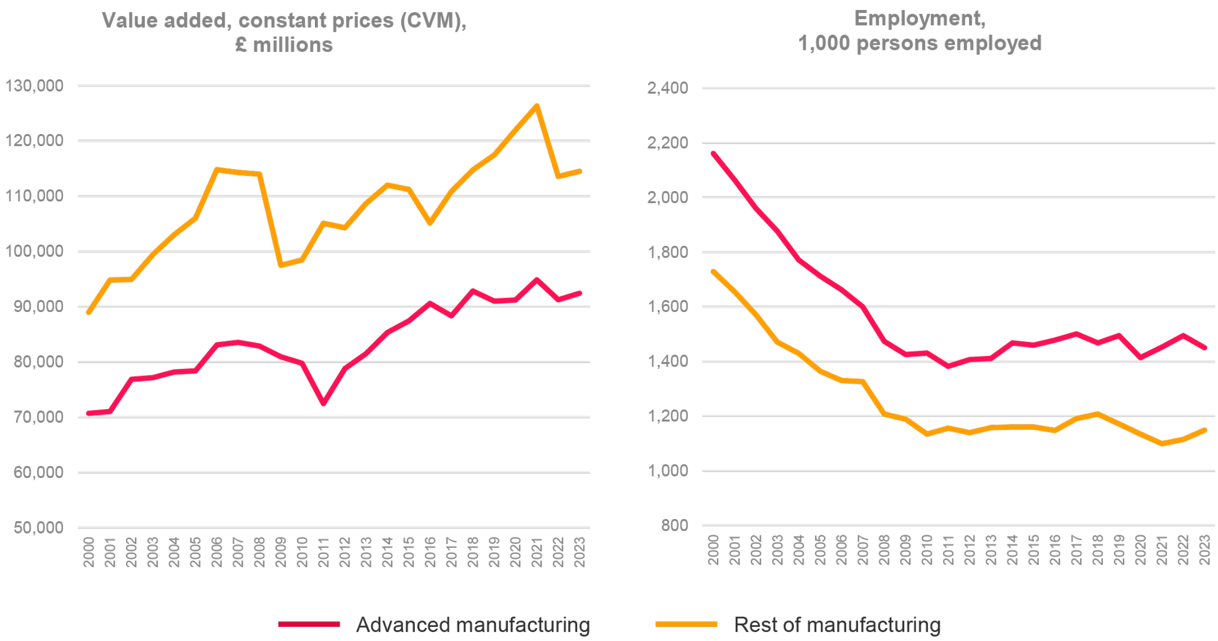
Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on ONS (2024). GDP output approach, low level aggregates, UK; ONS (2024). JOBS03 Employee jobs by industry (UK totals), Dec 2023; ONS (2024). JOBS04 Self Employed jobs by industry (UK totals), Dec 2023.

Figure 3.3 shows the value added and employment trends of the advanced manufacturing sectors identified. From 2000 to 2023, the trajectory of both advanced and non-advanced manufacturing sectors has had modest growth, with a 1.1% compound annual growth rate (CAGR) for both groups of sector. In terms of employment, advanced and non-advanced manufacturing sectors have seen similar trends. A sharp decline in employment was seen from 2000 to 2010, and employment levels have since been relatively stable.

Advanced manufacturing sectors' value added performance during the 2008/9 crisis was different from the rest of manufacturing. The advanced manufacturing sectors suffered a sharp decline in 2009 and started recovering from 2010 onwards. The non-advanced manufacturing sectors, in turn, had a more gradual but longer-lasting reduction in activity, facing reductions in 2009, 2010 and 2011 and only starting to recover in 2012. The advanced manufacturing sectors again suffered a sharper decline during the COVID-19 pandemic than the non-advanced manufacturing sectors.

The similarity of this performance across advanced and non-advanced manufacturing sectors highlights that it is likely that structural issues, such as infrastructure, skills and costs, are affecting the UK manufacturing sector as a whole.

Figure 3.3 Value-added and employment trends of advanced manufacturing sectors, 2000 to 2023



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on ONS (2024). GDP output approach, low level aggregates, UK; ONS (2024). JOBS03 Employee jobs by industry (UK totals), Dec 2023; ONS (2024). JOBS04 Self Employed jobs by industry (UK totals), Dec 2023.

3.5.2. Limitations of sector-level analysis

The approach described above should be seen as a first step towards a more detailed and robust methodology for identifying advanced manufacturing sectors. While the analysis offers a useful starting point to highlight sectors that may merit policy attention, it has notable limitations. In particular, sectors often contain a mix of both advanced and non-advanced firms, which means sector-level analysis can obscure important differences between firms. To address this, there is a clear need to move towards firm-level approaches that can more accurately capture the specific characteristics and behaviours of advanced manufacturing firms.

Take, for example, firms within the food manufacturing sector. A sandwich manufacturing company may remain highly competitive by continually adopting cutting-edge technologies and applying best practices in production management. Such a firm might use state-of-the-art food processing and packaging equipment to enhance throughput, maintain freshness and ensure consistent quality. It may draw on food science and safety expertise, while coordinating production schedules with modern supply chain management tools to efficiently balance ingredient sourcing, assembly and packaging. These practices allow the company to operate in a highly efficient, reliable and innovation-driven way. According to our definition, this type of firm would qualify as an advanced manufacturing firm. However, it would probably be overlooked in a sector-level analysis, as the food manufacturing sector typically does not score highly on the metrics used. This example highlights the importance of firm-level analysis to accurately identify where advanced manufacturing capabilities reside.

3.5.3. Firm level

Firm-level approaches to identify and measure advanced manufacturing offer several advantages. They allow more granular analysis of firms' performance and contributions to the economy, beyond sector boundaries. This means better targeting of policy instruments, such as tax incentives, innovation grants, accelerated depreciation schemes, and subsidised long-term financing. Other benefits include the potential to create networks and communities of practice among certified firms; and provide a foundation for recognition programmes, such as awards for high-performing firms.

At the firm level, many features associated with advanced manufacturing can be measured. **Table 3.4** presents a set of proxies for identifying such firms, grouped into 2 main categories: business outcomes, and advanced manufacturing qualities. The first category refers to the types of outcome typically expected from advanced manufacturing firms, such as innovation output, export intensity or productivity growth. The second focuses on measurable attributes of firms, such as R&D intensity, the use of enabling technologies, integration of services or workforce qualifications.

The table also links these features to the broader socio-economic benefits often associated with advanced manufacturing – such as creating highly skilled jobs, contributions to strategic policy goals like net zero, and national industrial resilience. While not exhaustive, this set of proxies provides an initial framework for identifying and analysing advanced manufacturing firms using firm-level data.

Table 3.4 Proxies for identifying advanced manufacturing firms

Socio-economic benefits/value: how society benefits from having advanced manufacturing firms	**Long-term international industrial competitiveness Provision of well-paid jobs Environmental sustainability**	
Business outcomes: how businesses benefit from adopting advanced manufacturing	**Revenue improvement**	• sales/revenue • profit margins • market shares • product quality and performance • "premium" on product prices • customer satisfaction rates
	Cost reduction	• input use (labour, material, utilities…) • administrative and operational costs (OPEX)
	Higher and more effective use of capital	• overall equipment effectiveness (OEE)

		• factory safety (accident/injury rates) • unplanned downtime/idle times/idle capacity • defect rates • inventory levels • lead times • time-to-market
Advanced manufacturing qualities: characteristics of advanced manufacturing firms	**Advanced production technologies** • material and product pre-/post-processing technologies • process control systems • assembly technologies	• use of advanced high-performance, energy-efficient production technologies • automation and robotisation levels • certifications (e.g. ISO ISO9001 and • ISO14001) • use of manufacturing process control systems such as SCADA and MES
	Advanced manufacturing support activities • manufacturing system planning • product development systems • manufacturing system planning • business operations • product life-cycle management • organisational quality management • production planning and control	• data analytics systems • automated process quality control • use of advanced enterprise systems such as ERP, MRP • use of product life-cycle management tools • use of client and supplier relationship management systems
	Skilled workforce	• number of scientific and technical personnel employed • wages offered
	Knowledge production and knowledge networks	• R&D Investment (% of revenue) • R&D collaboration initiatives • success in obtaining competitive innovation grants • intellectual property rights ownership (patents, designs, trademarks, and so on)

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge.

Box 3.2 presents a set of illustrative hypothetical examples of advanced manufacturing firms, describing firms that are close to what could be found by policymakers when undertaking firm-level analyses.

Box 3.2 Illustrative hypotheticals of advanced manufacturing firms

Sandwich manufacturing

A sandwich manufacturing company that remains competitive by keeping up with the latest technologies and employing best practices in production management.

Advanced manufacturing attributes:

- **Innovative technology**: Implements state-of-the-art food processing and packaging equipment that enhances throughput and maintains freshness, rather than introducing entirely new products.
- **Specialised knowledge**: Draws on food science and safety expertise to ensure every sandwich meets high-quality standards while adhering to strict hygiene practices.
- **Complex production**: Uses a coordinated production schedule and modern supply chain management tools to balance ingredient sourcing, assembly and packaging, ensuring that production runs are both efficient and reliable.

Synthetic biology

A small firm develops a unique fermentation process to produce rare bioactive compounds.

Advanced manufacturing attributes:

- **Innovative technology**: Uses a unique fermentation process to produce rare bioactive compounds that competitors cannot easily replicate.
- **Specialised knowledge**: Relies on deep expertise in microbiology and fermentation science to optimise the process and tailor conditions for different compounds.
- **Complex production**: Develops a multi-stage, integrated production system that coordinates several fermentation tanks, automated nutrient dosing and real-time monitoring. The system allows for rapid adjustments and quality control at each stage, creating a complex production environment that is hard for competitors to duplicate.

Clean steel

A regional steel producer pilots a new process that uses hydrogen instead of traditional fossil fuels to reduce emissions during production.

Advanced manufacturing attributes:

- **Innovative technology**: Pilots the use of hydrogen instead of fossil fuels in steel production, offering a cleaner alternative.
- **Specialised knowledge**: Leverages basic chemical and process engineering know-how to integrate hydrogen safely into the production process.
- **Complex production**: Adopts a modified production line that incorporates the hydrogen-based process while keeping the overall system simple.

Automotive engines

A manufacturer that produces reliable automotive engines through modern automated assembly and precision machining in an integrated production system.

Advanced manufacturing attributes:

- **Innovative technology**: Uses modern, automated assembly lines and precision machining tools to produce reliable, high-performance engines without radically reinventing the design.
- **Specialised knowledge**: Relies on decades of engineering expertise to optimise engine performance and maintain strict quality standards.
- **Complex production**: Employs an integrated production management system that coordinates automated machining, assembly and quality control steps, ensuring consistency and efficiency across the entire production line.

Semiconductors

A mid-sized semiconductor firm adopts a refined, low-temperature process for etching circuits, reducing defects during production.

Advanced manufacturing attributes:

- **Innovative technology**: Introduces a refined, low-temperature etching process that significantly reduces defects during chip fabrication.
- **Specialised knowledge**: Draws on deep expertise in semiconductor materials and process engineering to implement the new etching technique.
- **Complex production**: Develops a highly integrated production system where multiple process stages are tightly coordinated. The new etching process is embedded within a sophisticated quality-control loop that uses real-time monitoring and feedback. This integration requires careful synchronisation of equipment and processes, creating a production set-up that is difficult for competitors to replicate without similar investments in production complexity.

Aerospace

An aerospace supplier uses a specially designed vacuum infusion method to create lightweight composite parts for aircraft.

Advanced manufacturing attributes:

- **Innovative technology**: Uses a specially designed vacuum infusion method to produce lightweight composite parts for aircraft.
- **Specialised knowledge**: Combines knowledge of composite materials and basic aerospace engineering to develop parts that meet high standards.
- **Complex production**: Incorporates the vacuum infusion technique into a mostly conventional production set-up, enhancing part performance without a complete overhaul of the manufacturing process.

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge.

3.6. Conclusions

Advanced manufacturing has become a prominent concept in industrial policy discussions globally. In the UK it is identified as one of the 8 strategic priorities in the 2024 *Industrial Strategy Green Paper*. Despite its growing prominence, however, advanced manufacturing remains a contested and ambiguously defined concept. A clearer understanding of what it entails – and how it can be identified and measured – is both timely and essential. We hope this report contributes to that effort.

Our review of existing definitions has identified several core aspects that any robust definition of advanced manufacturing should consider. Based on this analysis, we have proposed a definition of advanced manufacturing, along with related definitions for advanced manufacturing processes, firms, sectors and value chains. We also reviewed a range of international practices for identifying and measuring advanced manufacturing, which vary in terms of their level of analysis (sectoral or firm level), the indicators used, and the types of data employed. From this, we synthesised a set of indicators and proxies commonly used in international practice.

We then applied a selection of these proxies to illustrate how advanced manufacturing sectors in the UK might be identified and quantified. This is not intended as a definitive methodology, but rather as a practical example of how selected indicators can be used to inform policy and analysis. Our initial focus was on the sector level, using available data classified by SIC codes. While this provides a useful starting point to identify areas of potential and sectors that merit policy attention, it has limitations. In particular, sectors often include a mix of advanced and non-advanced firms, which can obscure important differences in capabilities and performance.

To address this, we argue for a shift towards firm-level approaches that can more accurately capture the technological and organisational characteristics of advanced manufacturing firms. Such approaches offer several advantages: they enable more granular analysis of firms' contributions to the economy, enable targeted policy support, and allow for the design of more effective instruments that are better aligned with the realities of advanced manufacturing in practice.

4. Defining and identifying emerging sectors in advanced manufacturing

Key messages

- This section defines advanced manufacturing emerging sectors as "new or evolving industrial systems that use innovative manufacturing technologies, methods, and materials to produce high-value products or integrated product–service solutions that are hard to replicate or substitute".
- These sectors may involve new ways to produce existing products or, especially, new high-value products enabled by emerging technologies. They typically emerge in response to technological and scientific breakthroughs, shifts in market demand, and regulatory, institutional or policy changes. They are usually in the early, fluid stages of development, marked by high uncertainty and transformative potential.
- An analytical process for identifying advanced manufacturing emerging sectors is proposed. It begins by examining 3 key drivers of emerging technology development, demand growth, and regulatory, institutional or policy shifts, across a number of proxies. This generates a longlist of emerging areas (including technologies, products and sub-sectors), based on foresight, expert input and trend analysis.
- These emerging areas are then analysed in a synthesis step, where the intersections between the 3 drivers are identified. Areas that are simultaneously shaped by technological, market and policy dynamics are highlighted as emerging sectors likely to become relevant. However, the analysis also acknowledges key limitations, including those related to data availability, classification challenges and the inherent uncertainty of emerging trends.
- Several domains – such as advanced materials, additive manufacturing, biological manufacturing, AI and digital technologies, and advanced robotics – appear across multiple dimensions, indicating high growth potential and strategic significance for the UK.
- Still, being identified as an area of opportunity is a necessary but not sufficient condition; further validation and targeted policy assessment are needed.
- The final step of the process involves applying policy prioritisation criteria, including alignment with national industrial strategy, proximity to existing domestic capabilities, national security relevance, cross-cutting economic impact, and the need for new regulations or standards. This ensures that emerging sectors identified through the process are not only plausible but also strategically important and worth prioritising for policy action.

4.1. Introduction

This section proposes a refined definition of emerging sectors, with a focus on manufacturing. It also outlines proxy metrics and selected variables for identifying emerging sectors, illustrated through the UK manufacturing sector.

The UK *Industrial Strategy Green Paper* suggests that the growth of the UK economy can be unlocked by leveraging the country's unique strengths and untapped potential in both services and manufacturing sectors, particularly by seizing "opportunities to lead in new and emerging sectors".[73] The green paper also identifies 8 growth-driving sectors and sets out the need to find specific high-potential subsectors within them, as well as the need for further evidence gathering, public consultation and the use of broader analytical methodologies to refine the selection of high-growth subsectors. It concludes that identifying sectors that align with the Industrial Strategy's objectives must rely on a combination of evidence and informed judgement, including careful selection of metrics, data sources and methodologies.

Identifying emerging sectors, however, poses several methodological challenges. Unlike established industries, which operate within stable market structures and defined statistical classifications, emerging sectors are, by definition, unclear. And they may even fail before fully developing into established industries.

Against this backdrop, the rest of this section presents a recommended definition of emerging sectors, followed by an overview of the key drivers that underpin their development, namely technological advancement, growing market demand, and regulatory, institutional and policy shifts. For each of these drivers, relevant proxy metrics are discussed to support practical analysis. The section concludes with an initial exploration of potential emerging sectors within UK manufacturing, using a selection of these proxy metrics and variables to identify areas of strategic interest.

4.2. Defining emerging sectors

4.2.1. Key characteristics of emerging sectors

There is no single and accepted definition of emerging sectors, and terms such as "sectors" and "industries" are often used interchangeably in the literature. Academic and industry literature, however, consistently points to a set of distinguishing characteristics that differentiate emerging sectors from established ones, including:[74]

- **New or evolving industrial value chains.** Emerging sectors arise from the creation of entirely new value chains or the radical transformation of existing

[73] DBT (2024). Invest 2035: the UK's modern industrial strategy.

[74] For this study, existing definitions related to emerging sectors found in policy and academic literature were reviewed, focusing on key terms such as emerging industries, future industries, sectors, industries and emerging technologies. Refer to Appendix 4 for a list of relevant definitions reviewed.

ones. They lead to new products, services or business models that do not naturally fit into established sectors.[75]

- **Uncertainty and evolutionary nature.** Emerging sectors exist in the early, fluid stages of development, making their future impact highly uncertain. Some may evolve into major industries, while others may fail to materialise. Their definition and classification remain ambiguous, as they do not fit neatly into traditional industrial categories.[76]
- **Cross-sectoral convergence and boundary spanning.** Emerging sectors often span multiple industries, integrating knowledge, technologies and business models from different domains. Their classification is difficult using conventional metrics because of overlapping sectoral boundaries.[77]
- **Market potential and strategic importance.** Emerging sectors typically have high growth potential and are strategically important for economic and technological leadership. Many align with societal challenges such as climate change, sustainability and digital transformation.[78]
- **Creating innovative products and services.** Emerging industries often evolve in response to demand arising from the convergence of previously distinct products or the transformation of existing demand into new market opportunities. This alignment drives the creation of innovative products and services with higher value added.[79]
- **Adopting key enabling technologies.** Emerging industries are newly formed or re-formed industries through adopting cutting-edge technologies, such as new manufacturing methods and innovative business models.[80]

4.2.2. Key drivers of emerging sectors

Emerging sectors do not arise in isolation but are shaped by the dynamic interplay between technological advancements, market shifts and policy changes. These drivers influence both the pace and direction of sectoral emergence, often reinforcing one another over time. The PESTLE framework – which categorises political, economic, sociological, technological, legal and environmental drivers – is widely recognised in technology and strategic management. However, the innovation literature identifies 3 core drivers that have historically underpinned the development

[75] European Commission (2019). Emerging industries and value chains; European Observatory for Clusters and Industrial Change (2019). European Panorama of Clusters and Industrial Change.

[76] Forbes and Kirsch (2011). The study of emerging industries; Malerba (2002). A sectoral system of innovation and production; Tunzelmann and Acha (2009). Innovation In "Low-Tech" Industries. In *The Oxford Handbook of Innovation.*

[77] Malerba (2009). Sectoral Systems: How and Why Innovation Differs across sectors. In *The Oxford Handbook of Innovation*; Tunzelmann and Acha (2009).

[78] Chinese Ministry of Industry and Information Technology (2024). Translation of the Implementation Opinions of Seven Ministries; DBT (2024). Invest 2035: The UK's modern industrial strategy; European Commission (2019).

[79] European Commission (2019); Malerba (2002).

[80] Porter (1980). Competitive strategy; European Observatory for Clusters and Industrial Change (2019); Chinese Ministry of Industry and Information Technology (2024).

of new sectors: technological and scientific advancements (technology push); shifts in market demand and consumer needs (market pull); and regulatory, institutional and policy shifts (policy-led change).

- **Technological and scientific advancements**: Emerging sectors are often driven by disruptive technologies that introduce novel capabilities, products and services, production methods or business models. Initially, these technologies may struggle to compete in mainstream markets but can reshape entire industries as they mature. Technological breakthroughs, such as the internet, biotechnology, quantum computing or artificial intelligence, can lead to the creation of entirely new sectors.[81] This is known in the innovation literature as the ***technology-push driver*** of innovation.
- **Shifts in market demand and consumer needs**: Changes in consumer preferences, lifestyles and business demands play a crucial role in fuelling the growth of emerging sectors. For example, growing concerns about climate change and sustainability are increasing the demand for greener products and services, forcing industries to adapt and innovate. The transition to circular economy models, carbon-neutral solutions and digital services has led to the emergence of entirely new industries.[82] This is known in the literature as the ***demand- or market-pull driver*** of innovation.
- **Regulatory, institutional and policy shifts**: Emerging sectors often arise in response to new regulations, institutional shifts and policy interventions. For instance, bans on internal combustion engine vehicles in many countries have accelerated the rise of the electric vehicle (EV) industry, while government incentives for renewable energy have stimulated the growth of solar, wind and hydrogen-based industries. Similarly, large-scale government R&D funding and infrastructure investments play a key role in enabling emerging sectors to scale. This can be seen as ***policy-led change***.[83]

[81] Rotolo et al. (2015). What is an emerging technology?; Bower and Christensen (1995). Disruptive technologies: Catching the wave; Porter (1980).

[82] European Observatory for Clusters and Industrial Chang (2019); Chinese Ministry of Industry and Information Technology (2024).

[83] European Observatory for Clusters and Industrial Change (2019); Chinese Ministry of Industry and Information Technology (2024); DBT (2024).

4.2.3. Recommended definition of "emerging sectors" and "advanced manufacturing emerging sectors"

Based on the considerations above, we propose a definition of emerging sectors, as follows.

Emerging sectors

Emerging sectors are new or evolving industrial systems that produce new products, processes and services to meet existing or emerging demand. Emerging sectors exist in the early, fluid stages of development, making their future impact highly uncertain.

These sectors emerge in response to 1) advances in science, technologies and materials, or their convergence, 2) new market demand, with seemingly large but highly uncertain growth potential and 3) regulatory, institutional or policy shifts.

Emerging sectors develop distinct and coherent characteristics integrating diverse knowledge bases, technologies and market applications. They frequently operate across multiple industries, making their identification and measurement particularly complex.

Building on the definition of advanced manufacturing provided in the previous section, we can construct a definition of advanced manufacturing emerging sectors, as follows.

Advanced manufacturing emerging sectors

Advanced manufacturing emerging sectors are new or evolving industrial systems that use innovative manufacturing technologies, methods and materials to produce high-value products or integrated product–service solutions that are hard to replicate or substitute. Advanced manufacturing emerging sectors may involve new ways to produce existing products or, especially, new high-value products enabled by emerging technologies. These sectors emerge in response to a combination of technological and scientific breakthroughs, shifts in market demand, and regulatory, institutional or policy changes. They are typically in the early, fluid stages of development, marked by high uncertainty and transformative potential.

What distinguishes these sectors is the application and coordination of innovative production technologies, sophisticated support activities embedded in the production process or the techno-organisational structure required by complex production systems. These sectors often span traditional industry boundaries, integrating diverse knowledge bases and operating within complex value chains, making them challenging to identify and measure using conventional classifications. They represent emerging areas of strategic economic importance, with the potential to shape the future of industrial competitiveness and national technological leadership.

4.3. Identifying emerging sectors in advanced manufacturing

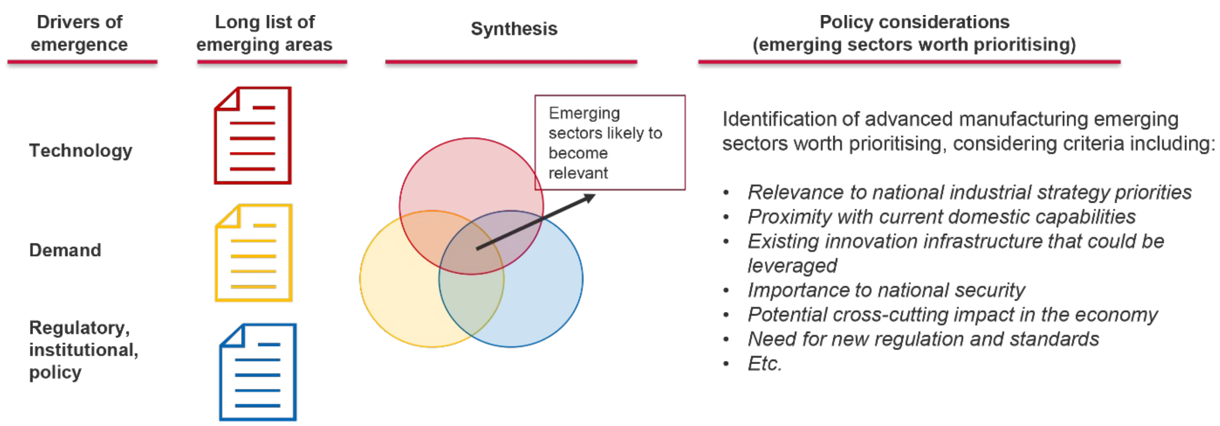
4.3.1. Analytical framework

Based on the insights from previous sections, we suggest a process to identify emerging sectors in advanced manufacturing in Figure 4.1. The process begins by examining 3 key drivers of emergence: technology development, demand growth, and regulatory, institutional or policy shifts. Each driver generates a longlist of emerging areas, reflecting signals of change or opportunity identified through foresight, expert input or trend analysis.

These emerging areas are then brought together in a synthesis step, where areas of intersection – with emphases on those shaped simultaneously by all 3 drivers – are identified as emerging sectors likely to become relevant. These sectors are not only technologically feasible and commercially promising but also supported by enabling policy or institutional conditions.

The final step considers policy priorities, applying criteria such as alignment with national industrial strategy, proximity to current domestic capabilities, relevance to national security, and the potential need for new regulations or standards. This ensures that the emerging sectors identified through the process are not only plausible but also strategically important and worth prioritising for further action.

Figure 4.1 Process for identifying advanced manufacturing emerging sectors



Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge.

4.3.2. Proxies for identifying emerging areas

National accounts and official statistics are not designed to capture the economic contribution of emerging sectors. A more feasible approach could focus on evaluating the drivers behind their emergence. Thus, the process suggests first focusing on obtaining “longlists” of emerging areas (sectors, products and technologies) across the 3 main drivers discussed earlier, namely technology development, demand growth, and regulatory, institutional and policy shifts.

Sectors, products and technologies that appear in the analysis of all 3 types of driver are particularly interesting, as they are more likely to become significant in the future. A selection of proxies is outlined in Table 4.1 and discussed in more detail next.

Specific proxies of relevance for advanced manufacturing emerging sectors are also provided. The next subsection then presents examples of how these indicators are applied.[84]

Table 4.1 Summary of key proxy metrics and evidence to identify emerging sectors, products or technologies

Key driver addressed	Proxies for identifying emerging sectors, products, technologies		Proxies for identifying advanced manufacturing emerging sectors
Technology development	Academic publications	• paper and patent trend analysis – tracking document counts over time • paper and patent citation analysis – examining citation patterns among documents • paper and patent text analysis – analysing the co-occurrence of words within document texts	• publications in related manufacturing and engineering journals
	News articles in professional and academic journals		• manufacturing trade association magazines/journals • professional engineering bodies' magazines/journals
	Patents		• process innovation patents • manufacturing technology patents
	Spin-outs, start-ups and scale-ups	• number of start-ups, spin-outs and scale-ups by technology and industry • equity investment volume/ number of deals of high-growth companies that raised equity	• spin-outs, start-ups and scale-ups with advanced manufacturing operations
	Established companies	• private R&D investment, employment, turnover, patenting activity by industry • volume/deal counts of mergers and acquisitions (M&A) by industry • volume/ deal counts of foreign direct investment (FDI) by industry	• companies with advanced manufacturing operations • number of robots used • business investment in advanced manufacturing domains (e.g. M&A, FDI) • supply chain analysis and mapping
Demand growth	Global and national market estimations	• market analysts' reports • import and export volume/ growth by products • value added as share of GDP/growth/weighted contributions by industries • productivity by industry • economic complexity by products	• market analysts' reports on advanced manufacturing domains • import and export volume/growth by manufacturing-related products • medium and high-tech manufacturing exports as share of total product exports • value added as share of GDP/growth/weighted contributions by manufacturing subsectors

[84] A full analysis of the drivers is beyond the scope of analysis conducted in this study, which provides initial insights based on existing studies, synthesising findings rather than conducting primary research. These insights offer a foundation for further investigation.

	Venture capital (VC) analysis	• VC investment/VC investment as share of GDP by industry or technology	• deep tech VC deal value in advanced manufacturing domains
Regulatory, institutional, policy shifts	National (domestic and international) funding priorities	• review of national strategies and priorities • review of national R&D strategies/programmes • review of existing foresight exercises (as early signal of shifting policy priorities)	• review advanced manufacturing strategies and priorities • review advanced manufacturing R&D strategies/programmes • review advanced manufacturing foresight exercises • review references to advanced manufacturing in other sectoral or emerging technology foresight exercises (e.g. quantum technology manufacturing roadmap)
	Public sector R&D investment portfolios	• government R&D investment portfolio by technology or industry • government grants by technology or industry	• government investment in pilot lines, testbeds and other advanced manufacturing infrastructure and tools • government grants to spin-outs and start-ups for manufacturing infrastructure (e.g. through UK Infrastructure Bank, British Business Bank)
	Regulatory shifts	• analysis of announced regulatory shifts – for example, environmental requirements, food safety regulations, financial regulations	• analysis of announced regulatory shifts in advanced industries (e.g. biopharmaceuticals, aerospace)

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge.

4.3.3. Emerging areas: technology

Academic publications and patents are broadly used by governments, international organisations, research institutes and academia as proxies to track technology development and identify emerging technologies.

For example, the Institutes of Science and Development, the Chinese Academy of Sciences (CASISD), publish annual research reports analysing academic publications, highlighting key research trends and research topics at global level.[85] Similarly, independent think tanks examine academic publications to identify critical technologies globally and facilitate international comparisons.[86]

Patent data is also commonly used to identify emerging technologies. For instance, policy documents by the UK's Department for Business, Energy and Industrial Strategy (BEIS) used patent data to track technology trends.[87] Meanwhile,

[85] CASISD. Official website.

[86] Australian Strategic Policy Institute (2024). Who is leading the critical technology race?

[87] The department for Business, Energy, and Industrial Strategy (2021). Methodology to Identify Emerging Technologies with UK Commercialisation Potential.

international and regional patent offices, such as the World Intellectual Property Organization (WIPO)[88] and the European Patent Office (EPO),[89] regularly publish studies on the frontiers of emerging technologies – such as quantum technology and AI – by extracting insights from patents and other forms of intellectual property.

Various analytical approaches using publication and patent data are used to detect or assess emerging technologies. Ranked from simple to complex, these methods include: 1) trend analysis – tracking document counts over time to identify growth patterns; 2) citation analysis – examining citation patterns among documents to assess technological influence and impact; and 3) co-word analysis – analysing the co-occurrence of words within document texts to uncover thematic relationships and emerging research areas.[90]

The technologies and industries in which spin-outs and start-ups operate act as an additional proxy for identifying emerging technologies and their primarily applicable industries. For example, the UK's Royal Academy of Engineering monitors the technological distribution of UK spin-outs to identify emerging technologies being developed within the country. As of January 2024, the top 3 emerging technologies among UK spin-outs were AI, genomics and precision medicines.[91]

Business R&D investment patterns, patenting activities, and domestic and international investment patterns are also useful indicators that can be used to better understand domestic technological and industrial strengths. For example, the European Commission has undertaken a study on advanced materials, identifying advanced materials patents and joining these with company data to understand industrial R&D investments by industries.[92]

4.4. Emerging areas: demand

Market analysis reports offer insights into emerging technologies by identifying trends in consumer demand, technological advancements and shifts in global supply chains.[93] These reports usually rely on data from financial markets and corporate earnings, and industry surveys highlight technologies experiencing rapid growth. For example, reports on advanced manufacturing have tracked the rise of automation, robotics and additive manufacturing.[94]

Trade data acts as a proxy for emerging products by revealing shifts in global trade patterns. This data is used to identify growing industries, such as electric vehicles and semiconductor manufacturing, by tracking increased imports of critical

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[88] WIPO. WIPO Technology Trends.

[89] EPO. Patent insight reports.

[90] Rotolo, D., Hicks, D. and Martin, B. R. (2015). What is an emerging technology? *Research Policy*, 44(10): 1827–1843.

[91] Royal Academy of Engineering (2024). Spotlight on spinouts April 2024, UK academic spinout trends.

[92] European Commission (2024). Industrial R&D&I investments and market analysis in advanced materials.

[93] World Economic Forum (2024). Top 10 emerging technologies of 2024.

[94] Carlos López-Gómez et al. (2017). Emerging trends in global advanced manufacturing: challenges, opportunities and policy responses.

components and rising exports of finished products. The expansion of advanced manufacturing sectors is often reflected in the growing trade of high-tech machinery and specialised materials.

Value added by industries provides a measure of an industry's economic contribution. Sectors with increasing value added can be identified as high-potential growth areas. Productivity by industry helps to identify sectors that are improving efficiency and scaling rapidly, as also presented in the UK *Industrial Strategy Green Paper*.[95] High productivity growth, often driven by automation and technological integration, signals a sector's competitive strength.

Indicators related to digitalisation and robotisation can also be used to measure advanced manufacturing, providing insights into industries that are early adopters of such technologies. For example, the International Federation of Robotics (IFR) reports the number of industrial robot applications from nearly all industrial robot suppliers in the world.[96]

Venture capital (VC) investment is also an indicator of emerging industries, as investors allocate capital to sectors with the potential to disrupt existing markets. The rapid rise of VC funding in industries like quantum computing, nanotechnology and autonomous systems has highlighted the emergence of new advanced manufacturing opportunities. Tracking VC trends allows analysts to predict which sectors are likely to experience significant growth in the near future.

For example, in its most recent deep tech report, the Royal Academy of Engineering highlights that both manufacturing and materials, as well as robotics, hardware and chips, have increased over time in both deal value and deal count.[97] For advanced manufacturing and materials, the report also highlights clear opportunities for additive manufacturing to address housing supply challenges, and for aerospace and IT to address more rapid and efficient movement of goods. For robotics and chips, application-specific semiconductor companies and drone products serving cargo transport and agriculture were among the largest VC deals.[98]

4.5. Emerging areas: regulation, institutions, policy

Emerging sectors often arise in response to new regulations, institutional shifts and policy interventions. For instance, bans on internal combustion engine vehicles in many countries have accelerated the rise of the EV industry, while government incentives for renewable energy have stimulated the growth of solar, wind and hydrogen-based industries. Similarly, industrial policy frameworks, government R&D funding and infrastructure investments play a key role in enabling emerging sectors to scale.

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95 DBT (2024). Invest 2035: the UK's modern industrial strategy.

96 International Federation of Robotics.

97 Royal Academy of Engineering (2024). State of UK Deep Tech 2024.

98 Ibid.

The composition of public sector R&D investment portfolios is a key way to identify national capacity and priorities of technologies, using these insights to refine their own R&D agendas and identify gaps or opportunities for collaboration. By analysing research funding streams from UKRI, other UK governmental departments and the European Union by technology areas, BEIS was able to identify the UK's R&D strength and commercialisation potential.[99] We assume that when billions of dollars are directed at a certain economic activity, this will probably grow in the future.

Foresight exercises are a critical tool for governments to anticipate future technological and industrial shifts, signalling where future innovation priorities may lie. Analysing the results of existing foresight exercises from other countries, and domestically, can enable future shifts to be anticipated. In the case of advanced manufacturing emerging sectors, references to advanced manufacturing are often made in other sectoral or emerging technology foresight exercises,[100] highlighting how nations integrate manufacturing innovation into broader technology strategies. By reviewing these references, policymakers can identify cross-sector synergies and emerging policy trends, informing decisions on funding, regulation and industry collaboration.

4.6. Identifying emerging areas in advanced manufacturing – preliminary analysis

In this section selected proxy metrics and evidence from Table 4.1 are used to provide preliminary insights into potential emerging sectors relevant to the UK.

4.6.1. Technology driver: an example of patent analysis

Patent data is commonly used to operationalise emerging technologies.[101] Introduced by the Japan Patent Office (JPO),[102] the "maturation map" or "technological maturation map" is a widely recognised patent analysis technique for tracking the life cycles of technologies such as offshore wind energy,[103] ocean energy[104] and wireless power transfer.[105]

A technological maturation map tracks the evolution of patented technologies by analysing changes in the number of patent applications and applicants over time.

[99] The Department for Business, Energy, and Industrial Strategy (2021). Methodology to Identify Emerging Technologies with UK Commercialisation Potential

[100] SRI International Center for Innovation Strategy and Policy (2023). Quantum Technology Manufacturing Roadmap.

[101] Rotolo, D., Hicks, D. and Martin, B. R. (2015). What is an emerging technology? *Research Policy*, 44(10): 1827–1843.

[102] Japan Patent Office (2011). Introduction to Patent Map Analysis.

[103] European Patent Office (2023). Patent insight report on Offshore wind energy.

[104] Lin, J. C. and Chen, W. M. (2016). Harvesting Green Energy from Blue Ocean in Taiwan: Patent Mapping and Regulation Analyzing. In Sustainable Energy-Technological Issues, Applications and Case Studies. IntechOpen.

[105] Kim, K. H., Han, Y. J., Lee, S., Cho, S. W. and Lee, C. (2019). Text mining for patent analysis to forecast emerging technologies in wireless power transfer. *Sustainability*, 11(22): 6240.

Based on these trends, patented technologies are typically categorised into 5 phases.[106, 107]

- **Inception phase** – Characterised by a few early applications from a limited number of patent applicants. Technologies in this phase are considered vacant.
- **Development phase** – A rapid increase in both applications and applicants occurs as new seed technologies emerge or societal demand grows. Technologies in this phase are often seen as emerging.
- **Maturation phase** – A turning point is reached when either the number of patent applicants or applications begins to decline while growth in the other slows. This phase signifies the transition to mature technologies.
- **Declining phase** – Both the number of patent applications and applicants decrease, the market for the technology shrinks, and former entrants exit the field.
- **Stagnant and recovery phase** – Decline may persist until triggered by new innovations or other factors, leading to renewed growth in patent applications and applicants.

A revised technology classification, based on all International Patent Classification (IPC) codes, was developed by WIPO in collaboration with the Fraunhofer Institute in 2008. Designed to cover all patented technologies, this classification includes 35 technology fields.[108]

Against this backdrop, technological maturation maps for the 35 technology fields have been developed to track their technology cycles from 2000 to 2022 (Figure 4.2).[109] To shed light on the most innovative patents, this report only considers patent applications received by the United States Patent and Trademark Office (USPTO), the EPO, the JPO, the Korean Intellectual Property Office (KIPO) and the China National Intellectual Property Administration (CNIPA). In 2023 these 5 offices accounted for 85% of global patent applications.[110]

[106] Kim, K. H., Han, Y. J., Lee, S., Cho, S. W. and Lee, C. (2019). Text mining for patent analysis to forecast emerging technologies in wireless power transfer. *Sustainability*, 11(22): 6240.

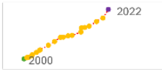
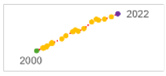
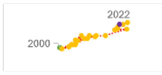
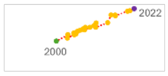
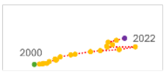
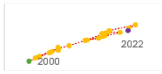
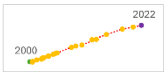
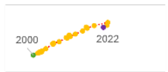
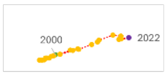
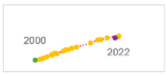
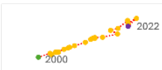
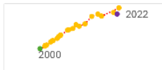
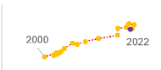
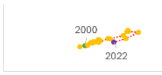
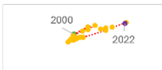
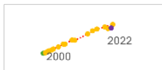
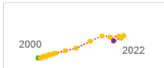
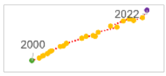
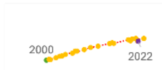
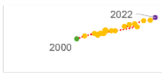
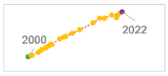
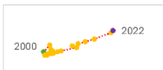
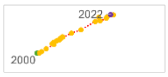
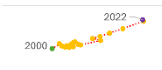
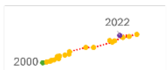
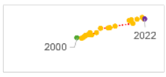
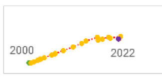
[107] Japan Patent Office (2011). Introduction to Patent Map Analysis.

[108] WIPO (2008). Concept of a Technology Classification for Country Comparisons.

[109] For a detailed methodology on technological maturation maps, see Japan Patent Office (2011). Introduction to Patent Map Analysis; Kim, K. H., Han, Y. J., Lee, S., Cho, S. W. and Lee, C. (2019). Text mining for patent analysis to forecast emerging technologies in wireless power transfer. *Sustainability*, 11(22): 6240.

[110] WIPO. IP Facts and Figures.

Figure 4.2 Technology life cycles of 35 technology fields identified by the World Intellectual Property Office (WIPO)

No.	Technology field	Technology life cycle (2000-2022)	Current phase	No.	Technology field	Technology life cycle (2000-2022)	Current phase
1	Electrical machinery, apparatus, energy		Development	19	Basic materials chemistry		Maturation
2	Audio-visual technology		Maturation	20	Materials, metallurgy		Development
3	Telecommunications		Maturation	21	Surface technology, coating		Development
4	Digital communication		Recovery	22	Micro-structural and nano-technology		Maturation
5	Basic communication processes		Recovery	23	Chemical engineering		Recovery
6	Computer technology		Development	24	Environmental technology		Maturation
7	IT methods for management		Recovery	25	Handling		Maturation
8	Semiconductors		Maturation	26	Machine tools		Recovery
9	Optics		Maturation	27	Engines, pumps, turbines		Declining
10	Measurement		Recovery	28	Textile and paper machines		Declining
11	Analysis of biological materials		Maturation	29	Other special machines		Recovery
12	Control		Maturation	30	Thermal processes and apparatus		Development
13	Medical technology		Maturation	31	Mechanical elements		Maturation
14	Organic fine chemistry		Development	32	Transport		Recovery
15	Biotechnology		Development	33	Furniture, games		Maturation
16	Pharmaceuticals		Maturation	34	Other consumer goods		Maturation
17	Macromolecular chemistry, polymers		Recovery	35	Civil engineering		Maturation
18	Food chemistry		Development				

Note: *Development*: a rapid increase in both patent applications and applicants; *maturation*: either the number of patent applicants or applications begins to decline while growth in the other slows; *recovery*: a renewed growth in patent applications and applicants after a period of decline.

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on WIPO (2008). Concept of a Technology Classification for Country Comparisons; and EPO – PATSTAT database.

Using the findings from Figure 4.2, and focusing on emerging technologies, further discussion can centre on technology fields in the “development” and “recovery” phases, as both include emerging technologies or early-stage innovation. As a result, 17 of the 35 technology fields are highlighted.

Building on WIPO’s identified technology fields, and using a correspondence table between technology fields and economic sectors classified by NACE code, the analysis shows that manufacturing sectors have the strongest relationship with these technology fields.[111]

Table 4.2 lists the 17 emerging technology fields, along with the top 5 manufacturing subsectors that have the strongest relationships with each technology field.

Table 4.2 Emerging Technology Fields and the Top 5 related Manufacturing Subsectors

Emerging technology fields from patent analysis	Top 5 related manufacturing subsectors (based on “concordance” analysis between technology fields and NACE sectors from Max Planck Institute)				
Electrical machinery, apparatus, energy	27.1: Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	26.1: Manufacture of electronic components and boards	27.9: Manufacture of other electrical equipment	29.3: Manufacture of parts and accessories for motor vehicles	27.4: Manufacture of electric lighting equipment
Digital communication	26.2: Manufacture of computers and peripheral equipment	26.3: Manufacture of communicatio n equipment	26.5: Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks	26.1: Manufacture of electronic components and boards	27.1: Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus
Basic communication processes	26.1: Manufacture of electronic components and boards	26.5: Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks	26.3: Manufacture of communicatio n equipment	26.2: Manufacture of computers and peripheral equipment	27.9: Manufacture of other electrical equipment

[111] Dorner, M. and Harhoff, D. (2018). A novel technology-industry concordance table based on linked inventor-establishment data. *Research Policy*, 47(4): 768–781.

Computer technology	26.1: Manufacture of electronic components and boards	26.2: Manufacture of computers and peripheral equipment	26.5: Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks	18.1: Printing and service activities related to printing	26.3: Manufacture of communicatio n equipment
IT methods for management	26.2: Manufacture of computers and peripheral equipment	26.1: Manufacture of electronic components and boards	27.1: Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	29.1: Manufacture of motor vehicles	28.9: Manufacture of other special-purpose machinery
Measurement	26.5: Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks	29.3: Manufacture of parts and accessories for motor vehicles	26.1: Manufacture of electronic components and boards	26.7: Manufacture of optical instruments and photographic equipment	28.2: Manufacture of other general-purpose machinery
Organic fine chemistry	20.1: Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	20.4: Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	21.2: Manufacture of pharmaceutic al preparations	21.1: Manufacture of basic pharmaceutic al products	20.5: Manufacture of other chemical products
Biotechnology	21.2: Manufacture of pharmaceutic al preparations	20.1: Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	21.1: Manufacture of basic pharmaceutic al products	24.4: Manufacture of basic precious and other non-ferrous metals	20.5: Manufacture of other chemical products
Macromolecul ar chemistry, polymers	20.1: Manufacture of basic chemicals, fertilisers and	20.5: Manufacture of other chemical products	20.6: Manufacture of man-made fibres	20.3: Manufacture of paints, varnishes and similar	20.4: Manufacture of soap and detergents, cleaning and

	nitrogen compounds, plastics and synthetic rubber in primary forms			coatings, printing ink and mastics	polishing preparations, perfumes and toilet preparations
Food chemistry	10.8: Manufacture of other food products	20.1: Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	20.5: Manufacture of other chemical products	28.9: Manufacture of other special-purpose machinery	10.5: Manufacture of dairy products
Materials, metallurgy	20.1: Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	28.9: Manufacture of other special-purpose machinery	24.4: Manufacture of basic precious and other non-ferrous metals	24.1: Manufacture of basic iron and steel and of ferro-alloys	23.1: Manufacture of glass and glass products
Surface technology, coating	20.1: Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	28.9: Manufacture of other special-purpose machinery	22.2: Manufacture of plastics products	28.1: Manufacture of general — purpose machinery	20.5: Manufacture of other chemical products
Chemical engineering	20.1: Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	28.9: Manufacture of other special-purpose machinery	28.2: Manufacture of other general-purpose machinery	29.3: Manufacture of parts and accessories for motor vehicles	22.2: Manufacture of plastics products
Machine tools	28.9: Manufacture of other special-purpose machinery	28.4: Manufacture of metal forming machinery and machine tools	28.2: Manufacture of other general-purpose machinery	25.7: Manufacture of cutlery, tools and general hardware	28.1: Manufacture of general — purpose machinery

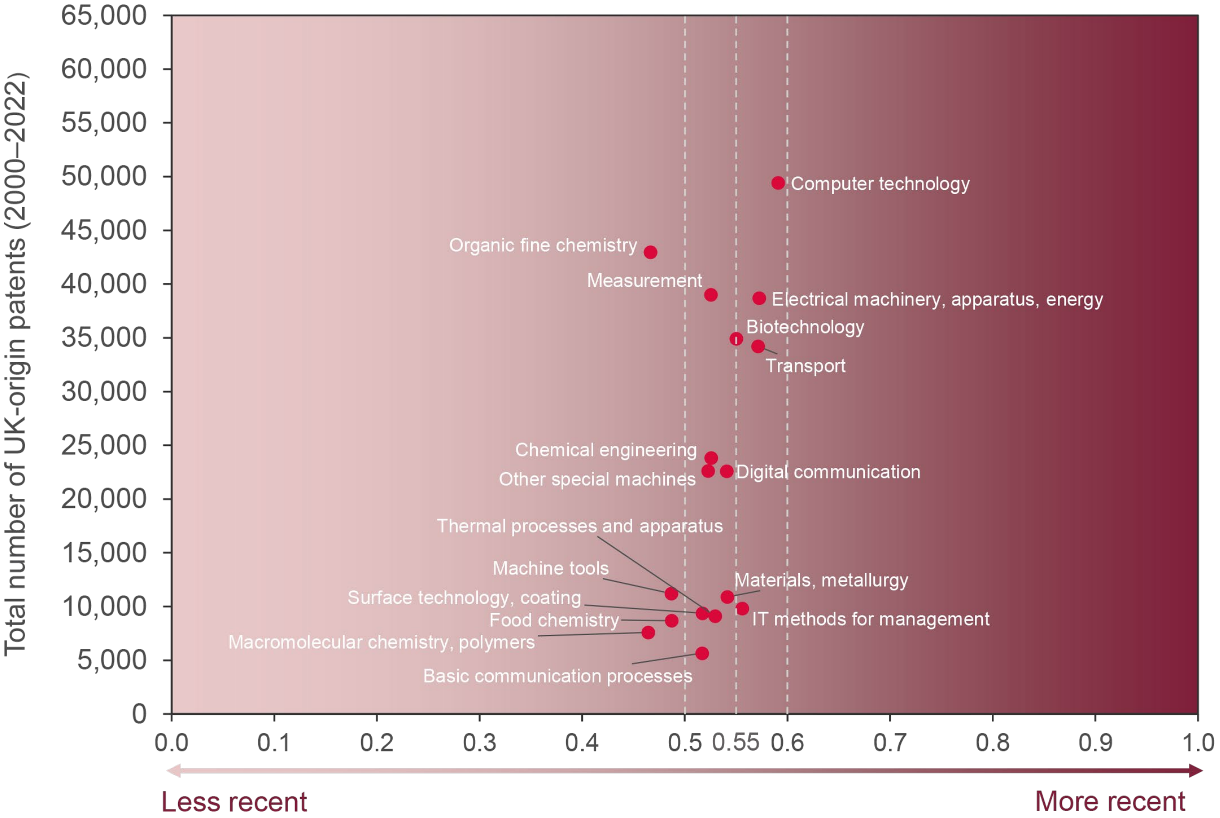
Other special machines	28.3: Manufacture of agricultural and forestry machinery	20.1: Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	28.9: Manufacture of other special-purpose machinery	28.2: Manufacture of other general-purpose machinery	25.4: Manufacture of weapons and ammunition
Thermal processes and apparatus	27.5: Manufacture of domestic appliances	29.3: Manufacture of parts and accessories for motor vehicles	28.2: Manufacture of other general-purpose machinery	28.9: Manufacture of other special-purpose machinery	28.1: Manufacture of general — purpose machinery
Transport	29.3: Manufacture of parts and accessories for motor vehicles	29.1: Manufacture of motor vehicles	30.3: Manufacture of air and spacecraft and related machinery	28.1: Manufacture of general — purpose machinery	27.9: Manufacture of other electrical equipment

Source: Max Planck Institute for Innovation and Competition - Department for Innovation and Entrepreneurship Research.

Figure 4.3 illustrates the UK's performance across the 17 identified emerging technology fields, based on the total number of UK-origin patents filed between 2000 and 2022 and the recency of filings in each field. Greater weight is assigned to patents filed in more recent years, highlighting fields where the UK maintains an active and growing presence in innovation.

Among these 17 emerging technology fields, between 2000 and 2022 the UK accumulated patents in **computer technology**, **electrical machinery and energy**, **biotechnology** and **transportation**, surpassing other fields. Meanwhile, UK patent applicants remain actively engaged in these 4 areas. Additionally, while the absolute number of patents in **IT methods**, **materials and metallurgy** and **digital communications** is lower, these fields are gaining more attention from UK innovators.

Figure 4.3 The UK's Patent applications in selected technology fields, 2000 to 2022



How to read: Y axis – innovation intensity is measured by the total number of published patents between 2000 and 2022. X axis – recency measures how recently patent applications were first filed for specific technology fields. It is calculated as a weighted average of patent applications, where a higher weighting is given to inventions filed in more recent years.

Note: The chart shows technology fields that, globally, are in a development phase (i.e. a rapid increase in both patent applications and applicants) or recovery phase (i.e. a renewed growth in patent applications and applicants after a period of decline).

The "innovation maturity matrix" depicts innovation intensity against the recency of innovation for technology fields identified by WIPO, based on relevant patent applications filed worldwide between 2000 and 2023. Recency and innovation intensity are calculated based on the annual number of patent applications counted by countries of origin. See WIPO (2024). Mapping Innovations Patents and the Sustainable Development Goals for methodological details.

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on WIPO (2024). WIPO IP Statistics Data Center.

4.6.2. Technology driver: an example of academic publication analysis

The Australian Strategic Policy Institute has developed a comprehensive, data-driven project that tracks 64 critical technologies across sectors such as defence, space, energy, environment, artificial intelligence, biotechnology, robotics, cyber-security, computing, advanced materials and key areas of quantum technology. This initiative is an early indicator of a nation's research strength and future capabilities in science and technology. The project covers highly cited research publications from 2019 to

2023 within these fields.[112] According to the findings, the UK ranked in the top 5 globally in 36 of the 64 technologies. The detailed list is provided in Table 4.3.

Table 4.3 Critical technologies where the UK ranked in the top 5 countries globally for publications, 2019 to 2023

Technology field	Critical technologies in which the UK ranked in the top 5 countries globally
Advanced information and communication technologies	Advanced optical communication (3rd)
	Advanced undersea wireless communication (5th)
	Advanced radiofrequency communication (4th)
	Distributed ledgers (4th)
	High-performance computing (4th)
	Protective cyber-security technologies (5th)
Advanced materials and manufacturing	Advanced protection (3rd)
	High-specification machining processes (4th)
	Smart materials (5th)
	Advanced magnets and superconductors (3rd)
	Continuous-flow chemical synthesis (3rd)
	Additive manufacturing (3rd)
Artificial intelligence, computing and communications	Advanced data analytics (4th)
	Machine learning (4th)
	Natural language processing (4th)
Biotechnology, gene technologies and vaccines	Synthetic biology (5th)
	Biological manufacturing (5th)
	Genetic engineering (4th)
	Genomic sequencing and analysis (3rd)
	Vaccines and medical countermeasures (3rd)
Defence, space, robotics and transportation	Advanced aircraft engines (5th)
	Drones, swarming and collaborative robots (4th)
	Hypersonic detection and tracking (3rd)
	Advanced robotics (3rd)
	Autonomous systems operation technology (3rd)
Energy and environment	Directed energy technologies (4th)
Quantum technologies	Post-quantum cryptography (5th)
	Quantum computing (3rd)
	Quantum communication (4th)
Sensing, timing and navigation	Inertial navigation systems (3rd)
	Radar (5th)

[112] Australian Strategic Policy Institute (2024). Critical Technology Tracker.

	Sonar and acoustic sensors (4th)
	Magnetic field sensors (4th)
	Atomic clocks (4th)
Unique AUKUS-relevant technologies (the trilateral security and technology partnership involving the USA, the UK and Australia)	Autonomous underwater vehicles (4th)
	Electronic warfare(4th)

Source: Australian Strategic Policy Institute (2024). Critical Technology Tracker.

4.6.3. Demand driver: an example of high-growth products in global trade

Globally, international trade data is a useful proxy for tracking the growth in global demand at the product level.

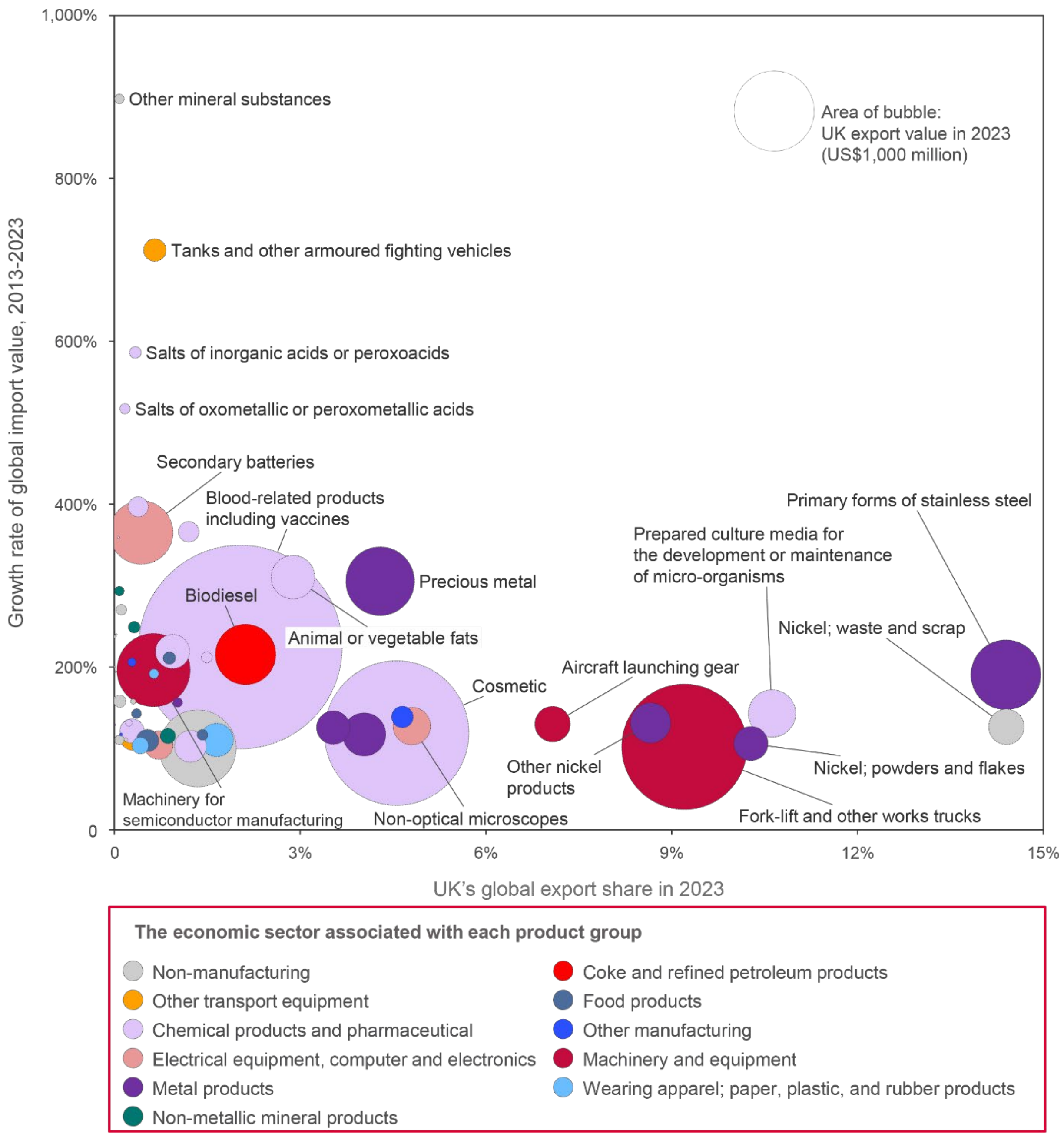
Our analysis identified 60 high-growth products out of 1,227 product groups, each experiencing over 100% growth in global imports between 2013 and 2023, with a minimum import value of US$1 billion in 2023. To connect these products to broader industrial sectors, a mapping between Harmonised System (HS) codes and industrial classifications has been established, referencing documents from the ONS and the UN. The UN provides a correspondence table linking HS codes to the Classification of Products by Activity (CPA). According to the ONS, the CPA structure relates directly to the NACE Rev. 2, with the first 4 digits being identical in most cases.[113] This allows a direct link between trade export codes and industrial classifications.

A full list of the 60 products is available in Appendix 5. This mapping helps to align global trading demand with sectoral insights, improving the understanding of which industries are behind global demand growth.

Figure 4.4 illustrates the UK's position across the 60 high-growth products by plotting the UK's global export shares in 2023 (X axis) against the growth rate of global import value for each product between 2013 and 2023 (Y axis). The area of each bubble represents the UK's export value for that product in 2023, with different colours highlighting the economic sectors associated with each product group.

[113] ONS. UK Standard Industrial Classification of Economic Activities 2007 (SIC 2007) Structure and explanatory notes.

Figure 4.4 UK Export Performance in "High-Growth" Products, 2023



Note: *High-growth products* are defined as products that experienced over 100% growth in global imports between 2013 and 2023, and the total value of imports was at least US$1 billion in 2023.

Statistical classification as per ONS SIC 2007: other transport equipment (SIC 30); chemical products and pharmaceutical (SIC 20 and SIC 21); electrical equipment, computer and electronics (SIC 26 and SIC 27); metal products (SIC 24 and SIC 25); non-metallic mineral products (SIC 23); coke and refined petroleum products (SIC 19); food products (SIC 10); other manufacturing (SIC 32); machinery and equipment (SIC 28); wearing apparel; and paper, plastic, and rubber products (SIC 14, 17 and 22).

For visual clarity, the data for flat panel displays and machines for additive manufacturing (e.g. 3D printers) is not shown in Figure 4.4. For the complete list of high-growth products, please see Appendix 5. The export data for nickel and other base metals may stem from contract transactions on the London Metal Exchange.

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on UN (2025). UNCOMTRADE database.

Although not shown in the chart for visual clarity, flat panel displays saw imports surge from US$43.6 million in 2013 to US$65.5 billion in 2023 (1,500x growth). Meanwhile, machines for additive manufacturing (e.g. 3D printers) grew nearly 20 times, reaching a market size of US$1.7 billion. However, the UK's presence in these markets remained relatively small in 2023, with a 0.03% market share and US$21 million in exports for flat panel displays, and a 3.13% market share and US$53 million for additive manufacturing machines.

The machinery of forklift and works trucks (US$2.4 billion), cosmetic products (US$3.2 billion) and blood-related products, including vaccines (US$6.4 billion), stand out with the largest value of UK exports in 2023. Meanwhile, the UK accounted for 9.2% of the global market share for forklift and works trucks, while cosmetic products and blood-related products, including vaccines, accounted for 4.6% and 2.0%, respectively.

From the perspective of the manufacturing sectors behind these high-growth products, the manufacturing of chemical products, pharmaceuticals, metal products, and machinery and equipment plays a significant role. While some nickel-related exports may stem from contract transactions on the London Metal Exchange,[114] most UK-produced stainless steel is for export by domestic manufacturers such as Outokumpu and Liberty Steel.[115]

4.6.4. Regulatory, institutional and policy shifts: an example of international policy strategies and priorities review

Research institutes monitor shifts in national strategy documents to track changes in R&D priorities. For example, Japan's National Institute of Science and Technology Policy (NISTEP) analyses US R&D and science, technology and innovation (STI) policies to identify the latest technology focus areas of the US government.[116] Additionally, NISTEP has developed a tool that continuously scans news releases from around 300 organisations – including universities, research institutes and private companies – to detect early signals of emerging technologies.[117]

Countries assess the emerging technology priorities of other nations by systematically reviewing their national strategies, priorities and R&D investments. Countries often benchmark their own priorities against those of leading innovators to remain competitive and adapt their policy responses accordingly.

For this study, we reviewed selected international government priority documents to understand international emerging priorities, including technologies and sectors

[114] London Metal Exchange. Guide to the London Metal Exchange.

[115] British Stainless Steel Association (2022). The importance of stainless steel in the UK economy – Rob Cooper in The Metal Magazine.

[116] NISTEP (2018). Changing landscape of Research and Development in the United States – Analysis based on scanning of published information.

[117] NISTEP (2019). A New Tool for Capturing Weak Signals -NISTEP's Horizon Scanning 'KIDSASHI'.

prioritised by international peers (the USA, EU, China and Singapore). Given this project's focus on emerging advanced manufacturing, only government documents with relevant priorities were included, and the review was restricted to publications from the past few years.[118]

Figure 4.5 offers an overview of 12 emerging technology domains identified across these priorities.

Figure 4.5 Emerging technological domains prioritised by selected countries and regions

Advanced manufacturing	Advanced materials	Aerospace	AI, digital and computing
Circular economy	Energy	Future telecommunications	Life sciences and biotech
Microelectronics and photonics	Other transport	Quantum technologies	Space and deep sea

Sources: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on the UK: DSIT (2023). UK Science and technology framework; Innovate UK (2023b). Materials and manufacturing vision 2050; Innovate UK (2023a). Innovate UK's 50 Emerging Technologies; BEIS (2021). Methodology to identify emerging technologies with UK commercialisation potential. The USA: US NSTC (2024). US critical and emerging technologies list update; US NIST Office of Advanced Manufacturing (2022). Advanced Manufacturing Technology Roadmap Program. China: Chinese Ministry of Industry and Information Technology et al. (2024). Translation of the Implementation opinions of 7 ministries on promoting the innovative development of future industries. The EU: European Factories of the Future Research Association (2023). EFFRA Vision for a Manufacturing Partnership in Horizon Europe 2021-2027; The EC (2024). Advanced materials for industrial leadership. Preliminary list of R&I priorities. Singapore: Ministry of Trade and Industry Singapore (2022). Industry Transformation Maps. A full list of technology priorities is available in Appendix 6.

Complementing the international review of government strategy and priority documents related to emerging technologies and sectors presented above, we reviewed the UK's priorities and strengths compared to its international peers. UK government priority documents and foresight exercises were reviewed to reveal the UK's most recent strengths and priorities.

At the highest level, we reviewed the Science and Technology Framework, published in 2023 by DSIT, for priorities.[119] The focus of this document was on 5 critical technologies, including **AI, engineering biology, future telecommunications, semiconductors** and **quantum technologies**. While it is not the aim of this strategy to provide more detail on these technologies, its publication was followed by detailed strategies for each of the 5 technologies, suggesting their importance.

[118] A full list of technology priorities is available in Appendix 6.

[119] DSIT (2023). UK Science and technology framework.

In 2023 Innovate UK published a list of 50 emerging technologies likely to be important to the UK economy beyond 2040.[120] The longlist of emerging technologies was gathered from surveys of the scientific community and experts, and a review of technology studies. This list was then filtered based on relevance – whether technology is emerging and whether there is relevant expertise in the UK. Finally, emerging technologies were shortlisted based on more than 30 criteria related to timing, additionality, UK capability, opportunity and social impact.

Within the list of 50 emerging technologies, the advanced manufacturing and materials category includes technologies such as **4D printing, nanoparticle manufacturing, biomimetic materials** and **metamaterials**. There are, however, other cross-cutting categories that will have implications for advanced manufacturing, such as **photonics and quantum technologies, clean technologies, biotechnologies, health and medtech, robotics** and **space technologies**.

In 2023 Innovate UK also published the *Materials and manufacturing vision 2050*,[121] which highlights the challenges and opportunities facing the UK materials and manufacturing sectors over the next 30 years. The results of this report are based on consultations with over 120 partners across academia, UKRI, Innovate UK, the High Value Manufacturing Catapult, DSIT and DBT, and a structured SWOT analysis. The SWOT analysis is based on extracting more than 1,000 salient points from over 170 recent documents and spread across an activity model for 10 focus areas: materials for the future economy, smart design, resilient supply chains, world-class production, longer in use and reuse, clean energy, proactive regulations and policy, future skills, networked relations, and evolving value models.

In 2021 BEIS published a *Methodology to identify emerging technologies with UK commercialisation potential*,[122] which shortlisted the top 25 emerging technologies by UK R&D strengths and further shortlisted the top 10 emerging technologies with commercialisation potential. The initial longlisting of emerging technologies, which led to a list of 300 emerging technologies, was based on criteria such as patents, public and private funding, the number of sectors to be impacted, technology readiness levels, time to impact, and the number of megatrends impacted. The second phase focused on R&D indicators, such as publications, impact of publications, private equity and VC investment, public investment and patents. The third phase focused on company indicators such as total numbers of companies, high-growth companies, growth in volume of equity investments, and so on.

Among the top 25 emerging technologies in the category of advanced materials and manufacturing were **advanced materials** and **2D materials**. However, other cross-cutting categories included advanced manufacturing-related emerging technologies such as **energy technologies**, **photonics**, **advanced sensing**, **microelectronics**, **robotics and autonomous vehicles**, **synthetic biology**, **agritech**, **personalised and precision medicine**, **medical imaging** and **targeted therapy**.

[120] Innovate UK (2023a). Innovate UK's 50 Emerging Technologies.

[121] Innovate UK (2023b). Materials and manufacturing vision 2050.

[122] BEIS (2021). Methodology to identify emerging technologies with UK commercialisation potential.

As presented in more detail in Appendix 6, the UK's priorities and strengths include 117 emerging technologies. This list is provided in Table 4.4. Ranking of these technologies is neither recommended nor possible, as each of the 4 UK-specific documents consider a different list of technologies with a different level of granularity and rely on different tools and evidence (i.e. some are more area-specific than others). They also do not necessarily provide rankings. Instead, they list technologies with strengths and opportunities for the UK.

Table 4.4 The UK's strengths in emerging technologies identified in priority documents and technology foresight exercises (longlist of 117 technologies)

Advanced manufacturing
Industry 4.0 tech: AI
Industry 4.0 tech: robotics
Industry 4.0 tech: internet of things (IoT)
Smart manufacturing (i.e. materials and techniques, intelligent control and sensing, improving production efficiency and reducing costs such as predictive maintenance)
Wireless sensor fusion; smart mechatronic systems, devices, and components; intelligent control systems and sensing
Precision engineering
Predictive maintenance
Additive manufacturing, including 4D printing
Planned and scheduled production (e.g. optimised scheduling, increased capacity)
Make-to-order manufacturing
Laser manufacturing
Lasers and optics
End-to-end integration of manufacturing networks, flexible distributed production
Concurrent, holistic and collaborative product–service engineering
Simulation and modelling (digital twins) of material behaviours and mechatronic systems (i.e. industrial metaverse, whole-system simulation)
Predictive model-based approaches across all levels from machine to supply chain
Digital end-to-end supply chain integration (digital thread)
Nanoparticle manufacturing

Advanced materials
Advanced materials general

Circular economy
Circular manufacturing, symbiotic manufacturing
De-manufacturing and recycling technologies
Materials and business models for circularity
Smart design for upgrade, retrofit, remanufacture, repair, recycle, low emissions, low material use
Closed-loop water system
Market for waste
Tracking products and materials
Waste conversion to feedstocks
Waste management

Energy
Decarbonising manufacturing plants
Electrification of industrial processes
Clean, renewable energy generation
Distributed power generation
Carbon, capture and use technologies
New, flexible, ultra-efficient energy management solutions
Flexible grids
Grid scale wireless energy transmission and charging
Hydroelectric energy
Solar energy
Wind energy
Nuclear energy
Nuclear fusion
Space nuclear power
Hydrogen energy and storage

Materials for hydrogen economy
High-performance material-processing technologies (improved traditional material-processing technologies, or Material 4.0; integration of smart advanced materials with process technologies)
Younger technology integration into process chains (photonics, other physical and chemical technologies; integration of smart advanced materials with process technologies)
Cutting-edge new materials, including superconducting materials, magnets
Lightweight solutions, including composites
(Multi)functional materials
Metamaterials
3D weaving
2D crystals/materials
Biomimetic materials
Nanomaterials
Recycled materials and packaging (including cross-linked polymer recycling)

Aerospace
Electric vertical take-off and landing (eVTOL) aircraft, electric propulsion
Novel propulsion technologies (including space propulsion systems)

Other transport
Autonomous vehicles

Quantum technologies
Quantum technologies general
Quantum and photonic computing technologies
Quantum sensors
Post-quantum cryptography
Quantum algorithms

Space and deep sea
Space manufacturing, lunar and Martian manufacturing
Lunar and Martian exploration

Energy-storage technologies
Next-generation energy materials and manufacturing (catalysts, coating, etc. improving environmental operating conditions)
Novel negative emissions technologies
Space-based solar power

Life sciences and biotech
Engineering/synthetic biology
Catalysis and industrial biotechnology
Biomanufacturing
Artificial cells and life
Programmable cells
Adult stem-cell generation
Fluxomics
Anti-ageing drugs
Antibiotic replacements
Biofabrication in tissue engineering
Biocatalytic membranes
Bioelectronics and electroceuticals
Microbe therapeutics
Phased genome assembly tools
Sensation detection implants
Whole body-on-a-chip device
Cell and gene technology: genetic engineering, genome and genetic sequencing and analysis
Sustainable materials, including bio-based and biodegradable
Personalised and precision medicine
Disease control (human)
Agritech
Omics
Medical imaging
Targeted therapy

Other
Hypersonics

AI, digital and computing
Artificial intelligence, machine learning, natural language processing, general
Data analytics, artificial intelligence and deployment of digital platforms for data management and sharing
Human–machine interactions (brain-inspired intelligence, brain computing, swarm intelligence, large models)
Human–machine interfaces
Augmented and virtual reality
Advanced computing general
AI emotion and expression recognition
Artificial general intelligence (AGI)
DNA data storage
Blockchain
Data privacy, data security and cyber-security technologies

Highly automated, autonomous and uncrewed systems and robotics general
Nanoscale robotics
Soft robotics

Future telecommunications
Future telecommunications general
5G/6G mmWave materials and electrical test technology
Very low earth orbit satellites

Microelectronics and photonics
Microelectronics and semiconductors general
Advanced semiconductors
Emerging microscopy techniques
Photonics
Sensors and actuators
Multispectral and hyperspectral imaging sensors

Sources: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge, based on DSIT (2023). UK Science and technology framework; UKRI (2023). Materials and manufacturing vision 2050; IUK (2023). Innovate UK's 50 Emerging Technologies; BEIS (2021). Methodology to identify emerging technologies with UK commercialisation potential.

4.6.5. Synthesis of emerging areas identified in preliminary analyses

In the previous subsection, we identified three key drivers behind the emergence of new sectors: technology development, demand growth, and regulatory, institutional, or policy shifts. These drivers form the basis for identifying a broad “long list” of emerging areas, using a set of proxy indicators aligned with each category. As illustrated in Figure 4.6, selected indicators such as patent analysis, research publication analysis, trade data, and national foresight and policy documents were used to detect signals of emerging activity relevant to UK manufacturing.

The synthesis exercise that follows this mapping plays a crucial role. By bringing together results from the different drivers, it becomes possible to contrast areas at different system levels (technology, products, sub-sectors) and think about their relationship. It also helps identify patterns of convergence – that is, areas that appear prominently across multiple indicators or drivers. Of particular interest are overlapping areas, where signals of emergence are evident across all three drivers. These intersections point to emerging sectors likely to become relevant, as they are not only supported by scientific and technological advances but also show signs of market traction and alignment with policy or institutional priorities.

Some areas appear across several dimensions, suggesting a high potential for growth and strategic importance in the UK context.

The preliminary analysis conducted in this section shows that additive manufacturing, for example, could be an area of strategic focus: between 2019 and 2023, the UK ranked third globally in terms of high-citation research publications in this area; while in 2023 the UK accounted for the 3.13% of global export shares of machines used in additive manufacturing, such as 3D printers, a market that expanded nearly twentyfold between 2013 and 2023, as measured by global exports, reaching a value of US$1.7 billion in 2023. Additive manufacturing is also recognised as a priority area in the UK's technology and innovation strategies, including Materials and manufacturing vision 2050, published by Innovate UK.

As one of the enabling technologies for additive manufacturing, materials represent a key strength for the UK in both scientific research and national innovation priorities. UK research institutions ranked 5th globally in high-citation publications on smart materials— materials that can adapt over time and have the potential for self-repair. UK applicants filed around 10,000 patents in the field of materials between 2000 and 2022, and relevant patenting activity has increased in recent years, indicating growing interest and innovation in this area. Innovate UK has also identified smart materials, alongside other advanced materials, as part of its list of 50 Emerging Technologies.

Our preliminary analysis also shows that biological manufacturing presents high potential for growth and strategic importance for the UK. Patent applicants from the UK filed around 35,000 biotechnology-related patents between 2000 and 2022 and continue to remain actively engaged in this technology area. Many biotech-related products experienced over 100% growth in global export markets between 2013 and 2023, and the UK is an export leader of products such as vaccines and cosmetic products, whose exports to the rest of the world amounted to US$6.4 (accounting for 2.0% of global exports) and US$3.2 billion (4.6% of global exports) respectively in 2023. In terms of policy priorities, biotech is recognised as a key enabling technology across multiple strategic areas, including symbiotic manufacturing within the circular economy, and biofabrication and tissue engineering in life sciences. Meanwhile, the Department for Science, Innovation and Technology also identifies engineering biology as one of five critical technologies essential for the UK future prosperity.

Transport is another emerging area of relevance to UK manufacturing. Between 2000 and 2022, UK patent applicants filed over 34,000 patents related to transport technologies, with application volumes increasing in more recent years. Between 2019 and 2023, high-citation research publications from UK institutions ranked within the global top five in several transport-related fields, including advanced aircraft engines (5th), drones (4th), and autonomous underwater vehicles (4th). The UK also demonstrates strong export performance in high-growth transport-related products— for instance, in 2023, it accounted for 7.1% of global exports of aircraft launching gear, valued at US$195 million. In parallel, Innovate UK has identified advanced and efficient aircraft technologies, along with advanced batteries for the electrification of transport, as emerging technology for the UK. In 2023, the UK exported secondary batteries worth US$625.9 million, representing 0.4% of global exports.

These areas of convergence are especially valuable from a policy perspective, as they represent opportunities where targeted interventions could help unlock broader economic and industrial benefits. This synthesis approach allows for the systematic prioritisation of advanced manufacturing emerging sectors, linking evidence across domains and ensuring that efforts are focused where technological feasibility, market opportunity, and institutional readiness align.

Figure 4.6 Summary of emerging technologies or products relevant to UK manufacturing

Key drivers	Selected indicators	Exemplified results from the preliminary analysis
Technology development	Patent analysis	**Emerging technologies of relevance in UK manufacturing** • Computer technology • Electrical machinery and energy • Biotechnology • Transport • Measurement
	Research publication analysis	**Emerging technologies of relevance in UK manufacturing** • Advanced protection • High-specification machining processes • Smart materials • Advanced magnets and superconductors • Continuous-flow chemical synthesis • Additive manufacturing • Biological manufacturing • Genetic engineering • Advanced aircraft engines • Drones, swarming and collaborative robots • Advanced robotics • Autonomous underwater vehicles • Electronic warfare
Demand growth	Export/import market analysis	**Emerging products of relevance in UK manufacturing** • Products related to machinery and equipment (e.g. machinery of fork-lift and works trucks; additive manufacturing machines; aircraft launching gear) • Products related to chemical products and pharmaceuticals (e.g. cosmetic products, blood-related products, including vaccines) • Products related to metal products (e.g., primary forms of stainless steel)
Regulatory, institutional, or policy shifts	Review of national priority documents and technology foresight exercises	**Emerging technologies of relevance in UK manufacturing** • Advanced manufacturing (e.g. precision engineering and nanoparticle manufacturing) • Advanced materials (e.g. high-performance carbon fibre) • Aerospace (e.g. advanced and efficient aircraft) • AI, digital and computing (e.g. human machine interfaces) • Circular economy (e.g. circular manufacturing, symbiotic manufacturing) • Energy (e.g. decarbonising manufacturing plants) • Future telecommunications (e.g. 6G) • Life sciences and biotech (e.g. biofabrication in tissue engineering) • Microelectronics and photonics (e.g. semiconductor advanced packaging) • Other transport (e.g. advanced batteries) • Quantum technologies (e.g. quantum sensors) • Space and deep-sea (e.g. Martian manufacturing)

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge

4.6.6. Policy considerations

From an industrial strategy perspective, not all emerging sectors require government intervention or targeted support. Emerging sectors become strategically relevant or “attractive” when their anticipated growth potential, demand pull or disruptive impact is perceived to be significant, offering a meaningful opportunity for national economic or technological advancement. However, this condition – the existence of growth potential – is necessary but not sufficient.

The UK’s *Industrial Strategy Green Paper* makes this point explicitly, noting that emerging strengths are defined as "sectors in which the UK could feasibly develop a comparative advantage, often because of their proximity to the UK’s current strengths".[123] This implies that national priorities should not be based solely on global growth projections. They must also reflect the UK's existing position in the global landscape and its capacity to shape future trajectories.

Similarly, although the UK may currently hold a technological lead in a particular domain, this does not automatically translate into the capabilities or institutional readiness required to scale that technology into a robust, competitive sector. Thus, for any emerging technology, product or sector identified as high potential or disruptive, it is crucial to assess its national relevance, including aligning domestic innovation capabilities, industrial base and supporting institutions.

To identify advanced manufacturing emerging sectors that are worth prioritising for strategic support, policymakers should consider a set of criteria that go beyond growth potential. These may include:

- **Relevance to national industrial strategy priorities**: alignment with long-term policy goals, mission areas or national innovation and growth strategies.
- **Proximity to current domestic capabilities**: the degree to which existing skills, firms, technologies or supply chains can support the sector’s development.
- **Availability of innovation infrastructure**: the presence of universities, R&D centres, testbeds or clusters that can accelerate scaling and experimentation.
- **Importance to national security**: the role the sector could play in defence, critical supply chains or resilience against geopolitical or systemic risks.
- **Potential for cross-cutting economic impact**: the sector’s ability to stimulate activity across multiple industries or value chains.
- **Need for new regulation or standards**: the emergence of novel technologies or models may require updates to policy, safety or compliance frameworks, where government action is particularly relevant.

These criteria help to ensure that policy efforts are targeted, feasible and strategically impactful, enabling the UK to focus its resources on sectors where it has the greatest chance of securing a sustainable competitive advantage.

[123] DBT (2024). Invest 2035: the UK's modern industrial strategy.

4.7. Conclusions

This section has explored the concept of advanced manufacturing emerging sectors – defined as new or evolving industrial systems that use innovative manufacturing technologies, methods and materials to produce high-value products or integrated product–service solutions that are hard to replicate or substitute. Advanced manufacturing emerging sectors may involve new ways to produce existing products or, especially, new high-value products enabled by emerging technologies. These sectors emerge in response to a combination of technological and scientific breakthroughs, shifts in market demand, and regulatory, institutional or policy changes, and are typically in the early, fluid stages of development, marked by high uncertainty and transformative potential.

To help identify such sectors, we have outlined an analytical process that begins with mapping a longlist of emerging areas based on signals from the 3 key drivers of emergence. These signals are derived from sources such as expert insights, foresight exercises and trend data. A synthesis step then identifies promising candidates for further consideration, with emphases on areas where all 3 drivers overlap. This approach offers a structured method to move from a broad and fragmented evidence base towards a more focused set of opportunities.

Several domains, including advanced materials, additive manufacturing, biological manufacturing, AI and digital technologies, and advanced robotics, emerged across multiple dimensions in our preliminary analysis. This points to their high potential for growth and strategic significance for the UK. However, it is important to note that identifying an area as promising is not enough on its own. Further validation is needed to assess the UK's readiness to lead in these areas, in terms of both technological capabilities and the institutional conditions required to scale and sustain them.

The final stage of the process involves applying policy prioritisation criteria, including relevance to national strategy, proximity to current capabilities, potential for economic spillovers, national security implications and regulatory needs. This ensures that attention is directed at not only plausible areas of growth but also those where the UK has the capacity – and imperative – to act.

5. Concluding remarks

This study provides an update of the evidence base of the changing value and structure of the UK manufacturing sector. Focusing on the UK, and drawing from international experience, the study focuses on the following key areas: the direct and indirect value of UK manufacturing; the role of services within manufacturing processes as well as manufacturing firms' business models; the definition and quantification of advanced manufacturing; the definition and identification of emerging sectors within advanced manufacturing.

The analysis presented in this study shows that UK manufacturing has weaker interconnections both with other sectors and within its manufacturing industries than comparator countries. The analysis finds no evidence of a potential undercount in the UK's manufacturing sector compared to other nations. In the UK, the sector's lower contribution to the national economy, relative to other advanced economies, is explained by both a smaller manufacturing base and weaker linkages with other sectors and within manufacturing itself.

The analysis has some limitations, however, including the aggregation of manufacturing industries with different patterns and trends, the exclusion of foreign inputs, and the inability to capture shifts in manufacturing firms' business models towards services.

In this respect, this study has also examined the role of services in modern manufacturing production processes and business models, comparing the United Kingdom with other advanced economies, focusing on two key concepts: servicification – the increasing reliance of manufacturing firms on services, associated with outsourcing and offshoring practice as well as the emergence of global value chains - and servitization – a firm-level strategy where manufacturers integrate services with their core product offering, adding value for customers.

Quantitative estimates of the level of servicification of manufacturing showed that while the UK's level of servicification is comparable to other advanced economies, certain UK manufacturing sectors, including pharmaceuticals, automotive, and aerospace show a higher reliance on professional services. This underscores the growing importance of services in enhancing the competitiveness and value of UK manufacturing.

In recent years, advanced manufacturing has also become a prominent concept in industrial policy discussions globally. In the UK, it is identified as one of the eight strategic priorities in the 2024 Industrial Strategy Green Paper. Despite its growing prominence, however, advanced manufacturing remains a contested and ambiguously defined concept. A clearer understanding of what it entails – and how it can be identified and measured – is therefore both timely and essential.

This study has proposed a definition of advanced manufacturing, along with related definitions for advanced manufacturing processes, firms, sectors, and value chains. This study has also reviewed a range of international practices for identifying and measuring advanced manufacturing and summarised a set of indicators and proxies commonly used in international practice.

These proxies have been applied to illustrate how advanced manufacturing sectors in the UK might be identified and quantified. This is not intended as a definitive methodology, but rather as a practical example of how selected indicators can be used to inform policy and analysis. The preliminary analysis outlined in this study focuses on the sector level, using available data classified by Standard Industrial Classification (SIC) codes. While this provides a useful starting point to identify areas of potential and sectors that merit policy attention, it also has limitations. Sectors often include a mix of advanced and non-advanced firms, which can obscure important differences in capabilities and performance. To address this, the analysis argues for a shift toward firm-level approaches that can more accurately capture the technological and organisational characteristics of advanced manufacturing firms.

This study has finally explored the concept of advanced manufacturing emerging sectors – defined as new or evolving industrial systems that use innovative manufacturing technologies, methods, and materials to produce high-value products or integrated product–service solutions that are hard to replicate or substitute. Advanced manufacturing emerging sectors may involve new ways to produce existing products or, especially, new high-value products enabled by emerging technologies. These sectors emerge in response to a combination of technological and scientific breakthroughs, shifts in market demand, and regulatory, institutional, or policy changes, and are typically in early, fluid stages of development, marked by high uncertainty and transformative potential.

To support the identification of such sectors, the analysis in these studies has outlined an analytical process that begins with mapping a long list of emerging areas based on signals from the three key drivers of emergence. These signals are derived from sources such as expert insights, foresight exercises, and trend data. A synthesis step then identifies promising candidates for further consideration, with emphases of areas where all three drivers overlap. This approach offers a structured method to move from a broad and fragmented evidence base toward a more focused set of opportunities.

Several domains, including advanced materials, additive manufacturing, biological manufacturing, AI and digital technologies, and advanced robotics, emerged across multiple dimensions in our preliminary analysis. This points to their high potential for growth and strategic significance for the UK. However, it is important to note that identifying an area as promising is not enough on its own. Further validation is needed to assess the UK's readiness to lead in these areas, both in terms of technological capabilities and the institutional conditions required to scale and sustain them.

The final stage of the process involves applying policy prioritisation criteria, including relevance to national strategy, proximity to current capabilities, potential for economic spillovers, national security implications, and regulatory needs. This ensures that attention is directed not only at plausible areas of growth, but at those where the UK has the capacity – and the imperative – to act.

The analysis presented in this study has highlighted the crucial role and complementarity of the services in manufacturing. If manufacturing significantly depends on services all along the manufacturing value chain, it becomes essential to incorporate key services into manufacturing strategies.

Appendices

Appendix 1 – Selected publications on the servicification and servitisation of manufacturing

Servicification of manufacturing, selected publications

- Cieślik (2024). From traditional to digital servicification: Chinese services in European manufacturing. *Networks and Spatial Economics*.
- Drake-Brockman and Stephenson (2012). Implications for 21st Century Trade and Development of the Emergence of Services Value Chains. *International Centre for Trade and Sustainable Development Working Paper*.
- European Commission (2014). *For a European Industrial Renaissance*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Report/COM/2014/014.
- Elms and Low (2013). *Global value chains in a changing world*. WTO Publications.
- Haven and Der Marel (2018). Servicification of Manufacturing and Boosting Productivity Through Services Sector Reform in Turkey. *World Bank Policy Research Working Paper 8643*.
- Kim (2021). *Servicification: Its Meaning and Policy Implications*. Korea Institute for International Economic Policy.
- Lodefalk (2013). Servicification of manufacturing – evidence from Sweden. *International Journal of Economics and Business Research*, 6(1).
- Mercer-Blackman, V. and Ablaza, C (2018). The servicification of manufacturing in Asia: Redefining the sources of labor productivity. *ADBI Working Paper Series*, 902.
- Miroudot and Cadestin (2017). Services in Global Value Chains: From Inputs to Value-Creating Activities. *OECD Trade Policy Papers*, 197.
- Pattnayak and Chadha (2022). Servicification and manufacturing exports: Evidence from India. *Economic Modelling*, 108.
- Swedish National Board of Trade (2010). *Servicification of Swedish manufacturing*.
- Tomiyama (2001). Service Engineering to Intensify Service Contents in Product Life Cycles. *IEEE conference paper*.

Servitisation of manufacturing, selected publications

- Baines et al. (2017). Servitization: revisiting the state-of-the-art and research priorities. *International Journal of Operations & Production Management*.

- Bustinza et al. (2024). AI-enabled smart manufacturing boosts ecosystem value capture: The importance of servitization pathways within digital-intensive industries. *International Journal of Production Economics*, 277.
- Crozet M. and Milet E. (2017). Should everybody be in services? The effect of servitization on manufacturing firm performance. *Journal of Economic and Management Strategies*.
- Huang et al (2024). Servitization of manufacturing and China's power status upgrading of global value network. *Structural Change and Economic Dynamics*, 68.
- Kowalkowski C. et al. (2017). Servitization and deservitization: Overview, concepts, and definitions. *Industrial Marketing Management*, 60: 4–10.
- Lewis, M. et al. (2004). Beyond products and services: opportunities and threats in servitization. Paper presented at IMS Intl. Forum, Italy.
- Mercer-Blackman, V. and Ablaza, C (2018). The servicification of manufacturing in Asia: Redefining the sources of labor productivity. *ADBI Working Paper Series*, 902.
- Nasirov and Castaldi (2025). Servitization as a strategy for diffusing radical technologies: An analysis of US top corporate R&D investors. *Research Policy*, 54(1).
- Neely A. (2008). Exploring the financial consequences of the servitization of manufacturing. *Operations Management Research*.
- Rabetino et al. (2017). Structuring servitization-related research. *International Journal of Operations & Production Management*.
- Raddats C et al. (2019). Servitization: A contemporary thematic review of four major research streams. *Industrial Marketing Management*, 83.
- Vandermerwe and Rada (1988). Servitization of business: Adding value by adding services. *European Management Journal*, 6(4).

Appendix 2 – Selected definitions of advanced manufacturing

Source	Definition
DBT (2023) Advanced manufacturing plan	"Production processes that integrate advanced science and technology, including digital and automation, to manufacturing. These processes use R&D, innovation, our extensive knowledge network, and our highly skilled population. This helps UK manufacturers create products that are meeting future technological demands and enable the UK to lead on the twin transitions of net zero and digitalisation."
US Government (n.d.) Advanced manufacturing	"Use of innovative technologies to create existing products and the creation of new products. Advanced manufacturing can include production activities that depend on information, automation, computation, software, sensing, and networking."
PCAST (2011) Report to the President on ensuring American leadership in advanced manufacturing	"The family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/ or (b) make use of cutting edge materials and emerging capabilities enabled by the physical / biological sciences, e.g. nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies."
De Weck et al. (2014) Trends in advanced manufacturing technology innovation	"Advanced Manufacturing is the creation of integrated solutions that require the production of physical artifacts coupled with valued-added services and software, while exploiting custom-designed and recycled materials and using ultra-efficient processes."
CSIRO (2016) Advanced manufacturing – a roadmap for unlocking future growth opportunities for Australia	"This report defines advanced manufacturing as the set of technology based offerings, systems and processes that will be used to transition the current manufacturing sector into one that is centred on adding value across entire supply chains. Advanced manufacturers are companies that rapidly create or adopt these technologies."
Next Generation Manufacturing Canada (2021) How to introduce your students to advanced manufacturing	"Advanced manufacturing combines science and technology with manufacturing capabilities to improve how we make things, leading to new and better products that are unique, smart, cleaner, and often autonomous. Advanced manufacturing enterprises don't just assemble or make things; they use cutting edge technologies, business and engineering know-how, software, data analytics, and artificial intelligence to solve problems – and address some of the world's most pressing challenges. Some of the industries that are at the forefront of advanced manufacturing in Canada include biomanufacturing and medical technologies, clean and autonomous vehicles, aerospace, robotics and automation, agrifood and agricultural equipment, textiles, electronics, 3D printing, and more. Why is advanced manufacturing important? Because it builds things better, safer, cleaner, and more productively for a better world."
Next Generation Manufacturing Canada (n.d.) How is advanced manufacturing different from manufacturing?	"Manufacturing is about adding value to raw materials and components to produce finished goods for customers. Advanced manufacturing uses new digital, materials, and production technologies to innovate and make things faster, cleaner, safer, and better than before. It is at the heart of a value-creating network of researchers, tech companies, and of course manufacturers creating value for customers through products as well as data-based services. Advanced manufacturing can be found in all sectors of industry, but is the most advanced in fields like automotive and

	aerospace, medical technologies and biomanufacturing, robotics and automation, electronics, textiles, and processing industries.”
TWI (n.d.) What is advanced manufacturing? (A complete guide)	“Advanced manufacturing is the practice of using innovative technologies and methods to improve and enhance competitiveness within the manufacturing sector. By incorporating cutting-edge advancements, such as artificial intelligence and composite materials, we can optimise every aspect of the value chain – from product conception to end-of-life considerations.”
European Commission (n.d.) Advanced manufacturing	“Advanced manufacturing represents a Key Enabling Technology. It uses new knowledge and innovative and cutting-edge technologies such as robotics, 3D printing, artificial intelligence, high-performance computing and modelling, to produce complex products like aeroplanes and medical devices. It also optimises processes towards products having no defects, avoiding any waste, reducing industrial pollution, material consumption and energy use.”
Gunawardana (2006) Introduction of Advanced Manufacturing Technology: A Literature Review	“AMT, defined broadly, is a total socio-technical system where the adopted methodology defines the incorporated level of technology. AMT employs a family of manufacturing (CAM), flexible manufacturing systems (FMS), manufacturing resource planning (MRP II), automated material handling systems, robotics, computer-numerically controlled (CNC) machines, computer-integrated manufacturing (CIM) systems, optimized production technology (OPT), and just-in-time (JIT). Although AMT places great emphasis on the use of technological innovation, management’s role is significant since AMT systems require continual review and readjustment.” “Advanced Manufacturing technology (AMT) represents a wide variety of mainly computer-based systems, which provide adopting firms with the potential to improve manufacturing operations greatly. It is generally expected that the resultant improvement in operational performance will enhance the firm’s ability to reap the underlying marketing, strategic and business benefits for which the systems were adopted.”

Appendix 3 – Identifying and measuring advanced manufacturing in the UK – an illustration

Steps

1. Calculated the value of the following indicators for each manufacturing sector:
    a. Innovation: share of sectoral turnover carried out by broader innovator firms[1]
    b. Skills: ONS Qualification Index Score[2]
    c. R&D intensity: sector research and development (R&D) expenditure/sector gross value added (GVA).
2. Applied a threshold at the value for the manufacturing sector as a whole (see tables below).
3. Classified the sectors that meet the threshold in at least two indicators as advanced manufacturing sectors.

☐ = Sectors above the manufacturing average in selected criteria

Innovation	
SIC code	Sector name
30	Manufacture of other transport equipment
29	Manufacture of motor vehicles, trailers and semi-trailers
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment n.e.c.
11	Manufacture of beverages
20	Manufacture of chemicals and chemical products
31	Manufacture of furniture
25	Manufacture of fabricated metal products, except machinery and equipment
17	Manufacture of paper and paper products
10	Manufacture of food products
32	Other manufacturing
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
13	Manufacture of textiles
33	Repair and installation of machinery and equipment
15	Manufacture of leather and related products
26	Manufacture of computer, electronic and optical products
23	Manufacture of other non-metallic mineral products
22	Manufacture of rubber and plastic products
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
18	Printing and reproduction of recorded media
24	Manufacture of basic metals

14	Manufacture of wearing apparel
19	Manufacture of coke and refined petroleum products

Skills	
SIC code	Sector name
12	Manufacture of tobacco products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
30	Manufacture of other transport equipment
19	Manufacture of coke and refined petroleum products
26	Manufacture of computer, electrical and optical products
11	Manufacture of beverages
33	Repair and installation of machinery and equipment
32	Other manufacturing
20	Manufacture of chemicals and chemical products
28	Manufacture of machinery and equipment not otherwise specified
29	Manufacture of motor vehicles, trailers and semi-trailers
27	Manufacture of electrical equipment
18	Printing and reproduction of recorded media
24	Manufacture of basic metals
25	Manufacture of fabricated metal products, except machinery and equipment
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
23	Manufacture of other non-metallic mineral products
15	Manufacture of leather and related products
14	Manufacture of wearing apparel
17	Manufacture of paper and paper products
31	Manufacture of furniture
10	Manufacture of food products
13	Manufacture of textiles
22	Manufacture of rubber and plastic products

R&D Intensity	
SIC code	Sector name
30	Manufacture of other transport equipment
26	Manufacture of computer, electronic and optical products
19	Manufacture of coke and refined petroleum products
29	Manufacture of motor vehicles, trailers and semi-trailers
27	Manufacture of electrical equipment

32	Other manufacturing
28	Manufacture of machinery and equipment not elsewhere classified
25	Manufacture of fabricated metal products, except machinery and equipment
20	Manufacture of chemicals and chemical products
23	Manufacture of other non-metallic mineral products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations[3]
24	Manufacture of basic metals
22	Manufacture of rubber and plastic products
10	Manufacture of food products
13	Manufacture of textiles
15	Manufacture of leather and related products
17	Manufacture of paper and paper products
33	Repair and installation of machinery and equipment
11–12	Manufacture of beverages and tobacco products
18	Printing and reproduction of recorded media
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
31	Manufacture of furniture
14	Manufacture of wearing apparel

Note: [1] Broader innovator firms are defined in the UK Innovation Survey as firms that have done at least one of the following activities in the reference period: 1. introduced a new or improved product (goods or services); 2. business processes used to produce or supply all goods or services that the business has introduced, regardless of origin – these innovations may be new to business or new to market; 3. engaged in innovation projects not yet complete or abandoned; and 4. investment activities in areas such as internal research and development, training, acquisition of external knowledge or machinery and equipment linked to innovation activities.

[2] The ONS Qualification Index Score compares how highly qualified population groups are. The index score assigns every individual aged 16 years and over in the population a rank (1 to 4) based on their highest level of qualification, excluding those whose highest level of qualification is unknown. The index score is then the average rank of all individuals in that population. The theoretical maximum value for the index score is 4.00, indicating that 100% of individuals in a population have obtained Level 4 or above qualifications. The minimum value for the index score is 0.00, indicating that 100% of individuals in a population have obtained no qualifications. Full methodology at ONS (2023). The ONS does not provide the value for the manufacturing sector as a whole, so this was calculated using the weighted average of the individual manufacturing sectors.

[3] The pharmaceuticals manufacturing sector did not officially meet the threshold for R&D intensity. However, based on previous analyses comparing R&D expenditure by SIC codes and by product group, the R&D expenditure is underestimated for this sector, given that it is carried out mainly by R&D firms not classified as pharmaceuticals manufacturing. We therefore decided to classify it as meeting the threshold for this indicator.

Source: Own calculation based on data from DBT (2024) UK Innovation Survey; ONS (2023) Education by Industry data tables, England and Wales, August 2023; and ONS (2024) Business enterprise research and development, UK: 2022.

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge on data from the ONS and UK Innovation Survey.

Appendix 4 – Selected definitions related to emerging sectors

Term	Definition
Industry	"Group of firms **producing products that are close substitutes** for one another" [definition used in industrial economics] **Source**: Porter (1980). Competitive strategy.
	"Most of these approaches [in industrial economics] have considered the sectoral boundaries static and delimited in terms of **similarity in techniques or similarity in demand**. Sometimes **strategic interdependence** has been added as another criteria for delimiting sectors." **Source**: Malerba, (2002). A sectoral system of innovation and production.
Sector	"Sectors are generally taken to be identifiably **similar aggregations of productive activities**. Conventionally, sectors of all types were supposed to be recognizably different from one another **not only in the goods and services they produced but also in the technologies and processes they used to produce them**. However, the **boundaries have blurred** over historical time in both dimensions. **Technologies** originally developed for one set of products **spill over** into use in the production or 'architecture' of other sets of products. Moreover, new technologies more often tend to **supplement and complement old technologies** rather than replace them. One simple consequence is that even 'old' products can be produced by, or partly consist of, elements drawn from what had previously been a totally different set of activities. Equally, markets have become more blurred through the **bundling of goods and services** (e.g. sales of music products via the Internet)." **Source**: Tunzelmann and Acha (2009). Innovation In "Low-Tech" Industries. In *The Oxford Handbook of Innovation*.
Sector	"A sector is a set of activities that are unified by **some linked product groups for a given or emerging demand** and which **share some common knowledge**. Firms in a sector have some **commonalities and at the same time are heterogeneous**. A sectoral system framework focuses on three main dimensions of sectors: (a) Knowledge and technological domain, (b) Actors and networks, **(c) Institutions**." **Source**: Malerba (2009). In *The Oxford Handbook of Innovation*.
Emerging Strengths	"Emerging strengths: sectors in which the UK could feasibly develop a **comparative advantage**, often because of their proximity to the **UK's current strengths** – this analysis considers: **forecast growth, the future importance of the sector, the UK's global position now and in the future**." **Source**: DBT (2024). Invest 2035: The UK's modern industrial strategy.
Emerging Industry	"Emerging industries are industries in **the earliest stage of development**…the concept of industry emergence corresponds to one temporal component, or interval, within an 'industry life cycle' model of how industries evolve over time." **Source**: Forbes and Kirsch, 2011. The study of emerging industries.
Emerging Industry	"Emerging industries are either **new industrial sectors or existing industrial sectors that are evolving or merging into new industries**. They **evolve in response to new technologies, market demands and value chain configurations.** They are most often driven by key enabling technologies such as advanced manufacturing, new business models such as innovative service concepts and by societal challenges such as climate change and sustainability demands that industry must address as a matter of survival." **Source**: European Observatory for Clusters and Industrial Change (2019). European Panorama of Clusters and Industrial Change.

Emerging Industry	"Emerging industries come into existence with the **creation of a new industrial value chain, or the radical reconfiguration of an existing one, driven by a disruptive idea or ideas**, leading to new products/services with **higher added value**. They often have **high growth rates and further market potential**, making them essential to future competitiveness and prosperity. Emerging industries can also benefit from the particular collaborative opportunities clustering provides." **Source**: European Commission (2019). Emerging industries and value chains.
Emerging Industry	"Emerging industries are newly formed or re-formed industries that have been **created by technological innovations, shifts in relative cost relationships, emergence of new consumer needs, or other economic and sociological changes** that elevate a new product or service to the level of a **potentially viable business opportunity**." **Source**: Porter (1980). Competitive strategy.
Future Industries	"Future industries, **driven by cutting-edge technologies**, are currently in the incubation stage or at the beginning of industrialization. They are forward-looking emerging industries with **significant strategic, leading, disruptive, and uncertain characteristics**." **Source**: Chinese Ministry of Industry and Information Technology (2024). Translation of the Implementation Opinions of Seven Ministries.
Sectoral System Of Innovation And Production	"A sectoral system of innovation and production is **a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products**. A sectoral system has a **knowledge base, technologies, inputs and an existing, emergent and potential demand**… Links and complementarities at the technology, input and demand levels may be both static and dynamic. They include **interdependencies among vertically or horizontally related sectors, the convergence of previously separated products or the emergence of new demand from existing demand**. Interdependencies and complementarities define the real boundaries of a sectoral system. They may be at the input, technology or demand level and may concern innovation, production and sale." **Source**: Malerba (2002). Ibid.
Disruptive Technology	"Disruptive technologies introduce a very different package of attributes from the one mainstream customers historically value, and they often perform far worse along one or two dimensions that are particularly important to those customers. As a rule, mainstream customers are unwilling to use a disruptive product in applications they know and understand. At first, then, disruptive technologies tend to be used and valued only in new markets or new applications; in fact, they generally make possible the emergence of new markets." **Source**: Bower and Christensen (1995). Disruptive technologies: Catching the wave.
Emerging Technology	"We conceive of an emerging technology as a **radically novel and relatively fast growing technology characterised by a certain degree of coherence persisting over time** and with the **potential to exert a considerable impact** on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and patterns of interactions among those, along with the associated knowledge production processes. Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat uncertain and ambiguous." **Source**: Rotolo et al. (2015). What is an emerging technology?

Critical Technology	"Critical technologies are current or emerging technologies that have the potential to enhance or threaten our societies, economies and national security. Most are dual- or multi-use and have applications in a wide range of sectors. By focusing early in the science and technology (S&T) life cycle, rather than examining technologies already in existence and fielded, the Critical Technology Tracker doesn't just provide insights into a country's research performance, but also its strategic intent and potential future S&T capability." **Source**: Australian Strategic Policy Institute (2024). ASPI's two-decade critical technology tracker.

Appendix 5 – High-growth products by global import growth, 2013 to 2023

Correspondence between high-growth products by global import growth (2013 to 2023) by Harmonised System (HS) and industrial activities (as per the UN's International Standard Industrial Classification of All Economic Activities – ISIC)

Rank	HS code	Product description	Import value growth rate 2013 to 2023	Imports value in 2023 (US$, billion)	ISIC code
1	8524	Flat panel display modules, whether or not incorporating touch-sensitive screens	149937%	65.5	279 Manufacture of other electrical equipment
2	8485	Machines for additive manufacturing	1840%	1.7	281 Manufacture of general- purpose machinery / 181 Printing and service activities related to printing
3	2530	Mineral substances not elsewhere specified or included	898%	17.2	089 Mining and quarrying n.e.c.
4	8710	Tanks and other armoured fighting vehicles; motorised, whether or not fitted with weapons, and parts of such vehicles	712%	12.1	304 Manufacture of military fighting vehicles
5	2842	Salts of inorganic acids or peroxoacids, excluding azides, n.e.c.	586%	6.2	201 Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
6	2841	Salts of oxometallic or peroxometallic acids	517%	9.6	201 Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
7	2825	Hydrazine and hydroxylamine and their inorganic salts; other inorganic bases; other metal oxides, hydroxides and peroxides	397%	16.2	201 Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
8	7104	Stones; synthetic or reconstructed precious or semi-precious, whether or not worked or graded but not strung,	366%	5.4	201 Manufacture of basic chemicals, fertilisers and nitrogen compounds,

		mounted or set; ungraded synthetic or reconstructed precious or semi-precious stones, temporarily strung for convenience of transport			plastics and synthetic rubber in primary forms
9	8507	Electric accumulators, including separators therefor; whether or not rectangular (including square)	365%	143.6	272 Manufacture of batteries and accumulators
10	2845	Isotopes other than those of heading no. 2844; compounds, inorganic or organic, of such isotopes, whether or not chemically defined	359%	1.0	201 Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
11	1518	Animal or vegetable fats, oils, fractions, modified in any way, excluding heading no. 1516; inedible versions of animal or vegetable fats, oils or fractions of this chapter, n.e.c. or included	310%	10.2	205 Manufacture of chemicals and chemical products
12	7115	Articles of precious metal or of metal clad with precious metal	305%	17.0	244 Manufacture of basic metals
13	6907	Ceramic flags and paving, hearth or wall tiles, unglazed; unglazed ceramic mosaic cubes and the like, whether or not on a backing	293%	16.7	233 Manufacture of other non-metallic mineral products
14	2616	Precious metal ores and concentrates	270%	14.9	072 Mining of non-ferrous metal ores
15	2715	Bituminous mixtures based on natural asphalt; on natural bitumen, on petroleum bitumen, on mineral tar or on mineral tar pitch (e.g. bituminous mastics, cutbacks)	249%	6.6	239 Manufacture of non-metallic mineral products n.e.c.
16	2506	Quartz; (other than natural sands), quartzite, whether or not roughly trimmed or merely cut, by sawing or otherwise, into blocks or slabs of a rectangular (including square) shape	240%	1.7	089 Mining and quarrying n.e.c.
17	2702	Lignite; whether or not agglomerated, excluding jet	237%	12.6	052 Mining of lignite
18	3002	Blood, human or animal; for therapeutic, prophylactic or diagnostic uses; antisera, other blood fractions, modified immunological products, (from biotechnological processes or not); vaccines, toxins, micro-organism cultures (not yeasts), similar products	225%	314.5	212 Manufacture of basic pharmaceutical products and pharmaceutical preparations

19	2836	Carbonates; peroxocarbonates (percarbonates); commercial ammonium carbonate containing ammonium carbamate	219%	19.1	201 Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
20	3826	Biodiesel and mixtures thereof; not containing or containing less than 70% by weight of petroleum oils or oils obtained from bituminous minerals	215%	26.6	192 Manufacture of refined petroleum products
21	2853	Inorganic compounds n.e.c. (including distilled or conductivity water and water of similar purity); liquid air (rare gases removed or not); compressed air; amalgams, other than precious metal amalgams	212%	1.2	201 Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
22	1502	Fats of bovine animals, sheep or goats, other than those of heading 1503	211%	2.7	101 Processing and preserving of meat
23	9617	Vacuum flasks and other vacuum vessels, complete with cases; parts thereof other than glass inners	206%	3.7	329 Other manufacturing n.e.c.
24	5301	Flax, raw or processed but not spun; flax tow and waste (including yarn waste and garnetted stock)	200%	1.7	011 Growing of non-perennial crops
25	8486	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays; machines & apparatus specified in note 11 (C) to this Chapter	196%	130.8	289 Manufacture of machinery and equipment n.e.c.
26	2609	Tin ores and concentrates	194%	2.0	072 Mining of non-ferrous metal ores
27	4706	Pulps of fibres derived from recovered (waste and scrap) paper or paperboard or of other fibrous cellulosic material	192%	2.2	171 Manufacture of paper and paper products
28	7218	Stainless steel in ingots or other primary forms; semi-finished products of stainless steel	190%	5.2	241 Manufacture of basic iron and steel
29	2613	Molybdenum ores and concentrates	162%	8.4	072 Mining of non-ferrous metal ores
30	0810	Fruit, fresh; n.e.c. in chapter 08	158%	26.8	012 Growing of perennial crops

31	0909	Seeds of anise, badian, fennel, coriander, cumin, caraway or juniper	157%	1.4	012 Growing of perennial crops
32	9304	Firearms; (e.g. spring, air or gas guns and pistols, truncheons), excluding those of heading no. 9307	157%	1.3	254 Manufacture of fabricated metal products, except machinery and equipment
33	3821	Prepared culture media for the development or maintenance of micro-organisms (including viruses and the like) or of plant, human or animal cells	143%	3.3	205 Manufacture of chemicals and chemical products
34	1504	Fats and oils and their fractions of fish or marine mammals; whether or not refined, but not chemically modified	143%	4.1	104 Manufacture of vegetable and animal oils and fats
35	7118	Coin	139%	1.5	321 Manufacture of jewellery, bijouterie and related articles
36	2846	Compounds, inorganic or organic, of rare-earth metals; of yttrium or of scandium or of mixtures of these metals	131%	3.0	201 Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
37	7508	Nickel; articles thereof n.e.c. in chapter 75	131%	2.9	259 Manufacture of other fabricated metal products; metalworking service activities
38	8805	Aircraft launching gear, deck-arrestor or similar gear, ground flying trainers; parts of the foregoing articles	130%	2.8	289 Manufacture of machinery and equipment n.e.c.
39	7501	Nickel mattes; nickel oxide sinters and other intermediate products of nickel metallurgy	129%	14.6	244 Manufacture of basic metals
40	9012	Microscopes (excluding optical microscopes); diffraction apparatus	128%	4.6	265 Manufacture of measuring, testing, navigating and control equipment; watches and clocks
41	7503	Nickel; waste and scrap	127%	1.3	381 Waste collection activities
42	8105	Cobalt; mattes and other intermediate products of cobalt metallurgy, cobalt and articles thereof, including waste and scrap	126%	4.9	244 Manufacture of basic metals
43	2937	Hormones, prostaglandins, thromboxanes and leukotrienes,	121%	31.7	211 Manufacture of basic pharmaceutical

		natural or reproduced by synthesis; derivatives and structural analogues thereof, including chain modified polypeptides, used primarily as hormones			products and pharmaceutical preparations
44	3304	Cosmetic and toilet preparations; beauty, make-up and skin care preparations (excluding medicaments, including sunscreen or sun tan preparations), manicure or pedicure preparations	119%	70.8	204 Manufacture of chemicals and chemical products
45	9306	Bombs, grenades, torpedoes, mines, missiles and similar munitions of war and parts thereof; cartridges and other ammunition, projectiles and parts thereof, including shot and cartridge wads	117%	7.1	254 Manufacture of fabricated metal products, except machinery and equipment
46	6703	Human hair, dressed, thinned, bleached or otherwise worked; wool or other animal hair or other textile materials, prepared for use in making wigs or the like	117%	1.3	329 Other manufacturing n.e.c.
47	1105	Flour, meal, powder, flakes, granules and pellets of potatoes	117%	1.3	103 Processing and preserving of fruit and vegetables
48	3801	Artificial graphite; colloidal or semi-colloidal graphite; preparations based on graphite or other carbon in the form of pastes, blocks, plates or other semi-manufactures	115%	4.1	239 Manufacture of non-metallic mineral products n.e.c.
49	8711	Motorcycles (including mopeds) and cycles; fitted with an auxiliary motor, with or without side-cars; side-cars	113%	34.0	309 Manufacture of transport equipment n.e.c.
50	0410	Animal products; insects and other edible products of animal origin, not elsewhere specified or included	112%	1.1	014 Animal production
51	2618	Granulated slag (slag sand) from the manufacture of iron or steel	111%	1.2	381 Waste collection activities
52	0804	Dates, figs, pineapples, avocados, guavas, mangoes and mangosteens; fresh or dried	110%	17.3	012 Growing of perennial crops
53	3918	Floor coverings of plastics, self-adhesive or not, in rolls or tiles; wall or ceiling coverings of plastics, in rolls of a width not less than 45cm	110%	10.4	222 Manufacture of plastics products

54	2004	Vegetables preparations n.e.c.; prepared or preserved otherwise than by vinegar or acetic acid, frozen, other than products of heading no. 2006	110%	14.3	103 Processing and preserving of fruit and vegetables
55	7504	Nickel; powders and flakes	106%	1.8	244 Manufacture of basic metals
56	8508	Vacuum cleaners	104%	17.4	275 Manufacture of domestic appliances
57	6103	Suits, ensembles, jackets, blazers, trousers, bib and brace overalls, breeches, shorts (not swimwear); men's or boys', knitted or crocheted	103%	10.0	141 Manufacture of wearing apparel, except fur apparel
58	2932	Heterocyclic compounds with oxygen hetero-atom(s) only	102%	12.8	201 Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
59	8427	Forklift and other works trucks; fitted with lifting or handling equipment	102%	26.4	282 Manufacture of special-purpose machinery
60	2716	Electrical energy	100%	68.0	351 Electric power generation, transmission and distribution activities

Note: Given that global imports equal global exports, we rely on import data, which is generally more reliable because of the stricter tax-related reporting requirements; the corresponding relationships between products and industrial sectors are established by referring to relevant documents published by the ONS and the UN.

Source: Cambridge Industrial Innovation Policy, IfM Engage, University of Cambridge based on UN (2025). UNCOMTRADE database accessed in March 2025.

Appendix 6 – Horizon scanning: review of selected national and international emerging priority documents

The UK

DSIT (2023). UK Science and technology framework.

- artificial intelligence
- engineering biology
- future telecommunications
- semiconductors
- quantum technologies

Innovate UK (2023b). Materials and manufacturing vision 2050.

MATERIALS FOR THE FUTURE ECONOMY

- develop materials for the hydrogen economy
- develop materials and business models to support circularity
- develop sustainable materials, including bio-based and biodegradable
- apply lightweight solutions, including composites
- apply photonics solutions
- computational materials (M4.0)
- (multi)functional materials
- advanced sensors for autonomy
- novel material processing

SMART DESIGN

- design for upgrade, retrofit, remanufacture, repair, recycle
- design for low emissions
- design for sustainable materials
- design for low material use
- design around capabilities
- single safe source of data
- use open, secure, collaborative platforms
- use advanced digital design tools
- adopt whole-system simulation
- apply structured and transparent de-risking
- increase use of simulation replacing testing
- accept a fail fast approach

RESILIENT SUPPLY CHAINS

- robust supply chains
- co-operation embedded in manufacturing supply chain
- optimally co-locate for industrial symbiosis
- implement catalysis and industrial biotechnology
- create a market for waste
- apply closed-loop water systems

WORLD-CLASS PRODUCTION

- distribute manufacturing
- centralise factories
- optimised scheduling
- increase capacity
- revive foundation industries
- advance process control
- reclaim materials and fluids
- improve production quality and control
- develop precision engineering
- integrate products
- focus on people
- improve systems intelligence
- deploy robotics
- cyber-security
- predictive maintenance
- interoperable processes and networks
- wireless, sensor fusion
- responsive reconfiguration
- industrial and operational autonomy
- agile additive manufacturing

LONGER IN USE AND REUSE

- improved design tools
- improved flow of data to designers
- systems to track product and materials
- adopt remanufacturing practices and standards
- employ through-life redesign
- increase logistics to recover and categorise products
- build and develop disassembly and recycling infrastructure
- leverage decommissioning of legacy structures
- waste converted to feedstocks

CLEAN ENERGY

- decarbonised, affordable and secure energy system powering UK manufacturing
- strong offshore technologies
- wind turbine
- hydroelectric and solar industry
- battery supply chains
- nuclear research and development
- hydrogen as an energy vector
- electrify industrial processes
- efficiency and distributed generation
- energy solutions

- managing demand and pricing
- next-generational materials and manufacturing
- flexible grids

Innovate UK (2023a). Innovate UK's 50 Emerging Technologies.

AI, DIGITAL AND COMPUTING TECHNOLOGIES

- AI emotion and expression recognition
- artificial general intelligence (AGI)
- biologically inspired AI
- brain–machine interface (BMI) technologies
- quantum algorithms
- DNA data storage
- new computing models
- novel immersive interfaces

ADVANCED MATERIALS AND MANUFACTURING

- 4D printing
- biomimetic materials
- nanoparticle manufacturing
- metamaterials

ELECTRONICS, PHOTONICS AND QUANTUM TECHNOLOGIES

- alternative and novel semiconductor systems
- emerging microscopy techniques
- hyperspectral imaging
- millimetre wave and terahertz technologies
- photon generators
- plasmonics
- post-quantum cryptography
- room temperature superconductors

ENERGY AND ENVIRONMENTAL TECHNOLOGIES

- cross-linked polymer recycling
- gridscale wireless energy transmission and charging
- hypersonics
- novel propulsion or ion based propulsion
- novel hydrogen production and storage technologies
- novel negative emissions technologies
- nuclear fusion
- space-based solar power

BIOTECHNOLOGY

- artificial cells and artificial life
- bacteria and microbe manufacturing
- biocatalytic membranes
- bioelectronics and electroceuticals
- hybrid microbe biotechnology
- programmable cells
- biofabrication in tissue engineering

HEALTH AND MEDICAL TECHNOLOGY

- adult stem-cell generation
- fluxomics
- anti-ageing drugs
- antibiotic replacements
- microbiome therapeutics
- personalised RNA therapeutics
- phased genome assembly tools
- sensation detection implants
- whole body-on-a-chip device

ROBOTICS AND SPACE TECHNOLOGIES

- fully autonomous vehicles
- nanoscale robotics
- robotic off-world manufacture
- soft robotics
- space nuclear power and novel space propulsion systems
- very low earth orbit (VLEO) satellites

BEIS (2021). Methodology to identify emerging technologies with UK commercialisation potential.

ADVANCED MATERIALS AND MANUFACTURING

- advanced materials
- 2D materials

ENERGY AND ENVIRONMENT TECHNOLOGIES

- energy generation
- energy storage
- energy management systems
- waste management
- carbon capture

ELECTRONICS, PHOTONICS AND QUANTUM

- photonics
- advanced sensing
- microelectronics

AI, DIGITAL AND ADVANCED COMPUTING

- AI and machine learning
- augmented reality and virtual reality
- blockchain
- high-performance computing
- cyber-security
- quantum computing

ROBOTICS AND SMART MACHINES

- robotics and autonomous systems
- autonomous vehicles

ENGINEERING BIOLOGY

- synthetic biology
- agritech

BIOINFORMATICS AND GENOMICS

- omics
- personalised and precision medicine
- disease control (human)
- medical imaging
- targeted therapy

The USA

US NSTC (2024). US critical and emerging technologies list update.

- advanced computing
- advanced engineering materials
- advanced gas turbine engine technologies
- advanced and networked sensing and signature management
- advanced manufacturing
- artificial intelligence
- biotechnologies
- clean energy generation and storage
- data privacy, data security and cyber-security technologies
- directed energy
- highly automated, autonomous and uncrewed systems (UxS) and robotics
- human–machine interfaces
- hypersonics
- integrated communication and networking technologies
- positioning, navigation and timing (PNT) technologies
- quantum information and enabling technologies
- semiconductors and microelectronics
- space technologies and systems

US NIST Office of Advanced Manufacturing (2022). Advanced Manufacturing Technology Roadmap Program.

MICROELECTRONICS

- 5G/6G mmWave materials and electrical test technology
- industrial artificial intelligence consortium to advance high mix production
- manufacturing roadmap for heterogeneous integration and electronics packaging
- microelectronic and advanced packaging technology

SUPPLY CHAIN RESILIENCE

- freeze–thaw and aseptic drying technology roadmap for pharma/biotech manufacturing
- developing a roadmap to strengthen the US manufacturing supply chain via the digital thread

FUTURE INDUSTRIES

- Consortium for Advanced Space Manufacturing
- quantum technology manufacturing
- roadmap for cellular agriculture: Initiative for Convergent-Manufacturing of Agriculture and Food Equity
- next-generation electric machines and systems for clean emissions

REVITALISING TRADITIONAL INDUSTRIES

- AI-enhanced multimodal sensing of materials and process for complete product of life-cycle performance
- iron and steel manufacturing: revolutionising US global leadership for a sustainable industrial supply chain
- advanced technologies for digitalisation of construction industry
- roadmap for accelerating production of large structures and systems

China

Chinese Ministry of Industry and Information Technology et al. (2024). Translation of the Implementation opinions of 7 ministries on promoting the innovative development of future industries.

Future industries

FUTURE MANUFACTURING

- develop smart manufacturing, biomanufacturing, nanofabrication, laser manufacturing, circular manufacturing
- make breakthroughs in intelligent control technologies, intelligent sensing technologies, simulation and emulation technologies
- promote flexible and shared manufacturing models
- develop industrial internet, industrial metaverse

FUTURE INFORMATION

- promote industrial application of technologies such as next-generation mobile

communications, satellite internet, quantum information
- accelerate breakthroughs in quantum and photonic computing technologies
- deep empowerment with brain-inspired intelligence, swarm intelligence, large models

FUTURE MATERIALS

- promote upgrading of advanced basic materials (non-ferrous metals, chemicals, inorganic non-metals)
- develop strategic materials such as high-performance carbon fibre, advanced semiconductors
- accelerate innovation and application of cutting-edge new materials such as superconducting materials

FUTURE ENERGY

- nuclear energy, nuclear fusion, hydrogen energy, biomass energy
- build a collection-storage-transportation-application chain of future energy equipment system
- develop new types of crystalline silicon photovoltaic cells, thin-film solar cells, related electronics equipment, energy storage

FUTURE SPACE

- develop crewed spaceflight, lunar and Martian exploration, satellite navigation, near-space uncrewed systems, advanced and efficient aircraft
- accelerate development and application of deep-sea submersibles, deep-sea operations equipment, deep-sea search and rescue and detection equipment, deep-sea intelligent unmanned platforms
- promote equipment development in deep-earth resource exploration, urban underground development and use, polar exploration and operations

FUTURE HEALTH

- accelerate industrialisation of cutting-edge technologies such as cell and gene technology, synthetic biology, bioengineered breeding
- promote new medical services empowered by 5G/6G, the metaverse, AI
- develop high-end medical equipment and health products integrating digital twins, brain–computer interaction, etc.

Creating iconic products

HUMANOID ROBOTS

- high torque density servo motors, highly dynamic motion planning and control, bionic perception and cognition, intelligent dexterous hands, electronic skin, focusing on developing and applying products in areas such as smart manufacturing, home services, and special environment operations

QUANTUM COMPUTERS

- strengthen development of fault-tolerant universal quantum computing technology
- enhance physical hardware indicators and algorithm error correction performance
- promote the collaborative deployment of quantum software and quantum cloud platforms
- leverage the superiority of quantum computing and explore penetration into vertical industry applications

NEW DISPLAYS

- accelerate research on quantum dot displays and holographic displays
- make breakthroughs in Micro-LED, laser, printing, and other display technologies for applications at scale
- achieve barrier-free, fully flexible, 3D stereoscopic display effects
- accelerate adoption in smart terminals, intelligent connected vehicles, remote connectivity, cultural content presentation, and other scenarios

BRAIN–COMPUTER INTERFACE

- achieve breakthroughs in brain–computer fusion, brain-inspired chips, and brain computing neural models
- develop user-friendly and safe brain–computer interface products
- encourage exploration in medical rehabilitation, self-driving, virtual reality and other typical fields

6G NETWORK EQUIPMENT

- research advanced wireless communication, new network architecture, cross-domain fusion, space–air–ground integration, and network and data security technologies
- develop conceptual prototypes of wireless key technologies
- form characteristic applications represented by holographic communications and digital twins

ULTRA-LARGE-SCALE NEW INTELLIGENT COMPUTING CENTRES

- accelerate breakthroughs in graphics processing unit (GPU) chips, cluster low-latency interconnect networks, and heterogeneous resource management technologies
- build ultra-large-scale intelligent computing centres to meet the needs of large model iterative training and application inference

WEB 3.0

- promote the application pilot of Web 3.0 in data exchanges
- explore the use of blockchain technology to connect platforms and data for key industries and fields
- research the digital identity authentication system for Web 3.0
- establish data governance and trading mechanisms and form replicable and promotable exemplars

HIGH-END CULTURAL AND TOURISM EQUIPMENT

- develop specialised and complementary software for cultural and entertainment creation
- promote the development of advanced performance and amusement equipment, high-end equipment for air, land and sea tourism, immersive experience facilities, smart tourism systems, and detection and monitoring platforms
- develop intelligentised, high-end and complete sets of cultural and tourism equipment

ADVANCED AND EFFICIENT AVIATION EQUIPMENT

development of next-generation large aircraft

- make breakthroughs in new layouts, intelligent piloting, interconnected avionics, more electric aircraft (MEA) systems, and open rotor hybrid engines
- promote research on advanced concepts such as supersonic, ultra-efficient subsonic and new energy passenger aircraft
- accelerate the development and application of electric vertical take-off and landing (eVTOL) aircraft, intelligent and efficient aviation logistics equipment

DEEP RESOURCE EXPLORATION AND DEVELOPMENT EQUIPMENT

- focus on deep operation needs with ultra-deep intelligent drilling rig engineering prototypes, deep-sea oil and gas underwater production systems, and deep-sea polymetallic nodule mining vehicles

The EU

European Factories of the Future Research Association (2023). EFFRA Vision for a Manufacturing Partnership in Horizon Europe 2021-2027.

Enabling technologies and approaches

- advanced and smart material processing technologies and process chains
- smart mechatronic systems, devices and components
- intelligent and autonomous hand and robotics, assembly and logistic technologies
- de-manufacturing and recycling technologies
- energy and power supply technologies
- simulation and modelling (digital twins)
- robust and secure industrial communication technologies, distributed control architectures
- data analytics, artificial intelligence and deployment of digital platforms
- new business and new organisational approaches

Co-creation through manufacturing ecosystems

EXCELLENT, RESPONSIVE AND SMART FACTORIES

- scalable first-time right manufacturing
- agile and robust optimal manufacturing

LOW ENVIRONMENTAL FOOTPRINT, CUSTOMER-DRIVEN VALUE NETWORKS

- demand- and consumer-driven manufacturing networks
- circular economy (symbiotic manufacturing networks)

PARALLEL PRODUCT AND MANUFACTURING ENGINEERING

- concurrent, holistic and collaborative product–service engineering
- virtual end-to-end life-cycle engineering from product to production lines, factories and networks
- manufacturing smart and complex products

HUMAN-DRIVEN INNOVATION

- co-creation in European knowledge networks
- managing constant change
- human and technology complementarity

European Commission (2024). Advanced materials for industrial leadership. Preliminary list of R&I priorities.

ENERGY

- renewable and low-carbon energy conversion and generation
- energy-storage systems
- energy distribution and the transmission grid
- renewable fuels

MOBILITY

- energy-storage and alternative fuels for different means of transport (advanced batteries, for example solid-state; fuel cells systems)
- advanced high-performance materials for lightweight, able to perform in harsh environments, highly reliable and durable transport applications (advanced lighter materials, advanced composite materials and structures)
- increased protection, resilience and durability for transport means and infrastructures
- increasing circularity and addressing environmental performance of materials

CONSTRUCTION

- improving energy efficiency in buildings
- making building structures more robust and longer lasting and better monitoring of structural integrity
- greater wellbeing in buildings
- materials to improve circularity and address environmental performance

ELECTRONICS

- advanced materials for better performance, including specific characteristics to perform in harsh environments, reduced energy consumption and new functionalities of electronic components
- advanced materials for new chip production and packaging technologies, including wafers and substrates beyond silicon for enhanced efficiency

Singapore

Ministry of Trade and Industry Singapore (2022). Industry Transformation Maps.

Advanced manufacturing and trade cluster

ELECTRONICS

- high-value components such as semiconductors, radiofrequency filters, hard disk media
- pilot novel emission abatement solutions and energy-efficient systems in new manufacturing facilities (process gas abatement, chilled process water through centralised abatement systems, district cooling, chilled water as a service)

UNDER THE FUTURE OF MICROELECTRONICS INITIATIVE

- heterogeneous integration
- compound semiconductors
- mmWave and beyond technologies
- sensors and actuators
- edge AI

PRECISION ENGINEERING

- Industry 4.0 (AI, internet of things, data analytics, robotics and automation)
- robotics
- additive manufacturing
- lasers and optics
- precision components
- remanufacturing

ENERGY AND CHEMICALS

- high-value-added chemicals
- chemicals and materials for nutrition and agriculture, hygiene and health, smart materials and mobility, and sustainability
- decarbonising manufacturing plants and manufacture sustainable products
- CCUS
- low-carbon technologies and sustainable products
- closing the resource loop

AEROSPACE

- aerospace manufacturing, including parts manufacturing, tooling machining
- specialised coatings
- aerospace maintenance, repair and operations (MRO)

- engine maintenance, repair and operations (MRO)
- engine components and avionics
- future aircraft development
- robotics and Industry 4.0 for aerospace
- unmanned aircraft systems (UAS)
- smart MRO
- airport technologies
- sustainable aviation fuels (SAFs)
- electric propulsion
- hydrogen-powered aircraft
- eVTOLs (electric vertical take-off and landing aircraft)
- air taxis

LOGISTICS

- best-in-class warehouse operations
- state-of-the-art warehouse management systems
- digitalisation

About us

Cambridge Industrial Innovation Policy (CIIP) is a global, not-for-profit policy group based at the Institute for Manufacturing (IfM), University of Cambridge. CIIP works with governments and global organisations to promote industrial competitiveness and technological innovation. CIIP offers new evidence, insights and tools based on the latest academic thinking and international best practices. This report was delivered through IfM Engage, the knowledge-transfer arm of the IfM, University of Cambridge.

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Department for Business & Trade

Analysis

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- Securing investment from UK and international businesses.
- Advising, supporting, and promoting British businesses to grow and export.
- Opening up new markets for businesses by removing barriers and striking trade deals.
- Promoting free trade, economic security and resilient supply chains.

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