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Sectoral Systems of Innovation and the UK's Competitiveness:

The UK Telecommunications Sector

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Executive Summary

We have explored the impacts and outlooks of key transformational drivers across the telecommunications industry in the UK: (1) the impact of 5G and 6G at both the **business model** and technology levels; (2) through convergence in technology, data and platforms **beyond the vertical** telecoms sector; and (3) the regulatory context that **enables new entrants and industry dynamics to evolve**.

We provide an analysis of 5G's growth potential and identify the most promising areas and disruptive implications of 5G while acknowledging other communications technologies. The economic impact of the telecom sector in the UK is larger than in other Organisation for Economic Co-operation and Development (OECD) countries, having a strong positive relationship between broadband investments, speed, and economic growth. Consequently, due to its deep impact on the performance of other sectors, such as healthcare, manufacturing and entertainment, the telecommunications sector needs to be viewed holistically as part of the digital sector at large. One of the major novel sources of growth identified is the emergence of new location-specific operator concepts that require and rely on entirely different economic logic and business models than traditional public nationwide telecommunications networks. It is also important to acknowledge that despite its focal impact on national economic performance, telecommunications is also a dynamic, global industry.

We identify three key principles that should be relied on when developing the telecoms sector:

- Focus on the development of new telecommunications innovation ecosystems
- Embrace convergence of the digital domain
- Imagine the role of data, platforms, and analytics beyond the vertical telecom sector

Introduction

This sectoral innovation study on telecoms focuses on identifying the critical elements with the most significant potential that can improve the productivity and competitiveness of the UK economy. Essentially, these elements concern the understanding of (1) the implications of 5G and 6G at both the business and technological levels; (2) the role of data, platforms, and analytics; and (3) the importance of the regulatory context.

We have analysed the status of the UK telecoms sector and identified recommendations for policymakers and industry representatives. These recommendations address, for instance, the UK's role in developing future 6G networks, how regulations should respond to the sector's changing needs, and the convergence of telecommunications technologies with other technologies, such as artificial intelligence (AI). We call for support for the development of an agile and open environment through new forms of public-private collaboration in 5G deployment, as well as research and development (R&D) and industry-academia collaboration.

We have highlighted the need for the UK's telecoms sector to invest in capabilities to offer and operate telecommunications networks in different sectors central to economic growth. We have also analysed 5G's growth potential and identified the most promising areas and disruptive implications of 5G and, eventually, 6G. One of the expected sources of growth and competitiveness identified is the emergence of new location-specific operator concepts at the service level, and private mobile communications networks at the infrastructure level.

There is an ongoing convergence of mobile communication networks with digital platforms, such as cloud service providers. This has triggered the need to consider the sector's transformation from vertical and hierarchical structures to horizontal platforms. Further sources of competitiveness and growth can be identified from the 'convergence' of telecoms with other sectors. Within the next ten years, the adoption of 5G technology will accelerate, creating opportunities to boost local businesses and ecosystems to new growth areas in the UK. Regulatory and policy bodies need to consider how to support the business potential of these novel services and players that 5G and 6G enable to foster competitive national innovation policies and new market developments.

This report summarises the key findings from our four periodic reports, with some further insights and recommendations for policymakers and industry.

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Section 1: Sector background

Status of the UK's connectivity landscape

The sector includes various kinds of telecoms services, devices, and infrastructure providers, such as mobile network operators, dedicated technology/ chipset manufacturers, infrastructure equipment providers, device manufacturers, operating system software providers, application developers, content providers, Internet service providers, mobile virtual network operators and fixed-line service operators.

Telecoms services can be further categorised as wired, wireless, satellite and other communications activities. Retail fixed (wired) and mobile services generated 75% of industry revenues and 25% of wholesale services during 2021. Significant differences exist between fixed and mobile telecom markets, but increased convergence is also occurring in the sector. The UK market is highly consolidated, with a few major players in mobile and fixed telecommunications and broadband: BT (biggest at £30bn), Vodafone (the most valuable brand), Sky, Virgin Media O2 and EE. There are approximately 8000 companies classified as telecom companies in the UK (DCMS), including

- medium & high-tech manufacturing, e.g., dedicated technology/chipset manufacturers, infrastructure equipment providers, device manufacturers, and
- Knowledge-intensive service providers, e.g., mobile network operators, operating system software providers, application developers, content providers, Internet service providers, mobile virtual network operators, and fixed-line service operators

We need to acknowledge that as telecommunications consists of various types of companies, in several, inherently different sub-sectors, this also impacts how and if we are able to measure the economic performance of the sector reliably. Moreover, categorising the companies broadly into wired, wireless, satellite and other, mainly hybrid, communications, does not take into account that many of these companies actually provide their services to several other specialised sub-sectors or even other industries outside telecommunications (let us consider geolocation, for instance, which utilises GPS, WiFi access points and mobile base stations to track an individual device's location). Therefore, defining what constitutes a telecommunications company is a challenging task, which directly impacts building an accurate picture of the UK's connectivity landscape.

Despite positive annual growth, the sector overall is considered a low-growth industry in advanced economies - even though telecom infrastructure is crucial to every sector in the economy and played a significant role in managing and surviving the Covid-19 pandemic. Telecoms has, for instance, contributed to intra-industry productivity growth effects of ICT (Southeast of England (73%) and the Northeast (56.9%), according to the UK Innovation Report 2023. 5G mobile telecommunications especially is expected to be the next "big thing" in the UK. The Department for Science, Innovation and Technology (DSIT) has anticipated that "if adopted at scale, 5G could enable productivity gains that add £159 billion in cumulative GVA between now and 2035, reflecting a potential annual GVA increase of £37 billion by 2035" (DSIT, 2023). Furthermore, they consider that 5G can transform the UK's public services and grow the economy, making factories and workplaces more productive, and jobs with better salaries. 5G is also considered the key to helping sectors across the economy maintain their international competitiveness.

Consequently, benchmarking telecommunications to others using measures such as gross value added (GVA) without knowledge of the sector's characteristics does not capture the actual value of telecommunications, and how this sector contributes to the overall economy's performance and productivity. Moreover, we also need to acknowledge that modern telecom is a global industry when it comes to technology, even though consumer service provisioning is done in local, national markets.

The UK has several advantages that can contribute to future growth, such as a wide knowledge base, a proven history of innovation, good regulatory practices, and a thriving and mature service industry that has stimulated the design of telecom infrastructure:

- The UK's telecom market remains one of the largest in Europe. It is characterised by fierce competition and market consolidation, but also a large number of small and medium enteprises (SMEs).
- Almost every UK business is dependent on telecommunications to transact business, as well as every branch of central and local government and defence and national security.

- The economic impact of the telecoms sector in the UK is larger than in other OECD countries, having, e.g., a strong positive relationship between broadband investments, speed, and economic growth.
- Telecoms account for less than 2% of the UK economy with £38 billion GVA (see §3 for definition), an increase of 22% in real terms between 2010 and 2019 compared to 18% growth for the UK economy as a whole.

We, therefore, want to emphasise the role of telecom as the most central enabler of a thriving digital economy in the UK. We need to view connectivity as the central element for future growth – irrespective of the technological choices behind it. Grasping the concept of connectivity as the source value with systemic impact requires switching one's mindset from vertical and traditionally supply chain-focused perspective to horizontal and cross-sectoral perspective. However, as structural and technological challenges persist in the sector, we must critically evaluate our capabilities in addressing: How can telecommunications providers reap the benefits of 5G-enabled disruptive business opportunities, and how can they transform their business models to monetise these opportunities to realise revenue growth? How to navigate new disruptive technologies and changing industry dynamics and customer segments? We have examined these opportunities and challenges in the telecom sector, with recommendations for improving the competitiveness and productivity of the UK economy. Specifically, we have explored the role of new technologies, policies and regulations, and—importantly—new business models and how they feed into direct and indirect benefits for the UK economy.

In the evolution of mobile communications, 4G, which was introduced in 2010, is in service to this day. The main goal of 4G technology was to bring high-quality, secure, low-cost services, multimedia and Internet access, with notably higher data rates than earlier generations. As of 2023, 4G still delivers ubiquitous high-speed wireless broadband and has unlocked the potential of mobile video and cloud services such as video games and high-definition mobile streaming. The use of these services grew tremendously during Covid-19 lockdowns, which greatly contributed to the GVA growth of the telecoms sector from 2019-2021. Today, 4G offers consumer data rates in megabytes per second, latency (time between transmission and reception) of (at best) 10s of milliseconds, and device density for approximately 2,000 connected devices per square kilometre.

However, the unprecedented growth in connected device numbers and mobile data traffic has also shown the limitations of 4G in addressing this enormous data demand, resulting in the development of a fifth generation of mobile communication technologies—5G. Compared to today's 4G technology, initially designed for high-speed mobile broadband, 5G is a complete redesign of network architecture with novel capabilities, flexibility, and agility to support an array of future service opportunities not available in previous generations of network technologies. 5G has the potential to connect one million devices per square kilometre, which is 1,000 times more than present mobile connections, and is 100 times faster than a typical home-based broadband connection.

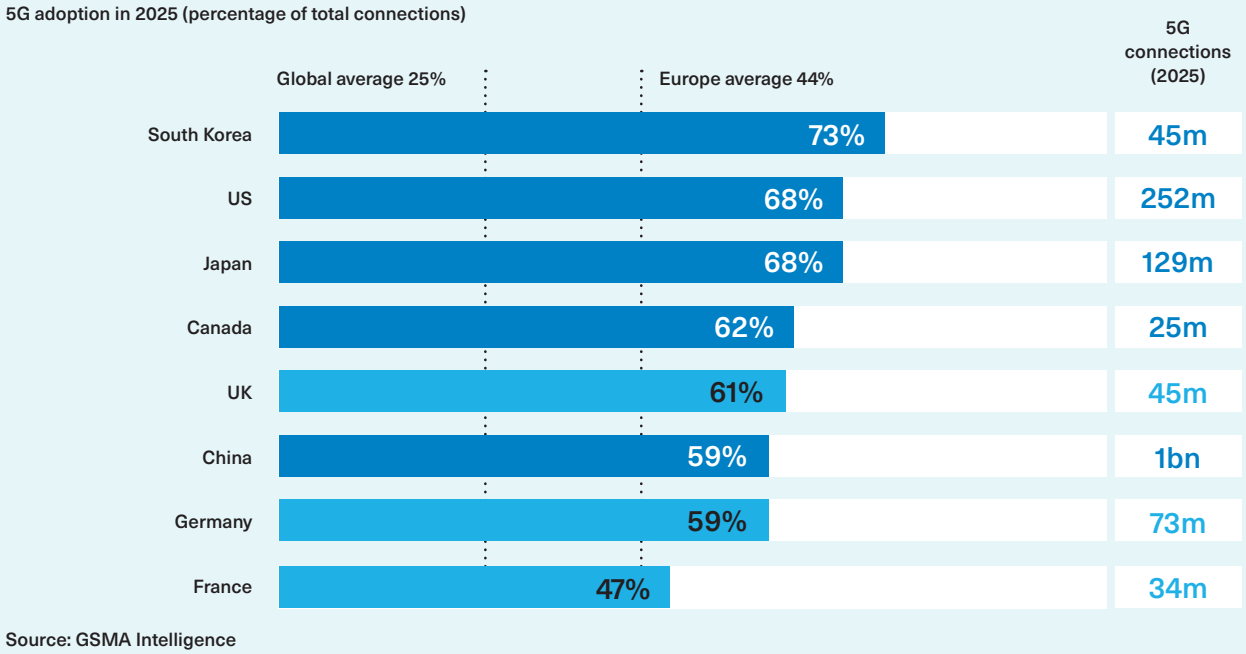
The National Infrastructure Strategy published in 2020 indicated that the UK government aims to enable a gigabit-capable connection to at least 85% of UK premises by 2025. Promoting gigabit-capable infrastructure is a priority for several countries in Europe. In Germany, for instance, the plan outlined in the "Gigabit Initiative for Germany'' is promising a gigabit network to all citizens by 2025. On the other hand, France aimed to have connectivity at a minimum of 30Mbps to all by the end of 2022. Sweden will have 98% of its citizens covered by a gigabit connection by 2025, with the rest covered by at least a 30Mbps connection. The European Commission has the "Connectivity for a European Gigabit Society" vision to provide a gigabit connection to all the main socio-economic drivers (schools, universities, transport hubs, airports, digital-intensive businesses, etc.) by 2025, with all European households having access to at least a 100Mbps connection. The vision is to have full gigabit coverage in the EU by 2030. In the UK, currently, there are over 10 million homes (37%) that have the capability to take advantage of gigabit-capable broadband; the coverage for superfast broadband (>30 Mbps) is at 96%. Mobile Internet is also a crucial part of the UK's connectivity infrastructure. 4G is currently the most widely available standard, with 91% of the UK's area covered by at least one operator. In 2017, the UK government launched the 5G Testbeds and Trials Programme to accelerate the adoption of 5G in the various sectors of the UK economy. The 5G Programme findings published in 2021 estimated the programme's benefits to be £2.58 billion or £15 for every £1 invested. Currently, 5G is available in 385 UK cities and towns. The technology front of telecom in the UK has been widely addressed in the 5G Supply Chain Diversification Strategy, as well as the Wireless Infrastructure Strategy.

Section 2:
UK performance and international comparison

International 5G development

The development of information and communications technologies as the backbone of telecommunications has impacted especially the methods of production as well as patterns of employment. In this section, we review the outlook of telecommunications based on the Eurostat classification of telecoms sector (J61), which includes wired, wireless, satellite and "other" telecommunications. We focus especially on benchmarking the UK against the biggest economies in the EU and those that are technologically advanced in the field of telecommunications.

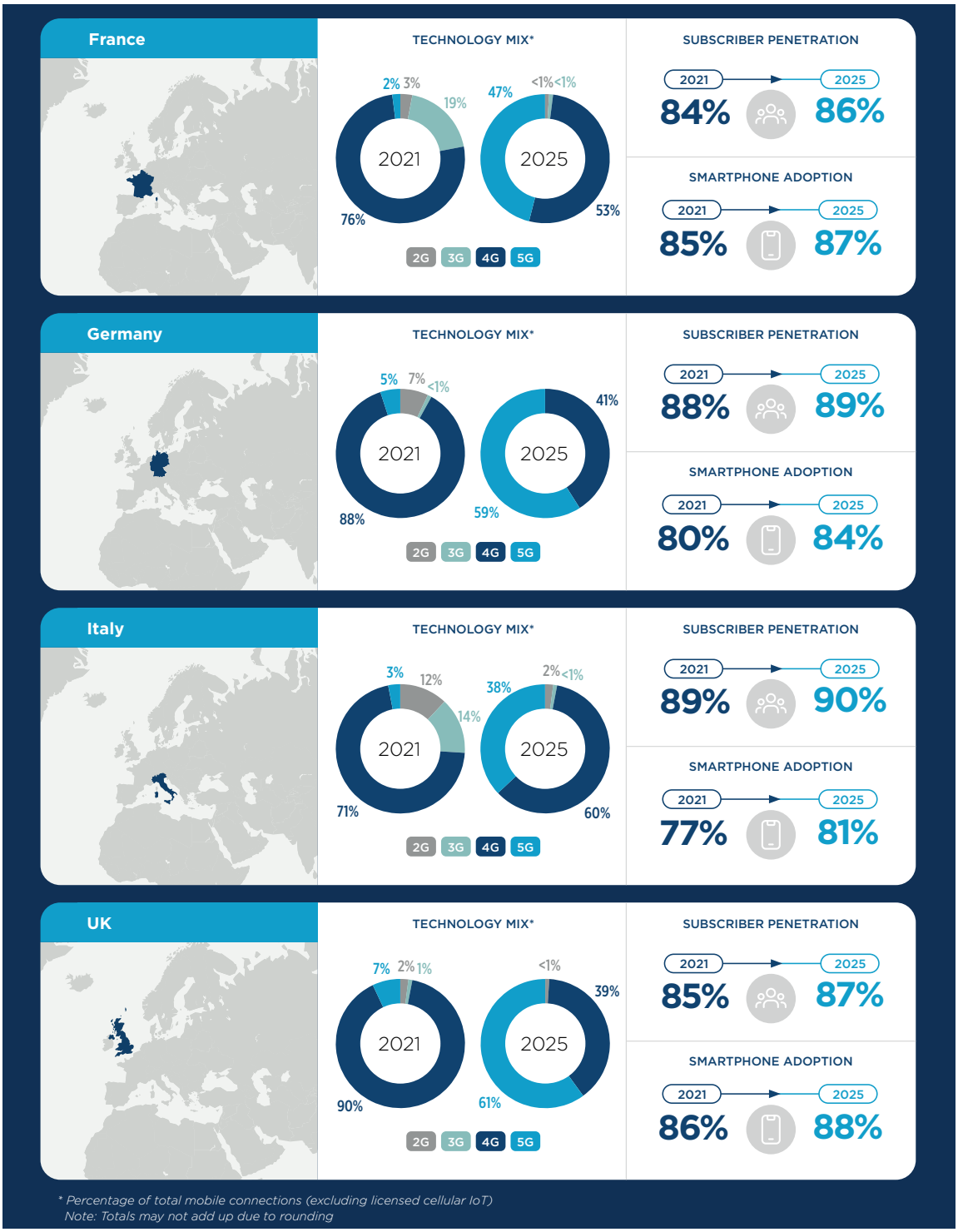
In general, the adoption of 4G peaked in Europe in 2022. Despite increasing investments in 5G, 4G is still expected to remain the dominant technology until 2025, with approximately half of connections. Most of Europe has deployed commercial 5G services, and nearly two-thirds of telecom operators in the region have launched 5G networks. Consumer 5G is growing steadily, with 5G adoption being led by Norway (16%), Switzerland (14%), Finland (13%), the **UK (11%)** and Germany (10%), while the overall European average is 6%. Even so, European countries are lagging behind global peers of South Korea, the US and Japan. It is anticipated that by 2025, the UK and Germany will have the highest 5G adoption rates in Europe, as illustrated in the GSM Association figure below.



Source: GSMA Intelligence

Figure 1: Global 5G adoption rates by 2025

The following figure gives more country-specific details on the development of the telecoms sector in the UK and the biggest economies in the EU. The UK and Germany are expected to be the biggest markets in mobile subscriptions; however, the total addressable market is approaching saturation point both in mobile services and the use of smartphones as the main communication device.



Source: https://www.gsma.com/mobileeconomy/wp-content/uploads/2022/10/051022-Mobile-Economy-Europe-2022.pdf

Figure 2. Telecommunications consumer market development (Image source: GSMA Intelligence, 2022)

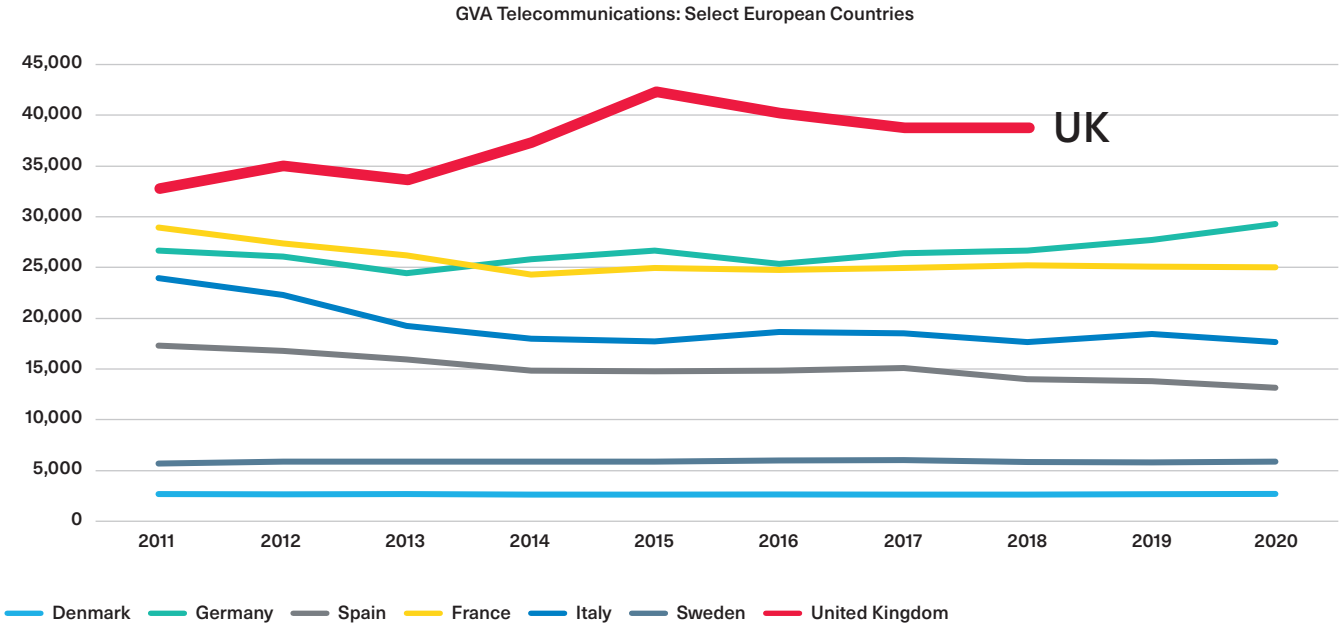


Figure 3. Gross value added of telecommunications in selected European countries

International comparison – gross value added (GVA) and industry turnover

Telecoms companies in Europe have invested greatly in the development of 5G, which also means that the companies have reached their highest investment intensity for many years, and the sector overall is considered a low-growth industry, especially in advanced economies. If we compare the GVA of different European countries, we can see that overall, none of them has experienced sharp economic growth.

Although Covid-19 increased the need for telecom services, the question of long-term profitability of the sector is a major concern. Despite telecoms being the central infrastructure in the modern economy, it has become increasingly difficult for telecom operators to generate a return on investment. As countries are investing in 5G and national broadband and high-speed internet coverage, also the sustainability of investments is a concern, as there is an acute discrepancy between the returns on investment in European telecoms infrastructure and the returns on investment of the largest services that run over this infrastructure, i.e., the Over-The-Top (OTT) services provided by major US- or China-headquartered companies, such as Meta, Amazon, Netflix and Google ((for further details, see e.g. Axon Partners Group report, May 2022[1]). Telecom operators have carried the investment burden; however, these other foreign service providers have benefited the most. There are no major UK nor European cloud providers and only a few major customer-facing content and applications providers.

In addition, the business models used by most European operators is to seek benefits from tying the provision of physical connectivity to the service layer. The physical layer mostly consists of network infrastructure such as towers and cables, whereas the service layer increasingly resides in software, as described in the previous chapter. Wireless telecommunications is the largest subsector, comprising approximately 60% of the sector. Therefore, we need to evaluate the industry dynamics in more detail to understand how the sector is performing and, most importantly, where new growth opportunities can be identified. The UK stands out especially in investments of tangible goods in satellite communications, but Germany and France in wired telecommunications activities. As we point out in our study, satellite communications is an important domain, especially in ensuring strategic autonomy.

Despite the market outlook for 5G, the telecoms sector seems to be inefficient in maximising the economic return on investment of their assets and investments to infrastructure, for instance. One reason is the dominating industry logic. The traditional radio access network (RAN) architecture transmits signals from mobile handsets and the core parts of mobile networks. In these RANs from 2G to 4G, the interface between the radio and the baseband unit equipment is closed and vendor-specific, i.e., they use propriety hardware and software. That is why Mobile Network Operators (MNOs) have tended to use a single vendor at a particular base station (or collection of base stations) for all elements of the RAN network, i.e., “end-to-end supply”. In practice, either Nokia or Ericsson (and Huawei) with global market share of over 80%.

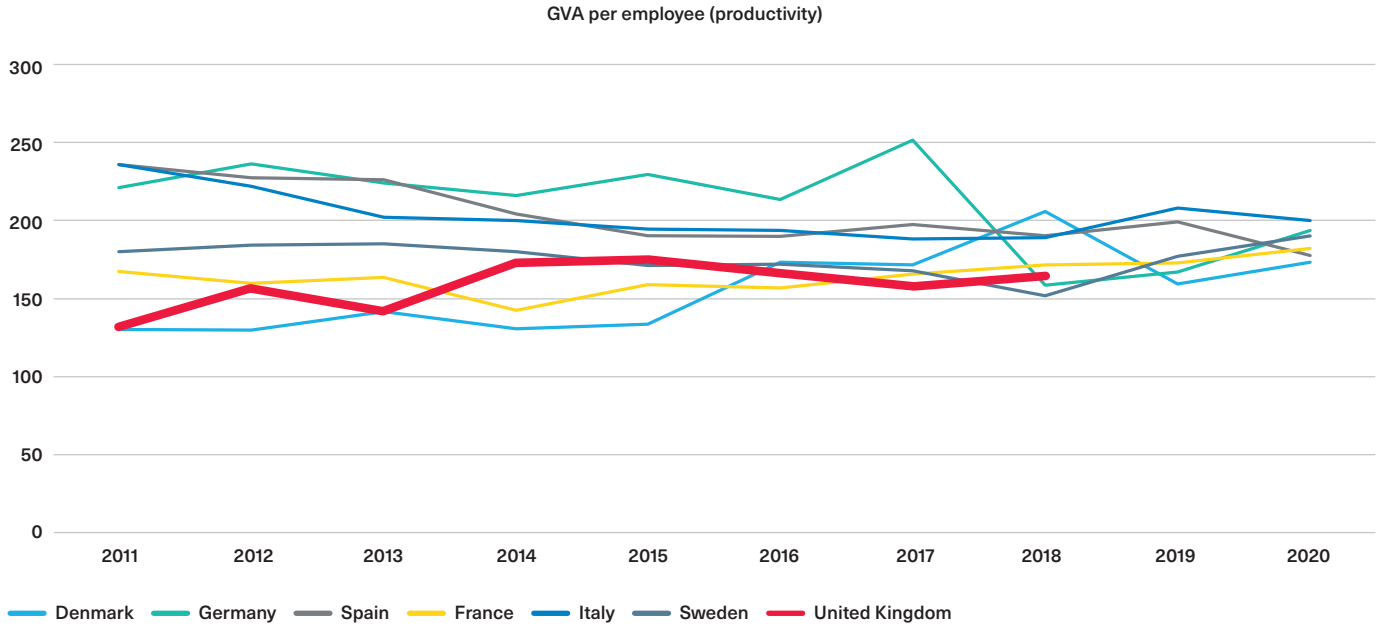


Figure 4. GVA per employee development in telecoms sector in selected countries.

Despite having the biggest number of employees in the sector, approximately 200,000, as opposed to approximately 100,000 in Germany, the overall telecoms industry GVA per employee, including wired, wireless, satellite and other telecoms, shows that the UK has experienced less GVA (Figure 4). However, perhaps due to the vast amounts of investments in all areas of telecoms, employment has not translated into increased or higher GVA per employee.

Suppose we split the industry further regarding the subsectors of wireless, wired, other and satellite telecommunications and review wireless telecom, which is the biggest subsector in terms of GVA per employee. In that case, the UK has performed even less successfully. Therefore, higher overall GVA of the sector does not equal higher competitiveness. We do need to acknowledge these sub-sectoral differences and the role of telecoms as an enabler for other sectors and consider the network effects. How value is perceived in the industry today and what value is being placed on connectivity irrespective of what technology it relies on has been one of the key factors why this industry is challenged with growth.

The major challenges for the telecoms sector, as raised by the European Telecommunications Network Operators Association[2] (ETNO), whose only UK member is BT:

- Low profitability increases the risk that the European communications industry outsources the skills required for new technology paradigms, which yields competence to non-European companies in e.g., China, India or the USA. The development of a stronger domestic position in the communications technology ecosystem has been a long-standing strategic challenge for Europe since the beginning of the 4G era, which is even more crucial for the UK now as a single market.
- Low valuation because of decreasing revenues in traditional communications services makes the sector more susceptible to aggressive mergers and acquisitions (M&A) and potential hostile approaches from non-European actors, some of which may have little interest in developing a digital advantage for Europe. Yielding control to outside entities could seriously damage the European aim of open strategic autonomy and dent any hope of a renaissance of innovation and investment in new digital communications technologies. This is highlighted even further due to OTTs reaping the benefits of content services, despite being equally dependent on connectivity.
- In terms of governance and ownership models, ETNO has observed that in addition to the vertically integrated model, several markets are now proceeding to separate network assets, fixed or mobile. Especially in Europe, this is a way to create value in a low-growth sector. How structural separation is implemented is particularly delicate, as breaking up vertically integrated players might hamper resources and skills to pioneer technology, especially vis-à-vis global competitors. This last point relates especially to the platformisation and cloudification of connectivity and communications. However, this last point is also the seed for new growth.

Sector	Applications	Operators (solution name)
Retail	Shopper behaviour, competitive intelligence, supply chain assurance and customer profiles	BT (BT Business), Orange (Flux Vision), Telia (Crowd Insights), Swisscom (Mobility Insights) and Telefónica (Telefónica Tech)
Government	Smart cities, traffic monitoring, digital behaviour, mobility and disease surveillance	BT (BT Business), Telenor (BDSG), Telia (Crowd Insights) and TIM (Cloud Hub)
Transport	Traffic analysis, environmental monitoring, emissions surveillance and population flows	Orange (Flux Vision), Telia (Crowd Insights), BT (BT Business) and Swisscom (Mobility Insights)
Manufacturing	Smart factories, automation, remote robotics, supply chain monitoring, environmental surveillance and health and safety	Telia (IoT Platform), A1 Telekom (A1 Digital), Elisa (IndustrIQ) and Deutsche Telekom (IoT Cloud)

Figure 5. Emerging sectors and applications for telecoms (Image source: Analysys Mason, 2022[3])

International market trends

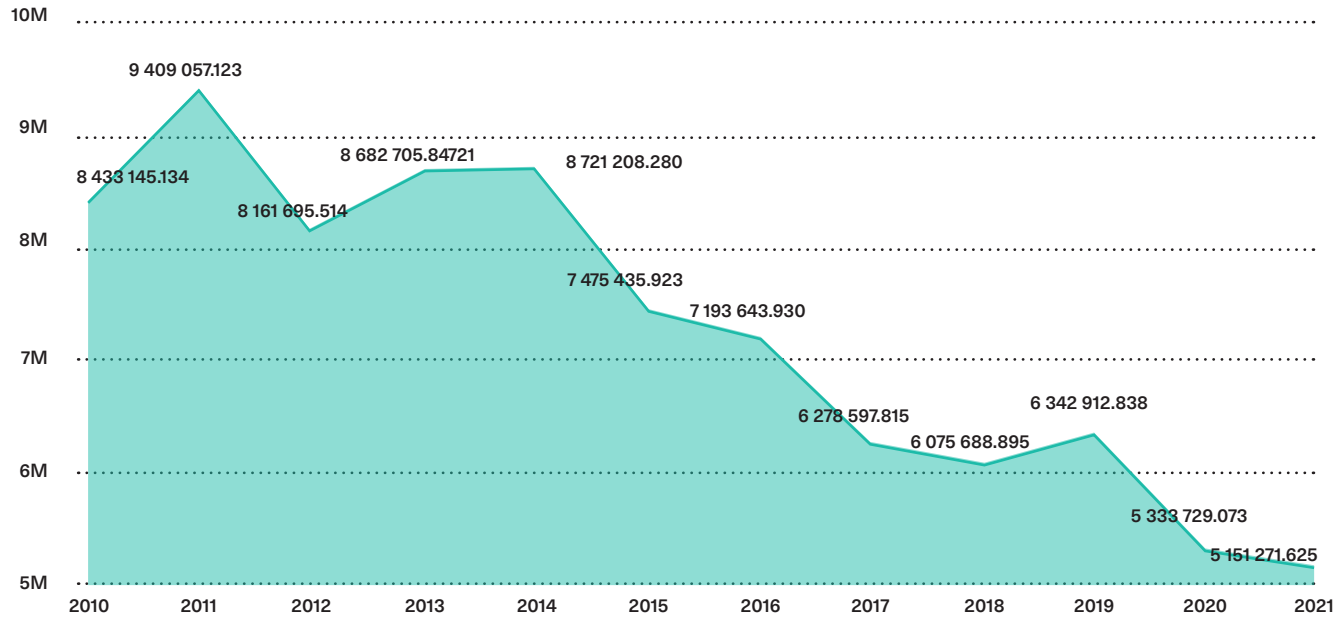
Although consumer services are still the most significant source of operator revenue, industry players have started acknowledging the need to explore growth opportunities beyond the consumer market. BT, announced last year that they are investing nearly £100 million in the development of B2B (business-to-business) and B2G (business-to-government) solutions that converge 5G with Internet of Things (IoT), cloud and edge computing, and AI. Operators in other countries have published similar strategies and growth plans. Figure 6 illustrates some of the applications where telecom operators have identified and experimented with novel business opportunities and use cases.

In the consumer sector, gaming and the metaverse are big domains where reliable and fast connectivity is needed. The gaming industry has relied on mobile and broadband connectivity for a long time, and operators have also started to consider the metaverse as a new domain for capitalising on the technical advantages of connectivity provisioning. Vodafone-Ericsson trial in 2022 was the first in the UK to experiment with virtual reality (VR) and network slicing[4]. Network slicing is one of the fundamental 5G technologies that allows the creation of separate, tailored network sectors that can be used for specific purposes - also in sectors like healthcare or security. However, it is generally believed that the primary economic impact of the metaverse will not be felt until the late 2020s, thereby limiting its immediate relevance for growth of the sector.

Policymakers have a central role in enabling the exploration and realisation of these kinds of converged business opportunities so that a return on investment can be made and broader economic and social goals can be achieved. As suggested in our recommendations, the UK can take advantage of convergence by building specific innovation programmes, similar to the UK's Supply Chain Diversification Strategy and Wireless Infrastructure Strategy. On the technology front, the UK already has several strategies in place. For instance, SONIC Labs was launched in 2021 as a joint testing facility for Open RAN between Ofcom and Digital Catapult, which the UK government partly funds. The UK Government is also funding an initiative under the heading: "Future RAN: Diversifying the 5G supply chain" with a budget of approximately £ 33.5 million across 15 projects. The 30+ companies in this initiative include the operators BT, O2, and Vodafone; cloud providers: AWS and Microsoft; technology providers: Amdocs, Cisco, Intel, Thales, and Toshiba; O-RAN players: Parallel Wireless and VIAVI; integrator Capgemini; as well as eight universities.

In comparison, similar funding in the EU seems limited, which means that industry-academia collaborations can foster innovation in the UK telecom sector and play a central role in boosting competitiveness, also in relation to other advanced countries. Especially as the traditional RAN architecture creates vendor lock-ins and tight supply chains, Open RAN especially can be seen to increase competition and new entrants also in the equipment and infrastructure side. In practice, the market dynamics of the telecoms industry enable relatively little choice for the supply of network equipment in the UK, and the market is dominated by two providers (Nokia and Ericsson). However, the introduction of Open RAN architecture, which is currently being developed and trialled as described above, could give MNOs more flexibility in choosing vendors as they deploy 5G and, subsequently 6G networks. Enabling a better "mix-and-match" approach for building new 5G networks and services fosters business model innovation, as MNOs can use different vendors for discrete elements within the RAN network instead of using a single vendor for end-to-end supply. The disaggregation of software and hardware in RAN equipment could lead to more innovation, given that software development is generally less capital-intensive. The general characteristics of the telecommunications market are such that, e.g., the benefits from innovations in the mobile RAN equipment market are significantly shared across vendors, then a larger number of potential innovators might discourage firms from investing in R&D. Therefore, R&D investment incentives may be stronger with some continued use of proprietary platforms or exclusive dealing in the mobile RAN market. Open RAN is considered an opportunity to kickstart a new round of innovation in the supply of mobile network equipment.

Supporting and enabling the development of industry dynamics in telecoms, especially in wireless mobile communications, is also the way to turn the negative trend of UK telecoms equipment exports, as demonstrated in Figure 6, into a positive one. However, this requires carefully considering the sector with a completely novel, holistic perspective that embraces the idea of technology convergence and ecosystem-driven value creation and capture.



NN: UNCTAD: Export: Telecommunication Equipment: United Kingdom
Source: www.ceicdata.com | United Nations Conference on Trade and Development

Figure 6. UK telecommunication equipment exports from 2010 to 2021

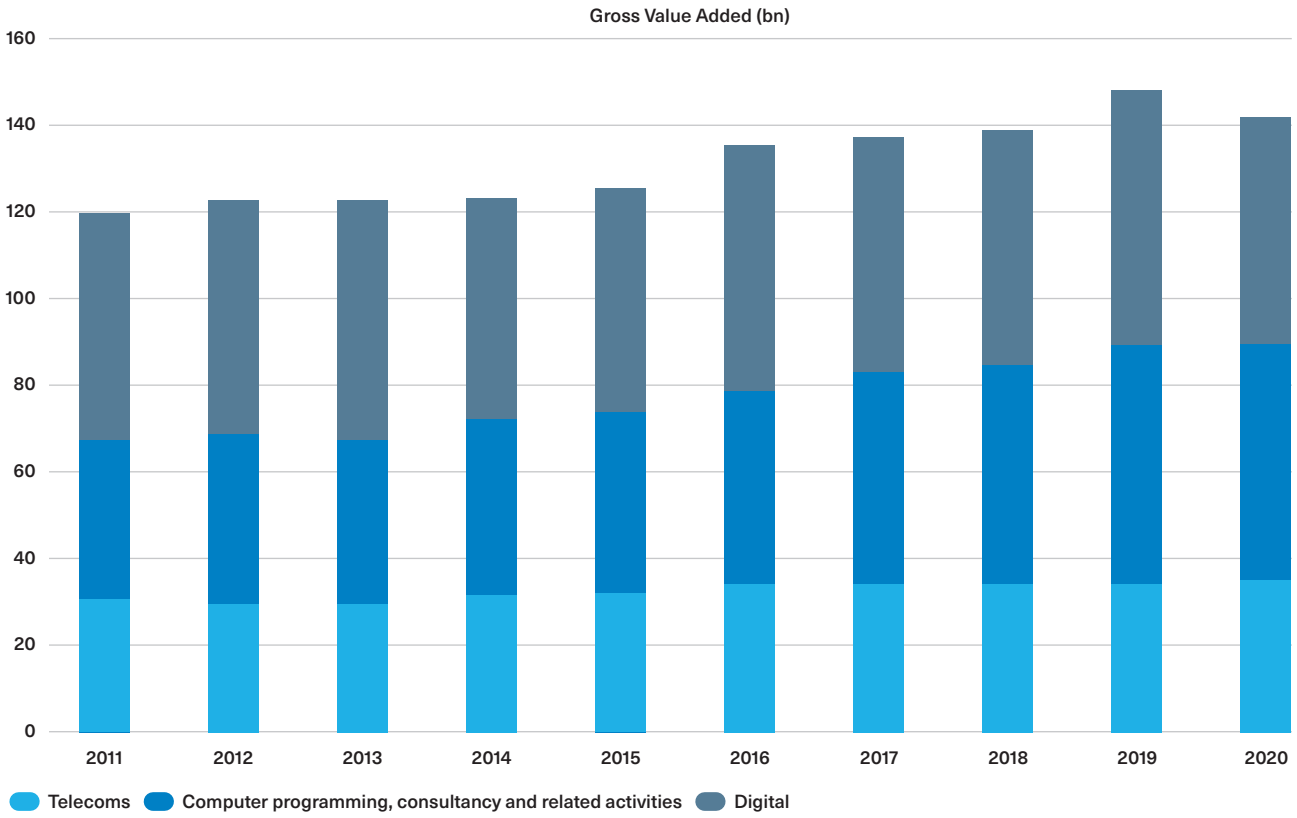


Figure 7: Gross value added of telecoms in relation to other sub-sectors of Digital

Performance of the sector – national insights

To understand the industry dynamics and the potential sources for competitiveness and dynamic capabilities especially at the systemic level, we also need to review the performance of the UK telecoms sector in relation to the digital sector in more detail (Figure 8). The UK telecoms industry GVA amounted to more than £38 billion in 2021, with a strong growth from £31 billion in 2020, as estimated by DCMS. Telecommunications is a sub-sector of the digital sector. GVA indicates the value of goods and services of a particular sector, excluding the value/cost of input. We have examined the growth of GVA in three related industries: (1) telecoms, (2) computer programming, consultancy, and related services, and (3) all other subsectors combined (labelled "digital"[5]). Telecoms and computer programming, consultancy, and related services are the two largest sub-sectors of the digital sector. Other digital sub-sectors include creative (film, TV, video, radio and music); information and service activities; and software publishing.

For comparison, as 2020 was the first year affected by the Covid-19 pandemic and the first year when the UK was not part of the EU, the GVA of telecoms was £34.6 billion compared to £54.2 billion, higher for the computer programming, consultancy, and related activities sub-sector. The increased need for broadband, mobile, voice and data traffic due to the long periods of lockdown during Covid-19 gave a boost to growth, but at the same time, telecom operators experienced sharp drops in average revenue per unit due to increased preference for bundling, more competitive pricing, and a reduction in roaming revenue due to Covid-19-related restrictions.

The £38 billion GVA of 2021 was 10% higher in real terms than in 2019. The GVA by the UK economy overall was 4% below 2019 levels in 2021. Between 2010-2019, the telecoms sector grew faster than the UK economy as a whole, as growth was altogether 22% during this period. It is worth noting that the most recent figures for the digital sector and telecom are presented separately from other DCMS sectors, as the responsibility for these policy areas has been transferred to the Department for Science, Innovation and Technology (DSIT) after this study has been completed. However, DSIT has already addressed in their Wireless Infrastructure Strategy that the productivity impact of 5G alone could lead to gains that add £159 billion in cumulative GVA between 2023 and 2035, which reflects a potential annual GVA increase of £37 billion by 2035" (DSIT, 2023).

If we review the industry's performance between 2010-2019, telecoms have contributed 20%—and computer programming and consultancy and related services have contributed 58% to the growth of the Digital Sector during this period. The Digital Sector contributed the most in terms of GVA to the UK economy (£150.6bn) in 2019. We can compare the performance of the

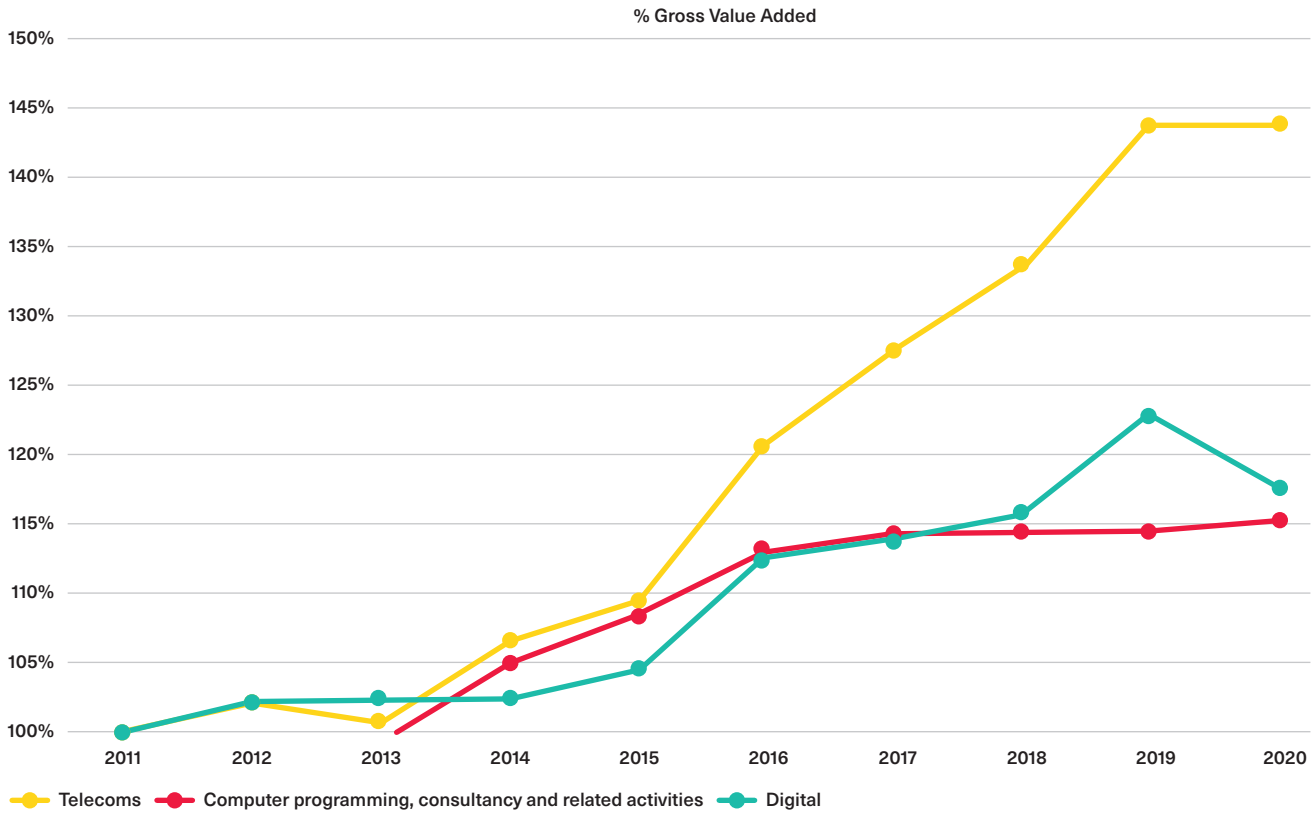


Figure 8: Change in gross value added

sector with others, such as Creative Industries with £115.9bn GVA and £74.5bn GVA in tourism. Looking at more traditional industries, the construction sector, for instance, contributed £129.3bn, the automobile sector £49.1bn, and agriculture £13.0bn. As another example, sports contributed £17.0bn in 2019 (DCMS statistics).

As we stressed in the previous section, the telecoms sector is an enabler of digitisation of all sectors of the economy. Benchmarking its performance with measures such as GVA does not acknowledge the direct and indirect impact on overall performance and competitiveness of the UK economy. The growth in productivity of various sectors of the economy can, in part, be attributed to the competitiveness of the related infrastructure; however, the decreasing revenues of telecom operators, in particular before the pandemic, may be partly attributed to the failure of the telecom industry to overcome the challenges related to out-of-date business models, regulations, and technology barriers. On the other hand, the latest statistics on GVA in the telecom sector do highlight an overall growth trend due to the increased importance of connectivity both in consumer and industry markets.

Employment, labour and research and development (R&D)

There are about 8000 companies classified as telecom companies in the UK. The market is highly consolidated, with a few major players: Vodafone, Virgin Media O2, EE and Three, known as mobile network operators (MNOs), that participate in the context of mobile broadband, but also a large number of SMEs in software and hardware development as well as services. BT, which also offers broadband services, is the biggest player in the sector. BT and Vodafone are the only telecom companies headquartered in the UK. Jobs in the digital sector have consistently increased year-on-year, reaching a 28% increase from 2011 to 2020, as shown in Figure 9 below, whereas employment in the telecom sector remained at the same level as in 2011.

Approximately 10,000 jobs in the sector are directly involved in telecom R&D, whereas the overall employment in R&D jobs in the UK is 280,000. Expenditure on R&D performed by UK businesses was £46.9 billion in 2021, an increase of £2.9 billion since 2020 and £5.9 billion since 2018. In 2021, telecom R&D made up 3.8% of total UK R&D spending. Businesses in telecoms sector have generally reduced their spending on R&D over the past 12 years, falling from £1.4bn in 2008 to £1.03bn in 2020 (Figure 9). This trend started due to the global financial crisis, with the Covid-19 impact more recently. Despite 5G infrastructure, gigabit and satellite broadband development, there has been no remarkable growth in R&D in recent years.

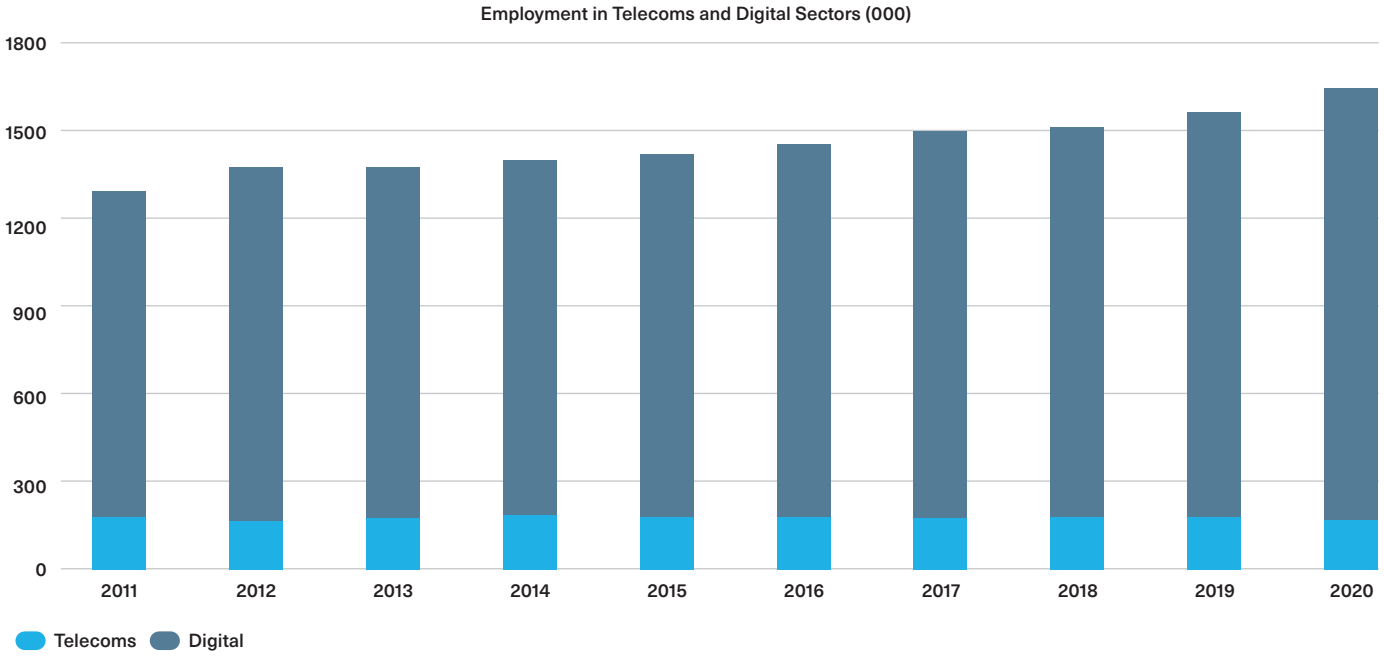


Figure 9: Employment in telecoms and Digital sectors

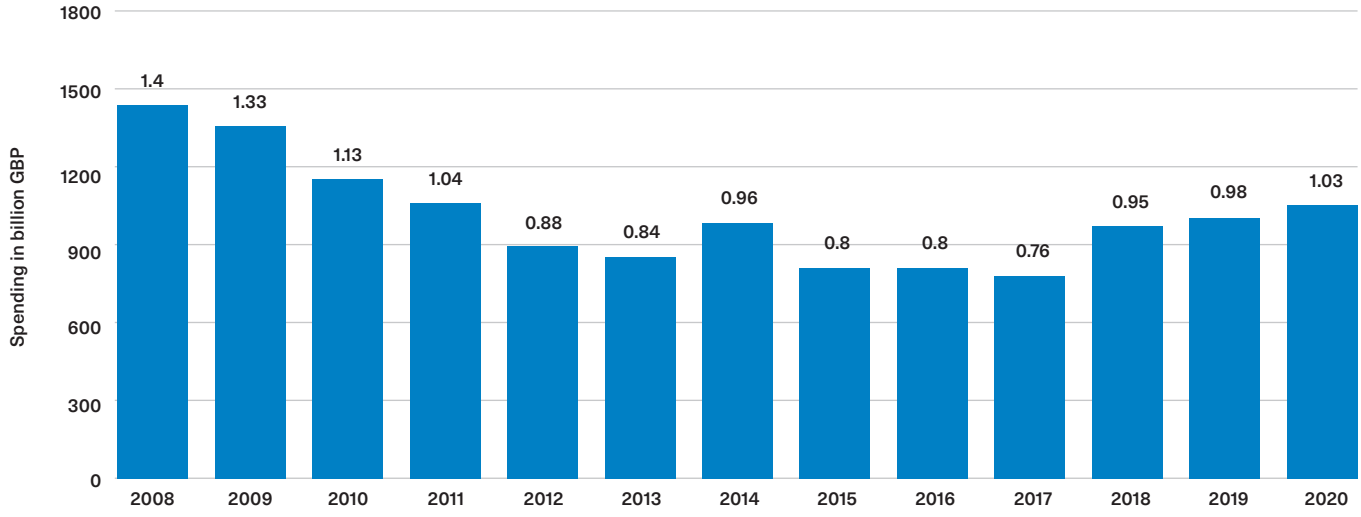


Figure 10: Telecoms R&D in UK (source: Statista)

Trade of digital and telecoms goods and services

The estimates of trade in services and goods are not directly comparable due to differences in data sources and definitions; there is also overlap with the digital sector and its sub-sectors. Overall, for trade in goods in the digital sector, imports have been consistently higher between 2015 and 2020, as is consistent with the wider UK economy (Figure 11):

- £48.6 billion of goods imports, 9.8% of total UK goods imports
- £22.1 billion of goods exports, 7.1% of total UK goods export

Trade in services by businesses in Digital Culture Media Sport (DCMS) Sectors in 2020 (current prices) is estimated as (Figure 12):

- £40.4 billion of service imports, 25.3% of total UK service imports
- £67.2 billion of service exports, 23.0% of total UK service exports

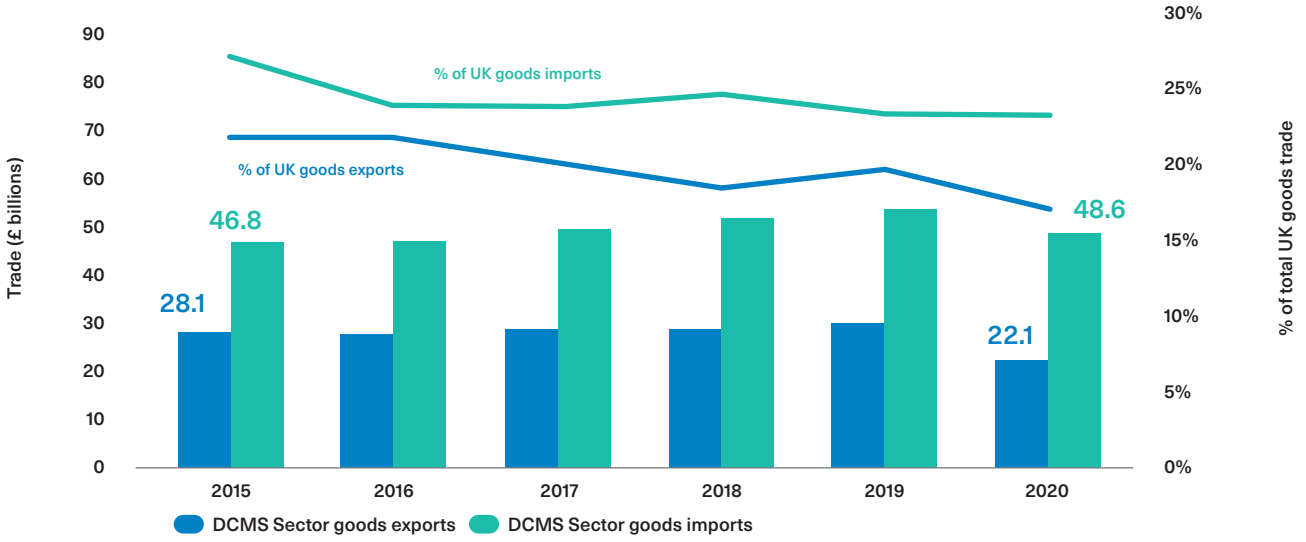


Figure 11: Trade in the DCMS Sector (excl. Tourism and Civil Society) goods, as a percentage of the UK total

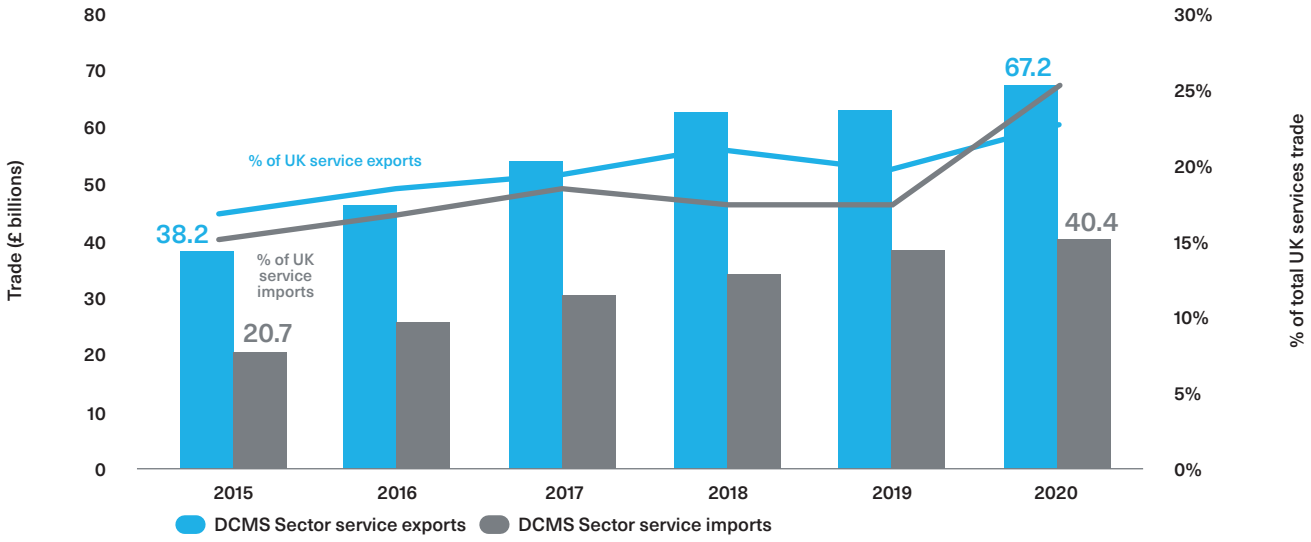


Figure 12: Trade in the DCMS Sector (Excl. Tourism and Civic Society) services, as a percentage of the UK total

In 2020, the value of services exported by businesses in DCMS sectors exceeded the value of services imported by £26.8 billion, predominantly due to businesses in the digital sector and the creative industries. Exports of services in both sectors are again driven by businesses in "Computer programming, consultancy and related activities" and "IT software and Computer Services". In 2020, trade in services by businesses in the Telecoms sector (which is wholly within the Digital sector, as stated earlier) was estimated as follows:

- £4.6 billion in service imports (2.9% of UK service imports, up from 2.0% in 2019).
- £6.2 billion service exports (2.1% of UK service exports, up from 1.7% in 2019).

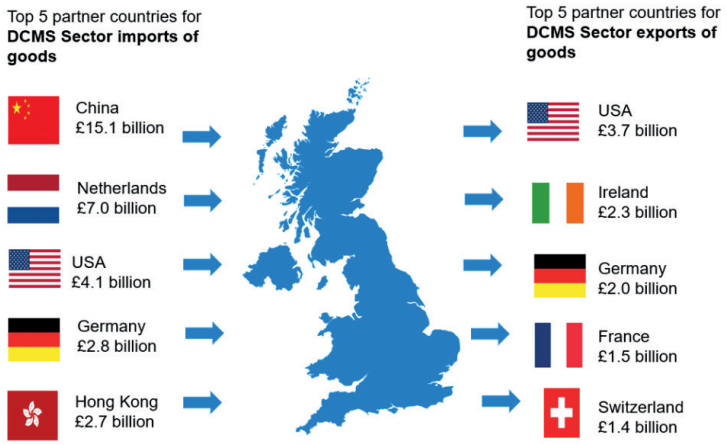


Figure 13: Top five trading partners in DCMS imports and exports in goods in 2020

The most important trading partners in the digital sector are shown in Figure 13 below:

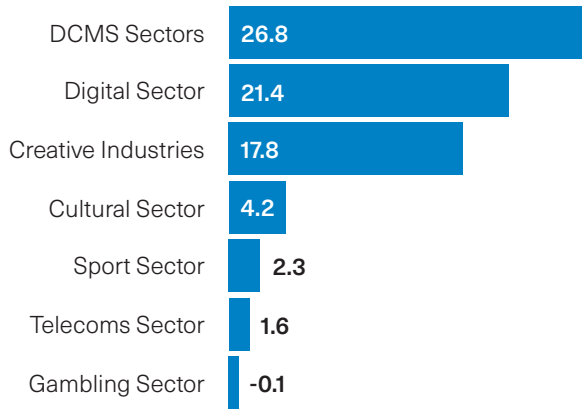


Figure 14: The net balance of trade in DCMS services in each DCMS Sector in 2020 (£ billions)*

*Digital and Telecommunications were separated from DCSM in February 2023 and brought under DSIT. As a result, we can expect new tools and approaches for evaluating the performance of the sector in the near future.

Section 3: Opportunities and capabilities

Key drivers and challenges of transformation in the telecoms sector

A key question in the telecoms sector, driven by dynamic technological advances, is how to ensure future-proofed and targeted policies and regulations to suit such a rapidly changing environment. The key trends that drive transformation in the telecoms sector can be summarised as:

- Evolving customer demands in both the consumer sector and industry: e.g., seamless online experiences and rapidly increasing demand for mass-customised data and high-resolution content.
- The convergence of technologies, such as artificial intelligence (AI) and machine learning (ML), cloud computing, edge computing, open radio access networks (RAN) and Internet of Things (IoT), together with platformisation due to (third party) data growth, analytics and automation, contribute to the blurring of industry boundaries.

Evolving technology domain

One critical development that affects telecommunications is the increasing availability of satellite-based communication services, which can support mission-critical infrastructure. In the agreed Eutelsat and OneWeb merger in early 2023, the UK is retaining a special share and exclusive rights in OneWeb for national security purposes. Satellite communications link the telecoms sector with the UK's space sector in broadcast, Internet, and communications services, which also strengthens the UK's position as a world leader in the satellite communications market.

The UK could become a global leader in the telecoms R&D areas central to national and digital sovereignty due to its strategic autonomy, e.g., in the control of data, algorithms, standards, protocols, processes, and critical infrastructure. We recommend that the focus in telecoms shifts towards industrial and enterprise customers due to increasing demand for application-driven data services. The primary focus both in the current 4G and early deployments of 5G was on reducing capital expenditure, optimising network performance, and building new revenue streams through better customer experience. The more that 5G development advances, the more it draws commercial attention to value-adding services. Despite massive investment in the current 4G/5G networks, the MNO's capacity to differentiate (and thus capture value) has still been limited because users have seen differentiation more at the device and content level.

The ongoing convergence of mobile communication networks with the digital platforms of cloud service providers has triggered a need to consider how the telecoms sector should transform from vertical, hierarchical structures to horizontal platforms, as new sources of competitiveness and growth can be identified from the "convergence" of technologies. Digital platforms enable software developers to add value through applications and complementary assets to the ecosystem by attracting users and building network effects. In addition to conventional direct and indirect network effects, data network effects (DNEs) are becoming increasingly important. As currently conceptualised, DNEs are the combination of platform owners' ability to collect proprietary user data from their platforms and use these data to train ML models that they can use to improve their services. Perhaps more important will be DNEs in a broader sense where parties other than the platform owners can create DNEs by accessing (and not necessarily collecting) data and use them to train ML models, not only to improve current services to current users, but to invent new ones.

Access to data is going to be key, and we are seeing how some of this access is becoming increasingly open, with general-purpose datasets (as opposed to proprietary ones) also increasing in importance. 5G and 6G are expected to amplify these trends. One further example of technology convergence is the exploration of artificial intelligence (AI) and the Internet of Things (IoT) by telecoms companies in so-called "Artificial Intelligence of Things" (IoT) solutions[6]. Telecoms players can have a central role in the deployment of enterprise AIoT solutions, especially due to the increasing deployment of 5G networks, edge infrastructure capabilities, and location-based data. Given their network and connectivity capabilities and AI and services focus, according to Frost & Sullivan report (2022b)[6], telecoms service providers are in a unique position to commercialise and monetise AIoT opportunities, especially in the industrial context.

In addition to the dynamism in the business, technology, and regulatory contexts, sustainable development has become an important driver in the telecoms sector. It will directly affect the design of future 5G and 6G telecoms infrastructure and services reliant on mobile connectivity. Traditionally, sustainability in telecoms refers to energy-efficient networks. Although the telecoms industry has continuously attempted to develop and implement more energy-

efficient technology solutions, end-user data demands and increased energy consumption have continued apace, developing into a serious concern with how overconsumption can hamper the benefits achievable from efficiency improvements[7].

Business model innovation, especially circular business models (CBMs), are seen as crucial for sustainable economic growth worldwide in various other industries. A key component of these CBMs is enabling technologies such as a fit-for-purpose and malleable telecommunications infrastructure that can facilitate two main technology pillars of circularity. First, digital instruments (such as digital twins, distributed ledgers, and digital wallets) are seen as being key to enabling widespread product tracking, tracing, and certification and in developing digital nudges to influence human behaviour. Second, telecommunications infrastructure is key to the realisation of business models that are based on widespread servitisation of goods and services.

In the global context, the UN Sustainable Development Goals (SDGs) have already been adopted as guidelines for developing future 6G. Future 5G and 6G will therefore be directly influenced by the need to decrease emissions of greenhouse gases and the harmful environmental impact of materials used in the manufacturing of the necessary hardware. Hence, at a global level, sustainability goals extend beyond resource efficiency, covering zero-emission aims and circularity[8]. This is something the UK telecoms industry should pay close attention to.

Changing industry dynamics

The ongoing convergence of mobile communication networks with the digital platforms of various web-scale cloud service providers has triggered the need to consider the transformation of the sector from vertical and hierarchical structures to horizontal platforms. New roles in the future mobile communication business ecosystem include system integrators, neutral hosts, and brokers. The traditional role of MNOs is to provide wide-area communication services in public networks, whereas neutral host networks may be able to provide services for MNO customers in specialised settings, similar to what we have already seen in the industry in terms of mobile virtual network operators that lease spectrum from the main MNOs (Vodafone, Three, EE, and Virgin Media O2); but in neutral hosts, the end user is completely unaware whence the network comes. For instance, the role of BT (formerly British Telecom) as a traditional fixed-line telecoms service provider has extended to broadband and mobile, but also to subscription TV and IT services.

Therefore, whenever addressing 5G business models, other kinds of technology-enabled business models, cloud technologies, and web-service models should also be kept in mind. We highlight that the emerging concept of private mobile networks provides the most interesting context, especially in local areas, in driving 5G disruption. The key question is, who is going to drive this transformation? Mobile operators have tried to lead industry change before but have not been very successful. Cloud operators have had better success in implementing transformation because they seem more comfortable with an open-source approach (MNOs tend toward proprietary systems) and therefore participate in and drive ecosystem dynamics that ultimately precipitate the transformation. Consider how Google has been driving the AI&ML ecosystem and how it is now reaping benefits from the resulting momentum.

The market for telecom services has seen huge advances in data speeds. Customers choose Over-The-Top (OTT) channels in today's digital age for a multitude of reasons, the most significant of which is the variety of viewing alternatives and costs available. Video, music, and other media content is delivered over the Internet through OTT solution providers. They are usually not restricted by price agreements and have a limited number of viewing options. Netflix, Amazon Video, Roku, Hotstar, HBO, and others are examples of OTT applications[9], along with messaging services such as WhatsApp. OTT applications and content are becoming increasingly familiar to both consumers and marketers[11]. Furthermore, smartphone display and sound quality, open-source platforms, and super-fast Internet Protocol (IP) networks, among other innovative services, act as motivators to attract more consumers to OTT providers' “freemium” (free basic services with paid-for premium add-ons) business models, resulting in an ever-increasing adoption rate and boosting market growth.

Regional mobile operators are maintaining 5G connectivity for consumers as a stable revenue source with a proven business model while they explore other growth opportunities (for example, bundling connectivity with value-added services and 5G enterprise solutions). It is the transformational power of 5G converging with cloud, edge computing, and AI that will enable the next generation of innovative digital services for enterprises. Frost & Sullivan (2022a)[10] note that not all manufacturers will opt for 5G, and only a select few with bigger visions for their businesses will transform their operations with 5G. As AI holds the potential to drive the most transformative change over the next decade, it is currently holding the spotlight as a technology innovator and automation enabler; network automation, particularly, is gaining traction as a must-do.

Challenges and opportunities for UK companies

5G will bring network and service capabilities that will ensure continuity, higher data rates, lower latency, massive simultaneous connections, and ubiquity of networks across the world, even in challenging situations for current 4G, such as high mobility (e.g., on trains) and in very densely (e.g., stadia, shopping malls) or sparsely populated areas. Radio access network (RAN) makes up the largest portion of 5G network infrastructure. There are many RANs but relatively few core networks. The move to 5G as stand-alone (SA) networks is happening more slowly than anticipated. 5G is presently being implemented in the UK in non-standalone mode, which means it still depends on the 4G LTE core network. Because setting up 5G base stations and networks is approximately seven times more expensive than acquiring more spectrum, investments require greater and more certain revenue projections.

The increased number and complexity of mobile-connected devices, together with the fast-growing number of frequency bands and variety of spectrum access concepts, heavily influence competitiveness in the sector; for example, localised spectrum licensing will enable distinct network deployments and lower barriers to entry for a variety of new stakeholders. Ofcom regulates spectrum allocation and has limited the amount of spectrum to 37% per MNO. MNOs install and manage a portion of their radio access networks through network sharing agreements to cut costs and optimise network rollout, but also through mobile virtual network operator (MVNO) agreements. Access to the necessary spectrum can therefore be a challenge for new industry players.

In the saturated consumer sector, the identification of use cases and business value between telcos and OTTs is challenging. In the industrial (B2B) sector, the key use cases can be summarised as in Figure 15 below. These can be mapped onto three broader capabilities:

- Massive machine-type communications for IoT and smart devices, sensors, utilities, manufacturing, and smart city services.
- Enhanced mobile broadband for entertainment, videos, video conferencing, “work and play”, smart appliances, devices and phones.
- Ultra-reliable and low latency communications for critical services; healthcare, security, and safety.

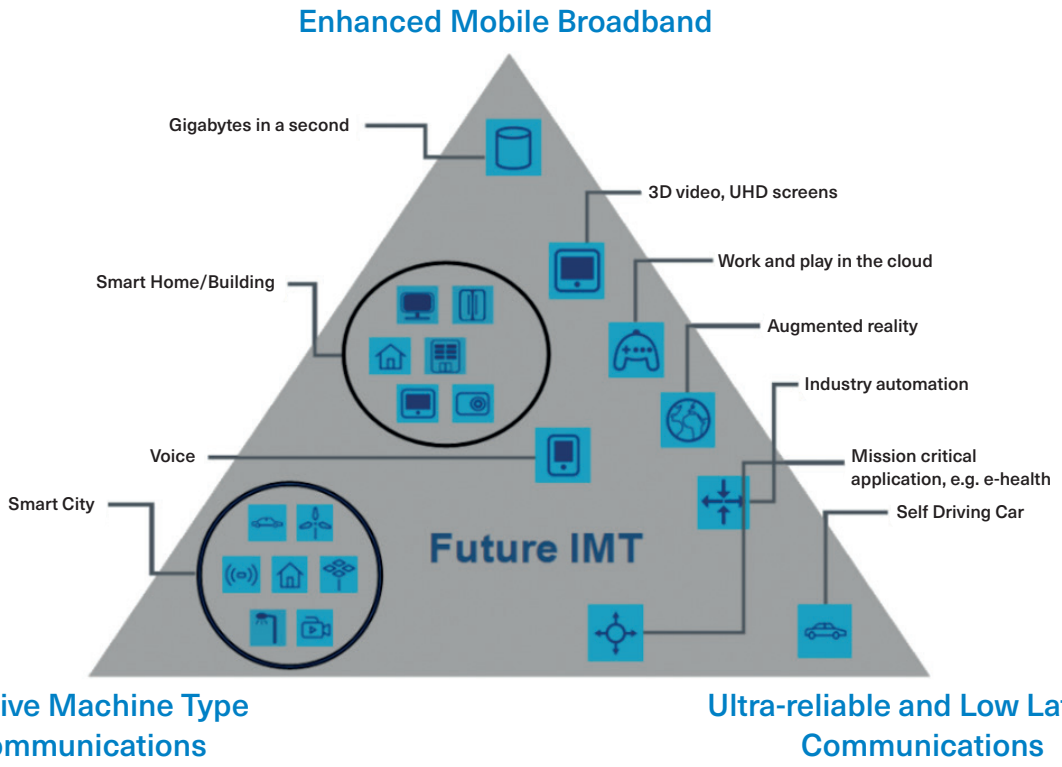


Figure 15: 5G use cases (Source: ITU-R)

Communal assets and public funding in telecoms have mainly been targeted at network infrastructure and radio spectrum. Telecoms network funding and support for deployment programs have conventionally been engaged with rural area coverage and other underserved areas, as set out in national strategies, including in the UK. Now they have been extended to public-private partnerships (PPPs) covering several segments of smart communities, such as logistics, transportation, health, public safety, and utilities. It is worth noting that sustainable development is becoming an increasingly important factor, especially in the case of PPP funding models. Together with the use of wireless telecom infrastructure as a digital platform, these developments highlight the role of collaborative standards development, modularity, and the complementarity of technological solutions in future telecommunications toward 6G. Therefore, even though in our study we focus on the near future 5G transformation over an approximately 10-year timeframe, we also consider the potential scenarios relating to 6G beyond 2030.

One key challenge relates to data privacy and security. 5G brings new technologies, often based on new complex software stacks, which may be more vulnerable to attacks, and it is increasingly critical to protect the telco infrastructure from malicious intrusions and disruptions. Besides the requirements to protect every data item on the entire network, customers are demanding anonymity and privacy, although younger generations have a greater willingness to share data, particularly if the sharing can lead to better service or discounts. Customers are increasingly distrusting global technology firms, which puts local telco operators in a good position to gain market share by positioning themselves as ethical users of consumer data and protectors of their privacy. Furthermore, the growing concern of energy usage from cloud-based computation and the associated data transfers can provide leverage for greener operators to gain market share.

Emerging operator concepts

One example of the disruption that 5G is creating in the telecoms sector is the emergence of the local (or micro) operator concept that complements traditional nationwide public MNO services through local and mainly private mobile communication networks for tailored use. 5G can provide local context-specific connectivity and content services for various end users, both humans and machines and highly localised and heterogeneous environments. Incumbents have already started to respond to this change by introducing commercial open radio access networks ("Open RAN") and, for example, Vodafone announced last year further support for stakeholders in the sector. This gives rise to new sources of growth and competitiveness. Open RAN can be described as a disaggregation of the radio access network into parts that are interconnected by standards-based, interoperable, open interfaces and protocols for communicating over those interfaces. The four core principles of Open RAN are open disaggregation, standards-based compliance, demonstrated interoperability, and implementation neutrality. Open RAN has implications, especially for industry standards relevant to the buildout of 5G infrastructure and the enhanced security, resilience, innovation, and competition in the UK's critical national infrastructure and beyond (UK Open RAN principles, 2022). Furthermore, Open RAN contributes to increased vendor diversity for telecommunications networks, considered central for the UK and other governments. Open RAN has, therefore, a potentially large impact on the emergence of new specialised operator roles for the telco sector[11].

Consequently, we have identified one of the major novel sources of growth and competitiveness as being new location-specific operator concepts and private mobile communications networks. It is worth noting that hyperscalers such as Amazon Web Services (AWS) and Microsoft; IT vendors such as Cisco and HPE/Aruba; and service providers such as NTT and Verizon also see potential in the private 5G network space and are offering private 5G managed services integrated with Wi-Fi. Their services leverage dashboards, workflows to automate configurations, and flexibility with core deployment (for example, the option of on-premises or cloud-based solutions). It is also worth noting that the term "mobile network operator" as a telecom service provider is subject to specific regulatory rights and obligations in national legislation, which highlights the need to review the applicability of current regulations in the case of local and private mobile communication networks. The localisation trend in 5G services in connection with spectrum management and regulation leads to the identification of centralised, fragmented, and hybrid configurations of converged connectivity and data platforms in 5G.

As new forms of local operators are expected to emerge in the near future, as envisioned in Figure 16 below, it is imperative to map the factors that influence the economic viability of these specialised operators and their respective business models. First, in 5G, new operators are able to accumulate value on new kinds of platforms and ecosystems. Second, 5G should be therefore considered as a dynamic connectivity platform that is converging with various other digital platforms. This has the biggest impact on the traditionally MNO-dominated sector, as these new platforms form ecosystems of complementary business models that are not necessarily hierarchically controlled by any of the stakeholders of the emerging ecosystem, disrupting the traditional roles of the MNO-dominated telecoms sector, as in the small cell networks, any player can be a so-called micro-operator. The local micro-operator is basically an entity that combines connectivity with specific content services in spatially confined domains, being dependent on the availability of spectrum resources. The two most important drivers toward local and private networks in connection with 5G are operations in higher carrier frequencies and the virtualisation and componentisation of the network infrastructure. The development of 5G networks in technological terms, therefore, aims at meeting increasingly stringent requirements for higher capacity, higher data rates, lower latency, massive device density, and reduced capital and operational costs in these kinds of heterogeneous environments.

Four key business opportunities for locally confined micro-operators can be identified: (a) offering hosted local connectivity to all MNOs in specific locations, (b) providing secure local networks for vertical-specific needs, (c) providing locally tailored services and (d) acting as a data operator for various customers. The first of these is appropriate in locations where it is neither feasible nor cost-efficient that all MNOs would build their own infrastructure. The second could be a working solution in environments with highly specialised needs, such as factories. Local tailoring of services may be needed when providing premium or personalised content, such as virtual reality/augmented reality services or relevant context-specific or locally generated data or information. A key element in this opportunity is to manage and tailor the local infrastructure. Finally, operators might govern application- or user-specific data and provide connectivity services on top of data that forms the central element of the business opportunity.

Figure 16: Operator concepts in 5G (adapted from *Ahokangas et al. 2019*[12])

New business models in telecoms

Whether a local operator is a new market entrant or an existing MNO pursuing new opportunities, several tensions have emerged that challenge new market development in the telecoms sector. Understanding and overcoming the following challenges are the keys for the successful development of dynamic capabilities in the sector:

1) To what extent can existing industry structures remain responsive? For instance, the current dominant model of bundling services and price competition by MNOs, not only in the UK but in the industry in general, cannot adapt forever to meet the evolving needs and demands of customers. The existing business models realised in the consumer sector, i.e., providing telecoms services in public networks, cannot simply be replicated directly in specific industrial 5G or local service contexts, as they require the development and use of private network operator services, as illustrated in the previous chapter.

2) New telecoms innovations are to be expected due to the development of wireless 5G and 6G telecommunications technologies and their convergence with other emerging technologies like AI, ML and IoT, but also with traditional broadband and satellite communications. This leads to the question, how fast can new innovations and solutions be commercialised, implemented, launched and adapted for the market? Agile development and continuous integration models in telecoms software may resolve some of the commercialisation challenges; however, the time-to-market for telecoms hardware, devices and equipment is much longer. Therefore, there is a need to align resource requirements and total cost of ownership approaches of traditional industry players towards new market development of digital-first services in telecoms transformation.

3) From here, we naturally move to tensions in business model transformation and creation in order to build innovations that contribute to the productivity of the industry through commercial viability. The key question is how to monetise data-driven telecoms software and hardware solutions and consequently build and support economically sustainable value-adding services, which boost the dynamism of the market by enabling new innovative players to enter the telecoms sector. We highlight this kind of disruption of traditional vertical industry structures and business models to emerge through ecosystems and platform logic.

4) When we are discussing the transformation and productivity of the telecoms sector as a whole, economic viability and sustainability concerns need to be coupled with societal and environmental needs. Not only are these driven by UN Sustainable Development Goals on topics such as ICT footprint and Green ICT or Circular Economy, but they can also function as a seed for building a competitive edge and new source of growth. Global OTTs that have greatly challenged the existing business models of telecoms operators are not able to fulfil all of the key requirements for national value-added telecoms services, e.g., sufficient capacity for peak periods, data protection, or disaster recovery and reliability.

Therefore, to realise the benefits that new innovations, service concepts, and business models can bring to the UK economy, it is critical that policies and regulations be not only tailored but flexible enough to support an industry that is going through such rapid change both in terms of industry structures and technology development [13-15].

Role of policies and regulations in driving productivity and growth

The growing importance of digital platforms for the delivery of communications services, and the emergence of new kinds of industry players, shake the structures of the traditional MNO-dominated industry, as we have described earlier. All major technology providers in telecoms have relied on licensing a value capture mechanism that relies on the European Telecommunications Standards Institute (ETSI). The collaborative standards development process has enabled massive downstream innovation and a mobile technology and application ecosystem.

The ongoing convergence of mobile communication networks with digital platforms and various web-scale cloud service providers has triggered the need to consider what a future-proofed and targeted regulation of the telecoms sector can look like and what is required to promote innovation so that novel innovations in products, services and processes can be turned into sources of national growth and competitiveness. The multi-layered, dynamic, and co-operative (simultaneous co-operative and competitive) character of the telecoms business environment is only expected to increase with the transition from 5G to 6G.

Within the next ten years, the adoption of 5G technology will speed up, creating opportunities for policymakers to support and boost local business networks and ecosystems in new growth areas. Regulatory and policy bodies should consider how to support the business potential of these novel kinds of services and roles that 5G enables. Many of the emerging industry players in 5G have not been part of the traditional MNO-centric value chains of the telecoms sector. Therefore, 5G as a technology is also shaking up the operating context for business

as firms increasingly cooperate vertically in open software architectures while simultaneously competing horizontally in sectors that are directly dependent on connectivity and communications.

Therefore, the specifics of ongoing 5G development should also be considered as the basis for an effective 6G policy framework. 5G is not only an extension of the previous generations of mobile communications technologies; the enhanced mobile broadband, massive machine-to-machine type of communications, and local, ultra-reliable and low latency communications enable completely new types of vertical and horizontal innovation, as we highlighted in previous sections. They mean more data, more devices, and instant response for both private and public sector services utilising mobile connectivity in the future (Ofcom, 2022). Therefore, a smart combination of regulation, innovation policy, and industry policy is needed. This can promote regulatory innovation, such as anticipatory regulation or sandboxing and agile policymaking in the telecommunications and digital ecosystem[16] (Serentschy, 2022).

Challenges and opportunities in 5G and 6G policymaking in the UK

The services dependent upon telecommunications have fallen under the responsibility of a range of different Departments in the past. In order to bring clarity to the policy front, The Department for Science, Innovation and Technology (DSIT) was established in February 2023. The DSIT brings together the relevant parts of the former Department for Business, Energy and Industrial Strategy as well as the former Department for Digital, Culture, Media and Sport. DSIT focuses on positioning the UK in the forefront of global scientific and technological advancement. Their responsibilities include driving innovations "that change lives and sustain economic growth", especially by delivering talent programmes, physical and digital infrastructure, and regulation to support the UK economy, security and public services, and they also provide funding for R&D. The existing 5G programmes, established prior to DSIT, supported by central and regional governments, test and explore the technical interoperability and integration of open networking solutions, vendors, and system integrators. For example, general opportunities in the telecoms sector within these programmes have been identified to include the development, trial, and use of new capabilities in core networks, as well as interactions involving a range of wireless networks (also potentially including a variety of traditional connectivity technologies in addition to future 5G radio networks, such as 2G, 3G, 4G, low power wide area networks, narrowband IoT, Wi-Fi and fixed wireless access networks (DCMS, 2022).

However, not only are these measures MNO-centric, but they are also traditional telecoms value chain oriented. They do not directly contribute to the advancement of convergence of connectivity and services with other sectors. Nor do they address the emerging service concepts and roles at the ecosystem level. The Wireless Infrastructure Strategy, published by the Department of Science, Innovation and Technology in April 2023, provides the most holistic and future-oriented perspective to the future of telecommunications, but as the name states, it also focuses on infrastructure. The UK still lacks bodies that would advance the value perspective of connectivity perspective, that would look beyond technical deployment options on how to ensure economic viability and feasibility. The dynamism of the industry makes this particularly challenging because connectivity is also a nationwide critical infrastructure, and not only consumer or enterprise market digital infrastructure. This means that as a critical infrastructure, telecommunications has direct implications for ensuring national security, not just economic growth. This kind of support is urgently needed to advance the development of emerging private local networks in particular. In addition, the role of digital platforms and cloud technologies in the context of telecoms has not been widely discussed but rather in connection with their growth at the expense of the existing MNOs and current vertical structures of the industry.

The novel opportunities that 5G is bringing highlight the value of innovation collaboration. The three cross-sectoral domains of current 5G use cases, mentioned earlier in this report, show vast potential in business: (a) machine-to-machine type of communications in the context of industrial telecoms, the (artificial) Internet of Things, and connected vehicles; (b) enhanced mobile broadband in smart devices that connect users and services, especially in the consumer sector; and (c) ultra-reliable and low latency communications that are relevant for critical infrastructure such as smart cities, connected health, and the energy sector. Each of these technical 5G use cases enables different kinds of value configurations. In addressing how national policies can support the economic development and innovation collaboration in telecoms, we also need to be aware of the role of international regulations.

ITU-R and Ofcom

Since mobile communications is based on wireless connectivity, the radio spectrum is the fundamental resource needed. In the regulatory domain, the International Telecommunication Union Radiocommunications unit (ITU-R) plays a fundamental role in the global management of radio-frequency spectrum and satellite orbits. Collaboration is a key factor for the cross-sectoral platform opportunities, especially in human-computer level 6G value creation and capture, where European and international collaboration in technology standardisation and global regulation is crucial. ITU-R is working on building a global vision for 6G. As an active participant in ITU-R, the UK can collaborate closely on drafting the central activities and policies in 5G and 6G, such as how much the European 5G action plan is applicable to the UK in relation to the importance of removing spectrum-related bottlenecks; Promoting early deployment and multi-stakeholder trials with 5G; Facilitating venture funds; and joining leading actors in the industry to promote global standards.

The newly established Department for Science, Innovation and Technology launched the UK Wireless Infrastructure Strategy policy paper in April 2023, according to which the "widespread adoption of 5G can bring a cumulative productivity benefit of £159 billion by 2035, driving growth and inward investment, and improving lives for communities in every corner of the country"(DSIT, 2023)

In addition to fixed and mobile communications, there is an increasing need for connectivity in a variety of other types of services such as broadcasting, amateur, space research, global positioning systems, emergency telecommunications, meteorology, environmental monitoring, and communication services orbits (ITU-R, 2022). Essentially ITU-R oversees the implementation of the Radio Regulations (RRs) and Regional Agreements as well as the timely and effective update of these instruments through the processes of the World and Regional Radiocommunication Conferences.

Ofcom represents the UK in several ITU activities, balancing the needs of various UK-based stakeholders and UK consumers, ensuring that regulations are practical, proportionate and serve the interests of UK citizens and consumers[17] (Ofcom, 2022). As the UK is now a single market, we need a deeper and more open collaboration with central and regional policymakers, Ofcom and industry players beyond MNOs. As Ofcom's role in 5G is "to work with the Government and industry to help the UK become a world leader in 5G," it will play a central role in the facilitation of the local private operator concept. Ofcom releases airwaves needed for 5G products to work, helps companies test 5G services, and helps get innovative new services off the ground. Ofcom also plays a role in helping smaller businesses and startups by giving them access to the airwaves they need to set up their own local 5G networks. These airwaves are licensed to mobile companies but are not always used by them. Therefore, we need a holistic and future-oriented policy that views novel business opportunities and innovations emerging from new value configurations, especially in the private 5G context, with an open and innovative approach. Ofcom's approach to the shared use of radio spectrum is more advanced than in the rest of Europe. It includes principles, such as "use it or lose it," which are uncommon in other European countries.

Section 4: Conclusions and recommendations

Recommendations for boosting productivity and dynamic capabilities in telecoms

We have explored the impacts and outlooks of key transformational powers telecoms industry transformation in the UK: (1) the impact of 5G and 6G at both the **business model** and technology levels; (2) through convergence in technology, data and platforms **beyond the vertical** telecoms sector; and (3) the regulatory context that **enables new entrants and industry dynamics to evolve**. We have also identified three key principles that should be relied on when developing the telecoms sector:

- Focus on the development of new telecommunications innovation ecosystems
- Embrace convergence of the digital domain
- Imagine the role of data, platforms, and analytics beyond the vertical telecoms sector

The overall perspective for developing policies and industry recommendations for boosting innovation and competitiveness in telecoms should have a holistic and future-oriented framework that addresses user-centric and sustainability-motivated approaches. Such a framework would consist of the following:

- A competitive innovation policy.
- Anticipatory regulation.
- Integrated triple bottom line of sustainability (economic, social, and environmental).
- Privacy, security, and safety of users.
- National and digital sovereignty.

Next, we will present our detailed recommendations.

Competitive innovation policy

Recommendation 1: Establish a National 6G Programme in the UK for industry-academia collaboration, especially on co-designing technology and supporting business model innovation and experimentation.

6G is expected to build on the extended use of several complementary technologies, such as artificial intelligence (AI) and machine learning (ML), which can be considered general-purpose technologies, making the development and standardisation of 6G a cross-industry effort which both leading developers and users of 6G need to collaborate with the developers and users of these adjacent technologies. Therefore, the UK's innovation policies should be benchmarked against both European and global innovation policies in other advanced economies. For international reference, it is recommended to benchmark, e.g., the first national 6G flagship programme that was initiated in Finland in 2018 (http://www.6gflagship.com), extended to the European level with the Hexa-X programme (https://hexa-x.eu/). In Europe, the aim is to create an internal market for European research, technology, and innovation in telecoms and extend and deepen 6G collaboration with like-minded countries to influence the creation of a global 6G. It is important to look beyond Europe as well. Similar 6G initiatives have been launched in several countries. Given the 6G visions of China, the US, South Korea, and Japan, and especially the respective investment programmes in these countries, the UK needs to be quick to initiate relevant collaboration efforts and ensure sufficient funding for national and international research collaboration to develop 6G and the ecosystems and platforms around it.

Recommendation 2: Invest in competence building for the development of value-adding services and flexible infrastructure.

The value added by the telecom sector is a key enabler for the growth of the value added of other sectors. Connectivity, whether wired or wireless, functions as a value enabler in the digitalisation of all other sectors of the economy. Key enabling technology perspective of 5G in particular calls for an interdisciplinary approach, the importance of which is only expected to increase when 5G transforms into general-purpose 6G technology in the future. With the increased integration expected across terrestrial and satellite networks, digital services, and AI and ML, education and training programmes need to adapt to provide a workforce with the required combination of skills across these domains. Education and training providers need to innovate in their programme provision, the government needs to support and stimulate this innovation, and companies need to invest in upskilling.

This means that both higher education programmes, vocational education and continuing education programmes, should acknowledge the dynamism of digital transformation and how the convergence of technologies impacts practically all sectors of the economy. Following the principles of lifelong learning and adjusting curricula to include innovation, management and entrepreneurship courses is a central way to invest in future-proofed and flexible competence building of existing and future workforce.

Anticipatory regulation

Recommendation 3: Boost new market development with a flexible, adaptable regulatory landscape in telecoms that supports the emergence and scalability of local private mobile networks.

Anticipatory regulation refers to a proactive, iterative, and responsive approach to regulation. For markets that are under rapid change, it emphasises flexibility, collaboration, and innovation in policymaking. The Digital Economy Act, which replaced the Electronic Communications Code in 2017, applies to the infrastructure forming networks that support broadband, mobile internet, telephone, cable television, and landlines in the UK. The act includes a set of rights that are designed to facilitate the installation and maintenance of electronic communications networks and digital infrastructure, also in relation to Ofcom and its functions. However, in 5G and 6G, it will be important to acknowledge how regulations take, for example, AI and cybersecurity into consideration. As set out in the 5G Supply Chain Diversification Strategy of 2020 and its goal to support the growth and resilience of telecoms supply chains, and as part of the National Cyber Strategy of 2022, the UK Telecoms Lab was launched in Birmingham in October 2022. Its aim is to bring together the government and regulators with industry in the context of a telecoms security framework. The UK Telecoms Lab functions as a test facility, especially for identifying national security risks and vulnerabilities in telecoms technology against cyberattacks (DCMS, 2022).

However, from a national competitiveness point of view, these strategies are limited as they do not consider wider economic, societal, and environmental issues. Different societal and environmental pressures have paved the way to analysing the evolving vertical-specific regulations as well as cross-sectoral horizontal needs of the market. In the 5G context, emerging new service concepts, such as local 5G operators, have the power to shake up traditionally consolidated industry structures. Market dynamism fosters competitiveness; therefore, the regulatory landscape should be aligned with economic incentives and policies that support market dynamism. This could be realised by developing a Telecommunications Innovation Strategy for the UK. A natural homebase for this would be the Department for Science, Innovation and Technology.

Recommendation 4: Develop a vision for data sharing and algorithmic decision-making that protects consumer interests while also creating an environment that supports business and technological innovation.

As we head toward the 6G era, it is evident that the UK's regulatory frameworks will increasingly be challenged and will require strategic, value-based consideration. There are fundamental differences between the market-based US approach, the rights-based European logic, and China's push-based logic for developing and utilising technologies, especially in relation to ML and AI. The parallel consideration of both *ex-ante* and *ex-post* regulation also contributes to the need to make the whole regulatory process more agile, especially in the context of new venture creation, to support the emergence of technology startups. Thus, while considering privacy, more effort could be put into, for example, establishing trusted data use at the industry level for sector-specific research and open data initiatives via innovative collaborative mechanisms and specialised public-private (and people) partnership projects and programmes, not only in R&D phase but also in the commercialisation of innovations. These efforts will have important implications for financing private local network initiatives for the development of telecoms startup ecosystems.

Recommendation 5: Seek a major role in international telecommunications standards and regulation setting.

In reviewing the evolution of regulations in Europe, from open telecoms markets (version 1.0) to a new (combined) perspective on innovation, investment, and regulation (version2.0), the birth of the Electronic Communications code (version 3.0), and regulation of all digital players through the Digital Economy Act (version 4.0), UK organisations need to be well prepared for the next phase of evolution based on platforms, AI, and 6G. The international work by the ITU-R on International Mobile Telecommunications (IMT) for 2030 and beyond that will eventually become 6G will be advanced by mid-2023. As 6G is expected to emerge as a connectivity platform that converges with other digital platforms, the whole regulatory landscape will face convergence in the future. Anticipatory, collaborative approaches to regulation in telecommunications can support national productivity in innovation, both in the private and public sectors. This calls for more open dialogue among different stakeholders in the digital sector in addition to Ofcom and DSIT, in order to ensure that the global vision of

technology trends and works can be realised in the UK. Meanwhile, strong participation in standards bodies and collaboration with like-minded countries will support the adoption of standards most suited to the economic success of UK companies.

Integrated triple bottom line of sustainability

Recommendation 6: Consider the triple bottom line of sustainability to support the sector's functioning as a catalyst for other sectors in the digital space.

The triple-bottom-line perspective of sustainability integrates economic factors with social justice and environmental protection. Sustainability sets new demands for telecom industry players, especially in 6G, as the combined environmental, societal and economic perspective of sustainability has become increasingly important in developing future technologies, along with the UN SDGs framework. The UN SDG sets specific goals and targets to be achieved by 2030 when 5G is expected to transition to 6G[18]. Energy efficiency has been a central design criterion in earlier mobile network generations. There is a long tradition of developing so-called "green radios," which has meant jointly considering both the energy and spectrum efficiency of networks to achieve sustainability. In 5G, green radios should also comprise energy efficiency in telecoms use case scenarios such as massive machine-to-machine type communications, have new optimisation frameworks based on ML and AI, and introduce new hardware dynamics, which links our report, especially with the 5G Supply Chain Diversification and Wireless Strategy discussions.

However, the transition from 5G to 6G extends sustainability to address also societal and economic sustainability concerns. This means that economic sustainability in the form of profitability should not overtake societal or environmental consequences. Neither should environmental sustainability, such as the footprint of networks, devices or services, be a sole design criterion if it impacts economic and societal progress negatively. Lastly, as 6G is expected to converge largely with AI, concerns for societal sustainability targets, such as human-centricity and ethical aspects, shouldn't be pursued at the expense of environmental or economic sustainability. Balancing these three perspectives of sustainability in the development of future telecoms innovations will ensure the sector's functioning as an innovation catalyst beyond technology.

Recommendation 7. Participate in cross-sectoral initiatives in the circular economy, e.g., servitisation models in 6G.

As we pointed out above, the UN SDGs have been adopted as the guideline for developing future 6G. Opportunities, value creation potential, and advantages of technology are the focus of economic sustainability. In turn, economic resilience emerges as the combined effect of technology's scalability, replicability, and sustainability. Societal sustainability in 6G means that people can participate and act in society in a new and beneficial way, given that it is affordable, and they can choose to use it or opt-out if necessary. Lastly, environmental sustainability will extend beyond resource efficiency to cover circularity and zero-emission aims. Companies can play a central role in business model innovation and innovation commercialisation, especially in cross-sectoral initiatives around sustainability and circularity. Here, specialised industry-academia research programmes could enable companies to explore with novel concepts.

Recommendation 8: Aim for leadership in sustainable development and deployment of 5G and future 6G networks to contribute to a more sustainable and resilient economy whilst also creating economic opportunities.

Although 6G is not yet directly within the European emissions trading system or under specific CO2 taxation, it is envisioned that such an arrangement will spread to new sectors in the future. Future 5G and 6G will be directly influenced by the need to decrease emissions of greenhouse gases and the harmful environmental impacts of materials used in manufacturing the necessary hardware. The new growth opportunity of 5G and 6G is envisioned in the various digitalising industry verticals that are increasingly being brought to the European Green Deal domain or under different environmental regulations. As a national response, the UK's Environment Bill 2020 was developed as the "government's manifesto commitment to delivering the most ambitious environmental programme of any country on earth".

Aiming for global leadership in this front, rather than aligning or non-aligning with EU regulations alone, may also provide a unique opportunity for the UK to become a global forerunner in telecoms sustainability and net neutrality. Mobile communications technologies are expected to converge and merge with other technologies and platforms. A good example of this is the local and private networks that are owned and operated by stakeholders that can be already within the emissions trading system. International collaboration in sustainability forums can increase UK's ability to identify new growth opportunities.

Privacy, security and safety of users

Recommendation 9: Manage and ensure network reliability, considering its increasing connections to trust, safety and privacy.

The UK's 6G development and deployment must address users' privacy, security, and safety. The developers of 6G envision local trust zones (Hexa-X, 2021), but more widely, the question concerns the built-in reliability of 6G in general. As 6G becomes intertwined with all the functions of everyday life, reliability will become a necessity. The more advanced 5G technology becomes and the more it is converging with ML and AI technology, the more businesses need to address security, privacy, availability, resilience, and compliance with ethical frameworks. Physical security and safety can be seen as consequences of reliability, as many digital systems in 5G and 6G use cases, such as autonomous vehicles and remote healthcare applications, depend on mobile communications. Reliability, trust, safety and privacy should be prioritised in the UK's 6G Strategy.

Recommendation 10: Develop sectoral legislation to support legal clarity in relation to management and security of raw data, metadata, and access to information on end-user devices.

Cybersecurity considerations, briefly discussed above in the context of anticipatory regulation, need to cover all aspects of security in the digital domain: (1) resilience against attacks; (2) preservation of privacy; and (3) ethical, safe application of automation to network operations and applications. To make 6G reliable, deep interaction between academia, industry and the authorities is required. The UK's legal framework provisions for ensuring security within and between the telecoms networks and coordination and control across multiple locations do not cover in detail the specific features and characteristics of 5G/6G local mobile communications networks, especially for those not deployed by the MNOs, such as local private mobile operator networks, and neither define their main characteristics. However, security and privacy are the main elements that need to be considered at the national level in all the network slice installations for local 5G/6G network deployment. Clarity in this aspect of regulation will reduce barriers to innovation. Exclusive reliance on the precautionary principle may not be the most effective way to induce innovation, so a balance needs to be struck between the precautionary principle and the innovation principle to ensure that commercial outcomes are not stifled. Codes of conduct and regulatory sandboxes can provide environments for business and technological experimentation while protecting broader user interests.

Recommendation 11: Embrace the development of "prosumer" telecommunications networks and create an environment that enables an open, collaborative ecosystem.

There is a need to innovate at a much faster pace than even very recently. The technology lifecycle is shorter than ever, where mature, accessible, and cheap telecommunications infrastructure can function as a key to accelerated discovery. The telecoms industry is challenged by both technical cybersecurity and reliability in relation to privacy, safety, and security of users. Users can become active members, i.e., "prosumers," in the telecoms ecosystem (in that users of all kinds not only use telecoms services but also plug into and provide complements to telecoms services and manage the availability and use of their own data), but the challenges stated above need to be considered in an open manner in order to facilitate competitiveness and responsible innovation in the telecoms sector. The UK could build competitive advantage by taking a leading role in open technology initiatives and open-source software in the context of prosumerism, thus promoting an open business ecosystem that encourages complements and collaboration among stakeholders.

National and digital sovereignty

Recommendation 12: Take a leading position in the development and commercialisation of communication networks that promote strategic autonomy.

Digital technologies have become a battleground in the competition for global leadership; consequently, they also contribute to increasing geopolitical tensions[19]. Already before Russia's war on Ukraine, phenomena such as trade wars, cyber espionage, disinformation, threats, and sanctions, as well as dependence on foreign suppliers, data colonialism via platforms, technological vulnerabilities, and risks to the economy, society, and democracy[20], have been topics of public discussion. The UK's strategic autonomy can help protect its vital digital infrastructure but can also act as a source for new opportunities and an increased role on the global 6G front. In contrast, for many EU Member States, for instance, national action requires EU-level coordination in many fields of society. This is not only a practical but also a legal-political challenge. Strategic autonomy and digital sovereignty need to consider data ownership, storage and use, algorithmic processes, and infrastructural in wired and wireless communications, satellite communications as well as in hybrid forms of connectivity. For the UK, the ability to make fast decisions independently can be an advantage in future 6G, and

firms should develop commercial strategies to exploit this in concert with regulatory authorities.

Recommendation 13: Perform strategic assessments of the impact of open technology initiatives on businesses in a proactive manner.

Open software initiatives are gathering pace in the digital space and upending business models that depend on proprietary systems. Such initiatives are likely to grow quickly in the telco space, creating business opportunities as well as threats. This will reduce the relevance of one of the key barriers to competition that telcos hold – their proprietary rights in software, hardware and network structure. Companies should undertake strategic reviews and prepare to counter the threats—and seize the opportunities—presented by these open technologies in a proactive rather than a reactive manner.

There are different implications for industry and policymakers. Summarising our 13 recommendations from this perspective, we highlight the following:

1. Incumbents
Software is becoming an increasing component of value creation, which also provides opportunities for export (ARM-like) while noting the growth of open platforms – rather than perceiving e.g. cloud-based platforms and markets as a threat to existing industry structure, incumbents should invest in exploring technology convergence. This also calls for business model exploration and experimentation with different complements, including both in-house and sourced technologies and services. Content providers are buying network infrastructure, e.g. fibre – This impacts the consolidated so-called natural monopoly nature of the telco sector, which again calls for opportunistic rather than protectionist industry strategies.

2. Government toward startups and scale-ups
Supporting scale-up culture nationally (Ex: open tech initiatives and innovation sourcing) is a key tool for boosting the emergence of new ICT and telecom companies. Here, especially government procurement practices and policies can drive UK innovation. A question naturally arises that to what extent should there be preferences for the use of national providers in the UK sector, but here, understanding the global nature of the telecom sector is an important implication for innovative public procurement policies, not only for technology sourcing but also various kinds of XaaS models (Software-as-a-Service, Network-as-a-Service, Platform-as-a-Service etc). This also implies new models for measuring success or export growth potential, which can be explored in industry-academia collaboration.

3. All stakeholders
One of the major factors for boosting competitiveness, economic growth and the development of dynamic and future-proofed capabilities in telecoms calls for building on UKTIN and 5G/6G Innovation Centre but *with enhanced business model component* and a wider range of players. Collaborating internationally with regard to standardisation and regulation (Ex: UK 6G research programme, not isolated) also in business research is an important aspect, as technology should not be developed in isolation without a thorough analysis on its potential for value creation, capture, delivery but also sharing via ecosystems and platforms.

4. Government toward incumbents
The UK also needs levers to stimulate true investment, as pricing regulation is not enough. New policies toward spectrum allocation should be developed by acknowledging emerging use cases and adjoining sectors as well. Here, international benchmarking of advanced economies, e.g., how the government in Singapore has contributed to national growth, can be a fruitful reference point also to the UK.

References

1. Axon Partners Group, Europe's internet ecosystem: socio-economic benefits of a fairer balance between tech giants and telecom operators, May 2022
2. State of Digital Communications 2023, ETNO European Telecommunications Network Operator's Association
3. Wood, R (2023) State of Digital Communications: 2023. Analysis Mason
4. Vodafone UK and Ericsson trial on-demand 5G network slicing – 5G Observatory
5. ICT sector - value added, employment and R&D - Statistics Explained (europa.eu)
6. Frost & Sullivan 2022b. Global 5G Network Infrastructure Growth Opportunities
7. Ahokangas, P., Matinmikko-Blue, M., & Yrjölä, S. (2022) Envisioning for a Future-Proof Global 6G from Business, Regulation and Technology Perspectives. Communications Magazine.
8. Yrjölä, S., Ahokangas P., Matinmikko-Blue M. (2021) Value Creation and Capture from Technology Innovation in the 6G Era. IEEE Access
9. Telecommunication Market: Global Industry Analysis and Forecast 2029 (maximizemarketresearch.com) MMR
10. Frost & Sullivan 2022a. Global 5G Developments and Outlook for 2023
11. Borreau, M. & Lemstra, W. Open interfaces and innovation in telecommunications. Report. September 2022
12. Ahokangas, P., Matinmikko-Blue, M., & Yrjölä, S. (2022) Envisioning for a Future-Proof Global 6G from Business, Regulation and Technology Perspectives. Communications Magazine
13. Bohlin E., Cappelletti, F. (2022). Europe's Future Connected: Policies and Challenges for 5G and 6G Networks. European Liberal Forum
14. A blueprint for telco transformation | McKinsey
15. To be or not to be | The future of the telco business model, Deloitte, DeloitteTMT-Telco-2030.pdf
16. Serentschy, G. (2022) A call for a wide-ranging digital policy authority for a 6G ecosystem. 09 September 2022, Policy paper. Serenchy Advisory Services GmbH.
17. Ofcom at the International Telecommunication Union (ITU) - Ofcom.
18. Matinmikko-Blue, M., Yrjölä, S., Ahokangas, P. (2021) 6G and the UN SDGs: Where is the Connection?. Wireless Pers Commun 121, 1339–1360. https://doi. org/10.1007/s11277-021-09058-y
19. Moerel, L., Timmers, P. (2021) Reflections on Digital Sovereignty. EU Cyber Direct, Research in Focus series
20. Timmers, P. (2020). 'There Will Be No Global 6G Unless We Resolve Sovereignty Concerns in 5G Governance'. Nature Electronics, 3(1), 10–12

Literature

1. Communications Market Report 2022 – Interactive data - Ofcom
2. Day2_Session5_Mettälä_Traficom.pdf (6gsummit.com)
3. DCMS Sectors Economic Estimates 2022: Business Demographics - Report - GOV.UK (www.gov.uk)
4. Digital sector worth more than £400 million a day to UK economy - GOV.UK (www.gov.uk)
5. GSMA Intelligence, The Mobile Economy Europe 2022
6. open-ran-competition-innovation.pdf (ofcom.org.uk)
7. State of Digital Communications 2023, ETNO European Telecommunications Network Operator's Association
8. Telecom Equipment Market Size, Share, Industry Forecast 2029 (fortunebusinessinsights.com
9. Telecommunications industry in the United Kingdom (UK) - Statistics & Facts | Statista
10. The economic impact of broadband – Ofcom
11. UK Government, 2022. Open RAN principles: https://www.gov.uk/government/publications/uk-open-ran-principles
12. United Kingdom Telecoms Infrastructure Market report, Statistics and Historic Data (budde.com.au)
13. United Kingdom Telecoms Market report, Statistics and Forecast 2020 2025 (budde.com.au)
14. Why collaboration is crucial for telcos and utilities (pwc.com)
15. Vodafone, 2022. Open RAN – all you need to know: https://www.vodafone.com/about-vodafone/what-we-do/technology/open-ran.
16. The Department for Science, Innovation and Technology, UK Wireless Infrastructure Strategy - GOV.UK (www.gov.uk)
17. The Department for Digital, Culture, Media and Sports, 5G Supply Chain Diversification Strategy - GOV.UK (www.gov.uk)

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