Gigabit broadband: what does it mean for consumers and society?

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Summary

Imagine a world where you could have remote access to a healthcare specialist who could assess, diagnose and potentially treat you at home; or a school lesson where you're virtually 'transported' to the surface of the moon to learn about the solar system; or a meeting with colleagues who are in different parts of the world which, unlike the one-dimensional video conference calls of today, provides the physical and emotional sensation of literally being in the same room as you. The technological building blocks—such as sensors, screens and processors—are ready or in development. These experiences are also dependent upon high capacity networks. Liberty Global is making this a reality, having made gigabit services available across its European footprint.

Digital services have already brought significant benefits to society in terms of wellbeing, convenience and user experiences. More of these could be unlocked as a result of the widespread roll-out of gigabit broadband, GigaCities as Liberty Global calls them, which are likely to allow a new generation of digital services to tackle some of the challenges faced in society today. This is a continuation of a trend that began over a century ago, which has seen the evolution of communications technology dramatically change the way we interact with each other by reducing frictions, or what economists call 'transaction costs'. Reducing these costs lowers barriers to interacting and transacting with one another, facilitating easier and happier lives.

Previous improvements in connectivity have led to significant benefits in terms of communication, sharing and reducing barriers to trade. Gigabit connections could continue this trend by reducing the significant frictions that remain—particularly in the areas of healthcare, commuting, social interaction and the environment.

Gigabit speeds and the accompanying fall in latency (a measure of the time taken for data to cross the network), could enable consumers to use a range of technologies - such as cloud-based gaming, digital health and virtual and augmented reality – in new ways. These changes are likely to be transformative rather than marginal.

This report identifies four key areas in which the mass-market roll-out of gigabit broadband has the potential to transform lives—by eliminating some of the 'frictions' that remain.

Revolutionising healthcare
According to Eurostat, 179m people within the EU have healthcare needs that haven't been addressed. A quarter of these people blamed a lack of time. Gigabit broadband could enable applications such as diagnostics-quality video streaming and sharing, which could allow consultations from home, reducing costs and the need to travel. As we live longer and more of us are likely to be living with chronic conditions, comorbidities and diseases associated with old age, remote healthcare is likely to allow patients to avoid travelling and the elderly to live independently at home for longer. Home-based telehealth has existed at the fringes of healthcare for some time. Gigabit broadband has the potential to transform the way healthcare services are delivered.

Changing the way we work
On average, we spend between 263 hours (in the Netherlands) and 358 hours (in the UK) per year commuting to our workplaces.

Evidence from the CIPD shows that around one third of UK professionals would like to work from home if possible; however, only 6% of professionals do

so, even though teleworking has been available for more than 20 years. Applications such as holographic conferencing and augmented reality presence enable professionals to collaborate more effectively without having to travel. In addition, through increased downstream and upstream bandwidth, a number of workers in professions that involve visualising 3D models or sharing immersive content will be able to collaborate and co-create with professionals from other countries and even continents.

Improving social and digital interaction

Social contact and interaction is good for reducing loneliness, improving mental health and maintaining our social capital. However, meeting up with friends and family involves transaction costs, which means that we may not see each other as often as we would like.

In Poland, for instance, 73% of people meet family and relatives less than once per week. Enabling easier and more realistic interactions between people can alleviate loneliness and isolation and increase social capital.

Not everyone can travel to or experience live sporting or community events due to physical or geographical limitations. Several companies, such as Facebook and Intel, are developing technology to allow consumers to experience live events in a more immersive way, such as being able to see an event from any angle the viewer wishes. Other companies, such as Google, are developing cloud-based gaming services, such as Stadia, to make games more lifelike, complex and richer. For the best experience, these will require high-capacity networks to be able to deliver on their promise of a much more immersive experience.

Helping to fight climate change

Annual emissions from commuting to workplaces are between 1.2m tonnes per year (in Ireland) and 19m tonnes per year (in Germany). By reducing the need to travel by making more connections virtually rather than physically, carbon emissions from transport can also be reduced. While physical meetings are unlikely to ever be completely replaced, improving the quality of virtual interactions means that they become better substitutes for physical meetings. Additionally, opportunities exist in VR learning, VR tourism and homeworking to reduce substantially carbon emissions from travel.

Gigabit networks can play an important role in reducing these transaction costs by supporting the emergence of new applications that deliver social and economic benefits. The technology to deliver many of these benefits is already here. Liberty Global is currently rolling out gigabit connections, which will be able to provide up to 10 gigabits per second speed in the near future.

Connectivity is a critical enabler at the heart of continued digital transformation. Gigabit networks can help to reduce the transaction costs we have identified, powering applications that could unlock benefits across society.

Glossary of terms

Terms	Explanation
Augmented Reality (AR)	Augmented reality is a technology that overlays and enhances the user's view of the real world and with which a user can interact
CAGR	Compound annual growth rate. This measures the growth over multiple periods,
Counterfactual	The hypothetical state of the world in which an action of interest or policy has not occurred (in this case, where the network is not upgraded).
Factual	The state of the world that actually occurs (in this case where the network is upgraded).
DOCSIS	Data Over Cable Service Interface Specification. DOCSIS is a data transmission standard used for delivering broadband data over coaxial cable television networks.
Externality	An indirect effect of someone's action on a market. Externalities can be to the benefit of someone else (a positive externality), or can have a negative effect and cause damage to someone else (a negative externality).
Internet of Things (IoT)	The connection of everyday objects to the internet and their ability to send and receive data and communicate between them
Network effect	The effect that an additional user of a good or service has on other users. Interconnection services are more useful when everyone has access to them.
Opportunity cost	The loss of alternatives when one option is chosen.
Transaction costs	Costs associated with overcoming the frictions that exist in a market, such as search, information, bargaining, decision-making, policing and enforcement.
Value of time	Monetary estimation of spending time. In a transport context, the value of time is the opportunity cost of spending time travelling, relative to an alternative (such as work or leisure)
Capacity	In communications, capacity is a measure of the quality of a link. Capacity refers to the amount of data (bits) a link can transfer in a given unit of time (seconds).
Throughput	The instantaneous speed of data (measured in megabits per second (Mbps) or gigabits per second (Gbps) being sent over a communications link.
Latency	In communications, latency is a measure of the quality of a link. Latency refers to the time it takes for a unit of data to transit a link. It is sometimes referred to as 'delay' or 'lag'.
Jitter	In communications, jitter is a measure of the quality of a link. Jitter is the variation or fluctuation of latency over time.
Volumetric video	A video technique that captures a three-dimensional space.
Virtual Reality (VR)	Virtual reality is a computer simulated environment with which a user can interact

1 Liberty Global's GigaCities network upgrade

High-quality broadband networks have become critical to digital economies.[1] As well as providing consumers with communication and entertainment services, fast and reliable broadband increases the productivity of businesses and provides individuals with access to substantial information and learning resources.

Liberty Global owns and operates a fibre-rich cable network infrastructure in the UK, Ireland, Belgium, The Netherlands, Poland, Switzerland and Slovakia. These networks deliver unified communications and entertainment services, increasingly through broadband Internet. Liberty Global is upgrading its networks in order to maintain a position of market leadership on connectivity and deliver transformational products and experiences. It is doing this by migrating to a new data transmission standard on the final segment of its network, which connects into consumers' homes.[2] This will increase download capacity dramatically from several hundred megabits per second to services capable of 1 gigabit per second (1Gbps). This upgrade will make capacity and quality improvements available at scale, across its European footprint. Investing in additional capability will create the headroom for the digital applications of the future. It will also reduce latency and improve reliability, improving the end-user experience. In the longer term, the upgrade to DOCSIS 3.1 will put Liberty Global on a roadmap towards 10 gigabits per second (10Gbps) broadband services. This upgrade will create substantial opportunities for many sectors of the entire economy.

The upgrade can be viewed within the wider context of digital transformation in Europe. The fourth industrial revolution will build on previous waves of digital disruption via technologies such as the Internet of things (IoT), robotics and virtual reality. Digital connectivity is expected to reshape the business landscape, the nature of work and the way we innovate. This is borne out in our report, where we identify potential areas for very high capacity digital connectivity to revolutionise healthcare, transform workplaces, improve social interaction and reduce greenhouse emissions. The EU's Digital Single Market strategy aims to connect more households to next-generation-access (NGA) and superfast networks, roll out 5G mobile networks, foster artificial intelligence (AI) development and boost digital skills. Broadband as an enabling technology is central to this strategy. [3]

Liberty Global commissioned Oxera to conduct an economic impact assessment of its Gigacity upgrade in order to understand the economic and societal effect on European consumers. More broadly, these impacts can contribute to the wider policy objectives on broadband throughout Europe.[4]

The scale of Liberty Global's upgrade is significant.[5] The full effect of this change is unlikely to be felt as a marginal increase in activity. Rather, the change provides an opportunity for transformative applications to emerge over

[1] Quality in broadband service includes bandwidth, reliability and measures of timeliness—such as latency and jitter.
[2] The DOCSIS standard currently employed within Europe is on version 3.0; following the upgrade, it will move to version 3.1.
[3] European Commission, 'The importance of the digital economy', https://ec.europa.eu/growth/sectors/digital-economy/importance_en, accessed 21 February 2017.
[4] Regulators and policymakers face the challenge of ensuring that society benefits from the improvements in broadband as quickly as possible while also supporting competition and ensuring efficient use of resources.
[5] Capacity at the household level is likely to double or triple.

time. On this basis, the past is not an ideal nor a complete guide to the impact of future transformative changes enabled by the GigaCities upgrade.

Oxera's framework for assessing the impact of the GigaCities upgrade

Understanding the precise economic impact of a change requires a clearly formulated **counterfactual**—a view of the state of the world with the proposed policy or change applied. The net effect of the policy or change could then be estimated as the difference between the counterfactual (i.e. with the upgrade) and **factual** (i.e. without the upgrade).

In this case, the GigaCities counterfactual has many unknowns. The precise path of development and innovation is not certain. It is a common feature of digital technologies that the next big mainstream application is not always known.

Oxera's framework has been developed with these challenges in mind. The logic behind our approach is to first establish the causal mechanisms that link digital communications with economic benefits, and then to assess the historical evidence in support of this. Next, we quantify transaction costs that remain in society today (i.e. the frictions associated with travelling, waiting, searching and interacting with others) that the upgrade could address. Looking to the future, we also recognise the potential for users to require 1Gbps connections in the near term (i.e. without transformational applications)—so we assess the factors that drive this need. Finally, we review the potential technologies that gigabit capable networks could unlock, and describe their potential economic impact.

We have structured this approach chronologically—reviewing past developments, assessing present factors and then scanning the horizon. The framework and report structure is outlined in Figure 1.1 below:

Figure 1.1 Framework for GigaCities upgrade impact assessment

Source: Oxera analysis.

This report addresses changes relevant to the UK, Ireland, Belgium, the Netherlands, Germany and Poland.[6] The Appendix contains details on the data and methodology used to quantify outputs in section 3.

[6] Note that following the sale of LG's German assets in July 2019, Germany is no longer within Liberty's footprint. We include it in our report as Germany (and Bochum in particular) was a trial area for the DOCSIS 3.1 technology.

2 How do digital communications technologies deliver economic and societal benefits?

2.1 Digital technologies have reduced transaction costs

To understand how digital technologies have contributed to lowering the cost of interaction between economic agents, it is useful to introduce the concept of transaction costs. Transaction costs are the costs associated with overcoming the frictions that exist in a market. In the early 1930s, the economist Ronald Coase introduced the basic concepts and then Oliver Williamson further developed the theory.[7] Six basic types of transaction costs are search, information, bargaining, decision-making, policing and enforcement. However, the list is not exhaustive.

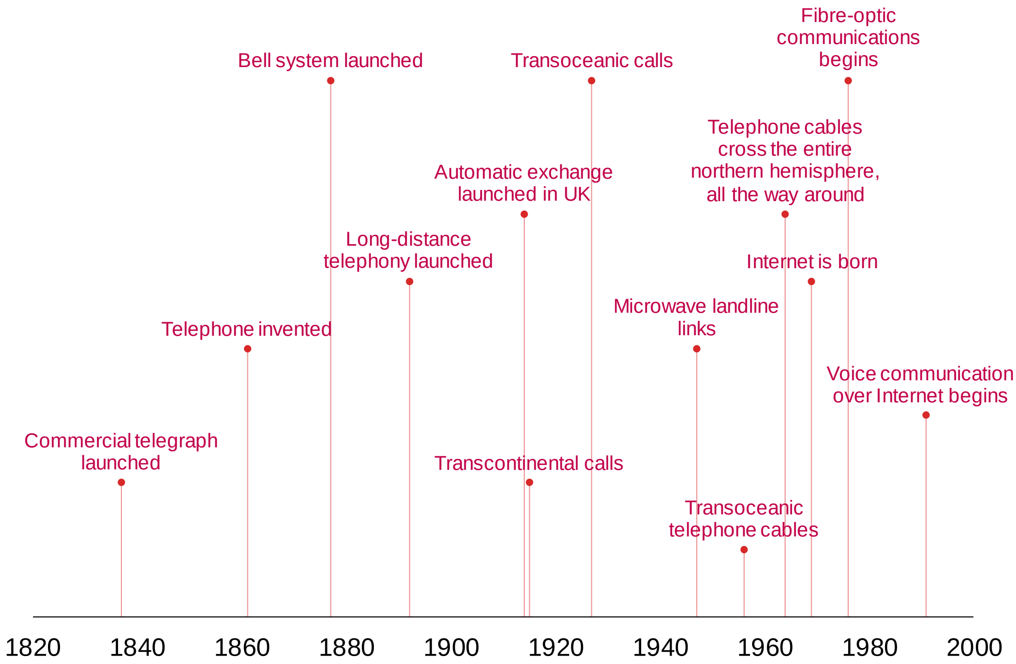
Improved communication reduces the frictions that exist between two or more parties engaged in an activity by ensuring that the same information set is accessible to all participants. For example, the introduction of bike-sharing schemes in the majority of large European cities is based on the continuous communication of information between the user of the bike and the provider through the Internet, such that enforcement of a contract is possible without the two being physically present in the same location. Similarly, searching costs were greatly reduced by the introduction of search engines, which provide information to Internet users within seconds.

2.2 Technology has a history of delivering step changes in connectivity

Digital and communication technologies have a rich history of delivering quantum leaps in capabilities. Many communications technologies we rely on today—such as transmission, routing, encoding and compression techniques—have origins in telephony methods. Looking back, digital and telephony communication provide almost 200 years of progress to review. Oxera has reviewed and plotted some of the major developments over time in Figure 2.1 below.

[7] Coase, R. H. (1937), 'The Nature of the Firm', *Economica*, **4**:16, November, pp. 386–405; Williamson, O. E. (1979). Transaction-cost economics: the governance of contractual relations. *The journal of Law and Economics*, *22*(2), 233-261.

Figure 2.1 Timeline of major telephone and communications developments, 1820s–2000s



Source: Oxera analysis of Vonage data; see Kunene, G., 'A History of Telecommunications: How Telecoms Became Just Another Interface', https://www.vonage.com/business/perspectives/a-history-of-telecommunications-how-telecoms-became-just-another-interface/, accessed 23 August 2019.

Note that this sample of developments is an abridged, high-level summary of major changes—a range of incremental contributions to telephony and digital technologies also occurred. Nonetheless, since the launch of telegraph lines in the 1830s, significant technical advances continued at regular intervals.

The technological developments have unlocked transformational changes in the way people communicate, often by reducing transaction costs. For example:

- voice-based telephony widened the potential user base, as it did not require individuals to use Morse code;
- trunk and intercontinental links brought even more connectivity, making it easier to communicate over much wider distances.

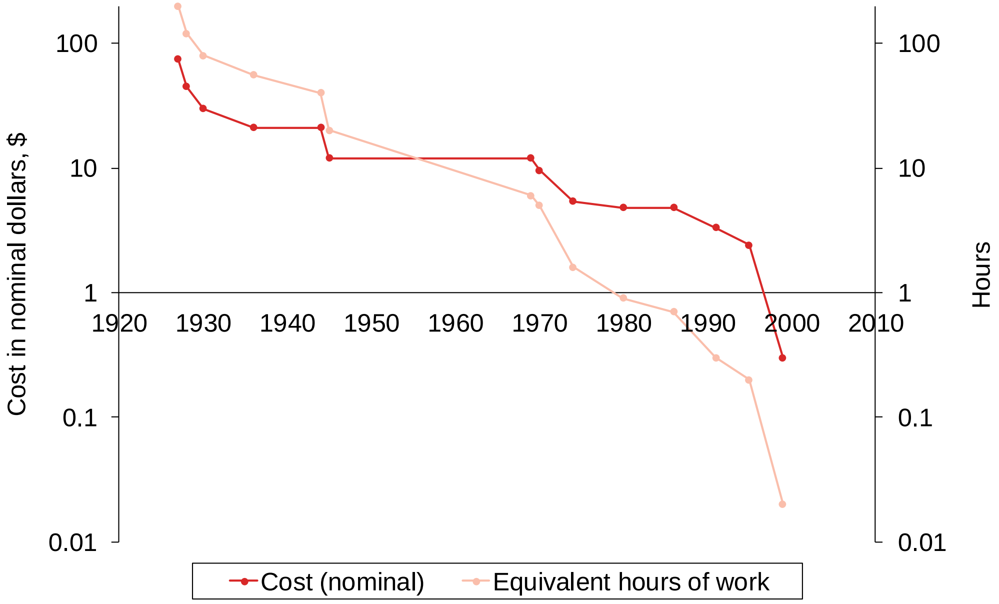
In 2019, we take for granted a level of connectivity that can reliably join a user to any one of 5bn subscribers by merely tapping a dozen or so digits into a handset.[8] Once connected, users can easily talk, video conference and share photos or other files.

Personal and business communications were not always so easy. Low uptake, low capacity and limitations of a given technology could restrict the potential use cases and, therefore, the benefits that consumers derived. These barriers to use would have put many interactions out of reach, reducing opportunities to trade, save time and gather information.

[8] ITU Recommendation E.164 on telephone numbering stipulates a maximum telephone number length of 15. There were approximately 5bn mobile subscribers at the end of 2018. See Ericsson (2018), 'Mobile subscriptions worldwide outlook', market report, November, https://www.ericsson.com/en/mobility-report/reports/november-2018/mobile-subscriptions-worldwide-outlook, accessed 23 August 2019.

The rapid technological change of recent years is associated with the falling cost of communicating, as shown in Figure 2.3 below.

Figure 2.2 Standard rate for three-minute call, New York City to London

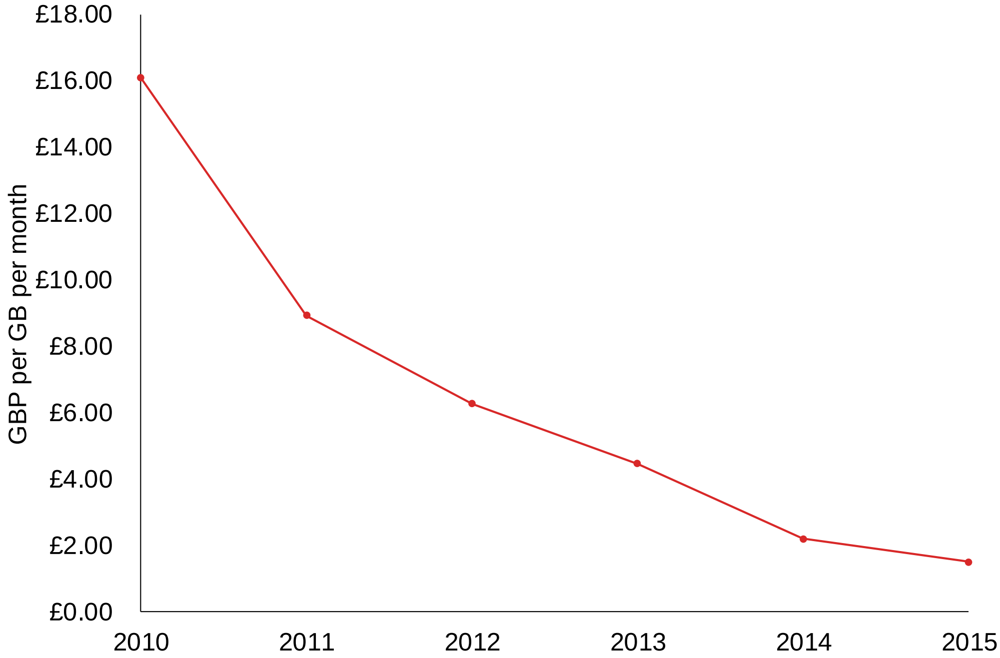


Source: Oxera analysis of Odlyzko, A. (2001), 'Internet pricing and the history of communications, report for AT&T Labs, http://www.dtc.umn.edu/~odlyzko/doc/history.communications1b.pdf, accessed 23 August 2019.

Not only has the nominal cost of calls between New York and London fallen rapidly, but the real cost (as proxied by the number hours required to work to pay for such a call) has fallen even faster.

Similar rapid falls in the costs for data services are shown in Figure 2.3 below.

Figure 2.3 Unit cost of transmitting a Gigabyte of broadband data, UK, 2010–15



Source: Oxera analysis of Abdirahman, M., Coyle, D., Heys, R. and Stewart, W. (2017) 'A Comparison of Approaches to Deflating Telecoms Services Output', Economic Statistics Centre of Excellence (ESCoE) Discussion Papers, December.

This sustained and rapid fall in unit costs has supported a transformation in how people share information and the speed at which business information flows. It has also enabled the emergence of platform services (such as Google), which have transformed the way individuals search for information. In addition, broadband consumers have benefited in real terms as the cost of data transfer has fallen – and it continues to do so.

2.3 Digital technologies have delivered transformational impacts

Digital services have transformed daily life. Examples of this include the following.

- **Online platforms**. Online platforms can overcome informational barriers and better connect consumers to the products and services that match their needs. In 2015, Oxera conducted a study on the benefits of online platforms and found that 97% of Internet users found benefits from a variety of platforms. The benefits related to improved convenience, greater choice and increased transparency.[9]
- **Location-based services** help people plan their journeys, locate service providers and coordinate search-and-rescue efforts. Oxera estimated the impact of the geo services industry to the economy in 2013, finding that geo-services saved over 1bn hours of travel time per year. The study also found that geo services enabled cost savings of between $8bn and $22bn per year in the agricultural sector, and that competition benefits (such as reduced prices) could amount to $2.8bn annually.[10] Geo services were

[9] Oxera (2015), Benefits of online platforms, October 2015
[10] Oxera (2013), What is the economic impact of Geo services, January 2013

estimated to save 3.5bn litres of fuel annually, which is equivalent to over 8m tonnes of CO_2.

- **Online education and cloud computing**. A recent study for Liberty Global by AT Kearney found that countries with higher price levels and investment in telecoms services performed better in measures of societal welfare, such as the uptake of online courses and the share of enterprises using cloud computing. The same study found that consumers in Europe aged 18–29 would require compensation of €32,500 in order to forgo broadband and Wi-Fi access for one year.[11] We consider the potential for further innovation in education in section 5.

- **Streaming media**. The ability to stream entertainment content has fundamentally changed the way we consume media. Streaming has made it easier to consume the content we want, when and where we want it, and to be able to interact with it—clearly reducing transaction costs. This trend began with music, where streaming displaced earlier forms of digital disruption such as the file-sharing platforms Napster and Kazaa.[12] Importantly, film and television streaming services have taken longer to diffuse due to the large data transfer requirements and patchy broadband reliability.[13] We explore the potential for further innovation in entertainment in section 5.

The fact that these transformational services have followed in the wake of Internet and broadband adoption is no coincidence. Improved connectivity is an enabler of a set of digital technologies.

The lowering of transaction costs enables digital technologies the opportunity to deliver benefits, but it also creates opportunities for those that may seek to harm others. There remains an important role for regulation in addressing online harms such as fake news, cyberbullying, security and data privacy. Overall, the scale of the benefits is likely to far outweigh the cost and challenge of addressing these issues.

It should be noted that the speed of transformation has increased rapidly over the past 20 years. This is due to:

- **Competition and deregulation**. In the past, regulation opened up former state monopolies that resulted in increased competition. Today, the focus is on supporting the necessary infrastructure investment in delivering next-generation access and superfast connectivity.

- **Standards**. The emergence of Internet protocol (IP) as a standard data technology has led to network convergence and the unbundling of the networking technology from its intended application. The adoption of similar standards in mobile (such as 2G, 3G and 4G), and Wi-Fi has enabled rich interconnectivity options.

- **Network effects**. An interconnection service is more useful when everyone has access to it. Now that most households have broadband and over 5bn

[11] AT Kearney (2019), 'Viewed through the Lens of the Consumer' Report for Liberty Global, February 19.
[12] Aguiar, L. and Waldfogel, J. (2015) 'Streaming Reaches Flood Stage: Does Spotify Stimulate or Depress Music Sales?', NBER Working Paper No. 21653, National Bureau of Economic Research, October.
[13] See World Economic Forum (2019), 'After music and TV, what is the future of streaming?', https://www.weforum.org/agenda/2019/07/after-music-and-tv-the-next-streaming-revolution-is-already-here/, accessed 4th September 2019.

users have a mobile device, the utility of the service increases and allows more use cases to evolve.

- **Rapid technical progress**. As semiconductor technology progresses in line with Moore's law, our handsets, tablets and devices have the capacity to undertake more complex, data-heavy tasks.[14] This also applies to broadband and Internet pipes—each generation of network technology typically has more power and bandwidth, enabling more capacity on the line. In addition, the falling cost per unit means that more sensors can be connected to networks as part of IoT. This could further unlock innovation and new applications.

[14] Moore's Law is an observation that the number of transistors in an integrated circuit doubles every two years. While there is evidence to suggest that this exponential rate of growth has slowed in recent years, it still implies very rapid progress.

3 How large are some of the remaining transaction costs in society?

3.1 Motivation

DOCSIS 3.1 technology offers increased capacity of up to 1Gbps, along with lower latency and improved reliability.[15] This increased broadband capability will significantly improve the speed and quality of internet usage. These gigabit connections have the potential to improve user experience and unlock new applications, through which transaction costs may be reduced.

We have identified four main areas in which transaction costs still exist in 2019 and which may be reduced through gigabit connections:

- healthcare access (particularly unmet needs);
- commuting transaction costs (particularly time spent travelling);
- maintaining social interaction (particularly frequency of contact);
- emissions (particularly commuting emissions).

The analysis undertaken provides a gross quantification of these transaction costs using the latest available statistical data for six European countries: Ireland, the UK, Germany, the Netherlands, Poland and Belgium.[16] As solutions to these frictions will be developed in the future along the lines of the apps and services, which will be explored in section 5, the gigabit connections could transform part of this gross quantification into benefits for consumers and wider society.

In addition to reducing transaction costs, gigabit connections have the potential to make transformational changes to how consumers access and use the Internet. They do not create value single-handedly, but they are necessary to unlock the benefits of the future through innovative giga-apps and services. These benefits will be discussed in section 5.

3.2 Transaction costs that could be addressed by revolutionised healthcare

The healthcare sector is characterised by a number of remaining transaction costs—access cost, travel costs and waiting costs. The latter two affect those who travel to a provider for treatment or a consultation, while the access costs prevent a number of people from receiving the healthcare they need. Healthcare technology could help to reduce these transaction costs in the future as well as increase the number of people who can receive the medical care they need, which will be described in more detail in section 5.1.

According to the latest data available from Eurostat, based on a survey of the EU 28 population aged 16 and older in 2017, 3.1% of all citizens, or 179m people, had unmet healthcare needs.[17] The reasons behind these unmet needs include:

- being too far away from the nearest healthcare provider;

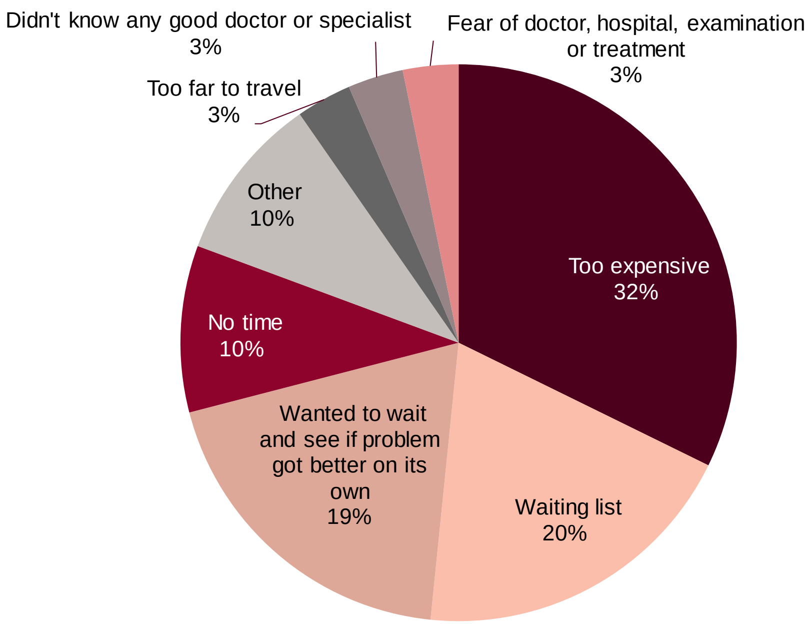
[15] CableLabs, https://www.cablelabs.com/technologies#DOCSIS%C2%AE-3.1-Technology, accessed 6 September 2019.
[16] A gross quantification (as opposed to a net quantification) only provides the scale of the immediate effect and does not make any deductions for indirect effects. Therefore, it is characterised by higher uncertainty.
[17] Eurostat, Self-reported unmet needs for medical examination by sex, age, main reason declared and income quintile.

- insufficient time;
- waiting lists;
- expense;
- lack of connection to good doctors or specialists;
- fear of doctors, hospitals, examinations or treatment;
- a desire to wait and see if problems get better on their own.

Figure 3.1 shows the split of reasons for the EU 28 area. For 23% of the respondents, time was a constraint in accessing the care they needed. This time was associated with waiting lists, finding time to go to a consultation, or long travel time. These transaction costs could potentially be addressed by increased online access to medical care.

In addition, more efficient delivery of healthcare might lead to a decrease in the cost of access, which has the potential to benefit 32% of the population with currently unmet needs. Moreover, future applications and services could also reduce search frictions for those who can't find a good doctor or specialist.

Figure 3.1 Reasons for unmet medical needs in EU 28 in 2017



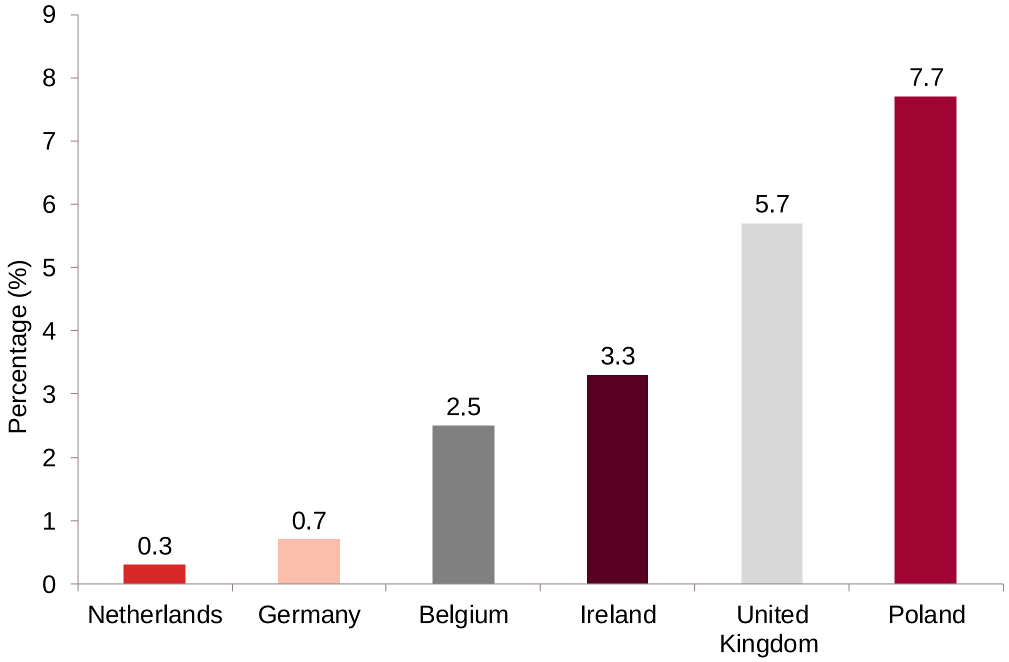
Source: Oxera analysis of Eurostat data (hlth_silc_13).

The following subsection presents the size of the unmet needs for medical care in six European countries.

3.2.1 Results by country

Figure 3.2 below shows the size of the unmet medical care across a number of European countries. The opportunity in addressing unmet medical needs can benefit up to 0.3% of the population who are aged 16 or older in Netherlands, 0.7% in Germany, 2.5% in Belgium, 3.3% in Ireland, 5.7% in the United Kingdom and 7.7% in Poland.

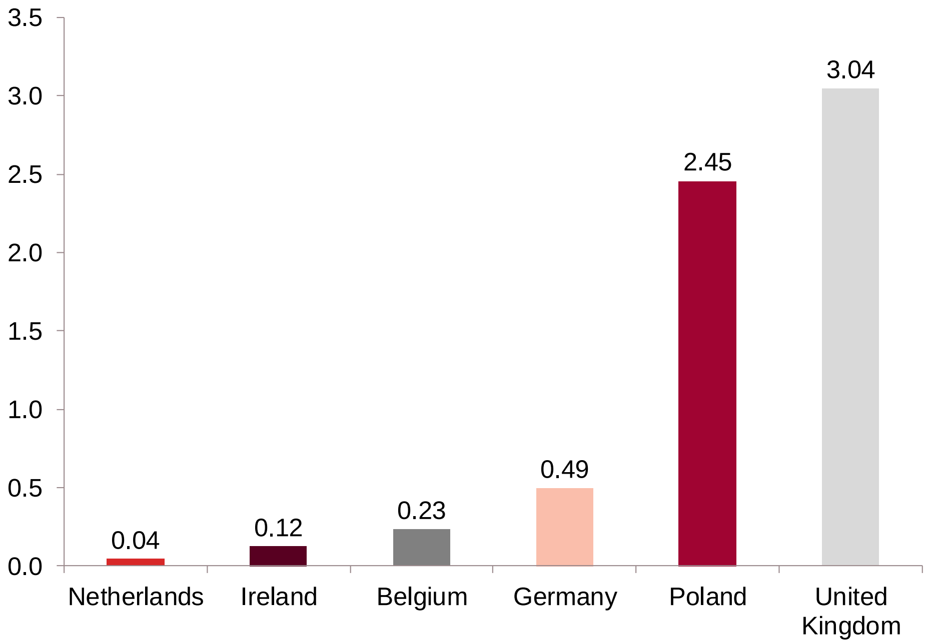
Figure 3.2 Percentage of population with unmet medical needs in 2017



Source: Oxera analysis of Eurostat data (hlth_silc_13).

Assuming that each person with unmet medical needs missed only one appointment, the total number of additional examinations needed is in the order of millions for large counties such as the United Kingdom and Poland (see Figure 3.3).

Figure 3.3 Estimate of the number of unmet examinations per year (m)



Source: Oxera analysis of Eurostat data (hlth_silc_13 and demo_pjan).

Improving access to healthcare helps to maintain better public heath, prevent and manage diseases and reduce the risk of future complications. Moreover, it can offers peace of mind to individuals who think they need medical care.

3.3 Transaction costs that could be addressed by transformed workplaces

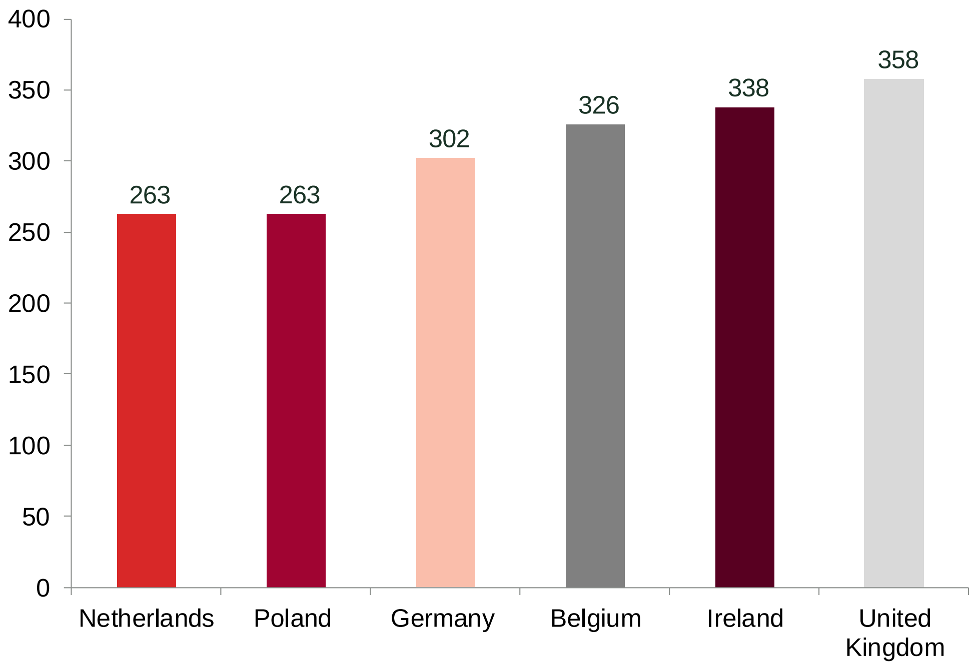
Travelling costs are one of the largest frictions in modern society. People travel for work, education, shopping, leisure, and other purposes; in particular, travelling between home and the workplace affects a large part of the economically active population.

Increased availability of fast and reliable Internet connections at home and VR and AR devices could lead to a new wave of homeworking possibilities. In the next subsection we describe the opportunity that exists in this area and set out the results of our analysis quantifying the current value of time associated with commuting that could be replaced by working from home. In section 5.2, we describe some of the technologies that could improve opportunities to work from home and the economic benefits that could arise in addition to reduced transaction costs.

3.3.2 Results by country

Looking at a selection of European countries, we observe that the average time spent commuting per year ranges from 263 hours in the Netherlands and Poland to 302 hours in Germany, 326 hours in Belgium, 338 hours in Ireland and 358 hours in the UK (see Figure 3.4). While working from home is not a viable option for all types of work, the opportunity working from home presents to address travelling transaction costs is sizable.

Figure 3.4 Hours spent commuting per commuter per year

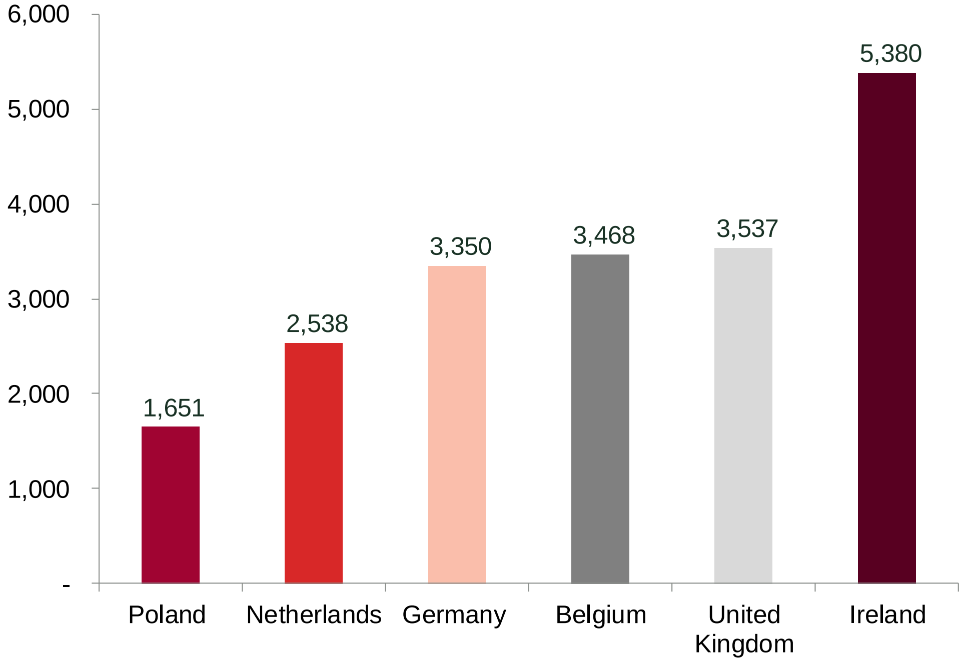


Source: Oxera analysis of Eurostat data on Commuting in the same region and Commuting in the another region (lfst_r_lfe2ecomm) and Eurofound data on Mean duration of commuting time one-way between work and home (qoe_ewcs_3c3).

To further assess the opportunity that arises from eliminating commuting time, we have used estimates of the value of time to arrive at an equivalent monetary assessment of these transaction costs. Our analysis indicates that the average commuter values the annual time they will spend commuting at €1,651 in Poland, €2,538 in the Netherlands, €3,350 in Germany, €3,468 in

Belgium, €3,537 in the United Kingdom, and €5,380 in Ireland (see Figure 3.5 below).

Figure 3.5 Value of annual time spent commuting per commuter (€)



Source: Oxera analysis of Eurostat data on Commuting in the same region and Commuting in the another region (lfst_r_lfe2ecomm), Eurofound data on Mean duration of commuting time one-way between work and home (qoe_ewcs_3c3) and value of time based on Wardman, M., Chintakayala, V. P. K. and de Jong, G. C. (2016), 'Values of travel time in Europe: Review and meta-analysis', *Transportation Research Part A: Policy and Practice*, 94, pp. 93–111.

Unlocking this opportunity would allow commuters to use the respective time for other activities, such as leisure or additional hours of work. At country level this represents a significant amount of hours and value as seen in Table 3.1 below.

Table 3.1 Time value associated with commuting by country per year

	Hours (bn)	Time value (€bn)
Ireland	0.8	12.1
Belgium	1.5	16.1
Netherlands	2.3	22.1
Poland	4.3	26.9
United Kingdom	11.5	114.2
Germany	12.6	139.5

Source: Oxera analysis of Eurostat data on Commuting in the same region and Commuting in the another region (lfst_r_lfe2ecomm), Eurofound data on Mean duration of commuting time one-way between work and home (qoe_ewcs_3c3), value of time based on Wardman, M., Chintakayala, V. P. K. and de Jong, G. C. (2016), 'Values of travel time in Europe: Review and meta-analysis', *Transportation Research Part A: Policy and Practice*, 94, pp. 93–111.

3.4 Transaction costs that could be addressed by new services and apps in social and digital interaction

Two of the main transaction costs involved in maintaining social interaction are time and geographical barriers. As future applications and services for social interactions will be developed in the future (as explored in section 5.3) these transaction costs could be reduced and the scale of the social interactions can be enlarged to include a wider group of people.

Over 70% of people in all age groups in the UK agree that being online helps them keep close to or in touch with friends and family, which indicates the importance of the Internet in maintaining social relationships.[18]

For the younger generation, who use a variety of online platforms on a daily basis (including social media, instant messaging, gaming networks, video chats and live streaming), the Internet is a positive way to create new friendships and maintain existing ones.[19] Being online is key for many young people's relationships; in a recent survey, 54% of respondents aged 8–17 said that they would feel isolated if they couldn't talk to their friends via technology, and 39% said that they had made friends online that they wouldn't have met otherwise.[20]

To assess the size of the opportunity that could be addressed by gigabit connections in reducing transaction costs relating to maintaining social interactions, section 3.4.3 presents data on how frequently people in each country meet with their friends and family. The premise is that some of the less frequent interactions could be changed by VR and AR applications and services.

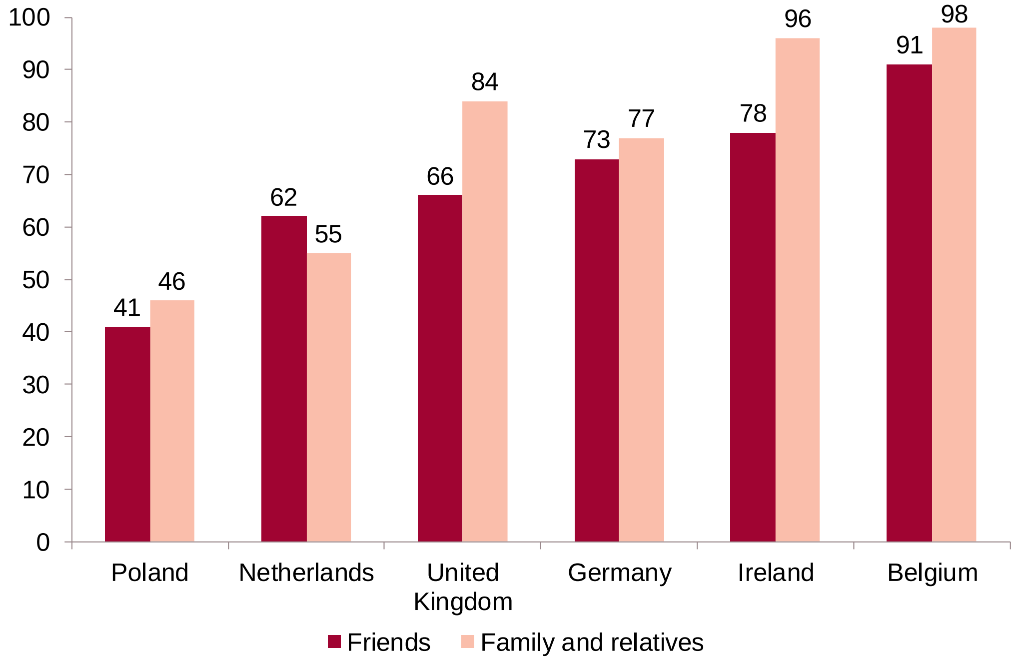
3.4.3 Results by country

Meeting up with friends and family involves transaction costs. When these costs are higher, this leads to a smaller number of social interactions.

On average, people aged 16 and older have 41 meetings per year with their friends in Poland, 62 per year in the Netherlands, 66 per year in the United Kingdom, 73 per year in Germany, 78 per year in Ireland and 91 per year in Belgium. Similarly, the annual average number of meetings with family and friends is 46 in Poland, 55 in the Netherlands, 77 in Germany, 84 in the United Kingdom, 96 in Ireland and 98 in Belgium.

[18] Ofcom (2018), 'Always On', based on Ofcom (2018), 'Communications Market Report', 2 August, p. 18, ofcom.org.uk/__data/assets/pdf_file/0022/117256/CMR-2018-narrative-report.pdf, accessed 9 September 2019.
[19] UK Safer Internet Centre (2018), 'Digital friendships: the role of technology in young people's relationships', 11 February, https://d1afx9quaogywf.cloudfront.net/sites/default/files/Safer%20Internet%20Day%202018/Digital%20Friendships%20-%20the%20role%20of%20technology%20in%20young%20people%27s%20relationships%20-%20SID2018.pdf, accessed 6 September 2019.
[20] UK Safer Internet Centre (2018), 'Digital friendships: the role of technology in young people's relationships', 11 February, https://d1afx9quaogywf.cloudfront.net/sites/default/files/Safer%20Internet%20Day%202018/Digital%20Friendships%20-%20the%20role%20of%20technology%20in%20young%20people%27s%20relationships%20-%20SID2018.pdf, accessed 6 September 2019.

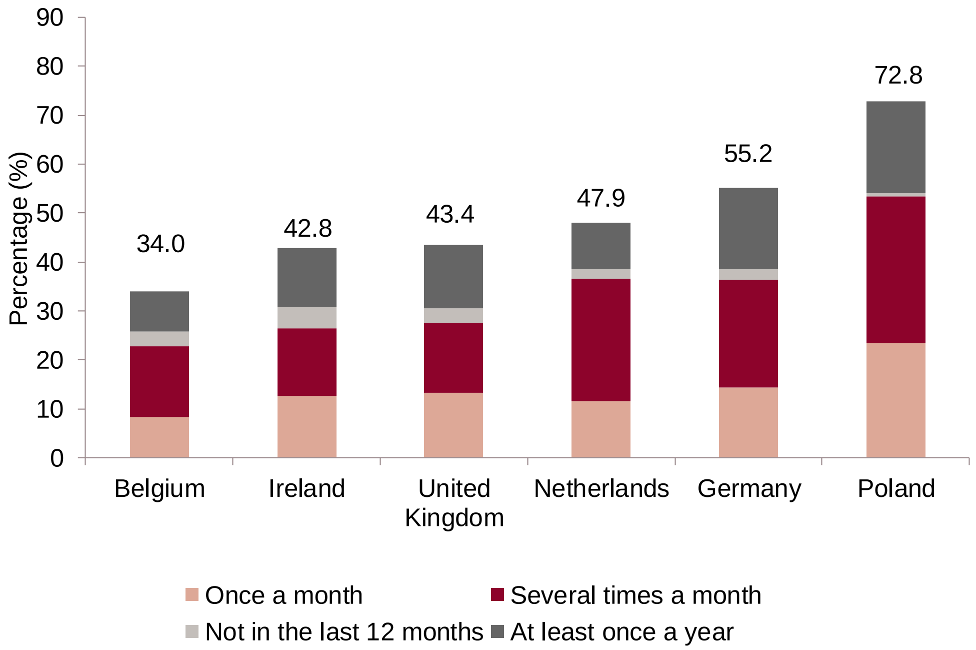
Figure 3.6 Average number of meetings per year with friends and family and relatives



Source: Oxera analysis of Eurostat data (ilc_scp09 and demo_pjan).

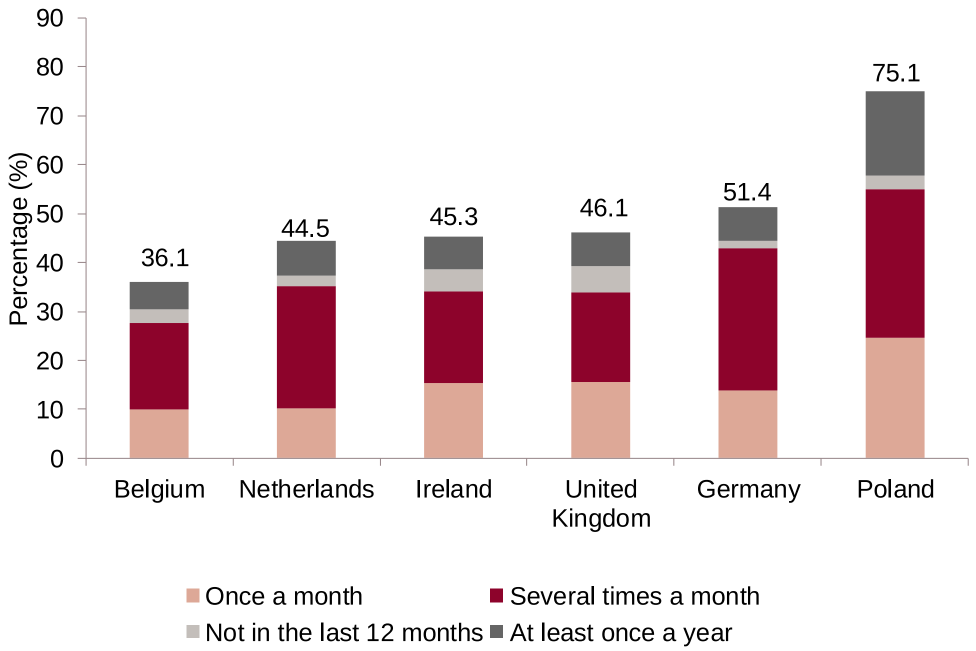
However, there is variation inside each country, as some people meet more frequently than others. Figure 3.7Figure 3.7 and Figure 3.8 below show the percentage of the population aged 16 and older who meet with their friends and family less than once per week. In their case, the frequency of their interactions could be increased by lowering the transaction costs associated with distance and time via future Internet applications and services.

Figure 3.7 Percentage of people who meet with family and relatives less than once per week



Source: Oxera analysis of Eurostat data (ilc_scp09).

Figure 3.8 Percentage of people who meet with friends less than once per week



Source: Oxera analysis of Eurostat data (ilc_scp09).

Enabling easier interactions between people can alleviate loneliness and isolation and increases the social capital.[21]

[21] Lelkes, O. (2010). Social participation and social isolation. *Income and living conditions in Europe*, 217, 240; Lelkes, O. (2013). Happier and less isolated: Internet use in old age. *Journal of Poverty and Social Justice*, 21(1), 33-46.

3.5 Potential for reducing emissions

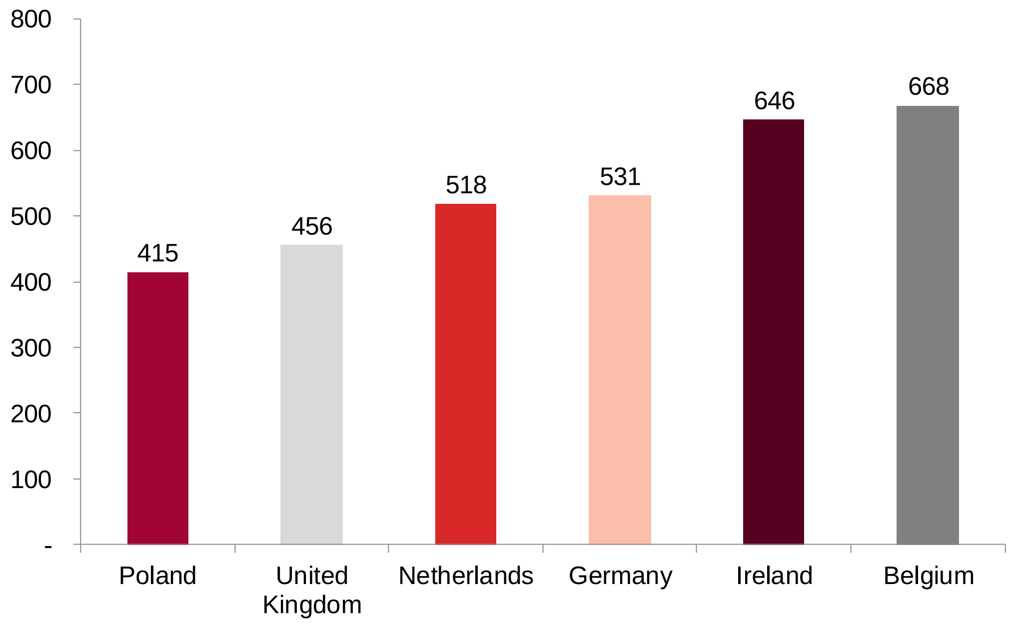
Currently, many activities that a person undertakes require travelling from one place to another. The length and the frequency of the journey can range from a short drive to the near-by cinema, to the daily commute to work or the long plane trip for a holiday. While these journeys are often seen as an undesired part of the activity they are also unavoidable and have negative externalities on the wider society through increased emissions.

In order to characterise the potential to be addressed by technologies that reduce the need to travel, which will be explored in section 5 and in particular section 5.4, we present below the emission footprint associated with commuting to work. This activity is common across a large number of citizens in each country.

3.5.4 Results by country

The average emission impact per commuter in a year is above 400 kg in all six countries after accounting for the type of transport used to travel. Irish and Belgian commuters have approximately 50% higher emissions than Polish commuters. According to Figure 3.9 the United Kingdom, Netherlands and Germany are in between these estimates.

Figure 3.9 Estimated average annual emissions per commuter per year (kg)



Source: Oxera analysis of Eurostat data on Commuting in the same region and Commuting in the another region (lfst_r_lfe2ecomm), Eurofound data on Mean duration of commuting time one-way between work and home (qoe_ewcs_3c3) and Data on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism.

Scaling the above quantities by the commuting population in each country leads to large carbon reduction opportunities that could be unlocked by future applications and services aimed at eliminating the need for commuting. A summary of these opportunities is presented in Table 3.2 below.

Table 3.2 Estimated emissions associated with commuting by country per year

	Emissions (1,000 tonnes)
Ireland	1,261
Belgium	2,647
Netherlands	3,326
Poland	6,502
United Kingdom	12,724
Germany	19,013

Source: Oxera analysis of Data on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism and the commuting model described in appendices A1.3 and A1.4.

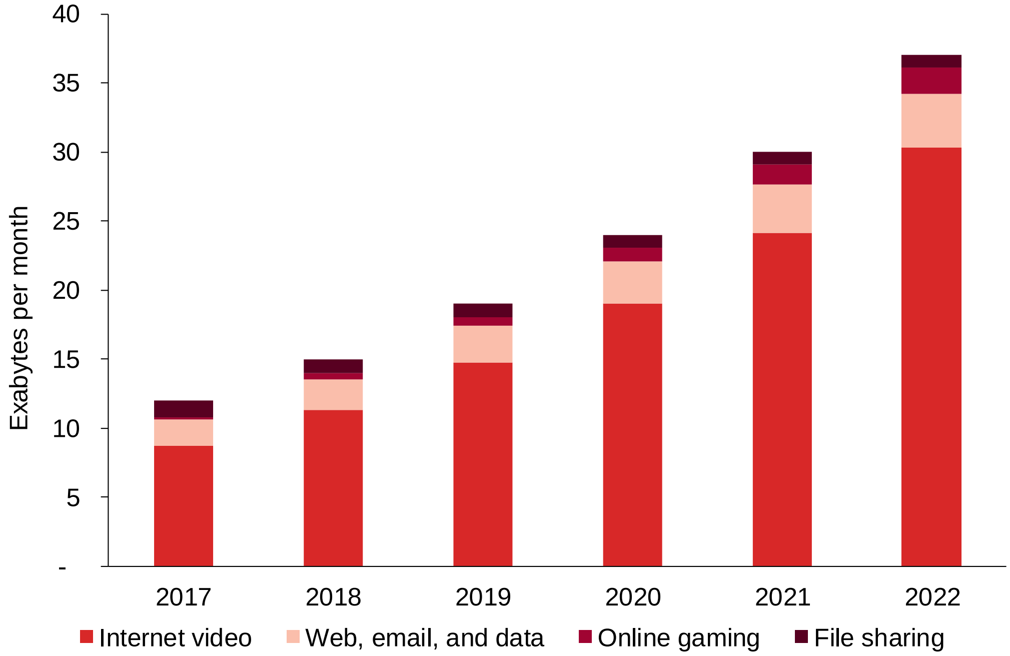
4 Near-term demand will require more capacity to fulfil

The impact of a network capacity upgrade such as DOCSIS 3.1 is not limited to transformational applications. Increases in consumption of data over time via present-day applications and devices will need to be accommodated, or else the network will become a constraint on activity or experience. In section 5, we explain how this process of increasing data consumption and device capabilities can also allow the development and mainstream adoption of novel applications. In this section, we describe present patterns of usage and how these could result in a requirement for 1Gbps line-speed capacity.

4.1 Structure of current demand by application

Data and broadband capacity requirements are highly dependent on the application used. A voice call may require as little as 30kbps for the duration of the call. Transactional applications such as online banking tools typically require even less bandwidth. On the other hand, video-streaming services can use around 5Mbps in high definition, and significantly more in Ultra HD or 4K formats. In aggregate, video based applications dominate broadband usage, as shown below in Figure 4.1.

Figure 4.1 Western European consumer traffic consumption, by application, 2017–22



Note: Oxera assumes that the application split for Western Europe is similar to Cisco's estimate for the global split. All data are forecast rather than actual, based on the Cisco VNI tool's estimation methodology.

Source: Oxera analysis of Cisco Virtual Networking Index tool, https://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html, accessed 5 September 2019.

Streaming entertainment and other video-based services account for around 75% of all traffic, and are forecast to remain the dominant application for the next few years. Note that the video grouping includes any application that makes use of video, such as healthcare technology and video conferencing—we discuss these further in section 5. We can also see that the amount of online gaming traffic (while small in comparison to video) is growing rapidly at approximately 65% CAGR (compound annual growth rate). In total, these two factors drive total demand growth to approximately 25% CAGR—a doubling every three years.

Holding all other factors constant, data-rich applications will increase demand for future data transfers, which will translate into higher broadband utilisation levels that will, in turn, require capacity upgrades.

4.2 Structure of current demand by time

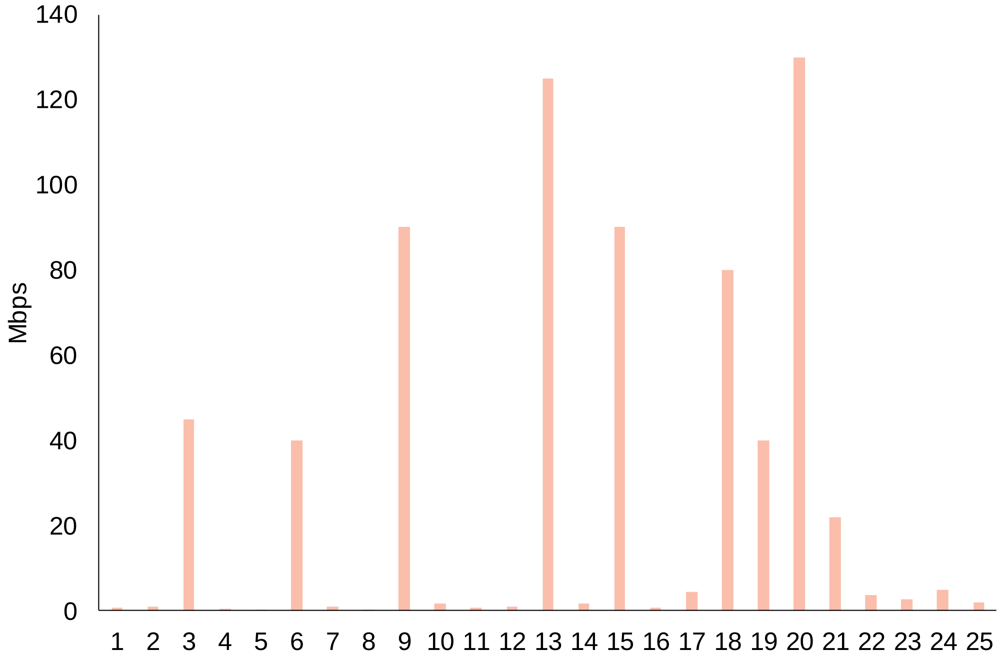
An additional complexity is that bandwidth and data are not always smooth and predictable over time. In the days when communications traffic was dominated by voice calls, determining capacity requirements was simple: a call required 4kHz of analogue bandwidth, and the local line was engineered to deliver 4kHz of bandwidth and no more. The line sat completely idle when not in use, and only one call was possible at a time. Utilisation of the line therefore depended on the call-arrival rate—the probability of each user making or receiving a call.

The wide array of applications supported by the recent digital transformation spread this demand out over different time intervals and scales. Some applications, such as file transfers and cloud-based backups, use our broadband connections at any time of day, including when we sleep. In addition, some applications use bandwidth intermittently in support of the service they provide, rather than consuming data at a constant rate. Video streaming can use a very high level of bandwidth when establishing a session, followed by periods of no usage as the application operates off local buffer memory. Video-compression techniques will mean that how much bandwidth is actually needed will depend on the specific service, required quality and the nature of the content being viewed.[22] In addition, network conditions (e.g. elsewhere on the Internet) can interact, causing re-transmissions. These factors make video traffic unpredictable and 'bursty', with peaks of throughput as high as 100Mbps.[23]

When combined over multiple applications available to a device or user, a very intermittent pattern of demand emerges. We have plotted a stylised timeline of bandwidth demand below in Figure 4.2.

[22] Dynamic content with a high number of moving images will require more bandwidth than content containing a high number of static images.
[23] See Martin, J., Fu, Y., Wourms, N. and Shaw, T. (2013), 'Characterizing Netflix bandwidth consumption', IEEE 10th Consumer Communications and Networking Conference, 11–14 January.

Figure 4.2 Stylised plot of device-level bandwidth demands over time



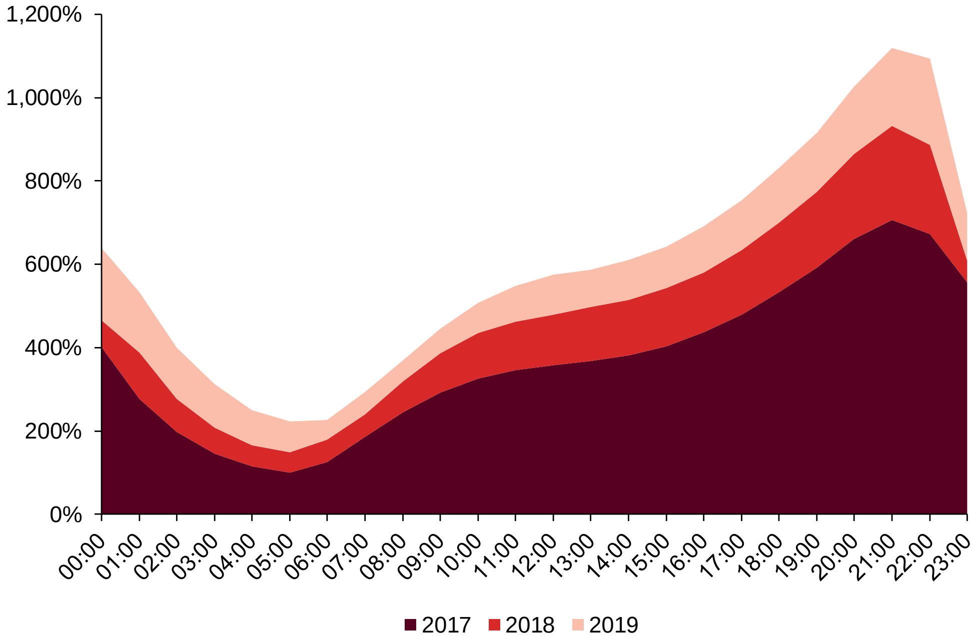
Note: We have intentionally not specified the timescale on the x axis. This is because real-world studies by Liberty Global show that this intermittent and unpredictable nature of broadband traffic occurs across different timescales (hours, minutes, and seconds).This 'self-similarity' of traffic across timescales has been studied in the field of network engineering. For an overview, see Park, K,, and Willinger, W., (1999) 'Self-Similar Network Traffic: An Overview', in Self-Similar Network Traffic and Performance Evaluation, K. Park and W. Willinger, Eds. New York: Wiley-Interscience, 1999.

Source: Oxera analysis.

While these peaks are within the reach of high-tier broadband packages available today, there are implications, especially in households with multiple users. Concurrent usage, particularly of popular video services, can mean that peaks in usage coincide and exceed capacity. In that situation, video services can respond in real time to adapt and use less bandwidth; however, those responses impose a cost on users. Service buffering and disruption to other household users can be a frustration, while a reduction in service quality can reduce the amount of enjoyment consumers derive from the content.

When this peaky demand profile is combined over multiple households, aggregate patterns begin to emerge easily. Figure 4.3 below shows the aggregated day-level traffic graph from Virgin Media in the UK.

Figure 4.3 Day-level aggregate data throughput in a weekday, Virgin Media network – indexed



Note: The network throughput has been rebased to 100% with reference to the lowest value in 2017. The data represents average traffic across the weekdays in the month of August.

Source: Oxera based on Virgin Media data.

Day-level demand shows a clear peak in consumption during the evening. Cisco expects that 'busy hour' Internet traffic will grow faster than traffic outside these peaks.[24] The driver behind this peak is the consumption of video services; usage of these services is highest when the most people within a household are at home and have time to consume then. This trend will ultimately place more pressure on broadband lines in order to meet demand.

4.3 Device capabilities and platforms will drive increased demand

In the near term, devices that use residential broadband connections (such as tablets, handsets and PCs) will continue to improve such that peak demand will increase too.

- **Improved connectivity via Wi-Fi 6.** The next version of Wi-Fi on the horizon is IEEE 802.11ax, which will have around four times more throughput than its predecessor. This will provide multi-gigabit capability.
- **Improved screens.** High resolution and pixel density allows users to consumer higher-quality content. The latest phone handsets on the market have HD- or 'Quad' HD-capable screens and may move to higher standards (4K, UHD) in the near future. Television manufacturers have 8K products either available or ready to launch in 2019.[25]

[24] Cisco (2019), 'Visual Networking Index: Forecast and Trends 2017–2022', p. 24, 27 February, https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.pdf, accessed 5 September 2019.
[25] See Archer, J. (2019), 'First 8K TV Streaming Service Announced – And It's Not Who You Think', *Forbes*, 15 March, https://www.forbes.com/sites/johnarcher/2019/03/15/first-8k-tv-streaming-service-announced-and-its-not-who-you-think/#27413e1326c4, accessed 5 September 2019.

- **Improved processor speeds.** Each generation of tablet, handset and PC typically receives a faster, more powerful processor than the device it replaces hence it can use more data.
- **Platforms adopting 8K content.** For example, service provider Rakuten TV intends to launch 8K streaming by the end of 2019.[26]

As users replace older devices or migrate to new service contracts, the increased capabilities of these newer devices will facilitate improved services and higher bandwidth usage.

4.4 Preferences and demographics mean that some users are likely to need 1Gbps connections relatively soon

The new digital habits that have emerged over the past few decades are placing increased demand on broadband services. In the very short term, even with the existing suite of applications, it is likely that some high-demand households will seek 1Gbps connectivity. Users today may not fully realise and value the need for such connections. However this is likely to change in the future when 1G connectivity is available at scale and applications can exploit these links – we discuss these potential applications further in section 5.

Moreover, as demographics shift, society is more likely to be familiar with and prefer digital and online services over the traditional ones. Younger cohorts and digital natives (those who have grown up with digital technologies) show particular preferences for on-demand and online services as the latter have become more important than offline activities.[27]

For the quality of experience to be maintained, the broadband network must be built to handle peak levels of demand, not the average.[28] While this is true of other network infrastructures (road, rail, electricity and water), broadband differs in the array of applications served and unpredictable nature of demand. An upgrade to DOCSIS 3.1 can address these challenges via a home broadband router replacement, allowing network operators to serve selected high-demand areas or users in a cost-effective way.

[26] Archer, J. (2019), 'First 8K TV Streaming Service Announced – And It's not Who You Think', 15 March https://www.forbes.com/sites/johnarcher/2019/03/15/first-8k-tv-streaming-service-announced-and-its-not-who-you-think/#27413e1326c4, accessed 5 September 2019.
[27] A recent study by Ofcom showed that young people (16–24 years old) in the UK spend more time online than they did watching television, are more likely to use the internet for online multiplayer games and account for a large proportion of and growth in VoIP and video-calling. See Ofcom (2019), 'Online Nation: 2019 report', 30 May.
[28] Dimensioning the capacity may use a probability weighted approach, such that the chance of exceeding the capacity is sufficiently low.

5 Transformational applications

The capabilities enabled by DOCSIS 3.1 technology could unlock applications with transformational benefits in addition to improving user experience in existing applications. The technology could improve network quality across several dimensions, including the following.

- **Increased capacity.** Up to 1Gbps of broadband capacity will significantly improve broadband speed and quality of experience across a large number of applications.[29]
- **Lower latency.** DOCSIS 3.1 will significantly reduce network delay ('latency') down to just 1ms for many applications.[30] It will improve the experience on time-sensitive applications such as streaming, video calls or video games. Low latency is particularly important for applications that do not benefit from buffered data and instead require real-time control.[31]
- **Improved reliability.** DOCSIS 3.1 will enable features such as proactive plant maintenance, which can detect degradation of the physical cables, and ensure that maintenance is undertaken before more disruptive faults develop.[32]

In line with the four main areas that have been identified in section 3, we have assessed how gigabit connections could lead to:

1. revolutionised healthcare;
2. transformed workplaces;
3. improved social and digital interaction;
4. reduced emissions.

This section sets out the wider social benefits from these four areas through examples of transformational applications that could emerge within the next few years. In the area of revolutionised healthcare we describe the impact of remote monitoring and diagnostic devices; in the area of transformed workplaces we describe the increased productivity associated with remote working tools and services. The improved social and digital interaction is described through applications of cloud-based video games, volumetric videos use for immersive entertainment and VR learning. Lastly we describe how these examples of transformational applications can contribute to reduced emissions.

For each application, we describe how they are intended to work, what benefits they could bring to society, and the role that gigabit connections could play in unlocking them. The examples provided rely on sources such as the public website of the device providers, CableLabs, which is a not-for-profit innovation and research and development lab that is funded by private entities (including

[29] CableLabs, https://www.cablelabs.com/technologies#DOCSIS%C2%AE-3.1-Technology, accessed 6 September 2019.
[30] CableLabs, https://www.cablelabs.com/technologies#Low-Latency-DOCSIS%C2%AE, accessed 6 September 2019.
[31] Tech Advisor, https://www.techadvisor.co.uk/how-to/game/lower-ping-3609346/, accessed 10 September 2019
[32] CableLabs, https://www.cablelabs.com/technologies/proactive-network-maintenance, accessed 10 September 2019

Liberty Global), technology companies such as Intel, and online publishers with a technology focus such as TechCrunch.

5.1 Revolutionised healthcare

As life expectancy has increased rapidly over the past century, so has the proportion of Europe's population aged 75 and over. Although quality of life is advancing rapidly, over-75s have a higher incidence of chronic disease, some with comorbidities, mental health problems, or memory difficulties.[33,34]

In addition, one of the greatest fears of the elderly is that they will eventually no longer be able to live independently at home.[35] Technology may be able to address both concerns and below we offer some examples that focus on this.

5.1.1 Healthcare applications

In general, medical consultations, assessment and diagnostics are currently delivered centrally from general practice surgeries (in the case of primary care) and hospitals (in the case of secondary care). This requires both patients and doctors to be physically present in the same location. Developments in healthcare technology could potentially alleviate this requirement, including the following.

- **Simple remote monitoring**. Remote assessment of some patients could be enabled by continuous collection of rich data at a patient's home and remote delivery of that data from the patient's home to their doctor.
- **Integrated patient-support applications**. CableLabs has developed a suite of applications that could enable older people to live autonomously in their home for longer.[36] In particular, CableLabs has developed applications that could help to ensure elderly people are taking the right medication, and that health issues are detected rapidly.
- **Remote diagnostics**. Diagnostics-quality[37] video streaming and sharing could allow remote consultations, where patients and/or doctors carry out consultations from their homes.[38] An example of this application, which has already been implemented, is the Telestroke Network in the UK as a collaboration between Liberty Global's subsidiary Virgin Media and the NHS. This network enables hospitals to offer out-of-hours remote stroke-diagnosis (where it previously did not) in Cumbria and Lancashire. Extending this network to stroke specialists' homes, whereby high-quality video technology is enabled, could allow stroke specialists to remotely

[33] The Netherlands Institute for Social Research (2019), 'Summary: Caring for older people living at home: Review of care for independent community-dwelling over 75s: problems and future developments', April.
[34] Office for National Statistics, https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/ageing/articles/livinglongerhowourpopulationischangingandwhyitmatters/2018-08-13, accessed 10 September 2019
[35] The Netherlands Institute for Social Research (2019), 'Summary: Caring for older people living at home: Review of care for independent community-dwelling over 75s: problems and future developments', April.
[36] CableLabs (2017), 'Behind the Tech: Connected Healthcare and The Near Future. A Better Place', 31 August, https://www.cablelabs.com/exploring-tech-near-future-connected-healthcare, accessed 6 September 2019.
[37] Real-time remote medical diagnostics using wireless video communications require specific quality criteria. See Rao, S. P., Jayant, N. S., Stachura, M. E., Astapova, E. and Pearson-Shaver, A. (2009), 'Delivering Diagnostic Quality Video over Mobile Wireless Networks for Telemedicine', *International Journal of Telemedicine and Applications*, 4 May.
[38] 'Diagnostics-quality' refers to the requirement for medical diagnosis data to be reliable, accurate and in real-time. High bandwidths may also be required to capture images at a high enough resolution to detect fine-grained details.

diagnose stroke patients in these regions at any time of day. This can lead to increased speed of access to treatment and improved patient outcomes.

- **Robotic support**. CableLabs is developing an intelligent robot that serves as an in-home companion and nurse. The robot would be capable of social interaction and may be able to build a rapport with the person under its care.[39] With full knowledge of the health treatments and drug regimens, it would ensure that patients take the correct medication throughout the day.[40] In addition, the robot would monitor the patients' movements in case they fall or suffer another medical emergency. All data captured by the robot would be analysed and shared with health professionals, as well as with patients' relatives (if desired) to provide peace of mind.

5.1.2 Economic benefits

Continuous monitoring of health data that is captured by sensors and applications can help some elderly people to live at home independently for longer. The future availability of home-based scanning devices could also make it possible to diagnose a number of diseases from home. This could enable the detection of neurodegenerative diseases such as Alzheimer's at an early stage.[41]

The availability of gigabit connections at home could mean that remote diagnosis could be offered not only by specialists who are working in remote hospitals, but also by out-of-hours specialists. These specialists may be able to offer stroke consultations to patients from their own home using diagnostic-quality video streams.

In future, this technology could mean that stroke patients no longer have to travel to a hospital with a stroke specialist or vice versa, increasing speed of access to treatment and improving patient outcomes. Previous estimates for the UK show that the costs of stroke are high, with £4.3b spent per year on direct care while another £2.4b is lost via the provision of informal care. The same study shows that strokes in the UK impose a further £1.3b loss in productivity.[42] Remote video monitoring has already been found to reduce NHS costs associated with stroke care by approximately £30,000 for each patient that avoids further care via early detection and treatment.[43] Additionally, the North Cumbria University Hospitals NHS Trust, whom Virgin Media provide with broadband network services, expects that the Telestroke Network could save social services £3.3m per year in residential and nursing care costs.[44]

[39] CableLabs (2017), 'Behind the Tech: Connected Healthcare and The Near Future. A Better Place', 'The Near Future, A Better Place, Intelligent Virtual Agent, 31 August, https://www.cablelabs.com/exploring-tech-near-future-connected-healthcare, accessed 6 September 2019.
[40] CableLabs (2017), 'Behind the Tech: Connected Healthcare and The Near Future. A Better Place', 31 August, https://www.cablelabs.com/exploring-tech-near-future-connected-healthcare, accessed 6 September 2019.
[41] CableLabs (2017), 'The Near Future. A Better Place. Brain Scans', video, https://www.cablelabs.com/thenearfuture, accessed 11 September 2019
[42] Saka, Ömer, Alistair McGuire, and Charles Wolfe (2009), 'Cost of stroke in the United Kingdom.' *Age and ageing,* 38(1), pp. 27-32, https://academic.oup.com/ageing/article/38/1/27/41534, accessed 10 October 2019.
[43] Polycom (2013), 'HS Cumbria & Lancashire Cardiac and Stroke Network (CSNLC) Improves Stroke Treatment and Saves Lives with On-Demand Telemedicine Powered by Polycom® RealPresence® Video Solutions', press release 1 May, https://www.polycom.co.uk/company/news/press-release-filter/2013/20130501.html accessed 16 October 2019.
[44] Dr O'Donnell, M., 'The Cumbria and Lancashire Telestroke Network: saving lives with remote stroke diagnosis', Virgin Media Business, https://www.virginmediabusiness.co.uk/customer-stories/the-cumbria-and-lancashire-network/, accessed 6 September 2019.

Improved video streams could enable home consultations and ensure there is no need for older persons to travel for consultations at the hospital or GP surgeries, reducing travel time and waiting times.

5.1.3 The role of better connectivity in unlocking transformative healthcare applications

Healthcare applications could draw on the benefits of 1Gbps connections in numerous ways, including the following.

- **Capacity.** Remote assessment of patients via video and audio streams would require high bandwidth. In order to enable accurate assessments and diagnoses via video, the quality of the video has to be high enough to enable precise identification of symptoms. High-resolution brain or body scans consists of large file sizes, requiring high transfer speeds to send and receive these files in time-critical situations. Incremental bandwidth requirements would also be added by the use of multiple connected monitoring devices sending, for example, constant streams of data to a provider for AI processing and diagnosis.
- **Latency.** Lower latency and low jitter could ensure that home-based diagnostic scanning devices could be operated without lag, ensuring continuous diagnostic-quality images.
- **Reliability.** Critical services, such as remote monitoring or stroke diagnosis, would be likely to require higher reliability than that offered by legacy services with lesser technological requirements. This increased reliability could help ensure the applications are fit for purpose and are able to send and receive data at critical moments. Increased reliability will also be important in establishing trust in the new service.[45]

5.2 Transformed workplaces

Recent research by the UK’s Chartered Institute of Personnel and Development shows that around a third of UK professionals would like to work from home, but they do not currently have access to such an arrangement.[46] A study in *Human Relations* showed that remote working increased female participation in the workforce and resulted in a better work–life balance.[47] Even though remote working was introduced over 20 years ago, the number of UK employees that said they work mainly from home is only 6% and it has not increased since 2014.[48]

In addition to the reduction in travel time that could be achieved through working from home, the increased availability of fast and reliable Internet connections at home and the development of new applications could lead to a new wave of homeworking possibilities. Below we look at some examples of technologies that could enable this.

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[45] CableLabs, ‘Proactive Network Maintenance’, https://www.cablelabs.com/technologies/proactive-network-maintenance, accessed 6 September 2019.
[46] CIPD (2019), ‘UK Working Lives: The CIPD Job Quality Index’, June, p. 5, https://www.cipd.co.uk/Images/uk-working-lives-2019-v1_tcm18-58585.pdf, accessed 9 September 2019.
[47] Chung, H. and van der Horst, M. (2018), ‘Women’s employment patterns after childbirth and the perceived access and use of flexitime and teleworking’, *Human Relations; Studies Towards the Integration of Social Sciences*, **71**:1, pp. 47–72.
[48] CIPD (2019), ‘Megatrends – Flexible working’, January 2019, p. 11

5.2.4 Description

Face-to-face meetings and collaboration allow workers to better share ideas by picking up and processing vocal cues, facial expressions and body language, which helps them to gauge reactions. These cues are the basis for building trust and professional intimacy.[49] Therefore, poor technology and low-quality internet access can act as a barrier when it comes to participating in meetings remotely; this can interfere in idea-sharing, restricting opportunities for development and innovation.[50]

To address this issue, a number of companies have developed a suite of emerging technologies that could enable remote working to mean a richer, more lifelike presence. These technologies could include real-time holographic displays, as well as AR video conferencing.

For example, reports indicate that Microsoft has created a telepresence technology that allows professionals from remote locations to work together in the same virtual space.[51] Augmented reality can create an illusion of physical presence and allow participants to read each other's verbal and non-verbal cues as if they were in the same room.

Smaller companies, such as Valorem Reply, are also developing technologies to enable volumetric conferencing,[52] mainly through the use of VR and AR.[53] Meanwhile, start-ups such as Meetingroom.io are taking a different approach, using VR to create shared virtual conference rooms that users can dial into and be volumetrically present.[54]

Telepresence technologies like these, which use high-resolution video calling, VR, AR and holographic images, could theoretically reduce barriers to working from home, as they could allow more natural social interactions.

The ability to work from home could also enable workers who live in more remote locations to access a wider range of jobs. Where outputs can be delivered digitally, it is possible that it could be more efficient, for example, to hire a worker in a remote location who can perform at the same level as a local worker but for a lower wage.[55]

5.2.5 Economic benefits

An increase in the number of people working from home could have a number of benefits, including reduced travel costs and travel time as discussed in section 3.2. In addition, a reduction in the need to commute could enable

[49] Kinsey Goman, C. (2013), 'Back To The Future With Face-to-Face Technology', *Forbes*, 25 July, https://www.forbes.com/sites/carolkinseygoman/2013/07/25/back-to-the-future-with-face-to-face-technology/#d9e161b44b74.
[50] Kinsey Goman, C. (2017), 'Why IBM Brought Remote Workers Back To the Office - - And Why Your Company Might Be Next', *Forbes*, 12 October, https://www.forbes.com/sites/carolkinseygoman/2017/10/12/why-ibm-brought-remote-workers-back-to-the-office-and-why-your-company-might-be-next/#fd1c9ce16da2, accessed 6 September 2019.
[51] Fink, C. (2017), 'The Trillion Dollar 3D Telepresence Gold Mine', *Forbes*, 20 November, https://www.forbes.com/sites/charliefink/2017/11/20/the-trillion-dollar-3d-telepresence-gold-mine/#51839e022a72, accessed 6 September 2019.
[52] Volumetric data contains the entire volume of data in three dimensions. Therefore, volumetric conferencing allows communications with a 3D projection of a person, see https://voxon.co/voxon-creates-the-worlds-first-volumetric-video-call-over-5g/, accessed 12 September 2019
[53] Valorem Reply (2019), 'Holobeam Holographic Telepresence Technology', https://go.valorem.com/HoloBeam.html, accessed 6 September 2019.
[54] See https://meetingroom.io, accessed 6 September 2019.
[55] Pelletier, A. and Thomas, C. (2018), 'Information in online labour markets', *Oxford Review of Economic Policy*, **34**:2, 2 July, pp. 376–92.

professionals to live further away from their places of work, giving them more flexibility.[56]

New technologies could enable professionals to productively and successfully work from home in a wider range of sectors than previously possible. Graphic designers, video editors, or computer-aided engineers that heavily rely on IT infrastructure or require very high bandwidth could benefit from gigabit connections at home. Digital start-ups formed of professionals from around the world could collaborate in virtual meeting rooms. For these types of digital professionals, the richer, more immediate contact enabled by this kind of collaboration could reduce the need for business travel, resulting in lower emissions.

Moreover, the near future could see a number of emerging professions that are characteristic of the digital age, such as Youtubers, who rely on very high downstream and upstream bandwidth to edit and upload videos.

5.2.6 The role of better connectivity in unlocking transformative remote working applications

The next generation of remote working applications are likely to require very high bandwidth. For example, this is a requirement in order to get a sufficiently high-quality image in virtual meetings or to be able to transmit volumetric videos and holographic imagery.

Audio and video need to be sufficiently reliable to be used in a professional context, meaning that both low latency and low jitter are required. This could enable participants to notice non-verbal cues such as a millisecond of hesitation or a widening of the eyes, which could be missed if there was a lag on a holographic projection. Gigabit connections at home could help to ensure that these transformative applications function as required.

5.3 Improved social and digital interaction

The development of VR and AR has the potential to rapidly change the way that people interact, learn and are entertained. Entertainment technologies are being developed which are not limited to a screen but completely surround the user. By using virtual and augmented reality the user's immediate surroundings are transformed into an illusory environment. This is referred to as immersive entertainment.

Video services for entertainment as well as video gaming are two main drivers of online interaction and broadband data demand as mentioned in section 4.1. The current predictions indicate that they will continue to grow and become two of the most important means of digital interaction.[57]

Since 2017, gaming has been the most popular form of entertainment in the world, surpassing TV, movies and music in terms of its share of revenue.[58] In the first half of 2019, consumer expenditure on games was more than 45%

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[56] Chung, H. and van der Horst, M. (2018), 'Women's employment patterns after childbirth and the perceived access and use of flexitime and teleworking', *Human Relations; Studies Towards the Integration of Social Sciences*, **71**:1, pp. 47–72.

[57] Cisco Virtual Networking Index tool, https://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html, accessed 5 September 2019.

[58] Reuters (2018), 'Investing in the Soaring Popularity of Gaming: Sponsored Content Brought to You by OppenheimerFunds', 13 June, https://www.reuters.com/sponsored/article/popularity-of-gaming?utm_source=reddit.com, accessed 6 November 2019.

higher than on video, and expenditure on games accounted for around half the expenditure in the total entertainment market.[59] In 2018, digital gaming services generated 80.1% of games revenues.

Due to physical and geographical barriers people may be limited in their ability to experience live sporting or social events. A number of new technologies explored below may allow such events to be experienced from home. New forms of digital interaction may also facilitate and improve social interaction. Immersive education and virtual socialising may help combat isolation, bring together different cultures and improve social inclusion.

5.3.1 Improved digital interaction through video games

The emergence of cloud-based gaming platforms as opposed to the traditional console or PC game is likely to have a significant impact on the gaming sector. These cloud-based gaming platforms can be regarded as 'Netflix for video games' where the quality of the broadband becomes more important than the capacity of the device used for playing the game; an example of such a platform would be Google's 'Stadia' service.[60]

Gigabit speeds would allow users to play games directly from the digital gaming platform, enabling them to choose a game from a library and begin playing it rapidly, without needing to download or install the game files first. These streaming services will be available on almost any device, such as desktop PCs, laptops, tablets and mobile phones.[61]

The game providers will undertake all the data-intensive graphics processing in the cloud, which means that the gameplay on users' screens will be sent from the cloud too. Player inputs will be sent to the provider's servers, processed there, and then streamed back to the user as video.[62] In the near future, it is expected that some providers will offer 8K video resolution and gameplay at 120 frames per second.[63]

5.3.2 Improved digital interaction through immersive entertainment

Immersive entertainment can also help to overcome physical and geographical limits, as consumers can live unique experiences from their home.

Several companies have been developing the technology required for immersive entertainment. For example, Facebook is developing Manifold, a 360-degree camera that allows six degrees of freedom video content, which allows a user to see video captured by the camera from any angle via VR.[64]

[59] Entertainment Retailers Association (2018), 'Entertainment fans spend more than £100m a week on digital services', press release, 3 January, https://eraltd.org/news-events/press-releases/2019/entertainment-fans-spend-more-than-100m-a-week-on-digital-services/, accessed 3 September 2019
[60] See https://store.google.com/product/stadia_founders_edition, accessed 9 September 2019.
[61] Singletary Jr., C. (2019), 'Google developer explains Stadia's advantage over the competition', Digital Trends, 7 May, https://www.digitaltrends.com/gaming/google-stadia-advantage-over-competition/, accessed 6 September.
[62] Knapp, M., Lynch, G. and Hood, V. (2019), 'Stadia: everything you need to know about Google's game-streaming service', Techradar, https://www.techradar.com/uk/news/stadia-everything-you-need-to-know-about-googles-game-streaming-service, accessed 6 September 2019.
[63] Knapp, M., Lynch, G. and Hood, V. (2019), 'Stadia: everything you need to know about Google's game-streaming service', Techradar, https://www.techradar.com/uk/news/stadia-everything-you-need-to-know-about-googles-game-streaming-service, accessed 6 September 2019.
[64] See https://facebook360.fb.com/2018/09/26/film-the-future-with-red-and-facebook-360/, accessed 9 September 2019.

Intel opened a volumetric video studio in Los Angeles in January 2019 and collaborated with Paramount Pictures to use the technology for cinema.[65] Intel had developed this technology for use in US football stadiums, where the cameras would capture play from all angles and stitch the footage together to create a 360-degree video of the match.[66] Similarly, the Oculus Venues app allows consumers to virtually attend events broadcast on TV, such as concerts or sporting events.[67]

The development of volumetric video technology may also find an application in maintaining and enriching social interactions.[68] The availability of real-time holographic displays, which are currently being developed for professionals (described in section 5.2), may, in the future, also allow relatives and friends to attend social events from remote locations. For example, grandparents could attend weddings or birthday parties from far away using holographic images that enable them to participate in key life events and maintain an emotional bond with their grandchildren.[69]

5.3.3 Improved social interaction through VR and AR learning

VR and AR learning can be described as education that is distributed by VR and AR headsets. This form of education can provide an engaging way to deliver education and provide students with an in-situ experience. For example, the VR application Nearpod has created lesson plans that allow users to experience the Egyptian pyramids, the Great Barrier Reef, or even Mars.[70]

Virtual learning may also offer a great alternative to students for whom the traditional classroom is less suited. Virtual learning may make it easier for those who can’t attend traditional schools to access education, such as home schoolers, children with learning difficulties, or where significant adjustments to education provision need to be made; for example in case of autism or ADHD. VR and AR could offer more personalised learning methods and give these students access to interactive learning opportunities from the safety of their own home. For example, applications being developed by Google and CableLabs could allow students to interact with 360 degrees scenes and 3D objects, which could be particularly beneficial for biology, anatomy, geology and astronomy for which learning opportunities are likely to be enriched through interaction with multi-dimensional objects and immersive environments.[71, 72, 73]

[65] Intel (2019), ‘Intel Studios’ volumetric video gives “Grease” new life 40 years later’, press release, https://newsroom.intel.com/news/intel-studios-volumetric-video-gives-grease-new-life-40-years-later/#gs.2mps7n, accessed 9 September 2019.
[66] Intel, ‘See more game than ever’, https://www.intel.com/content/www/us/en/sports/technology/true-view.html, accessed 13 September 2019
[67] Infuture Hatalska Foresight Institute and Liberty Global (2018), ‘Giga Entertainment: The Future Entertainment in the age of the Gigabit Internet, AI, IoT and MEC, October, https://2zn23x1nwzzj494slw48aylw-wpengine.netdna-ssl.com/wp-content/uploads/2018/10/upc_EN.pdf, accessed 6 September 2019.
[68] Volumetric data contains the entire volume of data in three dimensions. Therefore, volumetric video allows communications with a 3D projection of a person, see https://voxon.co/voxon-creates-the-worlds-first-volumetric-video-call-over-5g/, accessed 12 September 2019
[69] Valorem Reply (2019), ‘Holobeam Holographic Telepresence Technology’, https://go.valorem.com/HoloBeam.html, accessed 6 September 2019.
[70] Reality, ‘How Reality Technology is Used in Education’, https://www.realitytechnologies.com/applications/education/, accessed 6 September 2019.
[71] https://edu.google.com/products/vr-ar/expeditions/?modal_active=none
[72] https://venturebeat.com/2018/08/07/how-cablelabs-envisions-learning-with-video-walls-light-field-displays-and-ar-vr/
[73] https://techcrunch.com/2016/01/23/when-virtual-reality-meets-education/

In addition to making existing learning methods more effective, VR learning could also provide opportunities for new learning experiences and encouraging life-long learning. Regardless of their health, background, age, or income, users could virtually travel to historic sites and locations of great cultural value. Applications such as Unimersiv[74] and Google Expeditions may allow users to explore history, arts and nature through an interactive VR and AR experience. When used with an Oculus VR headset, users can explore 900 different expeditions[75] allowing children as well as adults and seniors to experience hard to visit places.

5.3.4 Economic benefits of improved social and digital interaction

In addition to more frequent interactions, as set out in section 3.4, improved digital interactions may also lead to an increase in consumer surplus. This would be driven by consumers getting a better user experience from both video games, immersive entertainment, learning and socialising due to the better quality and increased variety of content. Oxera have reviewed the material from Liberty Global on the consumer willingness to pay for higher speed connections and found that consumers have a willingness to pay for faster Internet connections.[76] The incremental willingness to pay is likely to be related to digital interaction applications and services given the proportion of bandwidth that is used on video and online games as mentioned in section . This suggests that consumers do value higher-quality content and have a willingness to pay for it.

The move to streaming game services is likely to lead to a market expansion as users will be able to use multiple devices to access the same cloud library of games without having to spend large upfront sums on consoles or other equipment. This makes access to cutting edge gaming significantly cheaper by removing the need for platform specific consoles. In addition, this could also stimulate the gaming industry by encouraging newer and smaller developers to enter the market as they will not be limited by console compatibility to reach users.[77]

Future use of volumetric videos for immersive entertainment could provide users with richer experiences in a specific environment or event. Rather than watching a football match on TV, people may be able to virtually attend the match from their own sofa, as if they were sitting in the stadium. Immersive entertainment is likely to bring a wide range of new experiences, all accessible from within consumers' homes.

VR and AR learning could help learning to become more inclusive as regardless of health, location, age, or income, users could use VR to learn new skills or visit remote destinations. Augmented reality learning may help students that have trouble learning in the traditional classroom to be able to access the same learning opportunities as other students. Used in this way VR and AR learning may improve social inclusion.

[74] See https://unimersiv.com/, accessed 9 September 2019.
[75] Unimersiv (2016), 'We just released the Acropolis experience on the Unimersiv App', 26 September, https://unimersiv.com/just-released-acropolis-experience-unimersiv-app/, accessed 6 September 2019.
[76] This is based on commercially sensitive sources for Liberty Global however it is also supported by other studies such as Liu, Y., Prince, J. and Wallsten, S. (2018), 'Distinguishing Bandwidth and Latency in Households' Willingness-to-Pay for Broadband Internet Speed', Information Economics and Policy, 45, December pp. 1–15.
[77] Singletary Jr., C. (2019), 'Google developer explains Stadia's advantage over the competition', Digital Trends, 7 May, https://www.digitaltrends.com/gaming/google-stadia-advantage-over-competition/, accessed 6 September 2019.

5.3.5 The role of better connectivity in unlocking transformative applications for social and digital interaction

To benefit from the transformational applications described above, users will need connectivity capable of transmitting the data generated by these applications.

For gaming services the experience is negatively affected if a user experiences delays and cannot react quickly enough to what is happening in the game. For these services to be successful, the connectivity needs to relay controller movements in virtually real time between the player and the server. This means low latency is crucial for this application.

Google's Stadia service requires latency of less than 40ms and data loss below 5% to ensure good-quality gameplay.[78] In addition, games are becoming richer, more lifelike and more complex. To be able to accommodate this, larger quantities of data need to be transmitted over the network.

Video requirements for immersive experiences are above the video streaming levels of today. Research indicates that 400Mbps may be required to be able to experience 4K 360 degree VR.[79] Intel's volumetric video of a football match, needs 38 5K cameras connected to servers processing up to 1TB of data every 15 seconds.[80] To watch the video, depending on the quality of their display, the user will need bandwidth of 167Mbps for HD VR and 500Mbps for UHD VR to get the optimal experience.[81]

In addition, as users are required to interact with the virtual environment, low latency is required. Where users are participating in practical applications through AR or where visual feedback is dependent on movement from the headset, it is critical to have low delay between input and output. Low latency will ensure that there is no perceptible delay between user movements and the representation of that movement on-screen. In practice, this requires latency of less than 10ms in order to prevent users suffering motion sickness.[82]

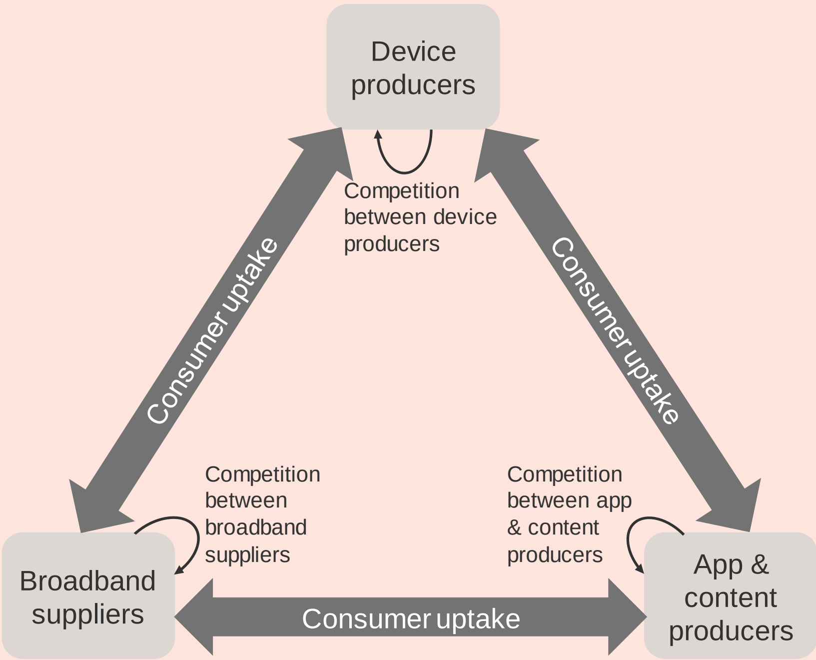
Immersive entertainment requires richer feeds, which therefore means higher bandwidth connections. This need is also driven by application and device manufacturers, who are incentivised to make full use of the available broadband capabilities in order to bring the most innovative applications to market. This is explained in more detail in Box 5.1 below.

[78] Knapp, M., Lynch, G. and Hood, V. (2019), 'Stadia: everything you need to know about Google's game-streaming service', Techradar, https://www.techradar.com/uk/news/stadia-everything-you-need-to-know-about-googles-game-streaming-service, accessed 6 September 2019.
[79] Mangiante, S., Klas, G.,Navon, A., Zhuang, G, Ran, J., and Silva, M. (2017), 'VR is on the Edge: How to Deliver 360° Videos in Mobile Networks'.
[80] Morris, C (2018), 'Intel claims it has the power to put you directly on a concert stage or NFL field, news article, 26 June, https://www.cnbc.com/2018/06/25/intels-new-technology-puts-you-directly-in-the-middle-of-nfl-action.html accessed 17 Sept 2019.
[81] Cisco (2019), 'Visual Networking Index: Forecast and Trends 2017–2022', Figure 19, 27 February, https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.pdf, accessed 5 September 2019
[82] Morris, I (2018), 'Vodafone's Holo Demo Dazzles Crowd, But Is It a Viable 5G Use Case?', news article, 21 September, https://www.lightreading.com/mobile/5g/vodafones-holo-demo-dazzles-crowd-but-is-it-a-viable-5g-use-case/d/d-id/746260, accessed 17 September 2019.

Box 5.1 How might gigabit applications go mainstream?

Gigabit connections are likely to have a niche user base initially; however, once a sufficient threshold of adoption is met, they could go mainstream – like with any other innovation. This is likely to happen because the incentives of the other participants in the market (users, device manufacturers and app and content producers) are aligned to use additional capacity. A stylised representation of the participants' interactions is shown below in Figure 5.1.

Figure 5.1 A virtuous cycle of innovation



Device manufacturers seek to win market share by making devices that support a wide range applications and content that users might want at the quality they expect (e.g. HD, 4K). Content producers and platforms compete for users' attention during the time they spend online via the quality of the content offered and the more immersive experiences they can offer. To do that, their content transmission can be specified as 'adaptive rate', which will default to the highest quality that the fixed broad connectivity can support. Broadband suppliers compete on quality and the ability to support the expected applications. This establishes a virtuous circle of innovation.

Initially, new and immersive applications are likely to be directed towards entertainment genres with high willingness to pay (such as sports). Over time, the cost of the technology is likely to fall, capabilities are likely to increase and user familiarity is likely to expand. As this happens, the virtuous cycle above could help to drive gigabit applications mainstream.

Source: Oxera analysis.

5.4 Reduced emissions through new applications

New technologies have the potential to significantly reduce carbon emissions. Currently, many activities that a person undertakes require travelling from one place to another. Reductions in carbon emission can be achieved by decreasing the need to travel. This section describes how some of the applications that are enabled by gigabit connections set out above can reduce the need to travel and thus reduce carbon emissions. In section 3.5 we have assessed how large these emissions are in the context of commuting to work as an example.

5.4.1 Description

Reducing carbon emission by decreasing the need to travel can be achieved in a wide range of recurring activities. In the three areas set out above, healthcare, workplaces and digital and social interaction, applications enabled by gigabit connections may reduce the need to travel.

Revolutionised healthcare

As set out in section 5.1, gigabit connectivity may alleviate the requirement for both patient and doctors to be physically present in the same location. The availability of home-based scanning devices and high quality video-streams could enable remote monitoring and remote diagnosis. Improved video streams and scanning devices could enable both patients and medical specialists to attend or carry out consultations from home. This would reduce the carbon emissions from the medical professional, the patient or both travelling to the hospital.

Transformed workplaces

Gigabit connections may also enable a number of other professions to work from home, reducing the need to commute, as described in section 5.2. Through holographic conferencing, augmented reality presence and virtual conference rooms professionals will be able to collaborate without having to travel.

Social and digital interactions

Climate benefits may also be achieved through improved digital and social interaction. Through a transformative application referred to as virtual reality learning, described in section 5.3.3, students could be able to learn through experience at a remote location without a requirement to travel. Future use of volumetric videos for immersive entertainment could allow users to virtually attend a football match rather than needing to travel to the stadium.

5.4.2 Economic benefits

Carbon emissions are in economic terms referred to as a negative externality: a cost incurred by a third party that has no link to the economic activity and for which no compensation is paid. Carbon emission contribute to global warming, which is found to have costs to society as a whole. While the precise impact of global warming is beyond the scope of this report, the Intergovernmental Panel on Climate Change (IPCC) identify a range of scenarios where climate change has adverse outcomes for adverse outcomes for livelihoods, health and well-being, ecosystems and species, services, infrastructure, and economic, social and cultural assets.[83] The IPCC indicates amongst other things that reducing carbon emissions may mitigate flood risk, reduce risk to marine biodiversity

[83] IPCC (2018), 'Global Warming of 1.5 degrees Celsius - Summary for Policymakers', October 2018

fisheries and ecosystems, and enable human and natural systems to adapt to climate change.

5.4.3 The role of better connectivity in unlocking applications for reducing carbon emissions

For each of the applications that may reduce carbon emissions a number of capabilities enabled by gigabit connections may be required.

For healthcare applications, capacity and resilience improvements will enable reliable, high-quality diagnostics and patient monitoring, reducing the need for travel. Further gigabit specific requirements are described in section 5.1.3.

Gigabit technology will support more immersive and responsive collaboration via remote workplaces, reducing the need to commute. Further connectivity requirements for applications that can improve remote working are set out in section 5.2.6.

The DOCSIS 3.1 upgrade will provide the capacity and low latency to enable AR and VR type interactions in the home. As these technologies become more immediate and lifelike, they will enable digital interaction to reduce the need to travel in order to be physically present. The connectivity requirements for applications that improve digital and social interaction are set out in section 5.3.5.

6 Conclusion

Oxera's review of previous waves of innovation has shown that past digital technologies have made profound advances in capability, at frequent intervals and over a long period. Evidence on the price and capability of services has shown that these changes have substantially lowered costs, improved functionality and made new experiences possible. Liberty Global's gigabit upgrade, which is adding substantially more capacity and lower latency and can be expected to continue this process.

It is common to discuss communications technology as an 'enabler'. The key economic mechanism within this enabling ability is the way in which communications technologies address transaction costs—cutting time, eliminating travel and reducing search frictions all unlock more opportunity for welfare-enhancing activity.

Oxera's analysis shows that the transaction costs that are still present in activities related to commuting, work, healthcare and maintaining social contact are significant. Half of the EU's unmet medical needs are due to services that are either too costly or are subject to lengthy waiting lists. Europeans who commute to work spend hundreds of hours a year doing so. The value of this lost time is worth up to €5,380 per commuter per year. These commuting activities also consume energy and emit greenhouse gases—up to 668kg of CO_2 per commuter per year.

There are applications on the horizon that could address these challenges. We have only considered the applications that are in development—and thus implying a reasonable chance for the commercial and technical obstacles to be overcome. More specifically, the applications reviewed require gigabit capabilities such as higher capacity, lower latency and improved reliability in order to operate.

Applications that use immersive and intimate workplace collaboration can reduce commuting and unlock valuable time, as well as benefiting wider society through reduced emissions. Access to a healthcare service that is transformed with high-quality remote diagnostics and remote monitoring could improve the coverage of those who currently have unmet medical needs. The use of virtual applications and services could increase valuable digital and social interaction, improving the quality of the time people spend together. These wide-ranging impacts, which could be enabled by gigabit broadband connections deployed at scale, will contribute to the wider digital transformation of Europe in the coming years.

A1 Data and methodology

A1.1 Approach: unmet need for medical care

The methodology set out in this annex underlies the analysis of the opportunity size related to the unmet need for medical care presented in Figure 3.1, Figure 3.2 and Figure 3.3.

To measure the size of the unmet needs for medical examination, we used the Eurostat data for 2017, which reports the percentage of the population aged 16 and older who reported an unmet medical need in the 12 months prior to the survey being carried out. To arrive at the estimate for the number of consultations that would have happened if there were no unmet medical needs in the last 12 months, we assumed that only one consultation per person was passed up.

The split of reasons at European level was calculated based on the reasons for unmet needs expressed by the population with unmet needs only.

For the comparison of the number of people who accessed medical care each year, we used Eurostat data on self-reported consultations of a medical professional during the four weeks prior to the survey in 2014 that covered people aged 15 and above. To make the data comparable with the basis of the respondents for unmet medical needs, we assumed that the four-week reference period was representative of the entire year, and that the same percentage of consultations applied to the persons aged 16 and older.

The percentage of the population that would have accessed the medical care in a year was estimated by summing up the percentage of the population who accessed medical care with the percentage of those who that had unmet needs. This assumes that those with unmet needs did not have any medical consultation in the preceding year, otherwise they would be double-counted. For this calculation, we assumed that in 2017, the same percentage of persons consulted a medical professional as in 2014, which is the most recent year for which data is available.

For Belgium, the data on the percentage of the population who consulted a medical doctor was missing. We assumed the data to be equal to the average for the EU 28.

A1.2 Data: unmet need for medical care

Table A 1 Data sources for unmet need for medical care

Description	Source
Self-reported unmet needs for medical examination and care by main reason declared in the last 12 months for 2017. It includes people aged 16 and older.	Eurostat [hlth_silc_13]
Self-reported consultations of a medical professional during the four weeks prior to the survey in year 2014. It includes people aged 15 or older.	Eurostat [hlth_ehis_am2u] 2014
Population on 1 January by age	Eurostat [demo_pjan]
Number of consultations per inhabitant 2016	Eurostat [hlth_hc_phys]

A1.3 Approach: commuting opportunity

The methodology set out in this annex underlies the analysis of the opportunity size related to commuting, specifically the value of time and emission presented in Figure 3.4, Figure 3.5, Figure 3.9, Table 3.1 and Table 3.2.

Value of time

The country estimate for the total size of the opportunity based on value of time was calculated according to the formula:

$$\begin{aligned} \textit{Value of commuting time per country} \\ &= \textit{Value of time} \times \textit{Commuting time per day} \\ &\times \textit{Commuting population} \times \textit{Working days} \end{aligned}$$

Table A 2 below describes the sources of data used for each component of the equation above. The estimates reported for the year 2019 are based on the data for the latest available year.

The commuting population data from Eurostat has been adjusted to account for the fact that part-time employees make fewer journeys compared to the full-time employees. We assumed that full-time employees commute twice as much compared to the part-time employees. In addition, in the absence of a split of commuter data by employment type (full-time/part-time), it was assumed that full-time and part-time employees commute in an equal proportion.

The value of time differs across countries and mode of transportation used. To account for this, our value of time variable has been calculated as follows:

$$\begin{aligned} \textit{Value of time} &= \textit{Value}_{car} \times \textit{Share of commuting}_{car} \\ &+ \textit{Value}_{bus} \times \textit{Share of commuting}_{bus} \\ &+ \textit{Value}_{train} \times \textit{Share of commuting}_{train} \end{aligned}$$

The value of time is based on the car, train and bus commuting only. Table A 2 below provides further detail on the data on modal transport composition used for each country. This implies that we assume a value of zero for the time commuting on other modes (foot, bicycle, motorbike, etc.), which results in a conservative estimate of the value of time.

Table A 2 Modal transport data

Country	Car share	Bus share	Train share
United Kingdom	Used the commuter car share in 2018 in England	Used the commuting share for local bus, London underground and other public transport in 2018 in England	Used the commuting share for surface rail in 2018 in England
Ireland	Used the commuter car share in 2016	Used the commuter bus share in 2016	Used the commuter train share in 2016
Poland	Used the commuter car share in 2010	Used the commuter public transport share for 2010	Used the commuter train share for 2010
Belgium	Used the commuter car share in 2011	Used 50% of the commuter public transport share for 2011	Used 50% of the commuter public transport share for 2011
Netherlands	Used the commuter car share in 2011	Used 50% of the commuter public transport share for 2011	Used 50% of the commuter public transport share for 2011
Germany	Used the commuter car share in 2012	Used 50% of the commuter public transport share for 2012	Used 50% of the commuter public transport share for 2012

Source: Oxera.

The value of time estimates from the meta-study were expressed in 2010 euros. We have used a GDP per capita inflator to estimate the 2019 value of time.

Emission impact

The estimate for emission impact of the average commuter in a year was obtained using data from the year 2017 on the emissions of cars, motorcycles, railways and buses. The calculation was based on the following formula:

$$\begin{aligned} &Emission\ impact\ of\ a\ commuter\ per\ year \\ &= \frac{1}{Number\ of\ commuters\ \times [1-(0.5 \times Part-time\ rate)]} \\ &\times (Emissions_{car} \times Commuitng\ share_{car} \\ &+\ Emissions_{bus} \times Commuitng\ share_{bus} \\ &+ Emissions_{rail} \times Commuitng\ share_{rail} \\ &+ Emissions_{motorcycle} \times Commuitng\ share_{motorcycle}) \end{aligned}$$

The annual data on transport emissions includes emissions caused by other activities apart from commuting. Therefore, our analysis adjusted the size of the impact by the share of commuting with each transport type. Data on purpose and mode of transport was available only for England, and we assumed the same shares for the rest of the United Kingdom and the other countries included in our analysis.

A1.4 Data: commuting opportunity

Table A 3 Data sources for commuting opportunity

Description	Source
Commuting in another region (2014-2018)	Eurostat [lfst_r_lfe2ecomm]
Commuting in the same region (2014-2018)	Eurostat [lfst_r_lfe2ecomm]
Average number of trips (trip rates) by purpose and main mode: England, 2018. The same percentage shares have been assumed for the rest of the UK	Department for Transport statistics, National Travel Survey
Structure of commuters to work in 2010 by means of transport (%)	Poland Central Statistical Office, Department of Labour, Commuting to work in 2010 based on LFS, p.14
GDP per capita 2018	World Bank, World Development Indicators
Percentage of people employed part-time 2018	Eurostat - Part-time employment and temporary contracts - annual data [lfsi_pt_a]
Travelling time of people usually resident and present in the state	Ireland Central Statistics Office, Population Aged 15 Years and Over at Work, Usually Resident and Present in the State 2011 to 2016 (Number) by Social Class, Means of Travel and Census Year, Table EZ040
Share of journeys to work by transport mode 2009–18	Eurostat [urb_ctran]
Value of time 2010 based on meta-study	Wardman, M., Chintakayala, V. P. K. and de Jong, G. C. (2016, 'Values of travel time in Europe: Review and meta-analysis', *Transportation Research Part A: Policy and Practice*, **94**, pp. 93–111.
Mean duration of commuting time one-way between work and home by sex and age 2005-2015	European Foundation for the Improvement of Living and Working Conditions (Eurofound) [qoe_ewcs_3c3]
Emission data by country and travel mode	Data on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU Member States). This data set reflects the GHG inventory data for 2019 as reported under the United Nations Framework Convention for Climate Change.
Greenhouse gas emissions by transport mode, United Kingdom: 2003–16	UK Department for Transport statistics, Energy and the Environment, Table ENV0201 (TSGB0306)
Share of passenger and freight train emissions	UK National statistics, Office of Rail and Road, Rail infrastructure, assets and environmental 2017-18 Annual Statistical Release, Publication date: 18 October 2018

A1.5 Approach: maintaining social contact

The methodology set out in this Appendix underlies the analysis of the opportunity size related to the maintaining of social contact presented in Figure 3.6, Figure 3.7 and Figure 3.8.

To measure the cost of maintaining social contact, we used Eurostat data for 2015 that reports the percentage of the population aged 16 and older who get together with family and relatives and friends every day, every week, once per month, several times per month, not in the last twelve months and at least once per year.

To estimate the number of meetings per person, per year, per country, we first multiplied the frequencies by the number of citizens aged 16 or older for each country for the year 2017. Then we multiplied the number of people who met every day by 365, every week by 52, several times per month by 2.5 times 12, every month by 12 and at least once per year by 1. We summed the total number of meetings and then divided it by number of citizens aged 16 or older for each country.

A1.6 Data: maintaining social contact

Table A 4 Data sources for maintaining social contact

Description	Source
Frequency of getting together with family and relatives or friends by sex, age and educational attainment level 2015	Eurostat [ilc_scp09]
Population on 1 January by age 2017	Eurostat [demo_pjan]

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