European Commission

Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe

FINAL REPORT

A study prepared for the European Commission

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1. Abstract

This study fills a major void in 5G research by forecasting the qualitative and quantitative socio-economic benefits of 5G. The study has been closely aligned with 5G-PPP activities and more than 150 experts have contributed to the research.

The study provides an insight to the perfect scenario if Europe can maximise the benefits of 5G. Forecasts have adopted conservative estimates and all assumptions are clearly presented to enable transparency in predictions.

The study focused on four verticals (automotive, healthcare, transport and utilities) that were the most frequently mentioned in previous research. Four different environments were identified to investigate the impact of 5G in smart cities, non-urban areas, smart homes and smart workplaces.

Ten 5G capabilities were identified and the most important in providing optimal outcomes in verticals and environments were identified.

Forecasts suggest that 5G deployment costs will be approximately €56.6 billion. The study investigated spectrum challenges and spectrum needs of 5G. Analysis showed there will be a requirement to share spectrum in all the spectrum ranges.

5G is expected to generate benefits of €62.5 billion per annum in the four verticals in 2025. Benefits of €50.6 billion are expected in the four environments. 63 per cent of these benefits will arise for business and 37 per cent will be provided for consumers and society.

2. Executive Summary

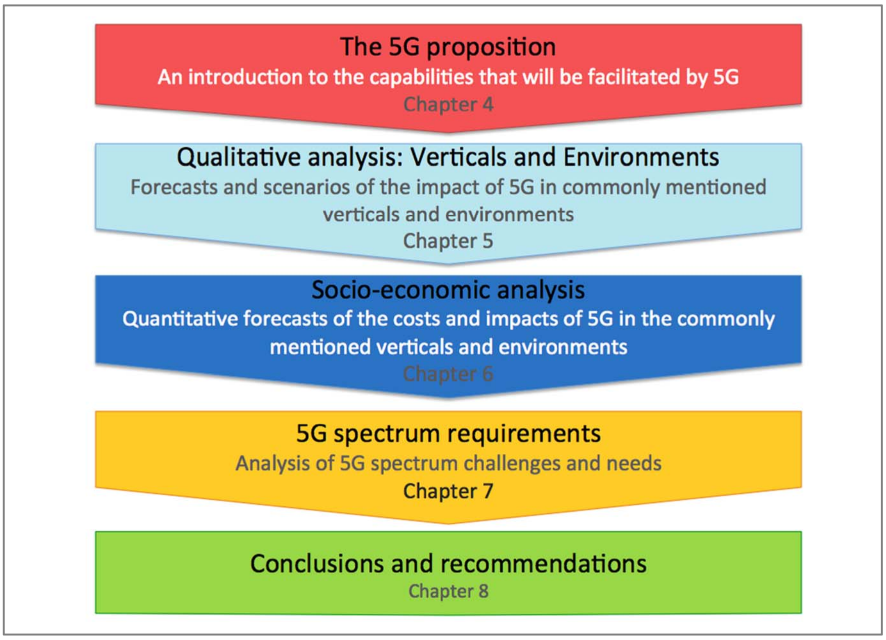
This European Commission supported study (SMART 2014/0008), which is forecasting the ***benefits, impacts and technical requirements to assist strategic planning for the introduction of 5G in Europe,*** will fill a major void in 5G research by forecasting the qualitative and quantitative socio-economic benefits of 5G. The vast majority of current research is focusing on technological developments and protocols to enable 5G to operate effectively and provide beneficial outcomes.

In the light of hype concerning 5G, this study is investigating what 5G might actually mean for industries, operators, users, society and other stakeholders. The study will provide an insight to a potential reality. Qualitative and quantitative methods have adopted conservative assumptions, but they have focused on the perfect scenario and maximum attainable benefits. They provide an insight to the perfect scenario if Europe can maximise the benefits of 5G.

Forecasts have been supported by contributions from more than 80 international experts that attended two European Commission hosted workshops. The study has also been closely aligned with 5G-PPP activities. Briefing papers and the outcomes of workshop discussions have been shared with an online study group comprised of more than 130 commentators[1].

This study demonstrates and quantifies how 5G can support two of the major goals of the Digital Single Market Strategy for Europe by supporting the conditions for digital networks and services to flourish in EU28 Member States and by providing technologies and infrastructure to maximise the growth potential of the European digital economy[2].

The Final Report is comprised of eight chapters. The focus for each chapter is provided in the graphic below. Chapter four provides an overview of ten key capabilities that will be facilitated by 5G. The remainder of the study investigates how these capabilities will lead to change and benefits in EU28 Member States.



5G capabilities (chapter 4)

[1] https://www.linkedin.com/groups/8314284

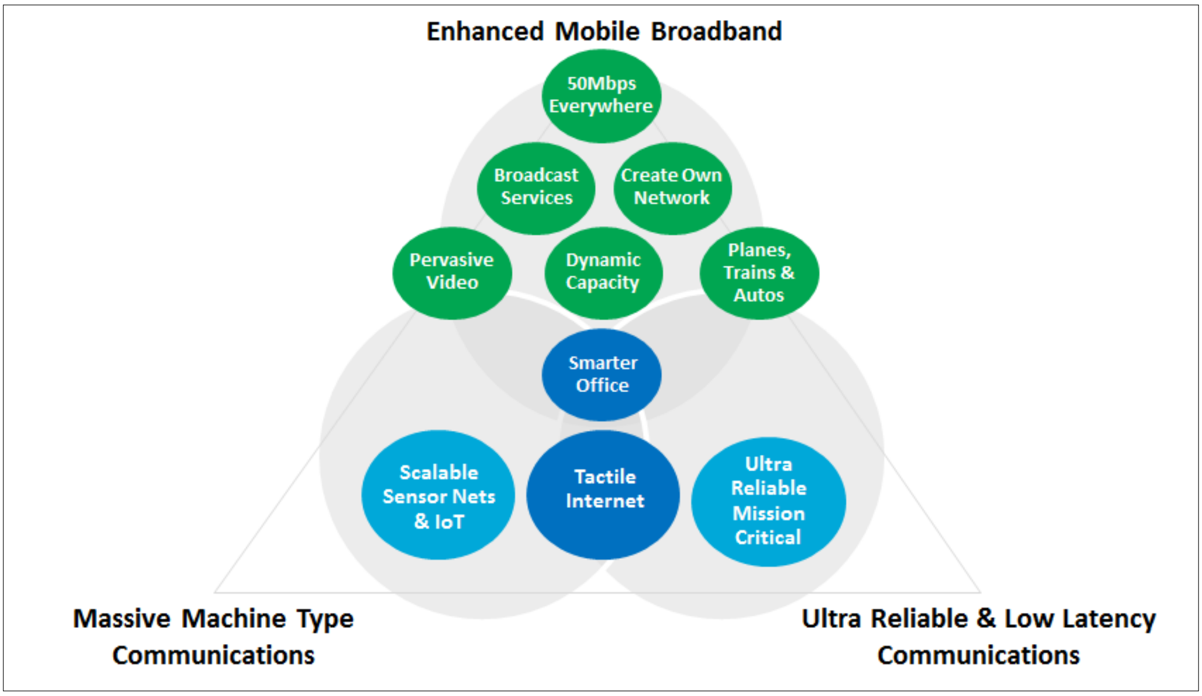
[2] European Commission. 2015. A Digital Single Market Strategy for Europe. COM(2015) 192 final.

5G will be different to previous generations. The goals of 5G include the creation of enabling solutions for vertical industries such as automotive, healthcare, transport and utilities. While it cannot be denied that wireless through its generations has delivered enormous socio-economic value almost beyond measure; no generation has ever set out with this fundamental goal as a priority. In this respect 5G will be quite different. It will be the first generation to explicitly target delivering socio-economic benefits and as a result many new 5G capabilities are anticipated.

The ten 5G capabilities identified in previous research include:

- 5G aims to enable a truly pervasive video experience;
- 5G will enable a revolution in the smart office;
- 5G goal is to deliver 50Mbps everywhere;
- 5G will allow you to create your own network if you that is what you want to do;
- 5G will support dynamic increase of capacity on the fly;
- 5G will enable a working solution on planes, trains and cars;
- 5G will deliver a single scalable solution for sensor networks and the IoT;
- 5G will enable an ultra-reliable network for mission critical applications;
- 5G will make the realization of the tactile internet possible;
- 5G will deliver a meaningful and efficient broadcast service.

The figure below maps these capabilities in the context of the three major use cases defined by ITU.



Qualitative analysis: Verticals and environments (chapter 5)

Chapter 5 provides an overview of desk research and the results of scenario development activities at workshops for the four verticals and environments. These activities largely focused on providing qualitative insight to the utilisation of 5G capabilities. Verticals were chosen for the study by selecting those most commonly mentioned in 5G use cases and White Papers.

Automotive is the most cited sector amongst verticals and use cases in 5G studies. The most optimistic future imagined during the workshop was a world in which the Automotive Industry is open to change; new business models emerge with high trust from users and related sectors supported by effective governmental frameworks and standardisation.

Two barriers and key disruptors were identified: 1). Business model flexibility: New and disruptive business models were envisaged. Workshop participants agreed about the need for open ecosystems and clear regulatory frameworks supporting investment for automotive mobility systems that can save increasingly expensive fuels and present options for the sector in relation to solutions for mass transportation. 2). Data privacy: There are concerns about who will own/commercialise emerging data-driven services, particularly as a result of more open systems and platforms.

Healthcare is one of the less cited verticals. The most optimistic scenario was one in which there is widespread acceptance of technology-driven innovation with health practitioners and patients are open to change, new business models emerge and they are supported by strong, clear regulations. In this scenario systematic change is possible and healthcare is not just treating illness but also in preventing illness and proactively enhancing wellbeing and quality of life.

A key disruptor in the healthcare vertical was thought to be data privacy, particularly in the light of wearable technologies collecting personal health data in non-clinical settings. Guidance and regulation of data privacy will be important.

Transport is an industry with a rich innovation roadmap spanning both infrastructure and ICT where numerous new connected devices and services could be supported and enhanced by 5G capabilities. In the most optimistic scenario transport data flows freely between once closed sub-transport sectors enabling new collaborations and application possibilities. Transport could be heralded as one of the first industries to deliver a true “IoT” experience enabled by a Pan European Integrated Transport system connecting everything (roads, cars, trains, planes, bikes etc.). Data and advanced data products (provided by analytics) are acknowledged by all stakeholders and protected as the fuel in the new value chain. In this vertical, more so than the preceding two examples, transport data sharing and access is fundamental to benefits realisation.

Utilities are a frequently cited sector, mainly because of considerable growth in smart meters and IoT devices and sensors that will be connected in smart homes by 2020. EC research predicts 2.95 billion smart home sensors and devices by 2025. The optimistic scenario envisages high levels of connectivity supported by a strong regulatory environment. There will be inter-vertical and cross-vertical collaboration, interoperability and integration, driving a new ecosystem of devices and networks designed to meet user needs.

Key disruptors were thought to be an over-emphasis on renewable energy and a weak regulatory environment. Economies of scale could be lost if a more local focus becomes prevalent, for example as a result of local generation and micro-grids based local energy distribution.

Throughout the analysis of sectors and environments particular attention was focused on the 5G capabilities that played the greatest role in supporting beneficial change and development. Workshops, attended by more than 80 experts, identified three key capabilities, these were:

- ***50Mbps everywhere*** - Truly ubiquitous coverage (*everywhere with 50Mbps)* is a necessary condition for the success of 5G within the context of all verticals and environments. In many Member States 5G could overcome the digital divide caused by poor broadband coverage, particularly in rural areas;
- ***Scalable solutions for sensor networks*** - support for large scale M2M/IoT networks was identified as a priority capability for all verticals and environments. Automotive, healthcare, transport and utilities have strong future visions that include a reliance on the IoT. Strategic and operational benefits realisation in verticals and environments is strongly tied to the existence of total knowledge of the *things*. Big Data insights, which can lead to real-time decisions and optimizations as well as longer-term strategic decisions, are only possibly with a fully realised IoT;
- ***Ultra tactile Internet*** - This was seen as a step-change capability that would have the potential to unlock more futuristic applications and services. Ultra tactile Internet allows for a wireless network to be used for control purposes. For real-time sense-respond-actuation cycles that enable both human-device control interactions and device-device interactions.

Socio-economic analysis (chapter 6)

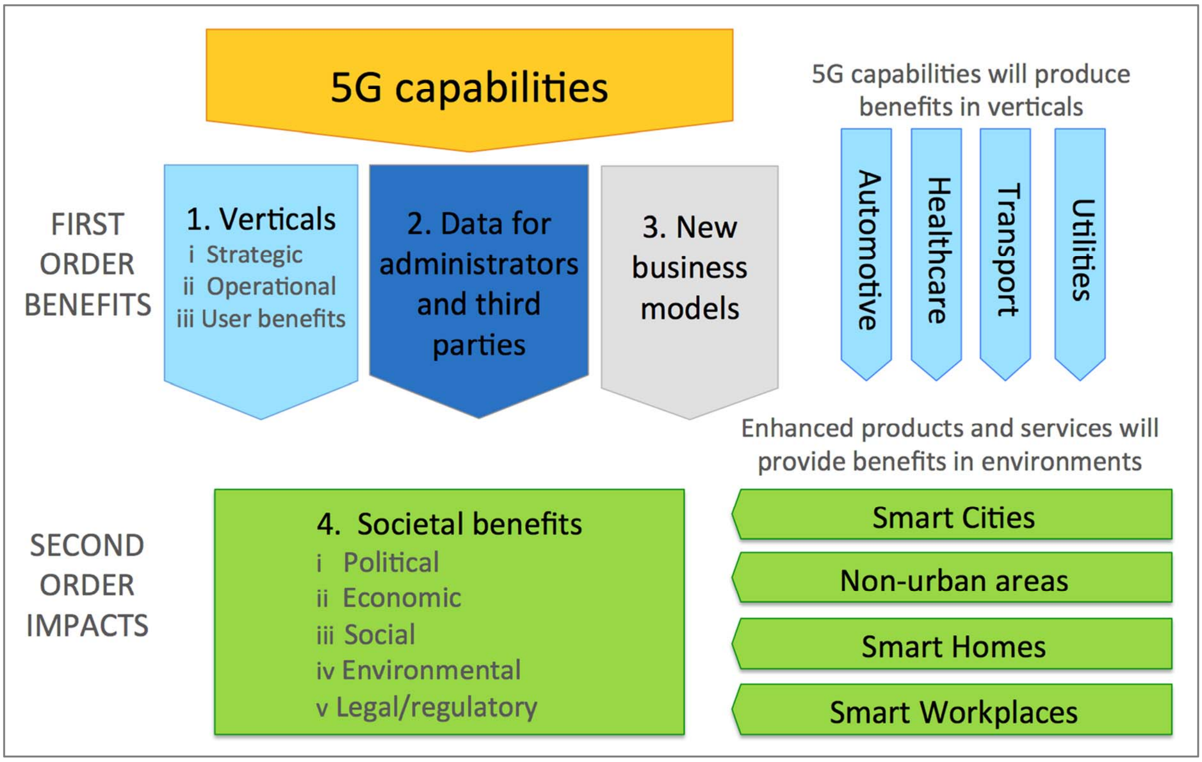
The development of scenarios and identification of key impacts described in chapter 5 provided a rich qualitative understanding of possible futures. Chapter 6 focused on the costs, benefits and socio-economic impacts of 5G capabilities. Quantifying these benefits is one element that distinguishes this study from others.

Quantitative forecasts have been developed from the best available evidence from previous studies. Assumptions made in forecasts are fully documented to enable readers to easily identify key factors in predictions. Throughout the study quantitative analysis has adopted conservative assumptions. Nonetheless forecasts have focused on the perfect scenario and maximum attainable benefits. They provide an insight to the perfect scenario if Europe can maximise the benefits of 5G

Estimates of the cost of deploying 5G took a high level approach analysing studies that provide an insight to the costs of 2G, 3G and 4G deployment in Europe. It is evident that each successive generation of mobile infrastructure has cost more than previous generations. Every generation has required more spectrum and cells have got smaller meaning there has generally been a linear increase in base station numbers that have been linearly reduced in cost by more efficient technologies. It is suggested that the total 5G cost estimate is probably conservative because 5G aims to deliver much more than previous generations which have traditionally only serviced very specific requirements (e.g. voice, data, video etc.).

The study estimates that in EU28 Member States the total cost of 5G deployment will be approximately €56 billion in 2020. Major investment in an economy has 'trickle-down' impacts across the whole of the economy. Input-output analysis is a quantitative economic technique that examines the interdependencies between different parts of an economy to examine 'trickle-down' impacts. Input-output analysis suggests that 5G investment will lead to 'trickle-down' or multiplier effects with a value €141 billion. These effects are likely to create 2.3 million jobs in EU28 Member States.

The study developed a new research framework to conceptualise the key benefits and impacts that will arise from the utilisation of 5G capabilities, see the figure below.



FIRST ORDER BENEFITS focus on the more direct benefits to the producers of goods and services.

SECOND ORDER BENEFITS arise from the 'knock-on' impacts from the use of goods and services. They generally focus on more indirect benefits to society. Second order benefits are examined by investigating the four 'environments' where impacts are most likely to arise.

A clear evidence base underpins quantitative forecasts. And all assumptions regarding the 'added benefits' of 5G (beyond 4G and other technologies) are clearly presented to enable readers to transparently understand key components in calculations. All forecasts are speculative and it would obviously be unwise to put excessive faith in any single prediction. The analysis is probably most useful in providing an insight to the relative differences in potential impacts between verticals and environments.

The tables below provide an overview of the nature of quantitative benefits and verticals and environments in 2025.

In total it is estimated that benefits of €113.1 billion per annum will arise from the introduction of 5G capabilities. €62.5 billion will arise from first order benefits in the four verticals examined in the study. Benefits are distributed across the four sectors between strategic (€19.8 bn) and operational (€11.8 bn) benefits arising to organisations within the verticals. Relatively high levels of benefits were also recognised for the consumers of goods and services (€17.1 bn) from the verticals. Third party benefits (€13.8 bn) reach a similar level of magnitude but they primarily come from one source, the impact of telematics information for third parties in the automotive vertical.

Verticals ***Benefits***	Automotive (€ mn)	Healthcare (€ mn)	Transport (€ mn)	Utilities (€ mn)	Total (€ mn)
Strategic	13,800	1,100	5,100	775	**19,770**
Operational	1,800	4,150	3,200	2,700	**11,850**

Consumer	13,900	207	-	3,000	**17,110**
Third Party	13,700	72	-	-	**13,770**
Total	**42,200**	**5,530**	**8,300**	**6,470**	**62,500**

Totals may not correspond due to rounding

Second order benefits in the four environments are significant – €50.6 bn per annum. But these benefits are lower than those accruing to the verticals. The greatest level of benefit is in the workplace (€30.6 bn) where IoT networks and access to more extensive information throughout the supply chain will enhance productivity and opportunities for mass customisation. Smart city benefits (€8.12 bn) primarily arise from the benefits of reduced congestion and subsequent reductions in pollution in cities.

One of the key benefits (€10.5 bn) identified in rural areas is ability of 5G to address the digital divide and overcome difficulties in providing broadband connectivity in more rural areas where current fixed networks struggle to provide adequate service. 63 per cent of the total vertical and environmental benefits of €62.2 bn per annum in 2025 are forecast to arise for businesses and 37 per cent will be provided for consumers and society.

Environment Benefits	**Smart City (€ mn)**	**Non-urban (€ mn)**	**Smart Home (€ mn)**	**Workplace (€ mn)**	**Total (€ mn)**
Economic	4,000	2,200	720	14,500	**21,420**
Social	4,100	8,300	-	-	**12,400**
Environmental	22	38	609	16,100	**16,770**
Total	**8,122**	**10,540**	**1,329**	**30,600**	**50,590**

Totals may not correspond due to rounding

5G spectrum requirements (chapter 7)

The penultimate chapter addresses the spectrum challenges and spectrum needs of 5G. Traffic demand was calculated from scenarios associated with the three challenging use cases (healthcare, utilities and motorway scenarios) developed during expert workshops. We followed the 5G communities' aspiration of achieving an "always sufficient capacity"[3] user experience based on forecasted spectral efficiencies and cell densities. The resulting spectrum requirements were calculated to determine how much spectrum is ideally needed to fully satisfy peak user demand by 2025 to support the challenging use cases above which result in high spectrum requirements.

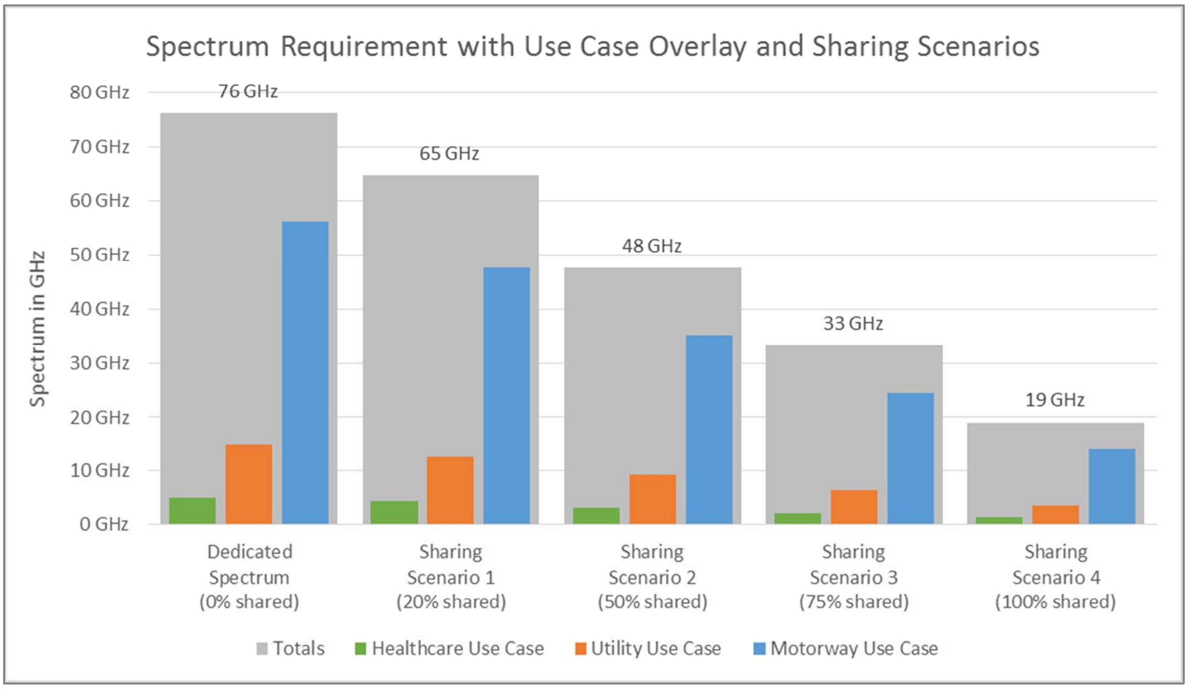
Analysis considered how 5G technology will use existing mobile spectrum and how access to new mmWave[4] spectrum bands will be required to meet the wide and varying demand from users. Estimates were recalculated for the different types of spectrum sharing that might be possible in future.

Analysis showed there is a requirement to share spectrum in all the spectrum ranges, particularly in bands below 6 GHz where it is beneficial to share as much spectrum as possible. The figure below shows the spectrum requirements across all use cases, frequency sub-ranges, sharing scenarios and total quantity when use cases are running concurrently. In the multi gigabit connectivity environment such as the motorway use case, there is not

[3] "Ofcom considers 5G technology", Daniel Thomas, Financial Times, January 2016

[4] Millimetre Wave – refers to frequency bands typically above 30 GHz

enough spectrum available in any of the ranges for service providers to hold dedicated spectrum and meet the needs of users. This situation becomes more problematical with reduced sharing.



The above diagram demonstrates the spectrum need to address all users traffic demand in an unconstrained spectrum environment. However, increased sharing, increase of cell density, prioritisation of critical traffic (e.g. emergency services) and reduction of non-critical applications (compression or optimisation of media streaming resolution) are some of the techniques that can be applied to reduce spectrum requirements.

In the utilities environment, where there are expected to be more than one million smart devices per km2 in urban and suburban areas, the 1 – 6 GHz frequency range is highly utilised and at least 75 per cent sharing is required to support the quantity of available spectrum in this range. The risk in this scenario is the uncertainty of incumbents' ability to share with 5G mobile service.

In the eHealthcare use case, there is a requirement for ultra-reliable connectivity because of 'safety of life' implications. Therefore certainty of access to spectrum will be vital for the service providers to meet the SLAs of the healthcare applications. In terms of the spectrum requirements a degree of sharing is required in each of the frequency sub-ranges. At least 50 per cent sharing is needed in the bands below 1 GHz and 1 - 6 GHz.

3. Introduction and study overview

3.1. Introduction

This document is the Final Report for a European Commission supported study (SMART 2014/0008) to forecast the benefits, impacts and technical requirements to assist strategic planning for the introduction of 5G in Europe.

This study is attempting to fill a major void in 5G research by forecasting the qualitative and quantitative socio-economic benefits of 5G. The vast majority of current research is focusing on technological developments and protocols to enable 5G to operate effectively and provide beneficial outcomes.

Standards and operational parameters have not yet been agreed for 5G but there is already considerable hype about performance and potential impacts[5].

Many would agree that it is foolhardy to estimate costs and benefits for a technology that has not yet been defined. This is compounded by the fact that commercial 5G release is unlikely to take place this decade and significant benefits are unlikely to be realised until the early to mid 2020's.

Nonetheless, in the light of hype concerning 5G, this study is investigating what 5G might actually mean for users, industries, operators and other stakeholders. The study will provide an insight to a potential reality. Our research has adopted a clear methodology, with a robust evidence base and transparency in sharing all qualitative and quantitative forecasts.

Qualitative forecasts have been supported by contributions from more than 80 international experts that attended two European Commission hosted workshops. The study has also been closely aligned with 5G-PPP activities. Briefing papers and the outcomes of workshop discussions have been shared with an online study group comprised of more than 130 commentators[6]. Qualitative elements have thus adopted a methodology that embraced the widest possible input from contributors. This type of crowd sourced style approach has, in many circumstances, been found to be superior to other methods[7].

Quantitative forecasts have been developed from the best available evidence and assumptions made in forecasts are fully documented. Quantitative forecasts have been distributed with selected international experts and shared with the online study group.

Qualitative and quantitative methods have adopted conservative assumptions, but they have focused on the perfect scenario and maximum attainable benefits. They provide an insight to the perfect scenario if Europe can maximise the benefits of 5G.

This study demonstrates and quantifies how 5G can support two of the major goals of the Digital Single Market Strategy for Europe by supporting the conditions for digital networks and services to flourish in EU28 Member States and by providing technologies and infrastructure to maximise the growth potential of the European digital economy[8].

3.2. The study

The study was undertaken in three stages, see Figure 1. In the first stage desk research and consultation was undertaken to gather and synthesise information about the impact of 5G capabilities on vertical sectors and the environments within which the goods and services provided by verticals will be utilised. Verticals were chosen for the study by selecting those most commonly mentioned in 5G use cases and White Papers.

Second stage activities involved engagement with experts at two workshops and through an online study discussion group. Four page briefing documents for the four verticals and four environments identifying the main uses and impacts of 5G capabilities were distribute to workshop participants and to the online discussion group at the start of the second stage of the study.

The first stakeholder workshop examining four verticals - automotive, healthcare, transport and utility sectors, was held on 22nd September 2015 in Brussels. The one-day workshop

[5] See for example http://www.bbc.co.uk/news/technology-31622297 http://www.mobileworldlive.com/featured-content/home-banner/5g-deciphering-hype/

[6] https://www.linkedin.com/groups/8314284

[7] Jame R. Johnston R. Markov S and Wolfe M. 2015. The value of crowdsourced earnings forecasts. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2333671

[8] European Commission. 2015. A Digital Single Market Strategy for Europe. COM(2015) 192 final.

maximised input from experts by dividing participants into breakout discussion groups, these were moderated by the study team for each vertical. Structured scenario planning methods were used to develop a hypothetical future view for 5G opportunities and constraints.

A second one-day societal workshop, held on 19th October 2015, utilised similar inter-active scenario development methods to examine four environments.

The workshops attracted a wide range of stakeholders such as mobile operators and manufacturers, telecommunication companies, content sectors, vertical sectors, potential civil use sectors, national regulators and members of the European Parliament. The expertise of workshop participants and online respondents was vital in obtaining a more extensive and granular understanding of verticals and environments and in identifying key benefits, impacts and barriers. The scenarios and stakeholders views provided vital information and insights for the third stage of the study.

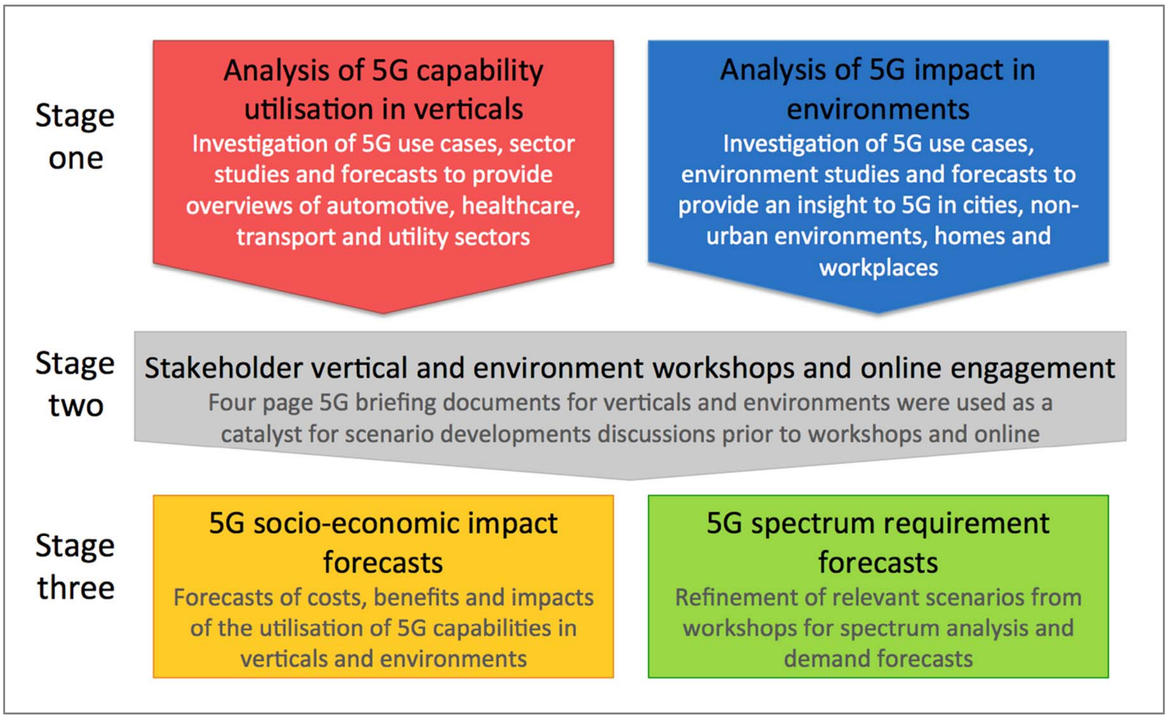


Figure 1 The three stage methodology for the study

The final stage of the study utilised scenarios and stakeholder insights to examine the importance of 5G capabilities in verticals and environments. Forecasts of potential costs, benefits and impacts arising from 5G utilisation were calculated. Forecasts of 5G utilisation until 2030 obviously require assumptions about uptake and impacts. All forecasts for verticals and environments were therefore shared with experts and stakeholders to gauge differences in viewpoints concerning assumptions and impacts. Stage three also utilised the scenarios developed during workshops for spectrum analysis and to develop demand forecasts.

3.3. Structure of the report

This report is comprised of eight chapters and annexes related to key elements of the study.

The next chapter provides an overview of the 5G proposition that has been presented at workshops and online. The proposition provides an overview of the prospects and parameters for 5G. It is expected that formal initial standardisation will begin in 2016.

Chapter 5 provides a qualitative overview of the key verticals and environments. Relevant research from previous studies is presented and the results of scenario planning undertaken in workshops is presented.

Chapter 6 focuses on results from the third stage of the study focusing on quantitative analysis of socio-economic impacts. This study will differ from others by focusing more on the costs and returns and socio-economic impacts of 5G. Forecasts of the costs for 5G capability development are presented. The key benefits and impacts arising from 5G are then calculated for the verticals and environments.

Chapter 7 continues the quantitative focus for the study by further developing workshop scenarios concerning the use of 5G to forecast 5G spectrum requirements. Policy and regulatory considerations are also examined.

The concluding chapter provides an overview of key qualitative and quantitative results from the study. Key catalysts and barriers in achieving the benefits are presented. The conclusion examines catalysts and barriers to achieving optimal benefits from 5G.

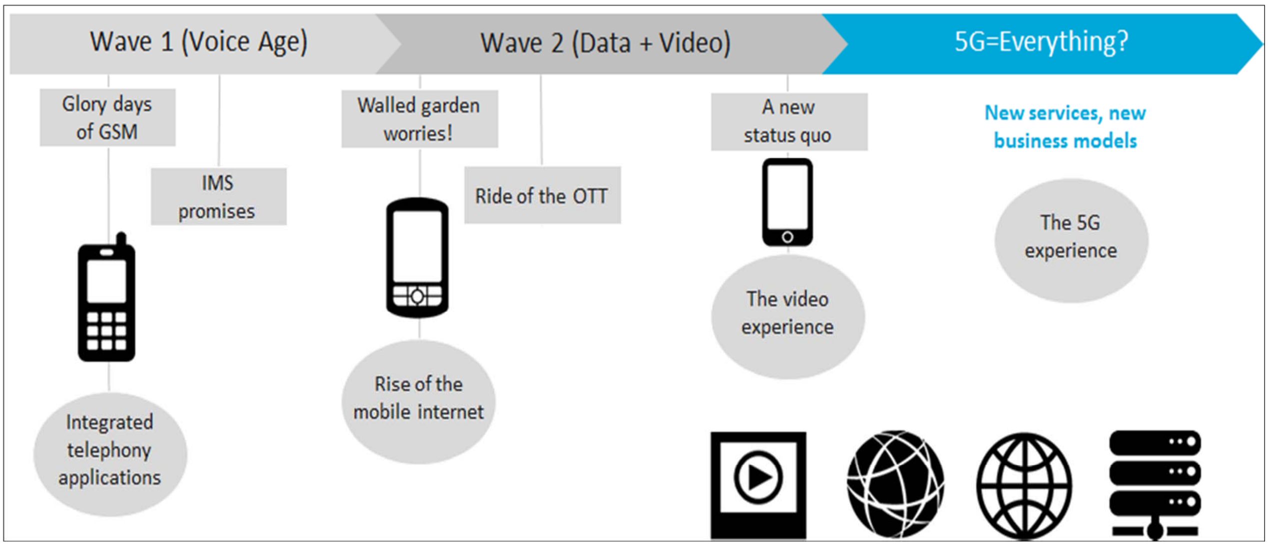
4. The 5G proposition

This chapter introduces the 5G capabilities identified by the study. These were shared in the study workshops and used to characterise the technical capabilities that the verticals and environments examined in the study will utilise to provide benefits.

4.1. Introduction

Even though it may seem sometimes like 4G has not yet quite delivered on all its promises and capabilities the 5G train is already rolling fast. 5G research activities have been underway for quite some time and further initial standardization will begin as early as 2016. The 5G Proposition is a rich one and builds on the heritage of previous generations but the goal in 5G is much broader and more ambitious than any previous generation.

Second generation wireless as characterized by GSM was about delivering a ubiquitous and secure voice solution. Third and Fourth generation technologies were progressively about delivering improved voice, mobile internet and video experience. Fourth generation systems such as LTE-Advanced were purposed primarily for the support of mobile video and in that function 4G performs exceptionally well. None of these requirements are going away in 5G. 5G will be required to support all of these capabilities and their various anticipated evolutions as well as new capabilities affected by the accelerating trend towards massive machine type communications or the so-called Internet of everything.



Source: InterDigital

Figure 2 A brief history of wireless technology

5G is aiming to be quite different. It is about more than just raising the bar on previous generations. The goals of 5G include the creation of enabling solutions for vertical industries such as automotive, healthcare, transport and utilities. While it cannot be denied that wireless through its generations has delivered enormous socio-economic value almost beyond measure no generation has ever set out with this fundamental goal as a priority. In this respect 5G will be quite different. It will be the first generation to explicitly target delivering socio-economic benefits and this will be a key goal to guide and drive the priorities of the many new 5G capabilities that are anticipated.

4.2. 5G: An International effort

5G is an international effort with Europe taking a strong lead with significant investment through initiatives like H2020/5GPPP. Around the world there are similar initiatives occurring in Asia through the Korean 5G Forum Initiative, the IMT2020 (5G) Promotion Group in China and the ARIB2020 & Beyond Ad Hoc Group in Japan. In the USA no formal public initiatives have as of yet emerged however it is clear that 5G activities are taking place in the big universities and in industry. There is further evidence of 5G driven research occurring in various NSF projects (e.g. FIA Program, Xdensification).

Beyond research the international community has further formed around traditional leadership initiatives in the area of wireless technology. The ITU is driving the requirements definition of 5G as they have done for previous generations. They are developing formal requirements for 5G around their IMT2020 thrust. In addition the ITU WRC met at the end of 2015 to discuss the first formal allocations of spectrum in 5G below 6 GHz and to provide a further resolution on spectrum above 6 GHz that will be in scope for discussion at WRC19.

The Next Generation Mobile Network (NGMN) Initiative is an international operator lead forum that is exploring key matters relating to 5G such as use cases, vertical market needs, spectrum and IPR. They have produced some excellent white papers outlining consensus Operator positions in many of these 5G related areas.

4.2.1. Standardization status

On the 17 and 18th September 2015 the 3GPP community gathered in Phoenix, Arizona for a dedicated 5G Workshop to discuss the roadmap for 5G. There were 550 participants from 159 separate organizations. Participants were mainly from the traditional Telecom industry however there were also several participants from non-traditional industries such as automotive and healthcare.

At the meeting much of the discussion centred on technology visions for 5G (of which there was considerable consensus) and core use case priorities where there remains significant on going debate on what should be the immediate and future focus of standardization. Broadly stated the on-going debate relates to the prioritization of a solution for an improved mobile broadband band capability vs. a nearer term focus on massive machine type communications for vertical markets. There was however consensus on the broad timeline for 5G standardization in 3GPP. It is expected to occur over three 3GPP releases. A study phase will be launched in late 2015 followed by the first standardization phase that is scheduled to complete by mid-2018. The second standardization phase has a targeted completion date at the end of 2019.

5G work related to Radio Access Network was officially kicked off in 3GPP in December 2015 with a study of use cases and requirements for the next generation radio technology. Individual working groups are expected to kick off their next generation radio studies in Q2 2016. On the Core Network side 3GPP activities are a little further advanced. Work on 5G actually started in 2015 in the SA1 group, where they started defining high level use cases and requirements for the next generation network.

4.2.2. Spectrum status

The World Radiocommunication Conference (WRC15) met throughout November 2015 to discuss general spectrum matters including allocations for IMT2020 (aka 5G). The result was basically a formal endorsement of the vision that 5G will be a tale of two spectrums i.e. below 6 GHz and above 6 GHz. The two main resolutions (European perspective) pertaining to new spectrum for mobile broadband application are summarized in

Table 1.

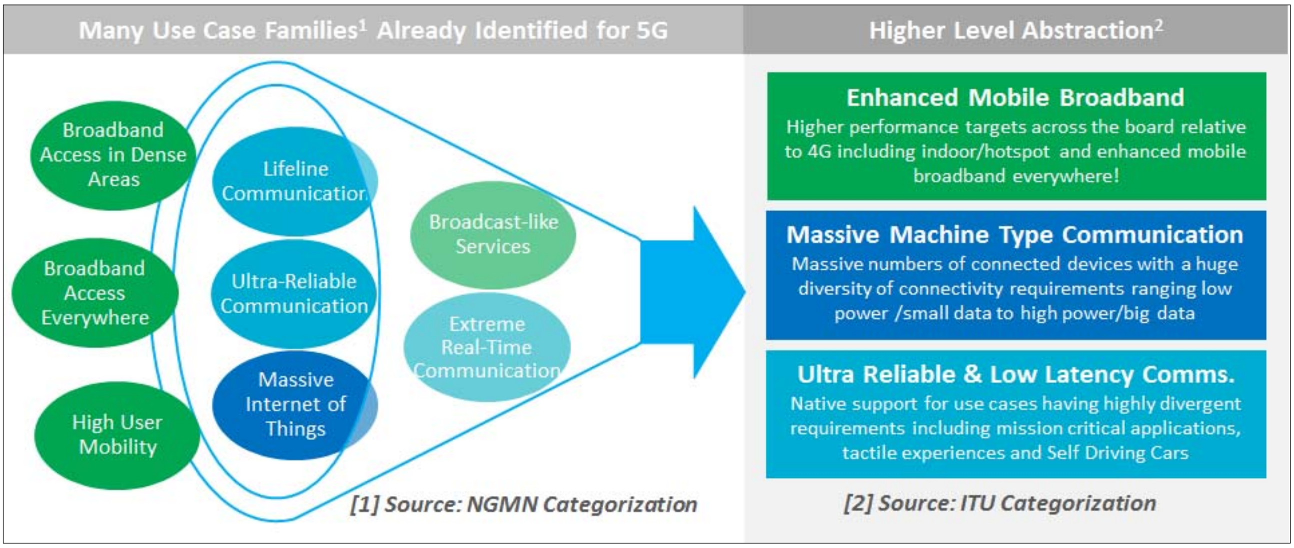
Table 1 Summary of the Key resolutions at WRC15 as pertinent to 5G

Resolutions below 6 GHz	Resolutions above 6 GHz
New or harmonized bands for IMT Use	*New bands agreed for discussion at WRC19*
▪ 700MHz Band (694-790 MHz) is now effectively agreed as global band ▪ L-Band (1427-1518 MHz) is agreed globally except 1452-1492MHz in Europe ▪ C-Band (4-8 GHz): 3400-3600 MHz extended to Europe and region 2 and 3 countries	No spectrum will be discussed between 6 and 24 GHz and in addition the satellite band of 27.5-29.5GHz is also off the table ▪ 24.25-27.5 GHz ▪ 31.8-33.4 GHz ▪ 37-40.5 GHz ▪ 40.5-43.5 GHz ▪ 45.5-47 GHz ▪ 47-50.2 GHz ▪ 50.4-52.6 GHz ▪ 66-76 GHz ▪ 81-86 GHz

Source: IMT-2020

4.3. *Emerging use case consensus*

The 5G Proposition is best defined in the use cases that are emerging. Generally there is considerable consensus across the industry on these use cases although they are sometimes presented a little differently depending on the forum in which they are being discussed.



Source: InterDigital development of NGMN and ITU categorizations

Figure 3 Converging position on use cases in 5G community

Figure 3 shows two of perhaps the most representative views on the 5G use cases from the NGMN and ITU respectively. Both express the same use cases however from slightly different levels of abstraction. The NGMN has defined eight use case families for 5G including broadband access everywhere and in dense areas, support of massive internet of things, and ultra-reliable & extreme real time communications. The ITU presents a slightly higher level abstraction that is equally valid but perhaps provides an easier snap shot of the new capabilities targeted in 5G. Per the ITU basis these are:

- **Enhanced Mobile Broadband**: Higher performance targets across the board; relative to 4G including indoor/hotspot and enhanced mobile broadband everywhere;
- **Massive Machine Type Communications**: Massive numbers of connected devices with a huge diversity of connectivity requirements ranging low power/small data to high power/big data;
- **Ultra Reliable & Low Latency Communications**: Native support for use cases having highly divergent requirements including mission critical applications, tactile internet experiences and self-driving cars.

4.4. 5G capabilities demystified

Much as there is consensus on the use case requirements in the 5G wireless community the new capabilities and value proposition of 5G are perhaps not entirely obvious to those not immersed in these discussions. For this reason and in order to help make the 5G value proposition and capabilities more accessible this section describes 5G in simpler terms and in manner more amenable to vertical industries. The manner in which these capabilities correlate to the definition of the ITU is illustrated in Figure 3. The ten new capabilities themselves are defined in Table 2. These user-friendly capability definitions are used throughout the remainder of the study.

Table 2 5G capabilities demystified

Ten 5G capabilities	Explanation
5G aims to enable a truly Pervasive Video experience	Virtual environments, ubiquitous telepresence, Augmented reality, holograms and other immersive technologies will allow you to be virtually present anywhere, or interact in real time with people all around the world as if you were in the same location. The experience is so immersive that it will come close to equalling a real human experience.
5G will enable a revolution in the Smart Office	Everything in your office and home will now be wirelessly connected. Everything is plug and play including HD screens, cameras and monitors. Everything is integrated and your office can literally be anywhere that you can access a screen and user interface.
5G goal is to deliver 50Mbit/s Everywhere	This simple but challenging capability goal is to realize a universal minimum data rate to enable high level quality of service everywhere.
5G will allow you to create your own network if you that is what you want to do	Think of this as like having your own spectrum or the ability to spin up your own network to your requirements without the hassles of ownership. Innovation in 5G, in particular in the core network (e.g. network slicing) will make this possibility much easier to realize in a highly flexible manner.
5G will support dynamic increase of capacity on the fly	Resources costs to maintain very high speeds for many users everywhere will likely be very high. However, 5G will be architected to allow very flexible reallocation of resources to dynamically increase the perceived capacity of the network to serve large numbers of users when they need it (e.g. traffic jams, stadiums, disasters).
5G will enable a working solution on planes, faster trains and cars	Today, most connectivity is directed at the ground to where most users are. 5G will expand this focus to the skies. More than this 5G will support the natural evolution of transport systems to the higher speeds that are being forecast.
5G will deliver a single scalable solution for sensor networks and the IoT	Imagine connectivity technology for all vertical market needs provided at such scale that it will meet with all of the cost points of today's systems. 5G is designing its entire system to support very large scale M2M/IoT networks.
5G will enable an ultra-reliable network for mission critical applications	5G will include operational modes that aim to exceed the so called five nines reliability and availability. This category of capability is seen as essential for the support of mission critical requirements found in current and anticipated future vertical industry applications.
5G will make the realization of the Tactile Internet possible	Think of this as whole new way of interfacing with technology. A revolution many times more profound than your touchscreen has been. This encompasses all forms of new user interface technology (e.g. augmented reality, remote robotics) where an almost instant access to content or control function is required to make the service possible and user acceptable.
5G will deliver a meaningful and efficient Broadcast service	Generic broadcasting is fading in favour of more personalized and targeted services. For instance, news and information can be broadcasted for a specific group of people at local, regional or national level. You could have your own broadcast services for your company, your office and your work place.

Figure 4 provides a mapping of these defined capabilities to the three major use case categories defined by ITU. It is important to note that nothing new is defined here. This presentation merely serves to provide an easier engagement mechanism with vertical industry players. It useful to note through this visualization that the defined capabilities are in some cases quite orthogonal however many are interdependent. Many of the core EMBB capabilities may be required to support or complement other capabilities.

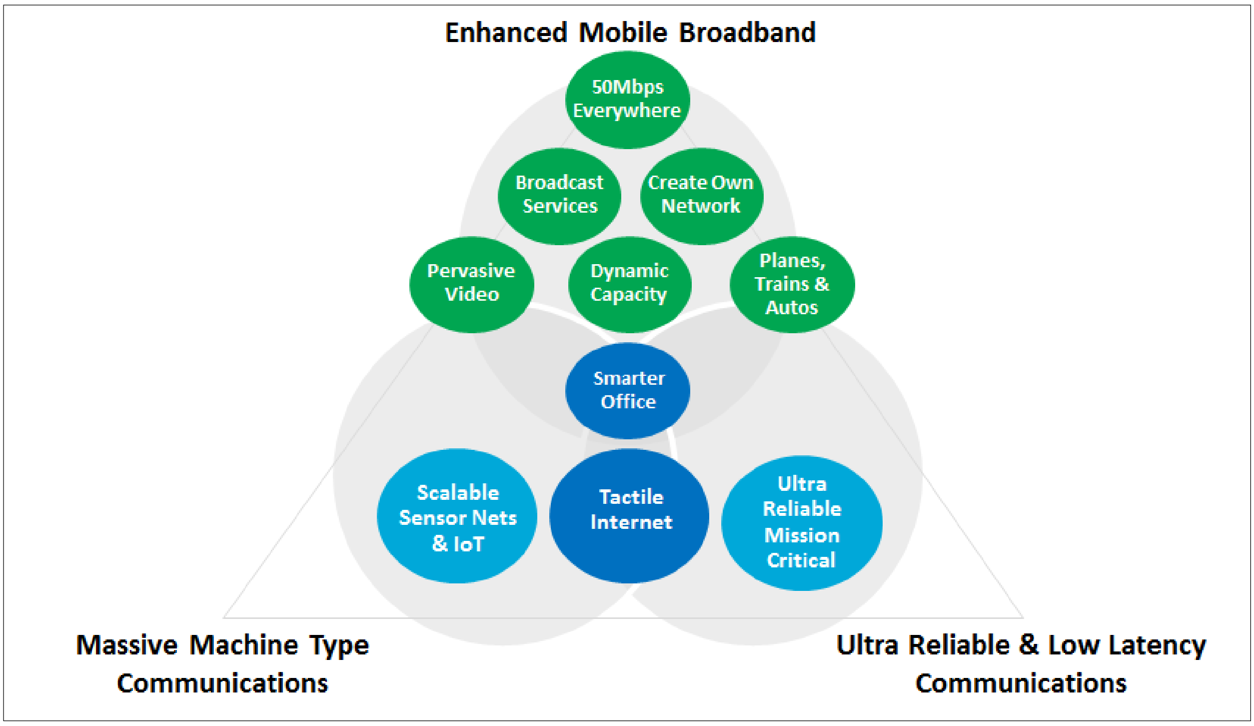


Figure 4 Mapping of 5G capabilities to the current ITU 5G use case model

5. Qualitative analysis: Verticals and environments

This chapter provides an overview of desk research and the results of scenario development activities at workshops for the four verticals and environments. The results of these activities largely focused on providing qualitative insight to the utilisation of 5G capabilities.

5.1. Vertical industries

The study of verticals enables the investigation of 5G capabilities at all stages in the supply and value chains from raw materials through to after sales maintenance and eventual disposal of goods and services.

5.1.1. The selection of key vertical industries

Verticals were chosen for the study by selecting those most commonly mentioned in 5G use cases and White Papers. Numerous studies and use cases were examined. Some studies treated verticals as homogenous, without distinguishing between the different devices or services that would be required. Other studies highlight the differences within and between verticals. For ease of cross-referencing Table 3 provides a flavour of the foci for nine of the leading studies.

Amongst nine leading studies the most common verticals were automotive (mentioned in six papers) and healthcare (five papers). A number of the studies also had an emphasis on transport and emergency response (three papers); transport was therefore selected. Three papers focused on utilities and/or energy, this sector was also included.

Table 3 An overview of verticals examined in key 5G studies

Paper	Vertical details
4G Americas	Automotive, health, public safety
Ericsson 5G	Automotive, health, government, utilities, manufacturing and transport
GSMA	Automotive, augmented reality, tactile internet, virtual reality
Intel	Specific verticals not mentioned
ITU	Specific verticals not mentioned
Metis	Activities: virtual reality office, smart grid, emergency communications, IoT, traffic efficiency and latency
NGMN	Automotive, health, energy and home
Samsung	Connected car, fitness and healthcare
Qualcomm	Autonomous vehicles, healthcare and emergency response

5.1.2. The scenario planning process

This structured scenarios planning exercise utilised in workshops enabled participants to contribute to the development of hypothetical future world views for each vertical. The futures that were developed became building blocks for further evaluation of the verticals in the final stage of the study.

Scenario planning is a structured process for gathering information. Formally, it is often described as a strategic foresight methodology. During the workshops participants were encouraged to ‘think the unthinkable’. Discussions highlighted that the future is not pre-determined or predictable, but instead it is full of ‘uncertainty’. Scenarios Planning explored these uncertainties to create “extreme” futures. The working thesis for the study was that the future lies somewhere between these extreme views.

The scenarios provided an insight into possible futures and the key catalysts and barriers to attaining and ideal scenarios. Discussions also enabled the study team to ask ‘big questions’ of the participants.

The scenarios also enabled later stages of the research to reasonably explore the level of impact that 5G capabilities might have on a vertical or environment and the level of need that a vertical or environment might have for 5G innovation. Section 1 of the Annex provides a further qualitative insight to the relationship between verticals and 5G capabilities by providing ‘*day in the life of’* scenarios to provide a richer understanding of the impact of 5G in 2025.

The remainder of this chapter provides a snapshot of key qualitative issues regarding verticals and environments covering aspects such as potential disruptors, catalysts and connectivity needs.

5.1.3. Automotive

Automotive is the most cited sector amongst verticals and use cases in 5G studies. It is a potentially huge market for ICT and 5G-enabled advances. There are more than 275 million motor vehicles in use in EU28 Member States.

The most optimistic future imagined during the workshop was a world in which the Automotive Industry is open to change, new business models emerge with high trust from users and related sectors supported by effective governmental frameworks and standardisation. This world is characterized by open business models attracting international players of different sizes and expertise. Innovative solutions happen as a result of good understanding of data privacy issues, which leads into trust from users, and effective frameworks fostering integration of systems and business propositions. This is seen as an enabling environment to create a vibrant ecosystem of global solutions.

With the proliferation of IT solutions in the automotive sector, in this ideal world there is a tight control of how car manufacturers and associated companies handle and share data related to cars and users. This increases the trust of users in companies and creates an environment that fosters innovation and new products. The use of data, better control of car functions and more efficient use of fuel and complementary energy sources, reduce maintenance costs and cars become cheaper to use. These advantages, combined with better recycling policies, global standardisation in the automotive industry and globally aligned governmental automotive-requirement policies enable effective economies of scale.

In contrast, the most pessimistic automotive future imagined by the group was one where supportive global regulation and open ecosystems did not emerge. In this world, just a few global corporations create end-to-end ecosystems where they can dominate or monopolise a global market with their offerings. They may present them as open systems, but in reality they are closed business model propositions with few powerful players involved. In this case, there is little privacy control from users, so the leading corporations can use data and information at their will. Hence, car users would have low privacy, and there would be few “monopolised” solution offerings.

Innovative data-driven solutions will come from unwillingly shared data from cars and drivers, who belong to closed groups of specific brand customers. Powerful stakeholders, like governmental institutions and insurance companies, may liaise with car manufacturers and service providers to get more information from drivers and their habits. The same might be the case for autonomous vehicles. This “private” exchange of information may lead to more restrictive services leading users to think poorly about extended connectivity, flexibility of wireless offerings and what the real benefit for them is.

The two most important, but highly uncertain drivers, that emerged during discussions were ***business model flexibility*** and data privacy. New and disruptive business models were envisaged. Workshop participants agreed about the need for open ecosystems and clear regulatory frameworks supporting investment for automotive mobility systems that can save increasingly expensive fuels and present options for the sector in relation to an increased offering of solutions for mass transportation.

The second automotive driver was ***data privacy***. One key reason for this driver was the interpretation of privacy by future generations of car drivers/users. It was highlighted that this might differ significantly from current privacy expectations. This factor, in combination with the proliferation of more open systems and platforms, could lead to different privacy definitions as compared to existent closed propositions. In turn, this raises concerns regarding who will own/commercialise emerging data-driven services.

In addition to the two driving forces that provided the main driving forces for the automotive scenario further driving forces were also identified for the automotive sector. These included increasing fuel economy, reducing pollution, global harmonisation, emerging markets/economies, shifting demographics and growth in urbanisation, safety and personal protection, data-driven customer services and the sharing economy.

Additionally the group identified key disruptors facing the sector. Over a five year horizon workshop participants identified:

Lifecycle of vehicles: Car manufacturers are learning from other sectors and speeding the integration of new technology in cars;

New companies penetrating the sector: With an ever increasing electronics in cars, more strict requirements for recycling used vehicles and the need for alternative fuel sources, the automotive sector is gradually incorporating more innovations from a variety of sectors;

Proliferation of e-mobility: Better communication services will enable people to reduce their physical mobility needs. This might impact the sector as the demand for vehicles could reduce;

IT innovation: More cloud and on-board services maintain the adoption of new innovations and services in cars. This could be disruptive, customer interest might shift towards services rather than the car.

Over a ten year horizon participants identified three potential disruptors; the *Availability of Fuel*, *Autonomous Driving* and the *Sharing Economy*. The first is an obvious disruptor. The second relates to a changing perception and experience of cars as they become less objects that have to be driven and more as a means of moving between two locations during which time can be used for other tasks such as work, rest, etc. The last disruptor could see ownership of cars decrease as the growth of ‘Mobility as a Service’ increases. Growth in self-driving vehicles and other solutions could lead to considerable re-alignment in the automotive value chain.

5.1.4. Healthcare

Healthcare is one of the less cited vertical sectors and less developed use cases in the 5G studies. The cost of providing Healthcare is projected rise by 15 per cent to account for 8.5 per cent of GDP in the EU28 Member States by 2060 when about 1 in every 8 people in Europe will be 80+ years old. Medical non-adherence is already costing EU governments an estimated €125 billion annually and contributes to the premature deaths of nearly 200,000 Europeans a year.

The most optimistic future imagined during the workshop was one in which there is widespread acceptance of technology-driven intervention in the health market and a very supportive regulatory landscape. In this scenario both health practitioners and patients are open to change and new business models. They are comprehensively supported by strong, clear regulations. In turn this is supported by common standards for the recording, sharing, transferring and anonymisation of health. And in this scenario the privacy concerns of the public are comprehensively assuaged.

Systematic change is possible, with not just an interest in treating illness but also in preventing illness and proactively building wellbeing and quality of life. New modes of health management are embraced by patients and health practitioners. This allows a move to preventative, life-long, crisis-avoiding remote and/or technology driven paradigm, with new opportunities opened up as large scale, longitudinal analyses of various cohorts are possible.

The most pessimistic scenario is one in which there is a complete breakdown. Health costs continue to spiral out of control and there is no improvement in the regulatory paradigm for connected health developments. Also there is little cultural acceptance of changes in the sector. Changes are only embraced on an ad hoc, piecemeal and reactive basis as dictated by crises. There is no sector-wide systematic investment in, or adoption of, new technologies and services. In this most pessimist scenario, no improvements are seen and the status quo is maintained, but facing a growing and aging population which places more strains on existing systems. No efficiencies or cost saving benefits are realized from ICT advances in health and only the wealthiest can get access to any benefits that may be available from niche ICT-driven improvements in the sector.

The two most important, drivers that emerged during the discussions were ***culture*** and ***regulation***. A key feature of the ***culture*** driver is the public and medical professional acceptance of technical solutions to health care. Acceptance can increase as people get more open to the idea, but it can be eroded due to concerns over issues such as privacy. Attitudes will change with generations.

The second driver for healthcare was ***regulation***. There are different regulatory policies needed to underpin development in healthcare, ranging from issues such as transparency, data ownership, privacy, data exchange, permissions around offering of services, and liability issues.

The discussion also identified a number of other driving forces and trends. These included: significantly increasing health costs, the aging population and the Global Market Place which will emerge as new kinds of delivery of health services become increasingly important and the need for the local will reduce

The group also identified key disruptors and that could affect the sector. Over a five year horizon the following were identified:

> ***Big Data:*** large data sets will enable new ways analysing treatments and health. They also enable regulation of the pharmaceutical industry to change as post-approval monitoring of drug efficacy is possible as well as the understating of drug interactions in non-trial scenarios;
>
> ***Wide area sensing – outside the hospital boundaries:*** new medical sensors in the community will lead to the creation of new datasets. These datasets can be

created outside of traditional clinical settings and this raises issues on their ownership, control of, sharing, storage, analysis and destruction***;***

National/EU legislation: there is high dependence on strong and transparent National or European regulation of health data. The calibration of the rights of patients, practitioners, insurers and the medical research community may close off or open up innovation and investment potential;

Private may leapfrog public and disrupt: large health insurers may innovate ad hoc systems and technologies that become de facto standards.

Over a ten year time horizon participants identified six potential disruptors. ***Multiple service providers*** could mean that the health system moves to become one where many health services can be provided by technology. ***Insurers*** may reward customers who stay fit and have healthy diets and so proactively predict future costs that a patient is *likely* to bring. From this their use of and access to patients' data may be problematic. The pervasive use of remote systems to sense and actuate medical technologies increases the need for ***cyber security***. Another potential disruptor is the ***ballooning population and the need to sustain health service to it.*** Two other disruptors might be the ability to diagnose and cure at arm's length through remote surgical practices (***remote curing)*** and, related to this, the increased ***dependency on high tech –*** where failure will be more disruptive***.***

5.1.5. Transport

As noted previously, there are more than 275 million motor vehicles in use in the EU28 Member States. Smart vehicles are likely to have in excess of 30 sensors and a large transport node could have more than 15,500 license exempt radio equipment devices.

The most optimistic future scenario imagined was one which could be termed "All is fair on the road to transport 2.0". In this there is friendly government policy coupled with a highly motivated industry. In a fair and competitive environment long held industry business models take on new shapes. In this scenario everything would be connected everywhere. An open application ecosystem emerges enabling a transformation of the travel experience and end user behaviors. Data and advanced data products are acknowledged and protected as the fuel in the new value chain. Application developers, data managers and innovators and hardware providers all prosper in a healthy ecosystem.

Early evidence of positive social and economic impact motivates greater government investment in new technology infrastructure projects. Transport systems evolve quickly, fuelled by a new balance of public and private sector support. The vehicle ownership model is displaced with increasing sharing models, resulting in a net reduction in road traffic, particularly in big cities. The proliferation of ubiquitous transport data helps support the accelerated introduction of autonomous vehicles and a profound shift in models both inside and outside of vehicles. This new, integrated society delivers enormous social and economic impacts all supported by a powerful backbone of wireless information and communications technology.

The most pessimistic scenario was one which could be called "Death by a Thousand Drips". In this scenario government is slow and is stuck in business as usual. Industry also remains stuck - in old practices and business models. The future of transport is not too bright and an opportunity would seem to have been lost. Command and control of transport systems remain and the positive socio-economic benefits are limited. Connectivity beyond minimal requirements is met but there is no drive to connect this infrastructure into the bigger story - the Internet of Things. Transport data becomes open but only over many years and through ambivalence and sporadic political whims that declare "all data must be made available". The end user experience isn't exactly bad in this world, but it's just not everything it could be.

In the discussion seven key drivers were identified. One is **urbanization** as by 2050 between 70 and 75% of the global population will be urban dwellers. The **technology & connectivity** driver can be broken down into non ICT innovation (such as that which might lead us to new roads) and ICT innovation (for example Intelligent Vehicles). Both the **aging population and also population growth** were considered key driving forces for transport. More sustainable patterns of behavior, moves towards more walking and cycling, multimodal solutions, and models of ownership might shift so that **different behaviors and a sharing economy** formed another driver. The huge expenditure required on public infrastructure was considered to make **climate change** an important driver. **Smart and integrated mobility** was another driver, coming from M2M increasing efficiency and the Internet of Things making it possible for different "modes" to communicate with each other. Finally, the wireless charging infrastructure, such as embedded in roads and hybrid drive trains, would make **energy and resources** a driver also.

The workshop also highlighted two key disruptors:

One is **changing business models** that might be more likely in the wake of the rise of big data and the Internet of Things.

The other disruptor could be **Government policies** in which transport is intertwined with government policy and only with this Government or political support will anything new really happen.

5.1.6. Utilities

It is predicted that by 2020 Utilities will account for two-thirds of the 30 billion smart, wirelessly connected devices in homes and industry worldwide. EIT ICT Labs forecasts a global market worth almost €400 billion for smart grid technology in 2020 while Pike Research predicts that investment in smart grid technologies in Europe will total $80.3 billion between 2010 and 2020.

In the most optimistic scenario everything works and the utility market thrives. Market confidence is encouraged by strong support from governments and this ensures a stable regulatory environment and sufficient and suitable harmonised spectrum. This prompts investment and enables competition. The critical concerns of the utility industry - such as trust, control and liability are resolved to enable 5G to be successful and to allow the EU to be ready to "Beat the Energy Crisis". In this environment manufacturers are confident, innovative and there will be economies of scale. There is potential not only for inter-vertical but also cross-vertical collaboration, interoperability and integration, driving a new ecosystem of devices and networks designed to meet the users demands. The utility providers invest heavily in technology and solutions to advance their competitive position and performance. 5G became a single network, improving all the relevant metrics and enabling the smart utility to support far larger numbers of devices, to be more efficient and fully ubiquitous. The networks enable very fast and reliable distribution and consumption of energy and water, with opportunities for consumers to readily consume and 'supply back' to the grid. There is spare capacity to meet the impacts of population growth, urbanisation and change of lifestyle.

The most pessimistic scenario is a world where nothing works as it should. Absence of harmonised spectrum and a lack of EU driven sector regulation and policies means that there is no clear direction or strategy. Lack of trust in connectivity and policies will have a severe impact on investment and innovation. There will be no collaboration within the utility vertical, and even less collaboration with other industries requiring similar type of connectivity. Utility providers have no clear solution and will use various type of spectrum and deploy fragmented networks that need manual integration. This is a recipe for disaster leading to reduced utility service availability to end users (more outages) and likely increase utility costs.

The workshop identified two important, but highly uncertain, drivers. One of these was **spectrum and control**. This is the international harmonisation and availability of sufficient spectrum. A harmonised spectrum is seen as a crucial enabler of the Utility IoT environment, giving manufacturers confidence in the market and allowing the industry to take advantage of economies of scale. This would subsequently foster innovation, integration and interoperability. Control is the utility providers' concern of using a network that they can't control and manage. Here there is a fundamental "trust" issue and linked concerns such as "liability".

The second important driver was **politics**. By this was meant the EU's master plan and all the different regulatory policies needed in this sector to set out a clear direction and strategy: enabling investment, innovation and development in the utility vertical. It was felt that clear policies would enable utility providers to work out their long term strategy and foster investment.

A number of other drivers were also noted by the group. These included Government policy, a harmonised spectrum, technology and connectivity, trust and control, renewable energy, urbanisation and population growth, environment, resource availability, technology improvement and different behaviours and economy. More understanding of utility network performance and usage will change providers' and users' behaviour.

For the future five years the group put forward three main disruptors:

> **Smart Meters**: the mass rollout of Smart Meters to end users was forecast to produce an installed base of almost 240 million smart meters by 2020;
> **Hyper-local generation**: this would take up of much more local energy generation and micro-grids based on renewable energies and local distribution;
> **Regulatory Changes**: such as EU regulation changes addressing matters such as balancing the form of supply, setting out availability targets and adoption to new / emerging market structures.

For a ten year horizon, participants identified four main disruptors. The first is Resource Security (security of utility resources in a growing market) which might cause major change. Secondly, increasing demand might result in limited or insufficient spare capacity. Thirdly, an available 5G infrastructure will change how utilities operate their networks. Finally, a renewables-only environment would be one where the market would completely change: generation will be more dispersed and the network power inputs would have to be more closely managed.

5.2. Environments

The study of verticals only focuses on the production and eventual disposal of goods and services. However, this focus omits consideration of the many additional areas and locations where 5G capabilities will also have an impact. For this reason four environments were selected for analysis.

Clearly there is a great deal of overlap between the verticals and environments - the verticals produce the goods and services that will predominantly be consumed within homes and workplaces. And cities and non-urban environments are predominantly composed of homes and workplaces, plus other public and private sector buildings. Care has been taken in the study to focus on each environment and vertical in order to prevent duplication and double counting, particularly when forecasting quantitative benefits and impacts in the next chapter.

5.2.1. The selection of environments

To examine additional impacts of 5G capabilities two pairs of ‘environments’ were selected. The first pair focused on cities and non-urban environments. The second pair of environments had a much smaller level of focus. It was felt that by examining homes and workplaces the impact of 5G capabilities at a more intimate or micro-scale could be more closely analysed. The four environment briefing documents emphasised the benefits of 5G capabilities using PEST categories (political, economic, social and technological impacts)

5.2.2. Smart cities

There are 468 cities with a population of over 100,000 in EU28 Member States. The level of urbanisation in the European Union is above 75 per cent and is predicted to rise to 80 per cent by 2020[9].

Cities contain large numbers of people and businesses that are already relatively well digitally connected by fixed and wireless technologies. Key benefits arising from 5G capabilities relate to enhanced communications and information access for policymakers, citizens, business and others inhabiting cities. There was generally a positive view that if policymakers had better access to information from sensors and other data sources about what was happening real-time in cities they would be able to manage cities more effectively.

Several of those in the workshop associated greater access to information for citizens with enhanced social benefits due to the ability of information and communication to create a more inclusive society. A major benefit of this was thought to be enhanced social capital in cities. Better transport due to enhanced wireless communications was thought to provide major benefits for cities in reducing congestion, this was subsequently expected to lead to reductions in hydro carbon consumption and less emissions and CO2 in cities.

Key economic benefits foreseen in Smart Cities

Three key, but wide ranging, benefits arising from enhanced wireless communications and 5G capabilities were emphasised by workshop participants:

> ***Transport improvements and reductions in congestion***: Several economic and other benefits were envisaged as transport networks become better co-ordinated. Greater access to real-time information by travellers should enable faster journey times within and between cities. Greater access to real-time information by transport providers should enable better co-ordination between different transport modes at multi-modal transport inter-sections.
>
> A key benefit, which had multiple impacts, was improvements in road traffic management facilitated by improved wireless communication. Enhanced information about traffic flows and journeys should enable traffic controllers to better manage traffic real-time and reduce congestion. Enhanced information about congestion should also enable drivers or autonomous vehicles to avoid congested routes and complete journeys more rapidly.
>
> ***Better information for administrators***: Enhanced access to information from numerous sensors located throughout Smart Cities in households, workplaces, from transport routes, citizens and platforms will provide policymakers with better access

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[9] EC. 2015. Data in smart cities: Analysis of the current situation SMART 2015/0045. Invitation to Negotiate. Smart city logo www.jdiaz474.wordpress.com/2013/06/27/de-las-smart-cities-reflexion-ante-los-nuevos-usos-de-los-opinometros-de-este-pueblo/

to real-time information about what is happening in their cities. Whilst it is not always the case that ‘more’ or ‘better’ information leads to better policymaking enhanced big data analytics should provide better insights into how cities operate. Identifying the magnitude and location of detrimental effects (congested areas, accident black spots, crime hot-spots, polluted areas etc.) and possible solutions or the impacts of solutions implemented to alleviate detrimental effects.

The workshop identified that enhanced wireless communications (and reduced costs and/or more reliable connectivity) provides opportunities for growth in the development of information platforms. New platforms are expected to be highly scalable, hybrid architectures that combine elements of database and search technologies in order to make information access dynamic and ad hoc.

Whilst more information was likely to be available the group highlighted that access to information might not be simple. It was suggested that barriers due to trust and privacy concerns were likely to increase in the future.

Key social benefits foreseen in Smart Cities

A number of social benefits were predicted as a result of enhanced wireless communications and 5G capabilities in Smart Cities.

Enhanced Social Capital: Social capital refers to the collective or economic benefits derived from the preferential treatment and cooperation between individuals and groups. Social capital has multiple definitions, but two elements that featured during discussions were firstly, benefits in terms of transparency, democracy and political involvement. The second element was enhanced involvement in volunteering and sharing expertise. Communication benefits were thought to be particularly useful during local or civic emergencies when citizens could help to overcome problems in their local area.

Assisting an aging or less able population: Several participants during the workshop noted that benefits could rise in supporting older and less able people in city environments. Easier access to public and private transport to assist mobility was thought to arise from enhanced wireless communications. Benefits in relation to independent living for those whose lives depend on assistance/care with the activities of daily living were also expected. More information and support can enable these individuals and their families to take the initiative in selecting solutions to enhance personal independence and independence in living in their own home or other preferred locations.

Key environmental benefits foreseen in Smart Cities

Improvements in transport management and reductions in journey times are expected to produce several environmental benefits. These include:

Reduced congestion, emissions and hydro-carbon consumption: Several benefits arising from improvements in transport planning and reductions in congestion have been presented from economic and social viewpoints. Clearly environmental benefits should arise. Some participants noted that enhanced access to information and communication could lead to more car sharing (both short-term vehicle rental and commuter journey sharing) and thus better optimisation of car resources in cities.

All participants highlighted that if reduced congestion was possible in cities this would have a number of ‘knock-on’ effects. Faster journeys should reduce the consumption of fuel (hydro-carbon and electricity). This in turn should lead to reduced emissions from vehicles and this should lower pollution and CO2 reductions.

Better living environment, particularly for those with asthma and bronchial diseases: Key benefits arising from a reduction in congestion can be reductions in noise and pollution problems. A reduction in pollution and particulates can be especially useful for those living in cities that have bronchial problems.

5.2.3. Non-urban environments

The context for non urban environments is that over 77 per cent of the EU's territory is classified as rural, 47 per cent is farmland and 30 per cent is forest. One fifth of the European population is employed in rural areas, but GDP per capita is only 70 per cent of the EU average and just 44 per cent in the EU-N12 Member States.

The rural environment has historically lagged behind its urban and suburban counterparts in terms of its access to, and exploitation of, cutting edge broadband access and the digital technologies that are enabled by it.

Key economic benefits foreseen in Non Urban environment

There are many economic benefits which could accrue to the Non Urban environment. 5G has the potential to make many existing services more economically feasible and it has the potential to enable new services and to support ancillary economic activity. Two key economic benefits were particularly highlighted by participants in the workshop:

Sustainable Capex Spending: A key economic benefit for the Non Urban environment from deployment of 5G networks would be reduced network capex through the pooling of resources. This could be achieved through extensive sharing of the spectrum and built network infrastructure. Certain services have to be provided in Non Urban areas, often by government. These include the provision of Public Safety networks, Defence, Utilities and Transport (ITS) systems. The virtualisation capabilities for 5G, and in particular network slicing, could potentially allow these bedrock services to share a common infrastructure. This would be in addition to providing additional capacity to more commercially oriented services which otherwise would not be viable. While much of this may already be technically possible 5G innately and expressly sets out to support it. Business models and regulations would need to adapt to provide this support and European state-aid rules may impinge on the feasibility of such an approach. The ability of networks with different demand and outlooks to cooperate in such ventures might cause concern.

ICT-dependent industry: 5G, and particularly increased capacity and connectivity everywhere, was seen as a key enabler of the development of ICT-dependent businesses in Non-Urban areas. The absence of communication capabilities puts such Non Urban environments at a disadvantage in terms of promoting and supporting indigenous SMEs and also attracting foreign direct investment to regions that could benefit from such investment. While the opportunities and diversity of connectivity and capacity in Smart Cities is likely to continue to outpace Non Urban areas, it was seen that 5G could address some of the Digital Divide.

Key social benefits foreseen in Non Urban settings

The social benefits resulting from enhanced wireless communications and 5G in Non Urban settings were also discussed by the group. The key and repeated conclusion of the group was that 5G, in providing much improved capacity and ubiquitous connectivity, would allow for the kinds of social benefits already available to urban areas right now using existing network technologies. Essentially, 5G's main impact was seen as comprehensively addressing the Digital Divide.

Participants in the group commented on the ability of 5G to address issues around social inclusion and social mobility on two fronts. The first pertains to the economic advantages already outlined. 5G has the potential to close some of the gap on the Digital Divide between urban areas and Non Urban areas. In making more businesses viable in the Non Urban setting it enables citizens in those areas to benefit from wider social and economic inclusion. This has the potential to be a virtuous circle of investment and increased. The possibility of having the Smart Office within the Non Urban environment was seen as a viable goal for 5G.

From a more conventional view, it was noted that 5G enables the achievement of aspects of individual social inclusion and mobility that are influenced by access to ICT-related resources in these marginal areas..

Key environmental benefits foreseen in the Non Urban setting

A key environmental benefit foreseen by the group was the opinion that 5G offers the ability to create ***shared networks***. In sharing infrastructure primarily to reduce costs and increase the economic feasibility of the network, the immediate and correlated knock-on effect is that there is no unnecessary duplication of infrastructure. This includes active network elements including base stations and also civil works and sites.

5.2.4. Smart homes

There are 214 million households in EU Member States and in 2013 76 per cent were connected to the internet. By 2020 the most connected Smart Homes could have more than 200 radio equipment devices.

Key economic benefits foreseen from Smart Homes

The group identified two key economic benefits, as well as a number of secondary benefits:

> ***Reduced energy spending*** was a key economic benefit from the deployment of 5G networks. The ability to track energy consumption real time would help shape usage to minimize energy. This would further reduce household spending on utilities such as electricity, gas and water. Furthermore, energy management, remotely controlled whilst away from home, would be an economic benefit. This can be done today but more informative control could come from a wider ecosystem of solutions and applications.
>
> ***Time saving***: the ability to increase the efficiency of specific activities within the home can help reduce the time spent on those. People living in smart homes can use their programmable devices which adjust to their movements and lifestyle.

The group also highlighted a number of secondary benefits for consumers living in smart homes, such as heat incentive tax, real time home insurance policy, and a changed and improved business model for the warranty on products.

Key social benefits foreseen from Smart Homes

When looking at social benefits which might arise from Smart Home the group saw three as being key:

Privacy/Security/Safety: Smart Homes can offer much improved security measures, such as alarm systems that are connected to the emergency services, remote access to CCTV around the home and other measures. The ability to control lighting, blinds, or other security features when accessed remotely was also seen as a key benefit. Smart homes could offer enhanced safety measures, such as smoke, fire and water sensors which, as well as detection, could also contact the emergency services.

Access control is similar to the security benefit but was seen as more specific. Examples given included the ability to remotely allow certain individuals access to the property. This might include deliveries to the home when the occupant is away or allowing scheduled maintenance personnel (appliance repair or plumber or electrician) access to the property whilst the occupant is away.

Enhanced medical support/assisted living was the opportunity for medical support and assisted living within smart homes. The proliferation and capability of remote sensors allows detection if someone has fallen over or not moved for a certain period of time and the alarm can be raised to the appropriate medical team. Enhanced communications provision within smart homes can provide assisted living in a number of ways, enabling elderly or less able people to live more independently.

Key environmental benefits foreseen from Smart Homes

There were three main environmental benefits anticipated to come from Smart Homes:

Reduced energy consumption and reduction in CO_2 emissions would be a clear benefit for the environment. Smart homes provide the ability to minimise energy consumption by enabling more efficient use of gas and electricity due to real time environment changes. The additional benefit from smart homes within a 5G environment was the ability to integrate existing heating infrastructure with capabilities from renewable energy sources.

Reduction in waste: Waste could be minimised by factors such as enhanced recycling options and more informed consumption of food. Appliances such as fridges and cookers will be able to offer more information on quantity and portion sizes. Over time this could lead to reduced wastage through enhancements to food ordering, storage and cooking.

Better and more informed ***electronic waste*** could be seen as both a negative and a positive benefit. There would be the need for more devices in the home, with the potential for increased wastage when these reach end of life. But the group also mentioned the opportunity for 5G to produce better, longer lasting products or ones which could be recycled more efficiently.

5.2.5. Smart workplace

There are 25.6 million active enterprises in EU Member States and EU enterprises employ 141 million people. The most connected SMEs could have more than 750 radio equipment devices which equates to approximately one device for every 1.5 sq. m of floor space.

Key economic benefits foreseen from Smart Workplaces

The economic benefits of 5G in the workplace broadly breakdown into three categories.

The most profound impact may be ***more integrated information***. A larger scale infrastructure for the support of the easy movement and sharing of massive amounts of information may be 5G's greatest value. Assuming that 5G and related technology innovation will provide security and privacy solutions to make this data anonymous, the economic potential in integrating behavioural information into the operation of Transport systems, Utility systems and even Telecom systems themselves could be very large.

Better inventory controls: the tighter data integration enabled in 5G should support all round improvement in supply chain management. With everything connected, traceability, inventory control and freight management will all improve as the supply chain becomes more fully integrated. 5G is also expected to provide benefits into smaller office environments.

New tools to empower the work place through the underlying enabling technologies of 5G could reshape the very notion of the work place. If the technologies deliver an "anywhere office" capability then the economic impacts could be profound - both positively and negatively. Individuals will be able to work from home or a hot desk location more easily and travel will be reduced. All this might have a negative impact on traditional cityscapes potentially impacting small businesses that provide food and other services. The effect is difficult to predict as truly positive or negative.

Key social benefits foreseen from Smart Workplaces

The social benefits of 5G in the work place are similar to those of the smart city. Specific areas identified by the group are given below.

Assistance with aging and disabled population: The capabilities being developed and/or enabled by 5G should provide better support to an aging and disabled population. This could be an important benefit with the forecast aging population of Europe. In this context 5G may enable people work longer in a manner that is flexible for them, resulting in happier more productive lives.

Overall improved quality of life: the emergence of the smartphone has improved the overall quality of life. In 5G, integration will be taken to the next level and in the smart work space this data integration, coupled with the more flexible user interfacing, will take quality of life and quality of work experience to the next level.

Key environmental benefits foreseen from Smart Workplaces

The most important environmental benefit from Smart Workplaces is seen as:

Cleaner environment through higher levels of data integration it is expected that office and work place efficiencies will be raised across the entire supply chain and all levels of enterprise definition. This should lead directly to reduced waste and inefficiencies.

5.3. 5G capability heat map

5.3.1. Introduction

In this section we present some initial conclusions by considering the 5G capabilities (introduced in chapter four) that will be most important in achieving the optimal scenarios in the preceding verticals and environments

Throughout the workshops discussions, with representatives from each sector, investigated how 5G will be relevant for their sector and participants prioritised the capabilities that they see as enabling he greatest economic benefits.

In the workshops participants identified three priority 5G capabilities for the verticals and environments (from the list of ten 5G capabilities) that would support benefits realisation. Many of the verticals, environments and capabilities intersect and interact with one another.

Workshops identified three 5G capabilities that were central to benefits realisation in many of the verticals and environments. These were:-

- ***50Mbps everywhere*** - a universal minimum data rate;
- ***Scalable solutions for sensor networks*** - support for large scale M2M/IoT networks;
- ***Ultra tactile Internet*** - new ways of interfacing with technology

Depending on the vertical and environment in question, these thee capabilities either support the realization of other 5G capabilities or, indeed, they are reliant on other 5G capabilities to be realised. The three capabilities are more closely examined in the remainder of this section.

5.3.2. 50Mbps everywhere

50 Mbps everywhere is one of the key enablers of the promise of 5G. 50Mbps everywhere unlocks and enables potential benefits for each of the studied verticals and environments.

Truly ubiquitous coverage, i.e. *Everywhere*, and capacity, i.e. *50Mps*, is a necessary condition for the success of 5G within the context of the verticals. A succinct way to elucidate the need for this capability is to imagine the 5G-enabled car of 2025. From the point of view of sectors that embrace and exploit advances in communications and ICT, *automotive* and *transport* are two that are compelling and highly developed sectors. The 5G Car of 2025 has many facets. On the one hand it has enhanced safety features, it has increasingly automated driving capabilities; it optimizes journeys with respect to comfort, safety, energy and time. For the occupants (mostly passengers), the 5G car of 2025 will be a space for work and play, for the enjoyment of video or the completion of work tasks.

The Car of 2025 is one example of a future *Smart Workplace* environment. It is a place where *pervasive video experience* will be a necessity. This will be for safety (e.g. the see-through use case) and for entertainment (e.g. 4K video) and productivity (e.g. video-conferencing).

Additionally, looking to the *healthcare* sector we see similar demands for the Smart Ambulance of 2025. This is basically a niche version of the Car of 2025– a niche *Smart Workplace* with additional demands, such as niche *pervasive video experience* that can handle medical imaging transmission for remote, real-time diagnostics.

However, there will be challenges in realising *50Mbps everywhere*. One of the key visions for healthcare is that 5G will enable the promise of reducing costs by moving the provision of care away from traditional clinical settings, i.e. hospitals in major urban areas. Healthcare generally has a universal obligation or objective, i.e. all of the population should receive the same level of service regardless of where they live. 5G should enable this inclusive social benefit.

There are obvious pinch points in *50Mbps everywhere*; principally in the more extreme *non-urban* environments and in the *Smart City* environment. The 5G Car of 2025 and the Smart Ambulance of 2025 will be expected to operate seamlessly at congested city-centre junctions, on motorways and on minor rural roads.

Consequently, the workshops prioritized two capabilities to address these environments such that the benefits of 5G accrued to all parts of society – both non-urban and dense urban. These capabilities were *Create your own network* and *Dynamic increase of capacity*. Capacity is obviously the key challenge for *50Mbps everywhere*. There is likely to be a lack of infrastructure in both environments, albeit for different reasons.

In non-urban areas, maintaining coverage is challenging without even thinking of capacity. The ability to *create your own network* essentially manifests itself as the ability to intensively share (passively and actively) all of the network elements, from base stations to spectrum. It amounts to the maturation of virtualization concepts. In non-urban areas this could allow for a single multi-tenant network which would allow for costs to be shared among both MNOs and verticals.

In the dense urban Smart City setting, these capabilities would enable the densification of the network through verticals and other users adding to the network infrastructure in a seamless manner. So, as network capacity problems arise, different actors can add to the infrastructure whether in industrial, public or private domains.

The companion capability is the ability to *dynamically increase capacity*. Spikes in demand, e.g. as a result of a traffic accident at rush hour in a city centre or at a cross roads in the middle of nowhere, and maintaining 50Mbps service for the resulting dense concentration of users will be difficult.

50Mbps everywhere may appear to be the least interesting or innovative capability, but it is an essential enabler for many of the other capabilities including Pervasive Video, Differentiated Broadcast and Smart Office. In turn, meeting this requirement for the challenging environments (Non-urban and Smart City) drives the need to realize the capabilities of *dynamically increasing capacity* and *creating your own network*. This capability is key to unlocking social benefits across all environments.

5.3.3. Solutions for scalable sensor networks

Solutions for scalable sensor networks to support large scale M2M/IoT networks is the second of the key capabilities that emerged from the workshops when all of the verticals and environments are examined together. IoT, as with *50Mbps everywhere*, unlocks and enables potential benefits for each of the studied verticals, and under each of the subheadings examined. In particular IoT has huge potential to benefit industrial strategy development in addition to the benefits it brings to industrial operations. Indeed, while the capability is described in terms of sensor networks, the workshop attendees discussed applications in terms of sensors and actuators – an important distinction in terms of the implications for new radio access technologies that can support massive numbers of attached devices concurrently with both uplinks (from sensors) and downlinks (to actuators).

The IoT capability was identified as a priority capability for each of the verticals. Automotive, healthcare, transport and utilities each have strong future visions that include a reliance on the IoT. The transport domain is contingent on there being a connected sensor environment that knits together each of the different underlying components, including vehicles, i.e. the automotive sector. For both of these sectors strategic and operational benefits are strongly tied to the existence of total knowledge of the state of the Things. Big Data insights, which can lead to real-time decisions and optimizations as well as longer-term strategic decisions, are only possibly with a fully realized IoT. All of the ‘knock-on’ benefits of safety, emission reduction, lower running costs etc. - are predicated on this complex interacting system being able to support networked automation and optimization. Realising IoT within these two verticals is seen as key to the success of the Smart City environment.

Within the Utilities vertical, IoT is seen as a key enabler of the Smart Home/Smart Workplace. The instrumentation of these environments that both consume and produce energy is necessary for the Smart Grid to be able to make more real-time decisions, which optimise power production, i.e. reduce costs.

While the bandwidth requirements of low data rate IoT is not onerous and would not drive demand for the *50Mbps everywhere*, the healthcare and utilities verticals both indicated the need for *ultra reliable IoT*. For operational reasons both verticals have applications demanding ultra reliability, e.g. real-time load balancing in smart grids and critical cardiac monitoring in healthcare, among other possible applications.

While ultra reliability was not identified as one of the ten headline capabilities for 5G by itself, the workshops indicated that it could, in certain circumstances, become and important requirement. While many of the examples that are often cited for sensor networks are delay-tolerant and ‘bursty’, e.g. environmental sensing, the workshops revealed a demand for a different service level. This demand, in part, drove the utilities sector to prioritise the capability of *creating your own network*, as it was seen that in the absence of overt support for, or Service Level Agreements ensuring, such a reliable service the vertical would have to provision its own 5G service.

5.3.4. Ultra tactile Internet

The final bedrock capability for 5G that workshops identified was enabling the *ultra tactile Internet*. This capability was seen as a *step-change capability* that would have the potential to unlock much more futuristic applications and services.

Ultra tactile Internet essentially allows a wireless network to be used for control purposes. For real-time sense-respond-actuation cycles that enable both human-device control interactions and device-device interactions. Its benefits could be used in all the verticals though it was only recognised as a priority capability in automotive and healthcare.

The automotive use-case envisages increased automation, driverless cars and the use of platooning[10]. These applications demand closer cooperation between networked *things*, i.e. platooning cars or between a roadside control systems that ‘drive’ cars. Essentially, this is a higher-bandwidth IoT application with a crucial challenge of ultra low latency. Like the more general application of IoT with the automotive and transport sectors, *Ultra tactile Internet* has the potential to expand the role of automation to cover more time-critical applications. The use of networked car control can be seen as either an alternative to the self-drive car or a complementary system to it, a safety or secondary fallback system. It also has similar potential application and benefit to the emerging UAV/drone sector.

The healthcare sector also identified *Ultra tactile Internet* as useful in a number of areas. These range from extension of current robotic surgery systems to remote diagnostics systems. The benefit of *Ultra tactile* was not necessarily seen as terribly futuristic, both rather as a natural updating of some current techniques and systems. However, it has the potential of allowing these systems to be used in more portable forms, and thereby employed away from traditional clinical settings.

Other environments where the capability was seen as advantageous were the Smart Workplace and the Smart Home. Essentially, it was not seen a long-range technology. Rather, it was seen as a capability that would be used within the home, within an enterprise or within another local area scenario. For healthcare, the Smart Workplace can be seen as any place that supports *Ultra tactile*, in the future this could be the Smart Ambulance.

[10] Vehicle platooning makes it possible for vehicles to travel together closely yet safely. This leads to a reduction in the amount of space used by a number of vehicles on roads, thus more vehicles can use the road without traffic congestion.

6. 5G socio-economic analysis

6.1. Introduction

The previous chapter focused on the results of research and the views of workshop participants and online study group discussion about the utilisation of 5G capabilities in verticals and environments. The development of scenarios and identification of key benefits and barriers provided a rich qualitative understanding of possible futures.

As noted previously this study differs from others by focusing more on the costs, benefits and socio-economic impacts of 5G capabilities. The third stage of the study therefore focused on modelling how and where benefits arise from utilising 5G capabilities.

Quantitative forecasts have been developed from the best available evidence from previous studies. Assumptions made in forecasts are fully documented to enable readers to easily identify key factors in predictions. To obtain feedback on the quantitative forecasts results have been distributed with selected international experts and shared with the online study group.

Throughout the study quantitative analysis has adopted conservative assumptions. Nonetheless; forecasts have focused on the perfect scenario and maximum attainable benefits. They provide an insight to the perfect scenario if Europe can maximise the benefits of 5G

6.2. 5G cost forecast

This study is investigating potential costs and benefits of deploying and utilising 5G capabilities. Prior to looking at benefits it is important to estimate the cost of 5G deployment for two reasons.

Firstly, the benefits arising from 5G utilisation have to be compared with the costs of development to ensure that deployment is economically viable and to analyse economic and social returns. However, as this section highlights the costs and benefits will be borne by a variety of stakeholders and beneficiaries. Costs of deployment will largely be borne by telecommunication businesses and the return on this investment will be received from citizens and businesses paying subscriptions and utilising 5G services. In addition, further costs and revenues will arise from the development of systems (including new business models) to organise data to support the development of large scale M2M and IoT networks.

The second reason for considering costs is that any major investment in an economy has ‘trickle-down’ or multiplier impacts across the whole of the economy. These are examined in the next section.

Even when the precise architecture of 5G is known it would be a major exercise to forecast deployment cost. This study has therefore not attempted to estimate the costs of the technological components for 5G infrastructure deployment. Instead it has taken a high level approach analysing studies that provide an insight to the costs of 2G, 3G and 4G deployment in Europe, see Figure 5.

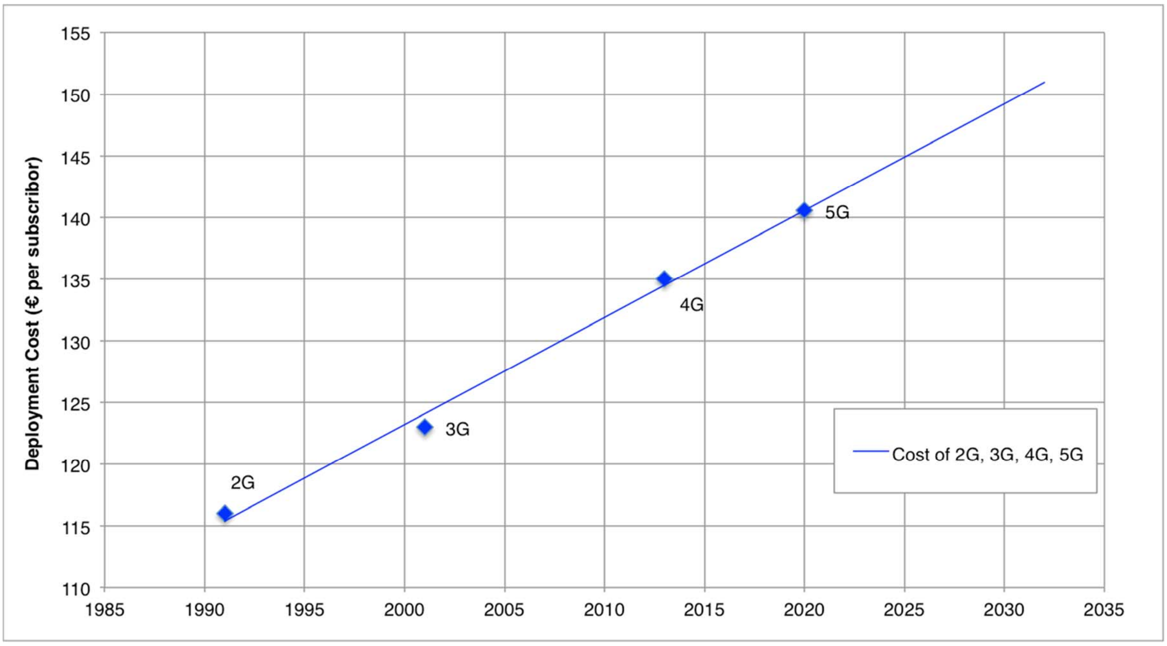
It is suggested that high level linear extrapolation methods are reasonable because every generation has followed some consistent trend lines. For example every generation has required more spectrum and cells have got smaller meaning there has generally been a linear increase in base station numbers that have been linearly reduced in cost by more efficient technologies. There has also been a fairly linear increase in service capabilities in every generation.

It is suggested that the total 5G cost estimate is probably conservative because 5G aims to deliver much more than previous generations which have traditionally only serviced very specific requirements (e.g. voice, data, video, etc.).

It is evident that each successive generation of mobile infrastructure has cost more than previous generations. Analysis by the study team of 4G investment in EU28 Member States estimated that 4G deployment cost €135 per subscriber.

It is therefore safe to assume that 5G will cost more than this previous level of 4G investment. While considerable caution has to be taken in extrapolating trends across three data points, the trend line in Figure 5 does provide an insight to possible 5G deployment costs[11]. If commercial deployment commences in 2020 the trend line estimates a cost of €141 per subscriber. In 2025 the cost per subscriber increases to €145 per subscriber.

This would equate to a total cost of 5G deployment in EU Member States of approximately €56.6 billion in 2020 and €58 billion in 2025.



Source: Inflation adjusted calculations based on data from Selian A. 2001.[12]

Figure 5: Estimating the cost of 5G deployment

[11] Costs relate to the radio network and transmission links. The network backbone, network maintenance, sales, marketing, billing and other administrative costs are excluded.

[12] Selian A. 2001. From 2G to 3G – The Evolution of International Cellular Standards. The 29th Research Conference on Information, Communication, and Internet Policy TPRC 2001. Edward R. Murrow Center for International Communications Research.

As well as deployment costs mobile operators will also incur costs associated with operating 5G networks. Analysis of the accounts of the four leading mobile operators[13] found that these operating costs were between 70 and 80 per cent of revenue[14].

Mobile service revenues are estimated by a number of different organisations. Ovum predict mobile service revenues of approximately €102 bn in 2020[15]. Ovum suggest no growth in the market between 2015 and 2020. Ericsson estimate mobile service revenues of approximately €95 bn in 2014[16]. They do not predict revenues for 2020. But if Ovum's no growth scenario is correct the same figure can be expected in 2020. GSMA are a little more bullish, predicting mobile service revenues of approximately €110 bn in 2020[17]. Estimates therefore range from €95 bn to €110 bn.

Using the range of percentages of operating costs (70 and 80 per cent of revenue) and revenues it is possible to estimate that operating costs arising from 5G deployment will be between €67 and €88 billion per annum in 2020[18]. As noted above Ovum foresaw no growth in mobile revenues between 2015 and 2020. If this trend continued the estimated range (€67 and €88 billion) would provide a useful estimate for the mobile operating costs incurred after 5G deployment.

6.3. Input-output analysis

The previous section provided forecasts for the costs of deployment of 5G in Europe. It was highlighted that any major investment in an economy has 'trickle-down' impacts across the whole of the economy. Input-output analysis is a quantitative economic technique that examines the interdependencies between different parts of an economy to examine 'trickle-down' impacts.

Input-output analysis highlights the dynamics of the inter-industry movement of capital as purchase and sale relationships. For instance, the deployment of 5G infrastructure and services will create output and employment effects in telecommunication, equipment, and construction industries, through indirect and induced multiplier effects[19].

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[13] Which comprise approximately 60 per cent of the revenue of the top 20 mobile operators in 2014 http://www.statista.com/statistics/221386/revenue-of-top-20-european-telecommunication-operators

[14] The four leading operators have different categories of expenses, but all include the same core cost areas. For example Vodafone used three main categories - *Direct Costs*: include interconnect costs and other direct costs of providing services, *Customer Costs*: include acquisition costs, retention costs and expenses related to ongoing commissions, *Operating Expenses*: plus customer costs other than acquisition and retention costs. Whereas Deutsche Telekom and Orange have a separate categories personnel costs and labour expenses respectively. In the case of Vodafone costs arising form mobile revenue generation were identified separately (70 per cent), the remaining three mobile operators only provided aggregate figures across all activities (these were Orange 72 per cent, Telefonica 77 per cent and Deutsche Telekom 80 per cent. See respectively http://www.vodafone.com/content/index/investors.html, http://www.orange.com/en/content/download/35031/1115118 /version/2/file/Orange+consolidated+Financial+statements++EN+2015.xlsx, https://www.telefonica.com/documents/153952/13347920/Consolidated_Annual_Accounts_2015.pdf/ca42c364-dab9-421a-8c46-1618829ce828 and ttp://www.annualreport.telekom.com/site0216/management-report/development-of-business-at-deutsche-telekom-ag/results-of-operations-of-deutsche-telekom-ag.html

[15] http://info.ovum.com/uploads/files/Ovum_Telecoms_Media_and_Entertainment_Outlook_2015.pdf

[16] http://www.ericsson.com/res/docs/2015/mobility-report/emr-mobile-business-trends-2015.pdf

[17] https://gsmaintelligence.com/research/?file=97928efe09cdba2864cdcf1ad1a2f58c&download. They predict global revenues of US$1.2 trilliion in 2020. Using revenue proportions for Europe from Ovum global forecasts this equates to approximately €110 bn.

[18] 70 per cent of €95 bn is €67 bn, 80 per cent of €110 bn is €88 bn.

[19] Analysys Mason and Tech4i2. 2012. The Socio-economic impact of bandwidth. SMART 2010

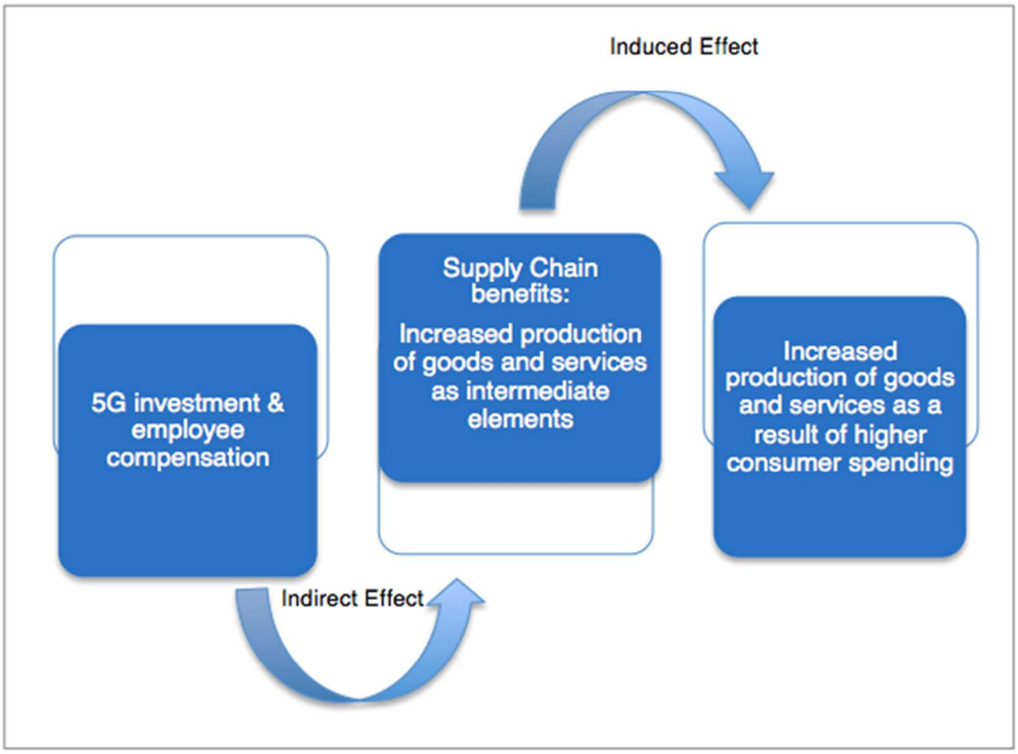
- ***Direct impact*:** This effect captures the effect that is generated directly from investment expenditure on 5G infrastructure and services;
- ***Indirect impact*** *(Type I multiplier effect):* This effect captures the intermediate flows within the supply chain, such as goods and services needed to deploy 5G infrastructure and services. The indirect effect measures the increased production and supply of services within the supply chain to operate the systems and provide 5G connections.

$$\textit{Type I Multiplier}= \frac{\textit{Direct Effect + Indirect Effect}}{\textit{Direct Effect}}$$

- ***Induced impact*** *(Type II multiplier effect):* This approach captures the change in consumers' spending and consumption of goods and services as a result of the higher household income and investment expenditure.

$$\textit{Type II Multiplier}= \frac{\textit{Direct Effect + Indirect Effect +Induced Effect}}{\textit{Direct Effect}}$$

The direct, indirect and induced effects are presented graphically in Figure 6.



Source: Adapted from Boston consulting Group. 2014.[20]

Figure 6: Direct, Indirect, and Induced effects of 5G Investment

Input-Output tables provide a quantitative representation of the interdependencies between different branches and industries of the national economy. The tables required for analysis were obtained from the OECD Input-Output database[21]. Analysis investigated output and

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[20] Boston Consulting Group. 2014. Digital Infrastructure and Economic Development: An impact assessment of Facebook's data center in northern Sweden. Available at: http://www.bcg.dk/documents/file164479.pdf

[21] STAN Input-Output: Total, Domestic and Import. Stat.OECD. https://stats.oecd.org/

employment effects of 5G investment targeting specific industries. The indirect and induced multipliers are calculated utilizing the input-output tables, through the following formula:

$$L = (I - A)^{-1}$$

Where:

- ***L*** is the Leontief-Inverse matrix, which is also known as the Total Requirement table.
- ***A*** is the matrix of the technical coefficients, calculated as the division of each cell of intermediate domestic supply by total industry supply. This matrix is also referred to as the Direct Requirement table.
- ***I*** is the identity matrix.

The Input-Output tables provide inter-industry relationships of sales and purchases in the form of a cross tabulation of 38 industrial sectors (resulting in a 1,444 cell matrix). 5G investment will be spent in specific areas/sectors to develop the necessary capabilities and infrastructure. Previous studies examining wireless infrastructure provide an insight to where the bulk of 5G investment will take place. This is relatively important because investment in different sectors has different 'trickle-down' impacts. This study followed the lead of other studies[22] by making the assumption that 45 per cent of investment would take place in the radio, television and communication equipment sector, 34 per cent in construction and 21 per cent in post and telecommunications.

5G investment leads to Type I and Type II multiplier effects of output and employment, these are described further in Section 2 of the annex. Table 4 provides an overview of the output and employment effect of the €56.6 billion 5G investment in the EU28 Member States. The table focuses on the more direct Type I impacts arising 'trickle-down' or multiplier effects. The table shows that these multiplier effects are expected to have a value of €141.8 billion. These effects are likely to create 2.39 million jobs in EU28 Member States.

Input output analysis also enables the impact of Type I multiplier effects to be investigated by sector. The highest levels of impact are in the sectors where investment initially takes place - radio, television and communication equipment, construction and post and telecommunications. The impact across the 'top ten' sectors is shown in Table 5. The ten industries most affected by 5G investment collectively account for 78.5 per cent of Type I impact. The table provides an insight to industries that will gain most from the deployment of 5G. Administrators may wish to ensure that these industries are prepared for the potential impact of 5G.

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[22] Analysys Mason and Tech4i2. 2012. The Socio-economic impact of bandwidth. SMART 2010/0033. Available at: Available at: https://ec.europa.eu/digital-agenda/en/news/study-socio-economic-impact-bandwidth-smart-20100033

Table 4: Input-output effect

	5G Investment 2020 (€m)	Type I direct input-output effect (€m)	Type I direct input-output employment effect
Austria	970	2,170	25,200
Belgium	1,230	3,150	36,300
Bulgaria	840	2,320	128,900
Croatia	480	1,540	64,400
Cyprus	100	470	20,800
Czech Rep.	1,200	3,990	143,000
Denmark	620	1,480	14,800
Estonia	150	560	13,600
Finland	600	1,501	19,900
France	7,030	17,110	224,700
Germany	9,280	20,740	211,100
Greece	1,220	2,180	101,300
Hungary	1,130	3,450	134,600
Ireland	490	1,210	10,700
Italy	6,830	15,700	186,830
Latvia	230	570	16,800
Lithuania	330	700	28,200
Luxembourg	60	122	600
Malta	50	190	3,900
Netherlands	1,870	5,030	68,300
Poland	4,350	13,040	569,553
Portugal	1,170	3,730	127,300
Romania	2,270	4,660	252,300
Slovakia	620	1,980	71,500
Slovenia	240	610	14,700
Spain	5,190	14,600	329,400
Sweden	1,060	2,450	25,300
UK	7,040	16,520	172,100
EU28	56,640	141,840	2,394,800

Source: Calculations based on data from Stat. OECD, The World Bank's World Development Indicators (WDI),Eurostat [nama_10_gdp] and [demo_pjan].

Due to rounding columns may not total.

Table 5: Type I effects in the ten sectors most affected by 5G investment

	Percentage of Type I impact	Type I impact (€ bn)
Radio, television and communication equipment	26%	35.5
Construction	18%	25.2
Post and telecommunications	11%	15.4
Other Business Activities	6%	8.7
Wholesale and retail trade	5%	6.7
Transport and storage	3%	4.3
Finance and insurance	3%	3.9
Electrical machinery and apparatus n.e.c	3%	3.8
Fabricated metal products; except machinery and equipment	2%	3.1
Basic metals	2%	2.5

6.4. *Impact and benefits modelling*

To provide a clear approach for research a framework has been developed to conceptualise the key benefits and impacts that will arise from the utilisation of 5G capabilities, see Figure 7.

Utilisation of 5G capabilities in the creation of new and enhanced goods and services will be undertaken by the private sector and the public sector, shown by the first order benefits in the figure. The enhanced goods and services will produce subsequent or ‘knock-on’ benefits for society, shown by the second order impacts in the figure. For example the incorporation of 5G capabilities in vehicles (by private sector manufacturers) will enable public sector administrators to better monitor vehicular flow and better manage traffic. Knock-on, second order impacts, of better traffic management for society will be reduced travel time, less consumption of hydrocarbons and reduced pollution.

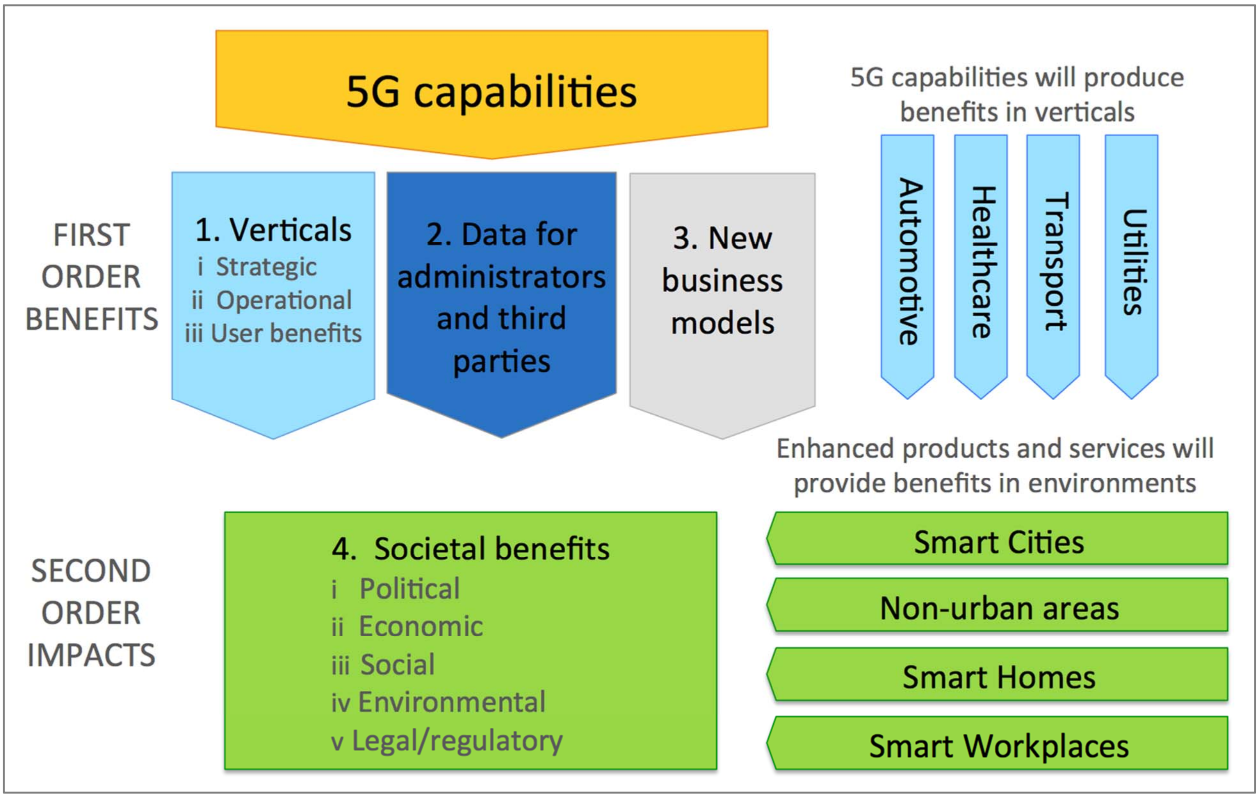

Figure 7 Benefits and impact modelling of 5G capabilities

FIRST ORDER BENEFITS focus on the more direct benefits to the producers of goods and services. These benefits predominantly fall into three categories. Key first order benefits include:

1. Verticals will utilise 5G capabilities to obtain benefits in three key areas of their activity:-

- ***Strategic benefits*** will arise from greater access to information about the supply chain, internal operations, market characteristics and consumer utilisation of goods and services;
- ***Operational benefits*** and enhanced productivity will arise from increased real-time access to information about operations (inside/outside the workplaces and throughout the supply chain);
- ***Direct User benefits*** should arise for consumers from access to 'improved' goods or services. Improvements could include cost, quality, usability, reliability and longevity.

2. Data and information for administrators and third parties: Enhanced access to 5G capabilities and information, including real-time data, will help administrators and other third parties to enhance the provision of services (to private and public sectors) including traffic management, security and healthcare.

3. New business models will utilise 5G capabilities to enable new business models to develop and new goods and services to be provided.

SECOND ORDER BENEFITS arise from the 'knock-on' impacts from the use of goods and services. They are generally more indirect benefits to society such as enhanced productivity (economic), reduced pollution (environmental) and enhanced security (legal/regulatory). Second order benefits are examined by investigating the four 'environments' where the impacts are most likely to arise, in the home, in the workplace, in non-urban environments and in cities. Separate impact papers are being prepared for the four environments.

6.5. Vertical benefits forecasts

The Figure 7 model provides clear categories of benefits that can be found in verticals. These included strategic benefits, operational benefits and direct user benefits. In addition benefits from data and information for administrators and third parties were also identified. The review of verticals in the next four sections uses these four categories to structure the presentation of quantitative benefits and the assumptions used in the calculation of benefits. New business models are also examined, but since these (by definition) are speculative with few antecedents quantitative benefits have not been estimated.

It was noted earlier that in some ways it is foolhardy to estimate costs and benefits for a technology that has not yet been defined. But in the light of hype concerning 5G, this study is investigating potential realities enabled by 5G capabilities. The quantitative forecasts in the remainder of this section have been developed from the best available evidence and assumptions made in forecasts are clearly presented.

Quantitative methods have adopted conservative assumptions, where appropriate forecasts from previous research have been utilised, for example predictions of growth in vehicles and smart meters. In many cases forecasts are not available therefore benefits have been calculated using the latest data, for example for healthcare costs or costs of congestion.

Forecasts based on 2104 or 2015 statistics obviously exclude consideration of the 10 million increase in EU28 Member State population between 2015 and 2030[23] and associated increases in other elements (healthcare, consumption of goods and services etc.) associated with this population growth. This once again will lead to forecasts being relatively conservative. Forecasts are largely based on 2014 and 2015 values. Inflation forecasts and standardisation into the future have not been undertaken.

Where appropriate forecasts for 2025 and 2030 are provided. However, many forecasts only predicted socio-economic values for benefits 'per annum' for 2025 and any period thereafter. 2025 is therefore used as the 'benchmark' date in this study. 2025 is also regarded as the point five years after the commercial introduction of 5G that 5G will be starting to make a significant impact.

Forecasts have focused on the perfect scenarios and key areas for benefits to estimate the maximum attainable benefits. They provide an insight to the perfect scenario if Europe can maximise the benefits of 5G. Quantitative forecasts have been distributed with selected international experts and shared with the online study group.

6.6. Automotive

The automotive industry has been one of the early adopters of connectivity technologies[24].. There are many different developments in the industry that could utilise 5G capabilities.

5G capabilities are expected to provide a powerful platform that enhances connectivity and improves data management and sharing between automotive manufacturers, motorists and other stakeholders. 5G will provide opportunities for next generation services within the automotive industry and the supply chain, allowing further improvement in vehicle design, vehicle production and performance. The workshop highlighted that 5G networks will have the ability to support a large number of connected cars, provide always-on connections, focus on optimising energy efficiency, provide real-time maintenance and enhance safety.

[23] Eurostat. 2015. proj_13npms.

[24] Ericsson. 2014. 5G What is it for?

5G capabilities will obviously not be introduced in vacuum. Advanced Driver Assistance Systems (ADAS) and autonomous vehicles are emerging trends in the automotive sector[25]. ADAS systems are utilising Dedicated Short-Range Communication (DSRC - a short-to-medium range, two-way wireless technology for vehicle to vehicle communication) and Intelligent Transport Systems (ITS[26]). To provide complete functionality (beyond vehicle to vehicle communications) DSRC and ITS require a dense infrastructure of roadside units to communicate with on-board units. Lack of this infrastructure currently limits adoption of this model. Commentators[27] have suggested this impasse could be resolved if major manufacturers deploy the technology (Toyota anticipates deployment on all vehicles after 2016) and/or administrations mandate the adoption of systems in the same way safety-belt regulations were introduced.

ADAS, DSRC and ITS demonstrate that systems are being developed which can already provide some of the capabilities put forward as major advantages utilising 5G in the automotive sector. This section focuses on vehicles with embedded connectivity that will be provided by 5G. It is likely that further developments will lead to driverless cars utilising 5G and other technologies in the more distant future[28].

6.6.1. Strategic benefits for vehicle manufacturers

Strategic benefits for vehicle manufacturers will primarily arise from better access to enhanced telematics information. Our analysis primarily focuses on passenger vehicle telematics solutions that have been factory-fitted by OEMs[29]. Workshops and online input identified several barriers to embedded telematics, These mainly concerned additional costs associated with embedded connectivity and a reliance by users to view their smartphones as the solution to in-vehicle connectivity.

Disruptive triggers that could overcome barriers to embedded telematics include[30]:

- The growing number of ***telematics mandates*** are being introduced by governments for services such as eCall or Stolen Vehicle Tracking;
- A ***revolution in pricing models*** is becoming more likely within the telecom industry as the number of connected devices owned by each consumer grows;
- The ***decoupling of apps from phones*** may eventually become reality as more content and services are hosted on the cloud rather than on native Apps.

Embedded telematics provides automotive manufacturers with the opportunity to gather more vehicle data and enable remote diagnostics. 5G will enhance the capability of automotive manufacturers to gather real-time data. The utilisation of 5G data management systems through cars' sensors will enable manufacturers to analyse components, particularly those leading to break downs and equipment failure. In the short-term this knowledge will allow efficient production of required components to meet anticipated demand[31]. In the long-

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[25] 4G Americas. 2014. 4G Americas' recommendations on 5G requirements and solutions

[26] EU Directive 2010/40/EU 7th July 2010

[27] Benkler Y. 2012. Open wireless vs. licenced spectrum: Evidence from market adoption. Harvard Journal of Law and Technology. 26, 1. 71 – 163

[28] Nokia. 2014. 5G use cases and requirements. Further benefits envisaged for driverless cars include reduced signage costs because information can be piped directly into the car. Observers have also suggested that social impacts could include a reduction in stress and higher GDP because the car becomes a seamless extension of homes and offices. These longer-term benefits are not included in benefit calculations.

[29] Original equipment manufacturers. After-market solutions for passenger cars or fleets are not considered.

[30] SBD. 2012. 2025 Every car connected: Forecasting the growth and opportunity

[31] Datafloq. Self-driving Cars Will Create 2 Petabytes Of Data, What Are The Big Data Opportunities For The Car Industry? https://datafloq.com/read/self-driving-cars-create-2-petabytes-data-annually/172

term enhanced knowledge will enable faults to be 'designed out' of future models. Enhanced information will also enable manufacturers to monitor and improve the driving experience and vehicle performance and build personal profiles for drivers (sitting positions, radio channels, air-conditioning and driving habits)[32].

5G will enhance vehicle relationship management (VRM) and other maintenance and warranty related services[33]. BMW was an early adopter of VRM through its TeleService telematics program. TeleService collects diagnostic data from the car and delivers this to dealerships, enabling them to know in advance whether vehicles require routine servicing or more advanced maintenance. This enables BMW to minimise vehicle downtime experienced by customers[34].

GM is able to collect diagnostic data from its 6 million Onstar subscribers in order to perform warranty analysis and detect trends relating to faulty components[35]. Using advanced data connectivity and management platforms, GM's 4,300 dealers have improved their services to respond to the customers' preferences. GM estimate the current value of telematics information as €615 per vehicle.

Assumptions: GMs current telematics systems have limited capabilities in comparison with those that will be possible in the future. We assume that the future (added) value of enhanced and real-time telematics will be 50 per cent more than current estimates (e.g. €307 per vehicle).

4G LTE and LTE Advanced will provide some of the functionality envisaged to be possible in the future. However, the ubiquitous capabilities offered 5G will enhance real-time proficiency. It is estimated that 5G will contribute 25 per cent of the future (added) value of real-time telematics.

Embedded 5G data capabilities will provide strategic benefits of approximately €76 per vehicle.

6.6.2. Operational benefits for vehicle manufacturers

A passenger vehicle is typically comprised of 6,000 mechanical, electro-mechanical and electronic parts. Assembly requires approximately 20,000 operations/actions per vehicle. These sequential and concurrent assembly operations must be synchronised with a similar numbers of logistical operations, frequently with a global reach, to ensure that vehicle products meet customer specifications within agreed time frames.

Assembly operations are comprised of combinations of people and programmable robots/machines, supported via semi-automated sensing, actuation, fixing and tooling elements. Necessarily the location of manufacturing operations must be physically distributed (throughout a manufacturing site or over many sites) yet interconnected physically and logically; by semi-flexible computer controlled conveyors (typically distributed over many kilo meters) the logistically operations of which will be flexibly co-ordinated with those of general (road, rail, sea and air) transport systems.

Networked assembly operations and parts and services throughout the supply chain businesses will be located throughout a country, EU28 Member States and globally. 5G data

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[32] Big Data Companies. Big Data – Big Benefits For Auto Makers And Users. http://www.bigdatacompanies.com/big-data-big-benefits-for-auto-makers-and-users/

[33] IBM Software. IBM big data for the automotive industry. http://www.oesa.org/Doc-Vault/Knowledge-Center/Operational-Performance-Content/IBM-Big-Data-for-Auto-Industry.pdf

[34] SBD. 2012. 2025 Every car connected: Forecasting the growth and opportunity

[35] DataFloq. 2014. Three use cases of how GM applies big data to become profitable again.

exchange capabilities will undoubtedly be the catalyst for further major advances in the globally competitive life cycle engineering and disposal of future generations of cars.

During recent decades the dominant strategic thrust of product realisation paradigms within the automotive sector has been that of 'mass customisation'; because such an approach can provide dual economies of:

- ***Scale*** - where large quantities of cars are made efficiently using optimised systems of people and machine resources);
- ***Scope*** - where variants within models and/or between models are accommodated by using common flexibly/computer controlled semi-automated resource systems that are also designed to operate efficiently in response to predicted variations in production demand.

The BMW Mini Plant in Cowley, UK is achieving the combined economies of scope and scale production. It successfully achieves mass customised cars at a factory heartbeat of 68 seconds (one vehicle is produced every 68 seconds; more than 1,200 per day) each of which individually meets distinctive customer specifications (there are claimed to be more than a million possible customer options).

5G data exchange capabilities will lead to both scale and scope benefits. In 2014 EU28 Member States produced 15 million passenger vehicles[36]. The value of each vehicle is estimated to be between €11,787 for imported vehicles and €20,889 for exported vehicles[37].

Assumptions: 5G will enhance data exchange capabilities for assembly operations and throughout the supply chain. It is assumed that production could be enhanced by one per cent due to 5G capabilities. This would equate to 150,000 vehicles. If the lowest vehicle estimates is adopted (€11,787), enhanced production would create 150,000 additional vehicles with a value of €1.76 billion.

5G data exchange capabilities will enhance productivity by 150,000 vehicles per annum. The additional vehicles will have a value of €1.8 billion per annum.

6.6.3. Benefits for consumers

The ability of vehicle manufacturers to improve the driving experience for drivers in the future was investigated in section 6.6.1. These improvements are also likely to include building a closer relationship between customers and their cars, even when they are not driving. Enhanced convenience will include services such as remote vehicle monitoring (if the driver wants to check the status of their vehicle), remote air-conditioning/heating activation (for excessively cold or very hot days) and 'find my car' (when a vehicle is misplaced).

Navigation services, and in particular traffic information, rank amongst the highest customer requirements in many consumer surveys. Traffic information in particular is increasingly viewed as a must-have service. Currently this information is generally delivered over analogue networks (such as RDS TMC) these channels only support low-bandwidth services, reducing the quantity and quality of the traffic information that can be delivered. These services are expected to be surpassed by premium services in three to five years time[38].

Until recently, in-car entertainment largely relied on connecting portable music players to the infotainment platform in a vehicle to play the driver's preferred audio tracks or view digital media. In the longer-term many vehicle manufacturers are also looking for ways to move

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[36] ACEA. 2015. The automobile industry pocket guide 2015/16. p10

[37] ibid. p50.

[38] SBD. 2012. 2025 Every car connected: Forecasting the growth and opportunity

beyond smartphone integration and connect the car directly to the cloud to obtain audio and video media and other information.

Automotive News suggests that a connected car is expected to provide users with benefits of €414 per vehicle annually[39].

Assumptions: 4G LTE and LTE Advanced will provide some of the functionality envisaged for vehicle users in the future. However, the ubiquitous nature of 5G will enhance real-time capabilities and connectivity to the cloud. It is estimated that 5G will contribute 20 per cent of the future (added) benefits to consumers.

Embedded 5G data capabilities will provide consumer benefits of approximately €83 per vehicle.

6.6.4. Benefits for administrators and third parties

The previous section examined benefits arising for consumers from 5G capabilities being utilised in the automotive vertical. Administrators can benefit from access to data from sensors in connected cars and fixed and mobile sensors placed in roads to monitor traffic densities and to determine average traffic speeds. This information can be used to enhance traffic management and, in the longer-term, improve safety measures on roads[40]. Access by administrators to services such as Emergency call (eCall)[41] can ensure a more speedy and effective response to accidents and better re-routing of traffic. Security-based telematics services such as Stolen Vehicle Tracking (SVT) can help to inform administrators and insurance companies of the vehicle thefts. This security feature could decrease levels of thefts and reduce insurance premiums for vehicle owners.

Automotive News suggests that a connected car is expected to provide benefits to administrators of €316 per vehicle annually through enhanced access to telematics data[42].

Assumptions: Automotive News estimates only provide information about the value of telematics for administrators. Calculating the cost of future real-time telematics information to insurance companies is complex. Embedded vehicle tracking sensors will considerably reduce costs, perhaps to ten per cent of current values (e.g. €25 of the current installation cost of €250 to retrofit tracking sensors). Assuming a relatively lengthy ten year payback on their installation, the information they generate might be worth €2.50 per vehicle per annum.

4G LTE and LTE Advanced will provide some of the functionality envisaged for administrators and third parties in the future. However, the ubiquitous nature of 5G will enhance real-time telematics capabilities. It is estimated that 5G will contribute 25 per cent of the future (added) benefits to administrators and third parties (e.g. €79).

Embedded 5G data capabilities will provide administrator and third party benefits of approximately €81.50 per vehicle.

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[39] Sedgwick, D. Automotive News. 2013. 'Big data' from a car is worth $1,400 a year, Cisco exec says. http://www.autonews.com/apps/pbcs.dll/article?AID=/20130805/OEM06/130809928#

[40] House of Parliament, Parliamentary Office of Science and technology. Big and Open Data in Transport. PostNote, Number 472. July 2014. www.parliament.uk/briefing-papers/POST-PN-472.pdf

[41] An emergency call (eCall) is made automatically by the car when on-board sensors (e.g. airbag sensors) register a serious accident. Via satellite positioning and mobile telephony caller location, the accurate position of the accident scene is fixed and then transmitted by the eCall to the nearest emergency call centre. An operator can talk with vehicle's occupants to get more information. If there is reply, emergency services can be sent to the exact accident's location.

[42] Sedgwick, D. Automotive News. 2013. 'Big data' from a car is worth $1,400 a year, Cisco exec says. http://www.autonews.com/apps/pbcs.dll/article?AID=/20130805/OEM06/130809928#

6.6.5. Potential new business models

It is virtually impossible to accurately predict the new business models that might arise within the automotive vertical or the new opportunities that might arise from the capabilities of 5G to better distribute information. Nonetheless, this section tentatively suggests some opportunities.

It is evident that the sale of telematics information could offer new sources of income for vehicle manufacturers or whoever 'owns' the data provided by sensors[43].

New business models have been suggested within the insurance industry. Vehicle insurance premiums are traditional calculated through risk algorithms for specific groups of drivers. The industry has undertaken telematics trials of usage-based insurance to observer how customers drive and more accurately assess the actual risk posed by drivers (through pay-as-you-drive or pay-how-you-drive)[44]. Telematics could also detect fraudulent claims made by customers and, through systems such as eCall, notify insurers of accidents[45].

The Brookings Institute estimate that usage-based insurance would reduce driving by eight per cent in the US. American drivers that have signed up for usage-based insurance have saved around €248 per year on their insurance premiums[46]. A key constraint on developing usage-based insurance has been the high cost of retrofitting hardware and the on-going communication costs. These problems should be overcome when telematics are embedded within vehicles[47].

Benefits arising from new business models are extremely speculative. Since the study is taking a conservative attitude to benefits forecasts potential benefits arising from new business models are not be included in forecasts.

6.6.6. Estimating benefits

Previous sections have presented the results of research to estimate the first order benefits of the utilisation of 5G capabilities in the automotive vertical[48]. For transparency all assumptions made in calculating benefits have been presented in a separate section at the end of each benefits category.

It is notable that in many of the studies reviewed in the previous section data is presented on a 'per vehicle' basis. A key forecast therefore concerns the number of vehicles that will be present in EU Member States when 5G is introduced, see Figure 8. As noted earlier the study has focused on the utilisation of 5G that has been factory-fitted by OEMs. We envisage that these vehicles will better represent those that will incorporate 5G capabilities[49].

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[43] IBM. Leveraging big data in automotive to solve key business problems. https://www-01.ibm.com/software/data/bigdata/industry-auto.html

[44] National Association of Insurance Commissioners. 2015. Usage based insurance and telematics http://www.naic.org/cipr_topics/topic_usage_based_insurance.htm

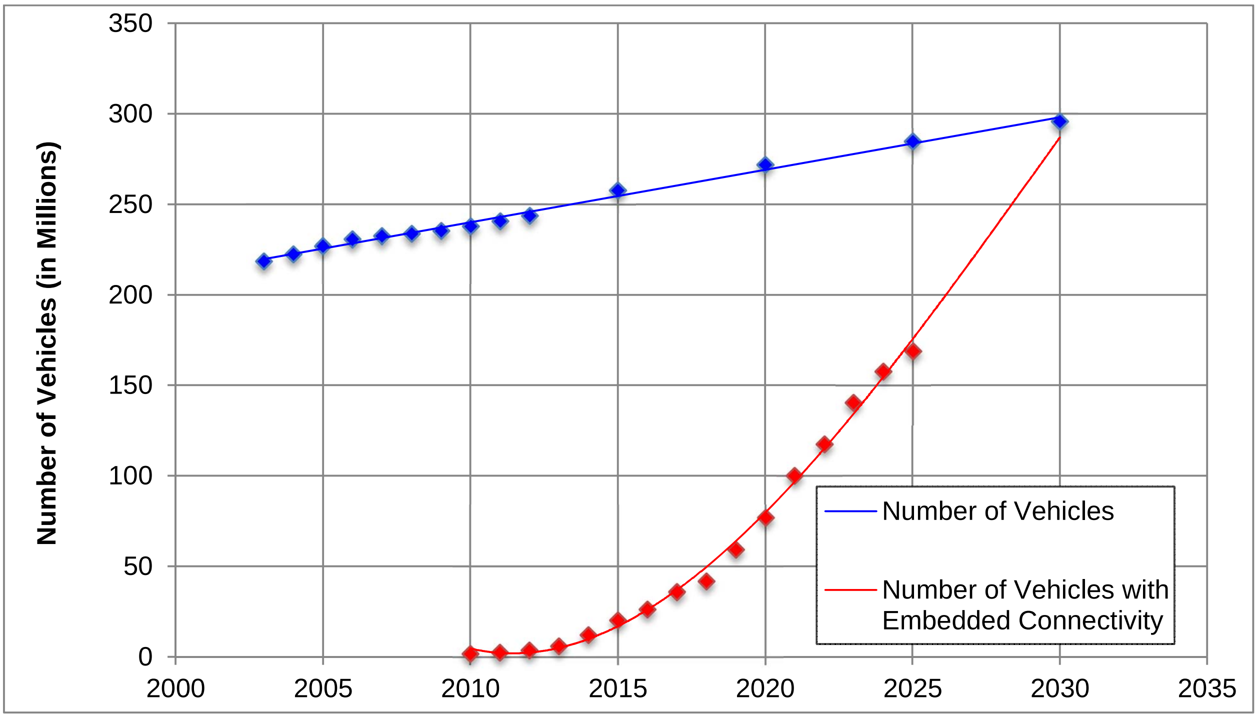
[45] SBD. 2012. 2025 Every car connected: Forecasting growth and opportunity

[46] Brookings Institution. 2008. Pay-as-you-drive auto insurance: A simple way to reduce driving-related harms and increase equity. http://www.brookings.edu/~/media/Research/Files/Papers/2008/7/payd-bordoffnoel/07_payd_bordoffnoel.PDF

[47] The cheapest Stolen Vehicle Tracking systems are currently about €250 to retrofit.

[48] As noted in the Annex second order impacts, such as improved traffic management and reduced pollution are captured separately to avoid double counting.

[49] Obviously vehicles with embedded connectivity prior to 2020 are unlikely to be able to use 5G capabilities, since the technology is only expected to be introduced at this date. It is expected that by 2025 5G will be the dominant wireless technology for embedded connectivity.



Source: Calculations based on data from Eurostat [road_eqs_carmot], Bodek K. and Heywood,J. 2008. Europe's Evolving Passenger Vehicle Fleet: Fuel Use and GHG Emissions Scenarios through 2035. *Laboratory for Energy and Environment*. GSMA. 2012. 2025 Every Car Connected: Forecasting the Growth and Opportunity.

Figure 8: Vehicles in EU28 Member States 2003 to 2030

Figure 8 utilises Eurostat historic data for vehicle numbers between 2003 and 2012. Forecasts between 2015 and 2030 are derived from several studies (details provided under the figure). It can be seen that forecasts provide a good fit with linear trend extrapolations from Eurostat data.

The number of vehicles with embedded connectivity for 2010 to 2025 are derived from a study undertaken by SBD for the GSMA[50]. Power regression techniques were used to extrapolate the number of embedded connectivity vehicles in 2030.

An overview of the automotive benefits arising from 5G capabilities is provided in Table 6.

Table 6: Automotive benefits per annum

	2025	2030
Connected embedded vehicles	168 m	274 m
Strategic benefits at €76 /vehicle	€12.8 bn	€20.8 bn
Operational benefits at €1.8 bn / annum	€1.8bn	€1.8bn
Consumer benefits at €83 /vehicle	€13.9 bn	€22.7 bn
Administrative benefits at €81.50 /vehicle	€13.7 bn	€22.3 bn

[50] Ibid. SBD. 2012

Total annual benefits	**€42.2 bn**	**€67.6 bn**

6.7. Healthcare

An ageing population, health inequalities and the social determinants of health present significant challenges to healthcare systems. Healthcare costs have steadily increased in recent years[51]. Cost-effectiveness, preventative measures and pharmaceutical pricing are important elements providing opportunities to reduce health costs. Technology innovations have been viewed as important elements in cost reduction activities.

The healthcare sector has not received a great deal of prominence within 5G reviews and White Papers. But concepts of Connected Health, Telemedicine, Digital Health, eHealth, mHealth and preventative health have embraced opportunities provided by technological advances.

There are many sub-sectors within the healthcare industry that could utilise 5G capabilities. Within those subsectors, it is important to consider current and potential innovations and business models to better understand the role and opportunities offered by 5G for healthcare. 5G capabilities are expected to provide a powerful platform that enhances connectivity and improves data management and sharing between patients (including healthy consumers), healthcare providers and other stakeholders.

Average EU 28 Member States public healthcare expenditure is €1,650 per capita in 2012[52]. This equates to total expenditure of €830 billion per annum in EU28 Member States

The healthcare industry is complex. There are multiple stakeholders who have different incentives to adopt new technologies and to engage in new behaviours. Healthcare in Europe operates on two main models[53]. The tax-funded model (e.g. UK, Scandinavia) is a single-payer, predominantly public, system. The second system is the social insurance model (e.g. Germany, Netherlands, France). This has multiple payers and owners of provider assets with fees being levied for services. Whether run under public or hybrid models all actors are battling to reduce escalating costs and improve the quality of care for an ever increasing base of patients and potential patients.

Unlike verticals such as automotive and utilities, in which many of the benefits of 5G capabilities are embedded within machine or M2M environment, the healthcare sector revolves around the human consumer. Consumers can be divided into three groups and 5G innovations will be relevant to each group in different ways. The ***chronically monitored*** group consists of people who are acutely or chronically ill and receiving or seeking treatment. Those not currently ill are divided between the ***information seekers*** that are simply interested in maintaining or improving their wellbeing and the ***motivated healthy*** that are generally fitness enthusiasts[54]. This section will predominantly focus on the healthcare sector. Benefits arising from 5G for the information seekers and the motivated healthy are considered in the examination of Smart Homes in section 6.14.

Between 2016 and 2030 there is expected to be considerable growth in non-communicable diseases (mainly cardiovascular diseases, cancers, chronic respiratory diseases and diabetes) with the consequent social and economic costs. Cardiovascular diseases are the

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[51] The DG for Economic and Financial Affairs projected in 2012 that public spending on health care would increase by one to two per cent of GDP on average across EU countries between 2010 and 2060,

[52] OECD EC. 2014. Health at a glance: Europe 2014. p121 to 122.

[53] The European Institute and UCL. 2012. The Future of Healthcare in Europe.

[54] "The future of connected health devices: Liberating the Information Seeker" – IBM Global Business Service, 2011. http://www-935.ibm.com/services/us/gbs/thoughtleadership/ibv-connected-health-devices.html.

main cause of mortality in nearly all EU member states, accounting for almost 40 per cent of all deaths in 2011. Cancers accounted for 24 per cent of all deaths[55]. Over the period from 2011-2030 the lost output from non-communicable diseases and from mental health was estiamted to be about five per cent of GDP globally[56]. In EU28 Member States this would equate to €696 billion in 2014.

5G capabilities are expected to provide a powerful platform that enhances connectivity and improves data management and sharing between healthcare providers, medical device manufactures, patients, medical and life insurers, the pharmaceutical industry and other stakeholders. Reducing the cost of health monitors, expanding their reach and their reliability has the potential to unleash many innovations in the sector.

6.7.1. Strategic benefits for healthcare providers

The strategic benefits for healthcare providers, whether they are the incumbent/traditional providers, or new entrants will primarily arise from the growth of enhanced health telematics information. Big Health Data will provide the sector with enhanced information to make better informed strategic decisions and promote preventative healthcare.

These benefits will be realised through more extensive continuous capture of bio-data from large population sets. Health devices collecting more bio-information more reliably in more locations from more people will be the bedrock of significant change in strategic and operational activates in the healthcare sector.

Currently, most healthcare information is obtained irregularly when a patient visits a clinician. This snapshot effect can miss out on patient behaviours and other biological data that may occur between face-to-face visits. Once of the roles of connected healthcare is to bridge this information and monitoring void. One of the most immediate benefits of more regular monitoring can be adherence to prescribed therapies. Medical non-adherence to treatment is estimated to cost between €140 billion and €420 billion annually[57].

One of the key benefits of connected healthcare is the capture, analysis and response to heath information. This can have two benefits. Firstly, promotion of healthy lifestyle choices and disease prevention. Secondly, ensuring patients get the most timely, appropriate treatment available. Preventative strategic benefits are examined in this section. Benefits associated with the provision of better care are examined in the next section.

Preventative healthcare strategies focus on encouraging patients to make lifestyle choices that help them remain healthy, such as proper diet and exercise, and take an active role in their own care if they become sick. □

European Commission research forecasts that there will be 567 million wearable devices in Europe in 2030, a 66 fold increase from the 8.5 million in EU28 Member States 2015[58]. The US supermarket chain Target has offered its 335,000 employees free Fitbits to stimulate their

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[55] OECD EC. 2014. Ibid.

[56] The Global Economic Burden of Non-communicable Diseases, Harvard School of Public Health and the World Economc Forum, September 2011. mental health and cardiovascular diseases account for almost 70 per cent of lost output, followed by cancer and chronic respiratory diseases http://www3.weforum.org/docs/WEF_Harvard_HE_GlobalEconomicBurdenNonCommunicableDiseases_2011.pdf

[57] Desai, Anish, Nilesh Mahajan, Sandeep Sewlikar, and Reshmi Pillai. 2014. Medication adherence: the critical step towards better patient outcome. International Journal of Basic & Clinical Pharmacology, 3 (5), 748-754. doi:10.5455/2319-2003.ijbcp20141006 http://www.scopemed.org/fulltextpdf.php?mno=163977 US per capita data recalculated for EU28 population

[58] Tech4i2 and Real Wireless. 2016. Identification of the market of radio equipment operating in license-exempt frequency bands to assess medium and long-term spectrum usage densities. SMART 2014/001.

wellbeing and reduce healthcare costs[59]. As a contributor to employees' insurance health costs Target has taken on the role of a new kind of preventative healthcare provider, albeit with an eye on its own bottom line. Current devices, such the Fitbit[60], are relatively limited in the information they are capable of recording, but they provide simple bio-information that can be used in many ways beyond personal tracking.

Health devices, which are more complex than current fitness wearables, will include software-enabled instruments that sense, monitor or measure particular medical conditions. They will be used for wellness, diagnostic or therapeutic purposes[61]. These devices will use many different techniques to transmit data, 5G is likely to be widely used. An example of one type of future device is the Tricorder[62] that monitors and diagnoses health conditions, overtime developing comprehensive personal health metrics.

New health care applications and wearable devices are collecting data (for big data analysis which will have further strategic benefits) and proactively providing wellbeing and healthcare advice. For example Asthmapolis has created a GPS-enabled tracker that records inhaler usage by asthmatics. The information is ported to a central database and used to identify individual, group, and population-based trends. The data are then merged with Centers for Disease Control and Prevention information about known asthma catalysts (such as high pollen counts or volcanic fog in Hawaii). Together, the information helps physicians develop personalized treatment plans and spot prevention opportunities[63].

Another company, Ginger.io, offers a mobile application in which patients with selected conditions agree, in conjunction with their providers, to be tracked through their mobile phones and assisted with behavioural-health therapies. The app records data about calls, texts, geographic location, and even physical movements. Patients also respond to surveys delivered over their smartphones. The Ginger.io application integrates patient data with public research on behavioural health from the National Institutes of Health and other sources.

A McKinsey study for the US Centre for Health System Reform Business Technology Office reported that healthy living and disease preventative initiatives could reduce healthcare costs by 2.6 to 3.7 per cent

Assumptions: McKinsey[64] estimate 2.6 to 3.7 per cent savings in healthcare costs due to healthy living and disease preventative initiatives. At the lower percentage (2.6) this would represent a saving in public sector healthcare costs in EU28 Member States of €21 5 billion per annum. We assume that 5G will contribute five per cent of these savings.

5G data capabilities will provide preventative strategic benefits of approximately €1.1 billion per annum in public healthcare costs.

6.7.2. Operational benefits for chronic healthcare provision

Big Health Data and enhanced health telematics will provide better information to enhance operational activities.

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[59] http://www.bloomberg.com/news/articles/2015-09-15/target-to-offer-health-tracking-fitbits-to-335-000-employees

[60] https://www.fitbit.com/

[61] IBM 2011 ibid.

[62] The XPrize Tricorder is the subject of $10million global prize to develop a hand held device that will be capable of monitoring and diagnosing health conditions. http://tricorder.xprize.org/

[63] McKinsey 2013. The big data revolution in healthcare. Centre for US Health System Reform Business Technology Office.

[64] Ibid. McKinsey 2013.

The previous section highlighted that 5G capabilities have the potential to expand the range and potential use of wearable devices to increase healthcare benefits. 5G capabilities – universality, reliability and ultra low latency can be embedded in wearable's and/or operate through smartphone devices. 5G capabilities can also be directly embedded in medical devices that can operate independently of consumer grade equipment. This bypassing of the smartphone and consumer equipment, while still leveraging the power of 5G networks, also opens up potential avenues for disruptive service and business models.

Based on current usage patterns McKinsey estimates that IoT based health sensors that monitor and treat illnesses could provide savings of ten per cent in healthcare costs in developed economies in 2025[65]. This is based on two sources of value—cost savings in treatment and the value of longer lives and improved quality of life that patients with chronic conditions could enjoy if IoT monitoring helps them avoid disease complications. The study estimates that these quality of life benefits could have a value of half the cost savings in health care costs. These benefits are not included as benefits in this section.

Assumptions: McKinsey estimate ten per cent savings in healthcare costs due to IoT. This would represent a saving in public sector healthcare costs in EU28 Member States of €83 billion per annum. We assume that 5G will contribute five per cent of these savings.

5G data capabilities will provide operational benefits of approximately €4.15 billion per annum in public healthcare costs.

6.7.3. Benefits for consumers

A number of health data storage and exchange databases have developed as a result of the potential to gather health telematics data[66][67]. These services allow patients to connect their wearable devices to cloud-based services that store, analyse and report on their condition. The data remains the private, confidential property of the consumer. However, participants can also consent to share their data with research bodies to advance scientific study or can volunteer for clinical trials.

Another reason for consumers to embrace health monitors and wearables will come from a purely financial motivation. A US life insurance company, John Hancock has partnered with Vitality[68], to provide benefits to its customers[69]. Just as driving insurance companies have been offering discounts to certain categories of drivers who fit speed and driving style monitors to their vehicles, John Hancock offers discounts of up to 15 per cent on life insurance premiums. Customers who use Fitbits and share data have their estimated 'age' adjusted based on Fitbit measurements[70].

The European insurance market is the largest globally with 35 per cent of the total global insurance market. Life insurance represents the largest segment of that market. The size of the life insurance market varies across the EU28 Member States from 80 per cent of the total

[65] Ibid. McKinsey 2013.

[66] Patients Like Me https://www.patientslikeme.com/

[67] Patients Know Best http://www.patientsknowbest.com/

[68] John Hancock-Vitality http://www.jhrewardslife.com/

[69] "John Hancock Introduces a Whole New Approach to Life Insurance in the U.S. That Rewards Customers for Healthy Living", John Hancock, April 2015. http://www.johnhancock.com/about/news_details.php?fn=apr0815-text&yr=2015

[70] When someone applies for a life insurance product Vitality assesses them and estimates their Vitality Age. This is on average 5 years more than their real age having an effect on their premiums.

in Finland, to 60 per cent in Belgium and just 20 per cent in Romania. In 2014, €714 billion was paid in life insurance premiums in Europe, an average of €1,900 per capita[71].

Assumptions: Some of the functionality to share data from wearables with life insurance businesses already exists. However, the ubiquitous nature of 5G will enhance real-time capabilities and connectivity to the cloud. It will enable enhanced monitoring of more people.

We assume that 5G improves the amount and range of data that can be reported but that 5G only comprises five per cent of total benefits. If there was uptake by 20 per cent of life insurance policyholders and 5G accounted for five per cent of the total reduction in premiums (15 per cent), that would result in approximately €207 million savings per annum in the European market (at 2014 prices) attributable to 5G.

5G IoT capabilities will provide consumer benefits of approximately €207 million per annum in reduced life insurance premiums.

6.7.4. Benefits for administrators and third parties

The previous sections detailed benefits that will accrue to the main stakeholders in the healthcare vertical; principally healthcare providers, medical devices/services providers, and consumers. No direct benefits are envisage for local administrators since their remit at present has little direct input to healthcare activities.

The pharmaceutical industry is a third party that has considerable interest in healthcare. Drug trials are an expensive and unavoidable cost for pharmaceutical companies. In 2005 the US pharmaceutical industry spent €1.06 billion (in 2012 value) on research and development for the average drug approved by the Federal Drug Administration.[72]. Another evaluation puts more recent costs even higher at €5.2 billion per drug in 2012[73].

Drugs under go four phases of research and development before final approval by regulatory agencies. Phase III, where the drugs are evaluated on human volunteers, is the biggest cost of any trial. For the average large company, Phase III accounts for 40 per cent of all its research and development, taking account of drugs that would have failed to even get to this stage.

IoT has the potential to track patient conditions more closely, to provide additional health information that can show potential side effects at an early stage and can track outcomes more closely. Just as in many other examples, the benefits of real-time continuous monitoring provides better, richer data sets for clinical trial teams and regulators to assess a drug more actively in the field. This would also enable drugs to be withdrawn more speedily if problems arose and for information to be fed back to volunteers.

The European Federation of Pharmaceutical Industries and Associations reports that €30 billion was spent on pharmaceutical research and development in 2012, of which 32 per cent, or €9.6 billion, was spent on Phase III trials[74]. McKinsey[75] suggests that IoT-based

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[71] Calculated for EU28 population over 24 (370.3 million people). In the 5G assumptions it is assumed that only 20 per cent of the population (the percentage in Romania) have life insurance policies.

[72] Stifling New Cures: The True Cost of Lengthy Clinical Drug Trials", Avik Roy April 24, 2012, Manhattan Institute for Policy Research. https://www.manhattan-institute.org/html/stifling-new-cures-true-cost-lengthy-clinical-drug-trials-6013.html

[73] The Truly Staggering Cost Of Inventing New Drugs http://www.forbes.com/sites/matthewherper/2012/02/10/the-truly-staggering-cost-of-inventing-new-drugs/#2715e4857a0b5a8924764477

[74] "The Pharmaceutical Industry in Figures", The European Federation of Pharmaceutical Industries and Associations, 2014, http://www.efpia.eu/uploads/Figures_2014_Final.pdf

[75] McKinsey 2015 ibid. Page 42.

solutions could conservatively reduce Phase III costs by 15 per cent. They cite a recent case study that suggested a saving of 85 per cent.

Assumptions: 5G capabilities could radically extend the reach and reliability of various wearable and portable health monitors that would provide rich bio-data from volunteer patients living *anywhere*. We estimate that if 5G capabilities comprised five per cent of savings (of 15 per cent), savings could amount to approximately €72 million per annum for the European pharmaceutical sector.

5G IoT capabilities will provide third party benefits of approximately €72 million per annum to the European pharmaceutical research and development sector.

6.7.5. Estimating benefits

Previous sections have presented the results of research to estimate the first order benefits of the utilisation of 5G capabilities in the healthcare vertical[76]. For transparency all assumptions made in calculating benefits have been presented in a separate section at the end of each benefits category. An overview of the benefits arising from 5G capabilities is provided in Table 7. Since no forecasts of increases in healthcare requirements between 2015 and 2030 have been made these 'per annum' benefits are used to provide values for 2025 and 2030 in Table 7.

Table 7: Healthcare Benefits per annum

	2025
Strategic benefits	€1.1 bn
Operational benefits	€4.15 bn
Consumer benefits	€207 m
Third party benefits	€ 72 m
Total annual benefits	**€5.53 bn**

6.8. Transport

The current transport Industry is made up of a complex array of transport providers, maintenance and administrators. This has led to a highly fragmented environment where national standards and proprietary approaches dominate.

[76] As noted in the Annex second order impacts, such as longer-term health benefits to consumers are captured separately to avoid double counting.

Freight transport is one the European Union's significant industries, with a market value of about €878bn in 2012[77]. This study focuses on in-land freight transport services. In 2013, based on tonne-kilometer statistics[78], 75.4 per cent of the total in-land freight transport was undertaken by road. Rail freight transport only accounts for 17.8 per cent and inland waterways transport makes up 6.7 per cent. This study has focused primarily on road based transport.

The transport vertical is striving to achieve better integrated, intelligent and smart transport systems. Advanced data sharing platforms enhanced by 5G networks play a pivotal role in addressing critical challenges and barriers within the freight transport industry. Particularly for the more efficient tracking of transported goods, for better utilisation of resources to ensure lorries operate at full carrying capacity with less idle time and in decreasing road congestion. 5G capabilities could also enhance vehicles' anti-theft systems which could lower costs of insurance[79].

6.8.1. Strategic benefits for transport

Strategic benefits for transport providers and manufacturers will primarily arise from better access to enhanced telematics information. 5G embedded connectivity in lorries is expected to provide a powerful communication channel, transferring large volumes of data on the lorry's performance and driver behaviour.

Automatic Vehicle Monitoring (AVM) systems generate data about vehicle position and status[80]. Enhanced AVM systems with 5G connectivity could produce more data in terms of volume, velocity and variety. This stream of data will enables transport providers to observe trends and seasonality within the freight industry, allowing them to make strategic changes for greater benefits and customer satisfaction. Transport providers can utilize this data to redistribute routes of freight transport to meet the changing demand to ensure timely delivery of goods.

The use of 5G data can be extended to greater strategic benefits when insightful data is transferred to automotive manufacturers. Embedded 5G connectivity within lorries provides automotive manufacturers with the opportunity to gather vehicle and real-time data and enable remote diagnostics. The utilisation of 5G data will enable manufacturers to analyse components, particularly those leading to break downs and equipment failure. In the short-term this knowledge will allow efficient production of required components to meet anticipated demand[81]. In the long-term enhanced knowledge will enable faults to be 'designed out' of future models. Enhanced information will also enable manufacturers to monitor and improve the vehicle performance and fuel consumption[82].

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[77] "Kille/Schwemmer (2013). Top 100 in European Transport and Logistics Services, DVV Media Group, Hamburg, p. 48", cited in: Fact-finding studies in support of the development of an EU strategy for freight transport logistics. Lot 1: Analysis of the EU logistics sector. Final report. Written by: Ecorys, Fraunhofer, TCI, Prognos and AUEB-RC/TRANSLOG. European Commission. January 2015. http://ec.europa.eu/transport/themes/strategies/studies/doc/2015-01-freight-logistics-lot1-logistics-sector.pdf

[78] Tonne-kilometre (tkm): is the transportation of one tonne of goods over a distance of one kilometre via various transport modes. Eurostat, [tran_hv_frmod]

[79] Freight Best Practice. Telematics for Efficient Road Freight Operations. Department for Transport. http://www.isc-consultants.co.uk/ISC/Distribution_Resources_1_files/FBP1042%20Telematics%20For%20Efficient%20Road%20Freight%20Operations-1.pdf

[80] Gualandi, S. Public Transport and Big Data. http://stegua.github.io/blog/2013/11/17/public-transport-and-big-data/

[81] Datafloq. Self-driving Cars Will Create 2 Petabytes Of Data, What Are The Big Data Opportunities For The Car Industry? https://datafloq.com/read/self-driving-cars-create-2-petabytes-data-annually/172

[82] Big Data Companies. Big Data – Big Benefits For Auto Makers And Users. http://www.bigdatacompanies.com/big-data-big-benefits-for-auto-makers-and-users/

Assumptions: GM estimates of the current value of telematics information as €615 per vehicle. We assume that the future (added) value of enhanced and real-time telematics will be 50 per cent more than current estimates (e.g. €307 per lorry).

4G LTE and LTE Advanced will provide some of the functionality envisaged to be possible in the future. However, the ubiquitous capabilities offered by 5G will enhance real-time proficiency. It is estimated that 5G will contribute 50 per cent of the future (added) value of real-time telematics. The strategic benefits of 5G is expected to provide about €153 per lorry.

Embedded 5G data capabilities will provide strategic benefits of approximately €153 per lorry

6.8.2. Operational benefits for transport

Enhanced access to real-time information about lorry location and their loads should offer opportunities for transport businesses, or newcomers providing new business models, to increase the efficiency of operations by ensuring lorries run closer to full capacity and lorries have less idle time waiting to be loaded.

According to Eurostat surveys, 24 per cent of the good vehicles within the EU are running empty. The surveys also reveal that the average loading vehicles is about 57 per cent of the overall available loading space. This inefficiency is estimated to reach €160bn within the EU27 Member States[83].

Assumptions: Freight transport lorries with embedded 5G connectivity are expected to reduce the cost of inefficiency due to the 5G's enhanced storage and sharing capabilities. It is assumed that 5G connectivity and better access to data for more efficient operations could reduce inefficiency costs (€160 bn) by two per cent.

Embedded 5G data capabilities will provide operational saving of approximately €3.2 billion

6.8.3. Benefits for consumers

5G provides enhanced systems for data management, sharing and storage and has key benefits on freight transport. For instance, the cloud-based Electronic Logistics Marketplace (ELM) creates an electronic platform linking shippers, carriers, and customers, and enabling effective communication and reduced delays[84]. Overall, the delivery process is expected to be faster and more efficient using fleet with embedded connectivity. This platform, enhanced by real-time 5G capabilities will provide greater information to consumers about goods that they have purchased which are being delivered to them. However, the value of improved access to tracking information to customers is difficult to calculate in quantitative terms and similar, less refined systems, already exist. The value of this benefit has not therefore been calculated.

[83] Final Report Summary – WINN (Europen Platform Driving KnoWledge to INNovations in Freight Logistics). Community Research and Development Information Service (CORDIS). http://cordis.europa.eu/result/rcn/173328_en.html

[84] Harris, I., Wang, Y., Wang, H. 2015. ICT in multimodal transport and technological trends: Unleashing potential for the future. *International Journal of Production Economics.* Volume 159, pp: 88-103. http://ac.els-cdn.com/S0925527314002837/1-s2.0-S0925527314002837-main.pdf?_tid=4e0eac74-8d22-11e5-bd84-00000aacb360&acdnat=1447761598_055be06a0f4b7fb3e03335e1585d51a1

6.8.4. Benefits for administrators and third parties

Section 6.6 described how 5G provides administrators and other third parties with key insights to road conditions, congestion and pollution[85]. Overall traffic benefits (for passenger vehicles (274 million in 2030) and lorries (33.7 million in 2030)) are included in the automotive vertical review. To avoid duplication these benefits are not repeated here to prevent double counting.

Clearly environmental benefits should arise as a result of a reduction in congestion and emissions. The roll-out of smart transport will reduce the size of energy used, leading to reductions in carbon emission. These additional benefits are examined and analysed in the Smart City overview.

6.8.5. Potential new business models

The sale of telematics information and data could offer new sources of income for transport providers as well as lorries' manufacturers[86]. This data could be complemented with data from other sources, including social networks to provide added value[87].

New business models have been suggested within the insurance industry. Vehicle insurance premiums are traditional calculated through risk algorithms for specific groups of drivers. The industry has undertaken telematics trials of usage-based insurance to observer drivers' behaviours and more accurately assess the actual risk posed by drivers (through pay-as-you-drive or pay-how-you-drive)[88]. Telematics could also detect fraudulent claims made by customers and, through systems such as eCall, notify insurers of accidents[89].

Benefits arising from new business models are extremely speculative. Since the study is taking a conservative attitude to benefits forecasts potential benefits arising from these possible new business models are not be included in forecasts.

6.8.6. Estimating overall benefits

Previous sections have presented the results of research to estimate the first order benefits of the utilisation of 5G capabilities in the transport vertical[90]. For transparency all assumptions made in calculating benefits have been presented in a separate section at the end of each benefits category.

It is notable that in many of the studies reviewed in the previous section data is presented on a 'per lorry' basis. A key forecast therefore concerns the number of lorries in EU Member States when 5G is introduced.

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[85] Motoring of the future – Transport Content. http://www.publications.parliament.uk/pa/cm201415/cmselect/cmtran/429/42906.htm

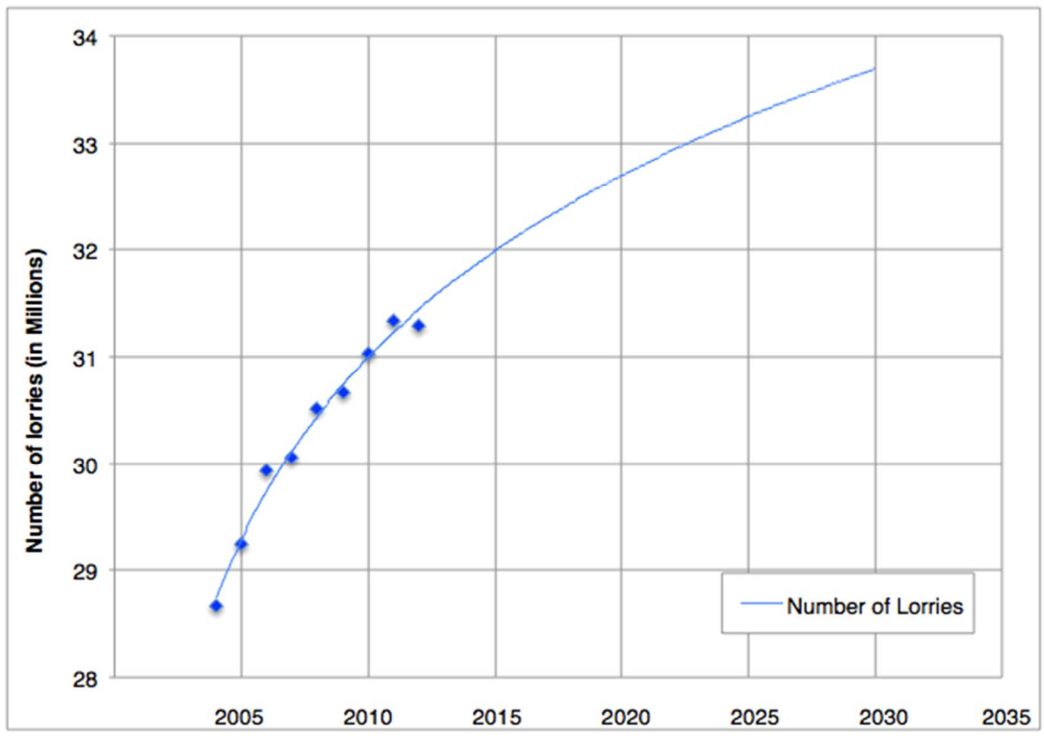
[86] IBM. Leveraging big data in automotive to solve key business problems. https://www-01.ibm.com/software/data/bigdata/industry-auto.html

[87] Gualandi, S. Public Transport and Big Data. http://stegua.github.io/blog/2013/11/17/public-transport-and-big-data/

[88] National Association of Insurance Commissioners. 2015. Usage based insurance and telematics http://www.naic.org/cipr_topics/topic_usage_based_insurance.htm

[89] SBD. 2012. 2025 Every car connected: Forecasting the growth and opportunity

[90] As noted in the Annex second order impacts, such as improved traffic management and reduced pollution are captured separately to avoid double counting.



Source: Calculations based on data from Eurostat: [road_eqs_lorroa]

Figure 9: Number of lorries in EU28 Member States 2004 to 2030

Figure 9 utilises calculations from Eurostat data of the number of lorries between 2003 and 2012 within the EU28 Member States. Future forecasts and trends on the number of lorries between 2013 and 2030 are derived from logarithmic trend extrapolations from Eurostat data[91].

An overview of the transport benefits arising from 5G capabilities is provided in Table 8.

Table 8: Transport Benefits

	2025	2030
Lorries	33.2m	33.7m
Strategic benefits at €153 / lorry	€5.1 bn	€5.2 bn
Operational benefits at €3.2bn per annum	€3.2 bn	€3.2 bn
Total annual benefits	**€8.3 bn**	**€8.4 bn**

[91] The use of logarithmic trend extrapolation for the number of lorries is based on the assumption of the efficiency within the freight industry. As clarified in section 6.8.2, 24 per cent of the good vehicles within the EU are running empty, and the average loading for the rest of the vehicles is about 57 per cent of the overall available loading space, suggesting an overall efficiency of 43 per cent. Advanced communication platforms (such as 5G) are expected to reduce the inefficiency within the freight industry, leading to fewer lorries running empty. As a result, the trucking companies will not have to significantly increase their lorry fleets every year to meet the demand and deliver the increasing amount of goods.

6.9. Utilities

For more than 20 years, the European Union has been at the forefront of global action to combat climate change. It has developed ambitious energy and climate policies, including the target of reducing its greenhouse gas (GHG) emissions by 80 per cent by 2050[92].

Government, commercial and environmental factors have already pushed utilities to develop the smart grid, bringing intelligence to the systems that generate, distribute, manage and secure energy and water. The socio-economic benefits of smart grids will increase as they evolve to support vast numbers of sensors and end points, and to deliver ubiquitous coverage with high security and low latency. Many of these challenges are likely to be supported by wireless technologies, including 5G.

Energy policy is still a patchwork of national policies. The regulatory environments in which utilities work vary significantly between countries, though most are progressing towards deregulation (division of transmission and retail supply, and elements of market competition), which has put new pressures on the companies to maximise efficiency.

Many of the benefits identified in this section arise from the increased deployment of 'next generation' smart meters. Most of the smart meters installed today use mobile phone-type signals to send meter readings to suppliers, and other wireless technologies to send information to in-home/premises displays[93]. The next generation of smart meters, which could be supported by 5G capabilities, will offer a range of 'more intelligent' functions, including real-time data exchange and better energy management.

6.9.1. Strategic benefits for utility suppliers

Strategic benefits for utilities providers will primarily arise from better access to enhanced information. Smart meters provide information and data on customer's use of electricity and gas, highlighting preference and seasonality patterns. 5G capabilities will enhance data storage and sharing, leading to further strategic benefits.

Strategic benefits of installing smart meters with embedded 5G capabilities will arise from increased access to data and real-time information provision. This will support efficient energy generation, enabling savings in generation capacity, particularly during periods of high demand. When supply loads are shifted from peak to off-peak periods, electricity providers observe savings in short-term marginal costs due to lower generation costs. The load shifting between peak and off-peak periods reduce the size of capacity investment in electricity. A UK government study found that the total strategic generation benefits that will arise from smart meters is about €1.1bn[94]. The strategic benefit from the estimated 53 million smart meters in the UK in 2020[95] is forecast to be €20.75 per meter[96]. Section 6.9.6 provides an overview of forecasts for smart meters in Europe between 2020 and 2030.

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[92] See https://ec.europa.eu/energy/en/topics/energy-strategy

[93] https://www.gov.uk/guidance/smart-meters-how-they-work

[94] Smart meter roll-out for domestic and small and medium non-domestic sectors (GB). Impact Assessment (IA). 30/1/2014. URN: 14D/033. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/276656/smart_meter_roll_out_for_the_domestic_and_small_and_medium_and_non_domestic_sectors.pdf

[95] Ofgem. Transition to smart meters. https://www.ofgem.gov.uk/gas/retail-market/metering/transition-smart-meters

[96] Calculations based on data from Smart meter roll-out for domestic and small and medium non-domestic sectors (GB). Impact Assessment (IA). 30/1/2014. URN: 14D/033.

Assumptions: It is assumed that 5G capabilities embedded in smart meters will provide further strategic benefits of ten per cent due to real-time data exchange and data sharing enhancements. Smart meters with embedded 5G connectivity will thus provide strategic benefits of €2.75 per smart meter. Section 6.9.6 forecasts that there will be 282 million smart meters in EU Member State in 2025 and 319 million in 2030.

5G data capabilities in smart meters will provide strategic benefits in the utilities industry of €775 million in 2025 and €877 million in 2030.

6.9.2. Operational benefits for utility suppliers

The main operational benefits for utilities are also likely to arise from data generated by smart meters. Smart meters with embedded 5G capabilities allow utilities providers to avoid frequent site visits for meter readings and safety inspections.

Smart meters are also expected to establish a more effective communication platform for maintenance and feedback. This will reduce costumers' enquiries and complaints, reducing call centre costs and introducing further operational benefits. More accurate and up-to-date billing systems, enhanced by smart meters with 5G capabilities, should also eliminate the requirements for utility companies to 'estimate' bills, leading to reductions in billing enquiries.

A UK government study found that utility supplier operational benefits from smart meters were €10.5bn. Some of the benefits identified will arise without 5G. For example €3.8 bn of benefits arise from avoiding regular visits for meter reading and €1.5 bn of benefits come form reduced enquiries about estimated bills[97]. The remaining operational benefits of better access to real-time data and better communication with customers thus yield €5.2 bn of benefits. This equates to €98.10 per smart meter.

Assumptions: It is assumed that 5G capabilities embedded in smart meters will provide further operational benefits of ten per cent due to real-time data exchange and data sharing enhancements. Smart meters with embedded 5G connectivity will thus provide operational benefits of €9.81 per smart meter. Section 6.9.6 forecasts that there will be 282 million smart meters in EU Member State in 2025 and 319 million in 2030.

5G data capabilities in smart meters will provide operational benefits in the utilities industry of € 2.7 billion in 2025 and € 3.1 billion in 2030.

6.9.3. Benefits for consumers

Increased use of smart meters is expected to enable customers to better understand their energy consumption by devices and activities (via IoT capabilities), allowing access to historical information and anonymised information about neighbours habits and best practices on energy use and consumption. Households' access to this data and information is important in reducing energy consumption[98]. Savings in energy consumption will obviously be dependent on household energy consumption habits.

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https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/276656/smart_meter_roll_out_for_the_domestic_and_small_and_medium_and_non_domestic_sectors.pdf

[97] Smart meter roll-out for domestic and small and medium non-domestic sectors (GB). Impact Assessment (IA). 30/1/2014. URN: 14D/033. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/276656/smart_meter_roll_out_for_the_domestic_and_small_and_medium_and_non_domestic_sectors.pdf

[98] Portilla, K. Will smart meters really help homeowners save energy? The Guardian. 23 June, 2013. http://www.theguardian.com/environment/blog/2013/jun/28/smart-meters-homeowners-save-energy

A UK government study[99] estimated that consumer benefits from decreased energy consumption facilitated by 5G are €5.7bn per annum[100]. This equates to €107 per smart meter.

Assumptions: It is assumed that 5G capabilities embedded in smart meters will provide further consumer energy saving benefits. In line with previous predictions these are estimated to be ten per cent. In reality it is probable that the benefits of knowing energy consumption of individual devices in a home will only be fully reached when IoT capabilities supported by 5G real-time data exchange and data sharing enhancements are introduced. The contribution of 5G could thus be significantly greater. Nonetheless, the ten per cent added value from 5G equates to €10.7 per meter.

Section 6.9.6 forecasts that there will be 282 million smart meters in EU Member State in 2025 and 319 million in 2030.

5G data capabilities in smart meters will provide consumer benefits in the utilities industry of € 3 billion in 2025 and € 3.4 billion in 2030.

6.9.4. Benefits for administrators and third parties

The deployment of smart meters and smart grids is expected to reduce emissions in the EU by approximately nine per cent[101]. These additional 'secondary' benefits are examined and analysed in the environmental overviews (smart cities and non-urban areas) to prevent double counting.

6.9.5. Potential new business models

New business models in the utility sector could include 'energy-as-a-service'. This requires energy companies or new entrants to move from being energy providers (delivering energy to their clients) to becoming 'energy service providers' delivering packaged energy-efficient solutions to clients. For example consumers might have heating and cooling services provided by the 'utility company' rather than the consumer owning their own boiler and air-conditioner equipment. Actors in the new business model might also provide and maintain all the smart appliances in a home. The consumer no longer pays for electricity or gas, but pays for the services of heating, cooling, use of a washing machine and fridge etc.

A fundamental building-block for this new business model is the availability of reliable energy consumption profiles for different consumer types (e.g. actuarial data). This data could unlock the financial services required to enable energy-as-a-service to domestic and commercial consumers, by allowing energy service providers to correctly price their services to consumers based on accurate models and predictions of consumer energy usage.

6.9.6. Estimating overall benefits

The EU is aiming to replace 80 per cent of electricity meters with smart meters by 2020, rolling out around 200 million smart meters for electricity and 45 million smart meters for gas

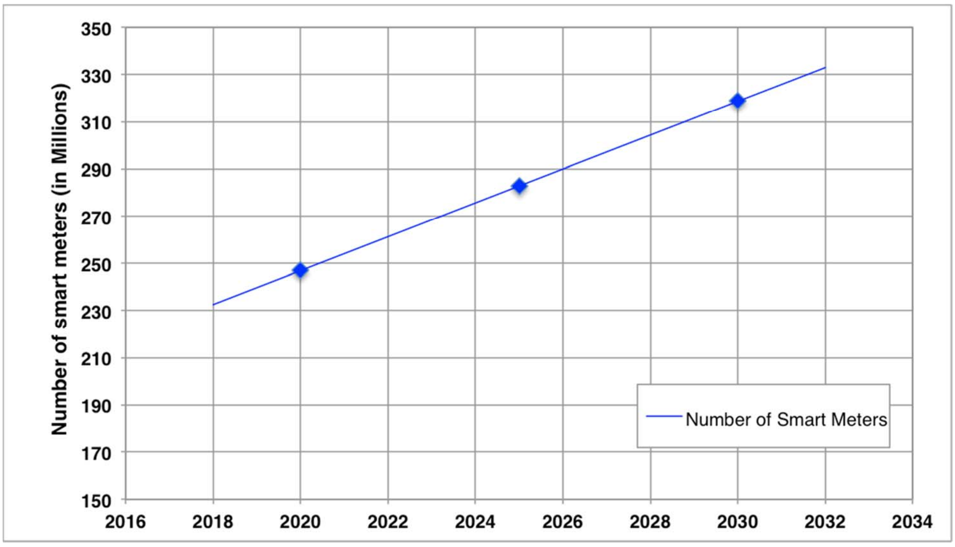
[99] Smart meter roll-out for domestic and small and medium non-domestic sectors (GB). Impact Assessment (IA). 30/1/2014. URN: 14D/033. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/276656/smart_meter_roll_out_for_the_domestic_and_small_and_medium_and_non_domestic_sectors.pdf

[100] Including savings in micro-generation of €39.5 m

[101] Smart grids and meters. European Commission. https://ec.europa.eu/energy/en/topics/markets-and-consumers/smart-grids-and-meters

with an investment of about €45bn[102]. By 2020, 72 per cent of EU customers are expected to have smart meters for electricity, while 40 per cent of EU customers are expected to have smart meters for gas.

Linear trend extrapolation methods were used to provide forecasts for smart meter deployment, see Figure 10. There are predicted to be 282 million smart meters in EU Member State households in 2025 and this number will increase to 319 million in 2030.



Source: Calculations based on data from the European Commission's report[103]

Figure 10: Number of Smart Meters in the EU28 Member States

Previous sections have presented the results of research to estimate the first order benefits of the utilisation of 5G capabilities in the utilities vertical[104]. For transparency all assumptions made in calculating benefits have been presented at the end of each benefits category. Table 9 highlights the number of smart meters in the EU28 as well as the monetary value of the strategic, operational and consumer benefits in 2025 and 2030.

Table 9: Energy Utilities Benefits for 2025 and 2030 in EU28

	2025	2030
Smart Meters	282m	319m
Strategic benefits at €2.1 / Smart Meter	€ 775m	€ 877m
Operational benefits at €19.8 / Smart Meter	€ 2.7 bn	€ 3.1 bn
Consumer benefits at €10.8 / Smart Meter	€ 3.0 bn	€ 3.4 bn

[102] Report from the Commission. Benchmarking smart metering deployment in the EU-27 with a focus on electricity. Brussels, 17.6.2014. COM(2014) 356 final. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0356&from=EN

[103] Report from the Commission. Benchmarking smart metering deployment in the EU-27 with a focus on electricity. Brussels, 17.6.2014. COM(2014) 356 final. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0356&from=EN

[104] As noted in the Annex second order impacts, such as improved traffic management and reduced pollution are captured separately to avoid double counting.

Total annual benefits	€ 6.47 bn	€ 7.37 bn

6.10. Conclusion: Vertical forecasts

The four preceding sections have provided quantitative estimates of the benefits of 5G capabilities in the four key verticals examined in this study. It is acknowledged that these verticals represent a very small proportion of the benefits likely to arise across all sectors of the economy. Nonetheless, they do provide an insight to four of the most commonly investigate use cases and verticals examined in 5G research and White Papers. Table 10 provides a comparison of benefits in the four key verticals in 2025. 2025 is selected as the year for comparison since these nearer-term forecasts are likely to be a little more reliable than the longer-term 2030 forecasts. However, benefits per annum in 2030 are broadly similar to those in 2025.

Table 10 Comparison of benefits per annum from 5G capabilities in four key verticals in 2025

Verticals *Benefits*	Automotive (€ mn)	Healthcare (€ mn)	Transport (€ mn)	Utilities (€ mn)	Total (€ mn)
Strategic	12,800	1,100	5,100	770	**19,770**
Operational	1,800	4,150	3,200	2,700	**11,850**
Consumer	13,900	207	-	3,000	**17,110**
Third Party	13,700	72	-	-	**13,770**
Total	**42,200**	**5,530**	**8,300**	**6,470**	**62,500**

Totals may not correspond due to rounding

In total it is estimated that benefits of €62.5 billion will arise from first order benefits in the four verticals examined in the study. It was noted earlier that whilst a thorough evidence base and transparent assumptions have been provided for all forecast it would be unwise to place great significance on any individual forecast. Instead it was emphasised that the most significant insights will arise from examining the relative differences between verticals (and environments)

The automotive vertical has the highest level of forecast benefits (€42.2 bn), significantly more than for the other verticals. Benefits from transport (€8.3 bn), healthcare (€5.5 bn) and utilities (€6.5 bn) verticals are considerably lower.

However, it is notable that within the automotive vertical benefits to businesses within the sector (the strategic and operational benefits - €14.6 bn) are lower than the benefits arising to consumers and third parties (€27.6 bn) that use the vehicles and data provided by the industry. In all other verticals the strategic and operational benefits to businesses in the industry are greater than those for consumers and third parties. Nonetheless, overall it is notable that benefits to consumers (€17.1 bn) and third parties (€13.8 bn) (e.g. beyond the businesses in the verticals) total €30.9 billion. This is just under half (49 per cent) of total benefits forecast for the impact of 5G in the verticals.

6.11. Environmental impact forecasts

Figure 7 in section 6.4 highlighted that second order benefits (or ‘knock-on’ impacts) arose from the use of goods, services and additional data provided by 5G capabilities in the four verticals examined in this study and the other sectors that will utilise 5G. These impacts are generally more indirect benefits to society such as time savings, lower purchase costs and other ‘savings’ (economic) and reduced pollution (environmental).

Second order benefits are examined by investigating the four ‘environments’ where the impacts are most likely to arise. The environments focus on two different scales of analysis - at the micro scale the study investigated 5G benefits for households and workplaces. At the broader scale the study investigated smart cities and non-urban environments. These two scales of analysis enabled the study to better identify specific benefits. Obviously the two larger scale environments are predominantly composed of homes and workplaces. Care has been taken in presenting the impacts of 5G to avoid duplication and double counting of benefits.

The next four sections, describing key benefits in the environments, are structured in a similar manner. A short overview of opportunities is followed by examination of economic, social and environmental benefits.

6.12. Smart cities

Smart cities use digital technologies and data to optimise the efficiency and effectiveness of city processes, activities and services. This optimisation is achieved by joining up diverse elements and actors into a more interactive intelligent system. 5G could play a considerable role in providing connectivity and supporting smart city development.

Transforming European cities requires investment and effort, especially in those with obsolete infrastructures. Cities are developing in a new era, different from the past, with more stakeholders and influencers affecting data generation, consumption, requirements and direction than ever before. Smart City development requires data in all its forms.

Access to and rights of data use will increasingly underpin the operation of cities and the provision of city services. Those developing smart cities are utilising and shaping the development of increasingly flexible data ecosystems to deliver ubiquitous access to data, information and online services and connectivity between administrators, citizens, businesses, equipment and machines.

An important capability provided by 5G in Smart Cities will be the ability to deliver scalable solutions for sensor networks and the IoT. The connectivity technology for stakeholders will be provided at a scale that will be more advantageous than cost points of today’s systems. Smart City bespoke data handling platforms are likely to become obsolete because the underlying capabilities of 5G will enable easier and more efficient aggregation.

6.12.1. Economic benefits in smart cities

As noted in section 4.4 one of the unique capabilities provided by 5G is support for the exchange of data in very large scale M2M/IoT networks. This will enable better traffic management from roadside sensors and real-time data from vehicles. Enhanced information about traffic flows and journeys should enable smart city traffic controllers to better manage traffic real-time and reduce congestion. Enhanced information about congestion should enable drivers and/or autonomous vehicles to avoid congested routes and complete journeys more rapidly.

Congestion in the EU28 Member States is generally located in and around urban areas and costs nearly €100 billion, or 1 per cent of the EU's GDP, annually[105]. These costs generally comprise fuel, vehicle operating costs plus a monetary valuation of time costs[106]. The Centre for Economics and Business Research report that these costs will increase by 50 per cent between 2013 and 2030[107].

In 2011 the EC estimated that the cost of EU infrastructure that would be required to match the demand for transport would be over €1.5 trillion between 2010 and 2030[108]. Better traffic management, smart motorway systems[109] and automated highway systems (AHS[110]) can be used to increase road network capacities by up to 100 per cent. Better traffic management, facilitated by 5G capabilities, should help to reduce infrastructure costs. If these benefits can be achieved with the support of 5G capabilities the €1.5 trillion infrastructure investment could be considerably reduced. Due to the speculative nature of any reduction a forecast for this saving is not included in forecasts

AT Kearney predict that one of the benefits of dynamic access to IoT data will be a reduction in congestion by ten per cent. They forecast the cost of congestion to be €133 billion per annum in 2025 and €150 billion in 2030.

The majority, but not all congestion, is located in urban areas. It is conservatively estimated city congestion will comprise 60 per cent of total congestion in EU28 Member States[111].

Assumptions: AT Kearney's prediction of a ten per cent reduction in congestion would thus lead to savings of €13.3 billion per annum in 2025 and €15 billion in 2030. 60 per cent of congestion arises in cities.

In 2025 and 2030 5G dynamic data exchange capabilities could be responsible for half of the reduction in congestion (4G and enhanced sensor deployment will comprise the remaining 50 per cent)[112].

5G data capabilities will provide congestion reduction benefits of €4 billion in 2025 and €4.5 billion in 2030

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[105] European Commission. http://ec.europa.eu/transport/themes/urban/urban_mobility/index_en.htm

[106] Scottish Executive. 2006. Costs of congestion: Literature based review of methodologies and analytical approaches.

[107] http://www.cebr.com/reports/the-future-economic-and-environmental-costs-of-gridlock. This equates to a compound annual growth rate of 2.41 per cent. This forecasts congestion costs of €133 billion in 2025 and €150 million in 2030.

[108] European Commission. 2011. Staff Working Document accompanying the White Paper - Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. SEC(2011) 391 final

[109] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/363993/Smart_motorways_-_Fact_Sheets.pdf "in-car' 5G capabilities will reduce the requirement for verge mounted radar units and sensor loops buried below the road surface that are required to monitor traffic in traditional smart highway and traffic systems.

[110] Ioannou P. 1997. Automated Highway Systems. Springer, New York.

[111] On average in EU28 Member States motorways comprise one to two per cent of the total road network (European Union Road Federation. 2015. Yearbook 2014-2015). Motorways are regarded as being largely outside of cities. In the UK, where motorways comprise 1.2 per cent of the road network, in 2014 motorways accounted for 20.7 per cent of motor vehicle traffic (www.gov.uk/government/organisations/department-for-transport/series/road-traffic-statistics Table TRA0202). In countries with higher proportions of motorway networks motorway vehicle traffic could be higher. Some congestion will also arise in the non-urban road network. It is therefore conservatively estimated that congestions in cities will probably comprise more than 60 per cent of all congestion.

[112] In 2025 congestion costs of €133 billion could be reduced by ten per cent (€13.3 billion). 60 per cent of this might arise in cities (€7.98 billion) and half of this might be due to 5G capabilities (€4 billion). This method is replicated for 2030

6.12.2. Social benefits in smart cities

Most of the early discussions concerning smart cities have focused on the better use of energy, transport, healthcare, smart lighting and attracting business investment. But social benefits will also arise to citizens, businesses and other organisations in cities.

5G capabilities will be used to optimise the efficiency and effectiveness of city processes, activities and services. This optimisation will be achieved by joining up diverse elements and actors into a more interactive intelligent system[113]. UK government[114] highlight that 5G capabilities will provide a Smart City with a modern digital infrastructure and enables citizens to access the information they need, when they need it. Greater access to information and inter-connection between citizens will be beneficial, but it is difficult to quantify these benefits and it is probable that, whilst laudable, these benefits will be relatively small in comparison with others investigated in this study.

One of the most important benefits arising from the utilisation of 5G capabilities, recognised; but rarely quantified in smart cities studies, are the benefits arising from better traffic management. 5G data exchange capabilities and data analytics provide the ability to reduce traffic congestion, identify traffic black spots and reduce accidents[115].

Benefits arising from traffic reduction were examined in the previous section. This section focuses on quantitative benefits arising from accident reduction. 5G will be important but it must also be acknowledged that sensors on vehicles will also play a part in reducing accidents. Many of these 'in-car' sensors will be able to work independently of integration with a 5G network or platform.

The European Union Road Federation Yearbook 2014-2015 provides an insight to trends in accidents and fatality levels. Road fatalities have more than halved in EU28 Member States from 53,344 in 2002 to 25,935 in 2013. This represents a cumulative annual reduction of 6.2 per cent. If that trend continues the number of accidents will reduce to approximately 12,000 in 2025 and 8,750 in 2030. The number of accidents involving injury in EU28 Member States is also declining from 1.5 million in 2000 to 1.078 million in 2012 (a cumulative annual reduction of 2.8 per cent, if this trend continues accidents with injury will have declined to 739,000 in 2025 and 641,000 in 2030). The impact of 5G capabilities in 2025 and 2030 will therefore be taking place against a trend of declining fatalities and accidents involving personal injury.

The European Transport Safety Council[116] estimated the monetary value of a road fatality in 2011 was €1.84 million. This fatality value is similar to figures provided in a 2004 study which estimated annual costs, both direct and indirect, of traffic injury in EU-15 countries as €180 billion[117]. In 2004 there were 1.16 million road accidents in EU-15 countries[118], the average value of an accident was therefore €112,000. Using this value[119] for road accidents the cost of the predicted 739,000 road accidents in 2025 is estimated to be €82.8 billion and €71.8 billion in 2030.

Some observers have rashly suggested that 5G could eliminate car accidents[120]. Others have suggested that telematics could lead to a 30 per cent reduction in road accidents[121].

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[113] EC. 2014. ibid

[114] Department for Business Innovation and Skills. 2013. Smart Cities: Background paper. The remaining three issues are process oriented – citizen centric service delivery, transparency of outcomes and openness to learn form others.

[115] Smart Minds. 2015. Road Accidents Will Happen and Now We Know When and Where. http://people4smartercities.com/series/road-accidents-will-happen-and-now-we-know-when-and-where

[116] ETSC. 2012. A Challenging Start towards the EU 2020 Road Safety Target. 6th Road Safety PIN Report.

[117] ETSC. 2007. Social and economic consequences of road traffic injury in Europe.

[118] ETSC ibid. Table 7.1

[119] Adopting a conservative approach without adjusting for inflation.

[120] Moiin H. 2015. The promise of 5G http://techcrunch.com/2015/08/15/the-promise-of-5g/

This study takes a rather more conservative view about the impact of 5G capabilities. As noted earlier the growing number of sensors on cars will lead to a reduction in accidents without the need for 5G capabilities. Better traffic management and 5G data exchange between cars will lead to a reduction in accidents; but we estimate that this will only amount to a five per cent reduction in road accidents.

Assumptions: 5G capabilities will provide a five per cent reduction in road accidents in 2025 and 2030. Extrapolating trends in the number of road accidents over the last ten years leads to a forecast of 739,000 road accidents with personal injuries in EU28 Member States in 2025 and 641,000 in 2030. The cost of these accidents was estimated at €82.8 billion and €71.8 billion respectively.

5G data capabilities will reduce the cost of road accidents by €4.1 billion in 2025 and €3.6 billion in 2030

6.12.3. Environmental benefits

Several benefits arising from improvements in transport planning and reductions in congestion have been presented from economic and social viewpoints. Clearly environmental benefits will also arise. Some participants noted that enhanced access to information and communication could lead to more car sharing (both short-term vehicle rental and commuter journey sharing) and thus better optimisation of car resources in cities. All participants highlighted that if reduced congestion was possible in cities this would have a number of 'knock-on' effects. Faster journeys should reduce the consumption of fuel (hydro-carbon and electricity). This in turn should lead to reduced emissions from vehicles and this should lower pollution and CO_2 reductions.

Eurostat report that total CO_2 emissions in EU Member States in 2013 were 4.61 billion tonnes. 501 million tonnes of these emissions were from vehicles on roads[122]. A European Commission staff working document highlighted that 37 per cent of road emissions arose from roads in cities[123]. This equates to 185 million tonnes of CO_2 emissions from traffic in cities[124].

The International Road Transport Union note that road congestion increases fuel consumption and thus CO_2 emissions by 300 per cent. They highlight that free flowing traffic is a prerequisite for reducing CO_2 emissions[125]. To maintain a conservative approach this study will simply calculate the volume of CO_2 emissions as a proportion of the time vehicles spend in traffic, without taking account of increased emissions in congestion.

Statistics on the time drivers spend in traffic is sparse. In the UK the 2013 national travel survey found that the average driver spends 364 hours travelling[126]. Inrix provide data on the

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[121] AT Kearney. 2016. The Internet of Things: A New Path to European Prosperity

[122] Eurostat. 2015. Greenhouse gas emission statistics. http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics

[123] European Commission. 2011. Commission staff working document : Accompanying the White Paper - Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. SEC(2011) 391 final. 63% of car emissions relate to travel on non-urban roads and motorways. http://ec.europa.eu/transport/themes/strategies/doc/2011_white_paper/white_paper_working_document_en.pdf

[124] Conversely this means that 63 per cent of emissions arise in non-urban environments. This equates to 316 million tonnes of CO_2 emissions. 5G capabilities should have the same impact on traffic reduction in non-urban areas as they do in cities. The same methodology as used in this section (6.12.3) is used to calculate the value of reduced CO_2 emissions in non-urban areas. 316 x 11% x 7% = 2.43 million tonnes. At €32 per tonne the benefit of congestion reduction is €77.7 million. 5G would be responsible for half of the reduction, thus the 5G benefit is €38.3 million in non-urban areas.

[125] https://www.iru.org/en_policy_co2_response_flowingtraffic

[126] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/342160/nts2013-01.pdf

time UK drivers spend in congestion. These range from 72 hours in congestion in Manchester to the lowest which was 40 hours in Leeds/Bradford[127]. If the lowest figure of 40 hours is used the average driver in the UK spends 11 per cent of their travel time in traffic[128]. CO_2 emissions as a result of congestion would therefore be 20.4 million tonnes[129].

Access research[130] have shown that traffic management can reduce Co2 emissions caused by traffic congestion by seven to 12 per cent. The lower value in this range was adopted to calculate a seven per cent reduction in the 20.4 million tonnes of CO_2 emissions as a result of congestion. This equates to 1.4 million tonnes.

A number of studies have estimated the cost of CO_2 emissions. A study undertaken by Stanford University found that the cost of CO_2 emissions could range between €32 and €197 per tonne [131]. If the lower figure in the range is taken the 'value' of reduction of 1.4 million tonnes of CO_2 emissions due to a reduction in congestion would equate to €44.8 million.

Assumptions: The previous assumption that 5G dynamic data exchange capabilities could be responsible for half of the reduction in congestion is adopted for the value of CO_2 emissions.

5G data capabilities will provide environmental benefits due to a reduction in traffic congestion in smart cities of €22.4 million per annum.

6.12.4. Estimating overall benefits

Previous sections have presented the results of research to estimate the second order benefits from the utilisation of 5G capabilities in smart cities. For transparency all assumptions made in calculating benefits have been presented at the end of each benefits category. Table 11 provides an overview of annual benefits in 2025 and 2030.

Table 11: Annual smart city benefits from 5G in 2025 and 2030

	2025	2030
Economic benefit – congestion reduction	€ 4.0 bn	€ 4.5 bn
Social benefit – accident reduction	€ 4.1 bn	€ 3.6 bn
Environmental benefit – pollution reduction	€ 22.4 m	€ 22.4 m
Total annual benefits	**€8.1 bn**	**€8.1 bn**

6.13. Non-urban environments

Over 77 per cent of the EU's territory is classified as rural[132] and one fifth of the European population is employed in rural areas, but GDP per capita is only 70 per cent of the EU

[127] http://inrix.com/press/2662

[128] 40 hours divided by 364 hours.

[129] 185 million tonnes of CO_2 emissions from traffic in cities multiplied by 11 per cent = 20.4 million tonnes.

[130] http://www.accessmagazine.org/articles/fall-2009/traffic-congestion-greenhouse-gases/

[131] http://news.stanford.edu/news/2015/january/emissions-social-costs-011215.html

[132] EC. 2013. The Common Agriculture Policy (CAP) and agriculture in Europe. http://europa.eu/rapid/press-release_MEMO-13-631_en.htm

average[133]. The rural environment has historically lagged behind its urban counterparts in terms of access to, and exploitation of, fixed and mobile broadband access and the digital technologies that are enabled by broadband access. 5G, through its inherent enabling of multi-tenanting for mixed uses and users could play a considerable role in providing an economically sustainable ICT-enabling infrastructure for the rural environment.

6.13.1. Economic benefits in non-urban environments

One of the key capabilities of 5G is the delivery of *50Mbps everywhere*. This capability, if it is realised, has the potential to transform non-urban areas that have consistently lagged behind urban areas in terms of broadband access quality. In many cases, 5G will be a permanent substitute for higher bandwidth fibre connections that are unlikely to be economically viable for telecommunication providers in remote rural areas.

Fixed broadband coverage in Europe is relatively good, but 90 per cent of homes without fixed broadband coverage are in rural areas[134]. A study for the European Commission[135] of fixed broadband connectivity in EU28 Member States found that five per cent of households, approximately 11 million homes, were unable to receive broadband above a digital inclusion threshold of 4 Mbps or higher.

In 2020, forecasts suggested that nine per cent of households (21 million) would not have access speeds of 21 Mbps or above (conversely 91 per cent would have this level of connectivity)[136]. Provision of the 5G capability to provide 50Mbps everywhere would overcome this inequality. The study estimated that the costs of providing fixed connectivity above 21 Mbps to these households would be €32.5bn.

It is probable that 5G will not be provided everywhere. There is a paucity of information about mobile telecommunications coverage. 3G coverage in EU15 Member States in 2010 was 94 per cent[137]. This is certain to have increased. In the UK Ofcom's 4G auction in 2013 was designed in such a way that one licence has to roll out 4G to cover at least 98 per cent of the UK population (when indoors) by 2017. Other UK mobile operators have indicated they intend to match the 98 per cent coverage for 3G and 4G[138].

Assumptions: It is suggested that 5G could reach coverage levels of 96 per cent in EU28 Member States. We assume coverage geography for 5G (suggested at 96 per cent, 224.6 million households) is the same as for fixed broadband in 2020 (91 per cent, 212.9 million households). 5G is likely to provide mobile connectivity at 20 Mbps or more to five per cent (11.7 million households[139]), of the nine per cent of households unable to attain this level of fixed broadband connectivity in 2020. This equates to 55 per cent of households not able to connect at 20 Mbps.

The cost of providing fixed connectivity to all unconnected households was estimated to be €32.5bn. 55 per cent of this amount might not be required if adequate connectivity could be provided by 5G. This equates to €17.8 billion. Nearly all other benefits in this study have been calculated on a 'per annum' basis. It is suggested that the total cost of €17.8 billion is

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[133] Volonteurope. 2014. Rural Isolation of Citizens in Europe.
[134] http://ec.europa.eu/digital-agenda/en/news/study-broadband-coverage-2012
[135] SMART 2014/0011 - Review of the scope of Universal Service.
[136] Information relates to 2020, but for the purpose of this study the situation is attributed to 2025 so that the potential benefits of 5G in 2025 can be calculated. 5G is not expected to be commercially deployed until after 2020.
[137] IDATE. Broadband Coverage in Europe – Final Report. 2011
[138] http://media.ofcom.org.uk/news/2015/mno-variations/
[139] 'Coverage' describes the ability of household to connect to a broadband network. For many reasons some households choose not to subscribe. Section 6.14 notes that only 83 per cent of EU 28 households subscribed in 2015.

calculated over an eight year time period (there is, on average, a ten year gap between each generation of telecommunications technology). This would equate to €2.2 bn per annum.

5G capabilities will result in fixed broadband deployment cost savings equivalent to €2.2 bn per annum

6.13.2. Social benefits in non-urban environments

The social immobility related to rural environments is a concern for EU28 Member States where citizens may experience isolation through both remoteness from larger population centres and through the effects of sparse populations on the ability to cost-effectively provide services. Rural isolation is manifested by social, labour and educational exclusion as well as the systems (or lack thereof) that reinforce these trends over time.

Broadband connectivity, at an adequate speed, provides numerous advantages in terms of well-being, education and training, health and welfare, economics and employment and community cohesion[140].

Distance learning has historically been a service that has enabled people living at a remove from schools and universities to participate in educational courses. In recent years, a new form of distance education has emerged - Massive online open courses (MOOCs). MOOCs have been embraced by prestigious universities such as Stanford, MIT and the Sorbonne[141], to offer access to an unlimited number of students to certain courses.

MOOCs work because they are able to embrace the economies of scale; the marginal cost of each student can be lower than €1[142]. Depending on the MOOC platform the service will be either totally free to the student or paid for through advertising.

Many people participate in MOOCs as an *intellectual diversion*; 25 million people enrolled on the major MOOC platforms between 2012 and 2015, but only a small percentage completed the courses. However, 72 per cent of respondents to a survey[143] of people who had completed a MOOC reported career benefits and 61 per cent reported educational benefits.

The benefits of online education and many other benefits derived from broadband access have not been estimated. But a 2010 study estimated benefits from connectivity for shopping. Offline UK households were estimated to be forgoing an average consumer saving of €711 per year[144], because they were unable to access information as quickly or benefit from the lower costs offered by online retailers and service providers.

Assumptions: Section 6.13.1 identified that 11.7 million households, which would otherwise be digitally excluded in 2020, would have adequate connectivity due to 5G. The UK study estimated benefits of €711 per consumer. This study takes the more conservative approach in applying this level of benefits to each household (rather than consumers). This equates to savings of €8.3 bn per annum.

5G capabilities will result in benefits from online purchasing of €8.3 bn per annum

[140] Analysys Mason and Tech4i2. 2012. Socio-economic benefits of bandwidth https://ec.europa.eu/digital-agenda/en/news/study-socio-economic-impact-bandwidth-smart-20100033
[141] http://www.paris-sorbonne.fr/MOOC
[142] "The Economics of MOOCs". Gregory M. Saltzman. US National Education Association. 2014. https://www.nea.org/assets/docs/HE/2014_Almanac_Saltzman.pdf
[143] "Who's Benefiting from MOOCs, and Why", Harvard Business Review, September 2015. https://hbr.org/2015/09/whos-benefiting-from-moocs-and-why
[144] UK Race Online 2012. Manifesto for a networked nation. 2010

6.13.3. Environmental benefits

Section 6.12.3 provided an overview of benefits arising from improvements in transport planning and reductions in congestion. A European Commission staff working document highlighted that 37 per cent of road emissions arose from roads in cities[145]. This implies that 63 per cent of emissions arise in non-urban locations.

Using the same methodology and assumptions as section 6.12.3 it is possible to calculate benefits arising from reductions in CO_2 emissions in non-urban areas. Calculations estimated 316 million tonnes of CO_2 emissions arose from congestion in non-urban areas. 5G capabilities should have the same impact on traffic reduction in non-urban areas as they do in cities. 11 per cent of driving time is spent in congestions and Access research[146] estimated that traffic management can reduce CO_2 emissions caused by traffic congestion by seven per cent. This equates to 2.43 million tonnes (316 x 11 per cent x 7 per cent). At €32 per tonne the benefit of congestion reduction is €77.7 million.

Assumptions: The previous assumption that 5G dynamic data exchange capabilities could be responsible for half of the reduction in congestion is adopted for the value of CO_2 emissions.

5G data capabilities will provide environmental benefits due to a reduction in traffic congestion in smart cities of €38.3 million per annum.

6.13.4. Estimating overall benefits

Previous sections have presented the results of research to estimate the second order benefits from the utilisation of 5G capabilities in non-urban areas. For transparency all assumptions made in calculating benefits have been presented at the end of each benefits category. Table 12 provides an overview of annual benefits.

Table 12: Non-urban benefits per annum from 5G

	2025
Economic benefit – fixed broadband reduction	€ 2.2 bn
Social benefit – online purchasing	€ 8.3 bn
Environmental benefit – pollution reduction	€ 38.3 m
Total annual benefits	**€10.5 bn**

[145] European Commission. 2011. Commission staff working document : Accompanying the White Paper - Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. SEC(2011) 391 final. 63% of car emissions relate to travel on non-urban roads and motorways. http://ec.europa.eu/transport/themes/strategies/doc/2011_white_paper/white_paper_working_document_en.pdf

[146] http://www.accessmagazine.org/articles/fall-2009/traffic-congestion-greenhouse-gases/

6.14. Smart homes

There are approximately 214 million households in EU Member States[147]. 83 per cent of EU households (183m) were connected to the internet in 2015[148]. Many analysts believe that the smart home of the near future is likely to contain 30 or more connected devices and sensors[149] with the possibility of 500 smart devices in homes by 2022[150].

Home automation has increased due to improved affordability, increasing simplicity and control through smartphone and tablet connectivity. This automation can cover lighting, temperature control, certain electronics and security devices. Smart homes can act as a multi-functional enabler for economical benefits, environmental improvements, and health/well-being enhancement. The concept of the 'Internet of Things' is closely tied to the popularisation of home automation[151].

6.14.1. Economic benefits in smart homes

5G capabilities will support data exchange with the growing number of sensors and devices in smart homes in the future[152]. Smart meters and other heating, ventilation and air conditioning devices should help to increase energy efficiency. These environmental benefits are considered in section 6.14.3. 5G capabilities and virtual reality are likely to provide social benefits.

A growing area of activity in smart homes is home security in relation to crime, fires and flooding. Growth in sensors is expected to make homes more secure and through drones, panoramic video and sound detection improve security and act as a deterrent to burglars[153]. 5G will play a role in supporting the development of more effective home security and decreasing crime.

Domestic burglary statistics provide an insight to police-recorded offences and housebreaking incidents. Statistics from the United Nations Office on Drugs and Crime department suggests that there were approximately 1.45 million domestic burglaries in EU28 Member States in 2013[154].

The UN does not have data on the cost of burglary, but the UK Home Office estimate that the cost of each domestic burglary is approximately €5,000[155]. These figures suggest that the approximate cost of domestic burglary in 2013 in the EU28 Member States is €7.2 billion.

***Assumptions**:* 5G connectivity, embedded in the home security systems, will provide additional security benefits. 5G capabilities are assumed to provide savings of about ten per cent on the cost of domestic burglary.

5G data capabilities are estimated to reduce the cost of domestic burglary by €720 million per annum

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[147] Eurostat http://ec.europa.eu/eurostat/statistics-explained/index.php/People_in_the_EU_ per centE2 per cent80 per cent93_statistics_on_household_and_family_structures

[148] Eurostat. isoc_bde15b_h.

[149] GSMA. Vision Of Smart Home, The Role Of Mobile In The Home Of The Future. September 2011

[150] Gartner. 2015 State of the Smart Home Report.

[151] Humotronix http://www.humotronix.com/home-automation.html

[152] http://www.huawei.com/minisite/5g/img/5G_Security_Whitepaper_en.pdf

[153] http://www.technologyintegrator.net/article/the-top-four-trends-impacting-the-connected-home-security-market-through-2020/

[154] United Nations Office on Drugs and Crime. UNODC Statistics. https://data.unodc.org/

[155] Mills, H. Skodbo, S. & Blyth, P. Understanding organised crime: estimating the scale and the social and economic costs. Research Report 73. October 2013. Home Office. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/246390/horr73.pdf

6.14.2. Social benefits in smart homes

A key social benefit identified during workshops was the opportunity for medical support and assisted living within smart homes. The proliferation and capability of remote sensors can detect if someone has fallen over or not moved for a certain period of time and an alarm can be raised.

Smart homes will be able to assist with the personal health and wellbeing of residents. Technology will enable the physiological monitoring of occupants (and notification of emergency services in the case of abnormalities), functional uses (automatic lighting, fall reduction, hazard detection), safety monitoring and assistance, social interaction monitoring and assistance (virtual participation in groups) and cognitive (medication reminder).

Smart homes could also have the potential to help older people and persons with disabilities to live independently and be active in society for more years than they are currently able to. Due to demographic changes throughout Europe the balance of active (working) versus inactive people will shift from 5:1 to 2:1 in 2030 and put pressure on both care systems and national budgets. This problem may be lessened by Ambient Assisted Living (AAL), indeed it is the focus of Action 78 of the Digital Agenda[156]. Outcomes from smart home projects looking at AAL such as ROBOCARE[157] have been reported to be positive in extending the length of community residence, enhancing physical and mental health status, delaying the onset of serious health problems and reducing the strain on family and care-givers[158].

5G capabilities are likely to support these activities but very little data exists about the these benefits nor the precise role that 5G will take. Quantitative analysis of these benefits was not therefore examined.

Enhancements to well-being and health from 5G capabilities are also expected. Section 6.7.3 highlighted that 5G capabilities could significantly reduce health insurance premiums, saving €207 million per annum. To avoid double counting this benefit is not duplicated here.

Section 6.7.3 also noted a McKinsey study that estimated IoT based health sensors that monitor health and treat illnesses could provide savings of ten per cent in healthcare costs in developed economies in 2025[159]. These benefits, supported by 5G capabilities, were estimated to be €4.15 billion per annum. Once again to avoid double counting this benefits is not duplicated here.

6.14.3. Environmental benefits in smart homes

5G is projected to enable greater use of smart meters in the home that can create significant monetary savings as heating, ventilation and air conditioning (HVAC) become more efficient. For example the Nest Learning Thermostat[160] is estimated to deliver savings of up to 20 per cent of HVAC use compared to standard assumed behaviour. This is achieved with methods such as automatically turning down the heating when the house is unoccupied. Likewise the

[156] Europa. Digital Agenda - Action 78. https://ec.europa.eu/digital-agenda/en/pillar-vii-ict-enabled-benefits-eu-society/action-78-reinforce-ambient-assisted-living-aal-joint

[157] Cesta, A., Cortellessa, G., Giuliani, M., Iocchi, L., Leone, G, Nardi, D., Pecora, F., Rasconi, R., Scopelliti, M., & Tiberio, L. 2000. The RoboCare Assistive Home Robot: Environment, Features and Evaluation. *The RoboCare Technical Reports.* RC-TR-0906-6

[158] Blaschke, C.M.; Freddolino, P.P. Mullen. E.E. Ageing and technology: A review of the research literature. Br. J. Soc. Work 2009, 39, 641–656

[159] McKinsey 2013. The big data revolution in healthcare. Centre for US Health System Reform Business Technology Office.

[160] Nest Labs. Energy savings from the Nest Learning Thermostat: Energy Bill Analysis Results. February 2015.

lights in a smart home can be turned on and off automatically based on occupancy sensors. Adaptive temperature devices were found to provide an added benefit of greater consumer welfare, as users felt more comfortable in their homes.

Smart homes can also utilise energy management by keeping track of the energy usage of each and every appliance in the house. This will allow the operation of heavy power consuming appliances to be scheduled to take maximum advantage of off peak electric rates[161].

The ability to track energy consumption real time given deployment of 5G enabled IoT and smart meters should help reduce energy consumption. Solutions to enable management through remote control of devices while away form the home can already be undertaken. But a wider ecosystem of solutions and applications supported by 5G networks in the future and improvements in the technology will enable more informative control from a billing and more efficient usage perspective.

Smart meters enable reduction in energy consumption and, as a result, reduction in carbon emission. Section 6.9 highlighted the EU is aiming to replace 80 per cent of electricity meters with smart meters by 2020. The utility vertical provided forecasts for smart meter deployment. There are predicted to be 282 million smart meters in EU Member State in 2025 and this number will increase to 319 million in 2030.

Recent estimates[162] from the UK government funded study indicate that environmental benefits from smart meter use are €1.14bn per annum, this includes carbon-related benefits as well as improved air quality benefits[163]. Carbon-related benefits are estimated to be €1.05bn, while benefit of improved air quality are €92.4m. Analysis identified that the environmental benefits of smart meters in the UK are €21.6 per smart meter (for 53 million meters in the UK)[164].

Assumptions: It is assumed that 5G capabilities embedded in smart meters will provide further environmental benefits of ten per cent due to real-time data exchange and data sharing enhancements. Smart meters with embedded 5G connectivity will thus provide environmental benefits of approximately €2.16 per smart meter.

5G data capabilities will provide environmental benefits in smart homes of about €609 million in 2025 and €689 million in 2030.

6.14.4. Estimating overall benefits

Previous sections have presented the results of research to estimate the second order benefits from the utilisation of 5G capabilities in smart homes. For transparency all assumptions made in calculating benefits have been presented at the end of each benefits category. Table 13 provides an overview of annual benefits.

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[161] Eng. Inji Ibrahim Attia Prof. Dr. Hamdy Ashour. Energy Saving Through Smart Home. The Online Journal on Power and Energy Engineering (OJPEE). Vol. (2) – No. (3).

[162] Smart meter roll-out for domestic and small and medium non-domestic sectors (GB). Impact Assessment (IA). 30/1/2014. URN: 14D/033. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/276656/smart_meter_roll_out_for_the_domestic_and_small_and_medium_and_non_domestic_sectors.pdf

[163] Ofgem. Transition to smart meters. https://www.ofgem.gov.uk/gas/retail-market/metering/transition-smart-meters

[164] ibid. Smart meter roll-out for domestic and small and medium non-domestic sectors

Table 13: Smart home benefits per annum from 5G

	2025
Economic benefit – burglary reduction	€ 720 m
Social benefit – health benefits recorded in section 6.7.3	-
Environmental benefit – pollution reduction	€ 609 m
Total annual benefits	**€1.32 bn**

6.15. Smart workplace

There are 25.6 million active enterprises in EU Member States, they employ 141 million people.

The 2030 Smart Workplace report predicts that by 2030 the workplace will be a dynamic, living entity that transcends the physical boundaries of the office and offers fluid interaction among on-site and off-site knowledge workers. Important characteristics of the smart workplace will include ubiquitous high-speed connectivity and growth through cloud networks. The ubiquitous nature of the smart workplace will go beyond machine-to-machine communications (M2M and IoT). The connectivity of devices, systems, and services in the smart workplace will be enabled by a variety of protocols, domains and applications.

6.15.1. Economic benefits in smart workplaces

Section 6.6.2 provided an overview of the way 5G capabilities can enhance operations in the automotive sector. Many of these benefits will be applicable across all manufacturing and service providing workplaces.

Section 6.6.2 noted that manufacturing assembly operations are comprised combinations of people and programmable robots/machines, supported via semi-automated sensing, actuation, fixing and tooling elements. The location of manufacturing operations and others in the supply chain is always physically distributed, yet interconnected through communications and digital ecosystems. The transport of raw materials to the workplace and the goods and services produced by the workplace are distributed by logistic operations which will be flexibly co-ordinated with those of general (road, rail, sea and air) transport systems throughout a country, EU28 Member States and globally.

5G data exchange capabilities will undoubtedly be the catalyst for further major advances in the globally competitive life cycle of engineering and manufacturing.

Section 6.6.2 assumed a one per cent increase in productivity due to improvements in the supply and value chain. The calculation of economic benefits in the workplace will adopt the same value and methodology.

Gross value added (GVA) of the manufacturing sector in EU28 Member States in 2012 was €1,620 billion[165]. To prevent double counting with automotive impacts it is necessary to

[165] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Value_added,_2012_%28billion_EUR%29_YB15.png

remove GVA generated by the automotive sector, however there is a paucity of data at this level of analysis.

Assumptions: 10.3 per cent of EU manufacturing employment is in the automotive sector[166]. It is reasonable to assume that this could correlate with GVA. It is therefore estimated that automotive GVA is €166.8 billion. Non-automotive manufacturing sector GVA is therefore assumed to be €1,451 billion.

A one per cent improvement in productivity created by 5G capabilities would equate to €14.5 billion per annum.

5G data exchange capabilities will enhance productivity by one per cent per annum creating productivity gains of €14.5 billion per annum.

6.15.2. Social benefits in smart workplaces

5G capabilities, wearable devices and sensors should increase safety at work. In 2012 there were 2.48 million accidents at work in EU28 Member States involving at least four days absence from work and 3,515 fatal accidents[167]. There is a relatively large amount of information about the ways in which connected cars will reduce accidents, but information about accident reduction at work due to technology is very limited. Benefits arising from 5G capabilities in reducing accidents are not therefore calculated.

6.15.3. Environmental benefits in smart workplaces

Section 6.15.1 highlighted the benefits of improved communication in the supply chain supported by sensors and 5G capabilities. McKinsey advocate the use of lean-value-add identification methodologies to map waste creation and energy consumption at every step of their operating processes[168]. These methods can identify where waste is created, how waste can be reduced and value recovery methods to reuse materials previously discarded as waste.

Eurostat provide details about waste generation by different sectors. The manufacturing sector produced 269 billion tonnes of waste in 2012[169].

A European Commission study examined the cost of waste management in the EU[170]. Costs for waste disposal varied considerably between Member States and between waste disposal methods. Composting costs varied between €16 and €73 per tonne, anaerobic digestion varied between €35 and €82 per tonne. Landfill waste disposal varied between €6 and €110 per tonne.

Assumptions: The lowest waste disposal cost is adopted, this was €6 per tonne for landfill. A one per cent reduction in waste creation by 5G capabilities would equate to a reduction of 2.69 billion tonnes. This equates to a saving of €16.1 billion per annum.

5G capabilities will reduce waste production by one per cent per annum creating waste disposal savings of €16.1 billion per annum.

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[166] https://www.acea.be/uploads/statistic_documents/POCKET_GUIDE_2014_32.pdf
[167] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Number_of_non-fatal_and_fatal_accidents_at_work,_2012_%28%C2%B9%29_%28persons%29_YB15.png
[168] http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/manufacturing-resource-productivity
[169] http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics
[170] ec.europa.eu/environment/waste/studies/pdf/eucostwaste.pdf

6.15.4. Estimating overall benefits

Previous sections have presented the results of research to estimate the second order benefits from the utilisation of 5G capabilities in the workplace. For transparency all assumptions made in calculating benefits have been presented at the end of each benefits category. Table 13 provides an overview of annual benefits. The benefits for the smart workplace are relatively large in comparison with the other environments. This is predominantly because they calculate the productivity benefits and environmental savings for manufacturing industry[171] in EU Members States.

Table 14: Workplace benefits per annum from 5G

	2025
Economic benefit – productivity improvements	€ 14.5 bn
Social benefit – none forecast	-
Environmental benefit – waste reduction	€ 16.1 bn
Total annual benefits	**€ 30.6 bn**

6.16. Conclusion: Environment forecasts

The four preceding sections have provided quantitative estimates of the benefits of 5G capabilities in the four key environments examined in this study. It was highlighted previously that it is important to emphasise it would be unwise to place great significance on any individual forecast. Instead it was emphasised that the most significant insights will arise from examining the relative differences in benefits between environments. Table 15 provides a comparison of per annum benefits in the four environments in 2025[172].

Table 15 Comparison of benefits per annum from 5G capabilities in four environments in 2025

Environment Benefits	Smart City (€ mn)	Non-urban (€ mn)	Smart Home (€ mn)	Workplace (€ mn)	Total (€ mn)
Economic	4,000	2,200	720	14,500	**21,420**
Social	4,100	8,300	-	-	**12,400**
Environmental	22	38	609	16,100	**16,770**
Total	**8,120**	**10,540**	**1,330**	**30,600**	**50,590**

Totals may not correspond due to rounding

[171] With the exception of productivity benefits for automotive, which were calculated in section 6.6.

[172] For many environments only a single per annum calculation was possible. 2025 is selected as the year for comparison since these nearer-term forecasts are likely to be a little more reliable than the longer-term 2030 forecasts. However, benefits per annum in 2030 are broadly similar to those in 2025.

In total it is estimated that benefits of €50.6 billion will arise from second order benefits in the four environments examined by the study. This figure is roughly half (53 per cent) of the €95.9 billion identified for the first order benefits in verticals.

Within the four environments benefits are relatively large across all three categories (economic, social and environmental). It should also be remembered that €11.4 billion of benefits from reductions in household energy consumption were included as consumer benefits from 5G capabilities in the utilities vertical and are excluded here to avoid double counting.

The highest level of benefits (€30.6 bn) across the four environments arises in the workplace where 5G capabilities are forecast to increase the productivity and reduce waste from businesses. In the other three environments benefits are relatively small, totalling €20.0 bn. But it is notable that all these benefits arise to householders and/or society.

6.17. Conclusion

This concluding section provides an overview of 5G costs, benefits and impacts presented in the preceding forecasts in this chapter.

Section 6.3 provided a forecast of the costs of 5G deployment in EU28 Member States. Input-output analysis estimated the additional Type I effects that will arise from trickle-down impacts of investment in 5G deployment. An overview of these costs and benefits is provided in Table 16.

Table 16 5G costs and input-output effects

5G deployment costs	**€ 56.6 bn**
Type I output effects	€ 141.8 bn
Type I employment effects	2,394,000 jobs

Source: Section 6.3

Table 17 provides an overview of the quantitative forecasts of the annual benefits for verticals and environments arising from the utilisation of 5G capabilities described in earlier parts of this chapter. As noted earlier in some verticals and environments forecasts were made for 2025 and 2030 in others it was only possible to appropriate to calculate annual benefits for 2025 and thereafter.

Table 17 Annual vertical and environmental benefits in 2025

	2025	Total
Verticals benefits per annum		**€ 62.5 bn**
Automotive[a]	€ 42.2 bn	
Healthcare[b]	€ 5.5 bn	
Transport[c]	€ 8.3 bn	
Utilities[d]	€ 6.5 bn	

Environmental benefits per annum		**€ 50.6 bn**
Smart cities[e]	€ 8.1 bn	
Non-urban areas[f]	€ 10.5 bn	
Smart homes[g]	€ 1.3 bn	
Smart workplaces[h]	€ 30.6 bn	
Total annual benefits	**€113.1 bn**	

Sources: Vertical benefits [a] Section 6.6, [b] 6.7, [c] 6.8, [d] 6.9, environmental benefits [e] 6.12, [f] 6.13, [g] 6.14 and [h] 6.15.

Total deployment costs are estimated to be approximately €56.6 bn. The benefits of 5G capabilities in four key verticals and four environments are forecast to be €113.1 billion per annum in 2025. As noted previously it would be unwise to place great significance on individual forecasts. The most significant insights arise from examining relative differences within and between verticals and environments.

Second order benefits in the four environments are significant – €50.6 bn per annum. But these benefits are slightly lower than those for the verticals (€62.5 bn per annum).

Within the verticals automotive had the highest level of forecast benefits (€42.2 bn), significantly more than for the other verticals. Benefits from transport (€8.3 bn), healthcare (€5.5 bn) and utilities (€6.5 bn) verticals were considerably lower.

Table 10 provided a breakdown of benefits in the four verticals it was notable that within the automotive vertical benefits to businesses within the sector (the strategic and operational benefits - €31.6 bn) were similar to the benefits arising to consumers and third parties (€30.9 bn) that use the vehicles and data provided by the industry. In all other verticals (except utilities) the strategic and operational benefits to businesses in the industry are greater than those for consumers and third parties.

Table 17 shows that benefits from second order environmental forecasts are roughly half (€50.6 bn; 53 per cent) of the €95.9 billion identified for the first order benefits in verticals. Table 15 revealed that the highest level of benefits (€30.6 bn) across the four environments arises in the workplace where 5G capabilities are forecast to increase the productivity and reduce waste from businesses.

Table 10 and Table 15 both identified benefits accruing to businesses[173], consumers/ society[174] and third parties[175]. Table 19 provides an overview of impact of 5G capabilities on these three groups of beneficiaries.

Table 18 Beneficiaries of the vertical and environmental impacts

Beneficiaries

[173] Business benefits are defined as strategic and operational benefits in the four verticals totaling €31.6 bn and benefits in the workplace environment (€30.6 bn). Thus in total 5G capability benefits to businesses are calculated to be €62.2 bn.

[174] Consumer benefits are defined as consumer benefits in the four verticals totaling €17.1 bn and benefits in the smart, city, non-urban and smart home environments (€20.0 bn). Thus in total 5G capability benefits to consumers and society are calculated to be €37.1 bn.

[175] Third party benefits could arise for public administrations or new public or private sector businesses in the four verticals. These benefits were estimated to total €13.8 bn.

Businesses	€ 62.2 bn
Consumers / society	€ 37.1 bn
Administrators and/or third parties	€ 13.8 bn
Total annual benefits	**€113.1 bn**

Businesses are forecast to obtain just over half of the total benefits (€62.2 bn; 55 per cent) predicted by this study. Since these benefits will arise to the groups introducing 5G capabilities there should be little stimulus required to promote the adoption of the new wireless capabilities so long as returns on investment are beneficial.

Benefits for consumers/society and administrators/third parties might, in some cases, be harder to achieve because several (but not all) require the introduction of 5G capabilities by business and the two groups benefit due to trickle down benefits and/or the exchange of data, particularly telematics data. Achievement of these benefits might require assistance and support from government and regulators.

If one simply compares benefits to businesses (€62.2 bn) and consumers (€37.1 bn) (ignoring benefits to administrators and/or third parties which could arise to public or private sectors) it is evident that businesses are the largest beneficiaries from the introduction of 5G capabilities - 63 per cent and 37 per cent respectively. However, as noted previously this comparison only focuses on four verticals. The workplace environment investigation provides a broad insight to manufacturing industry as whole, but more benefits might arise in other verticals. It is not envisaged that too many additional benefits will be found for consumers and society.

7. 5G Spectrum analysis

7.1. Introduction

In this section we address the spectrum challenges and spectrum needs of 5G based on the outcomes of work undertaken in preceding tasks. The demand drivers were derived from the four main vertical sectors discussed earlier in the report and based on the 5G communities' aspiration of achieving an "always sufficient capacity" user experience. The spectrum analysis considers how 5G technology will use existing mobile spectrum and need access to new mmWave[176] spectrum bands, to meet the wide and varying demand from the vertical users.

We conducted a sensitivity analysis based on different environments and sharing scenarios to provide a holistic view of the factors which will drive EU-wide 5G spectrum requirements.

More specifically, we draw on the outcomes from the stakeholder workshops to derive the challenging use cases and associated applications to quantify the spectrum requirements and how the diverse needs of the verticals can be satisfied in those cases. We use the 'day in the life' stories for each of the four verticals (Automotive, Healthcare, Transport and Utilities) that describe the main challenging applications that will drive spectrum demand. The spectrum requirements are estimated for these cases and then recalculated depending on the different type of spectrum sharing that might be possible in future for 5G service providers.

The outcome of the analysis informs the recommendations for future spectrum policy that will need to be in place to support these potential use cases and applications within the vertical sectors considered.

7.2. Spectrum overview: current and future needs and sharing

7.2.1. Spectrum allocations and needs in future

The current mobile spectrum situation in Europe is governed by established EC Spectrum Decisions[177] and standardised mobile frequencies, typically below 4 GHz are utilised. There are a number of 'traditional' mobile frequency bands; 900 MHz and 1800 MHz that have been in use since the commencement of GSM in the early 1990's and 2100 MHz since the commencement of 3G in 2000. In the last five to six years, the regulators within the EU Member State countries have been awarding new spectrum to Mobile Network Operators (MNOs) for 4G services in the 800 MHz and 2600 MHz bands.

These five core mobile bands are the most common mobile bands used by MNOs today and are now typically used for delivering mobile broadband to consumers and businesses. In some countries the existing mobile technologies have been refarmed such as GSM technology to UMTS in the 900 MHz band and in the case of 1800 MHz this has been refarmed from GSM to LTE in some countries (this band skipped the 3G mobile generation).

The quantity of existing mobile spectrum across the bands equates to 590 MHz as shown in Table 19 below. In all but one of the bands (2600 MHz TDD) there is an uplink and downlink allocation. In 2600 MHz TDD there is a single allocation of 50 MHz which splits uplink and downlink in the time domain.

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[176] Millimetre Wave – refers to frequency bands typically above 30 GHz

[177] Radio Spectrum Decisions EC, https://ec.europa.eu/digital-agenda/en/news/radio-spectrum-decisions

Table 19: Mobile frequency bands assigned and actively used across EU28

Band (MHz)	UL (MHz)	DL (MHz)	Total (MHz)
800	30	30	60
900	35	35	70
1800	75	75	150
2100	60	60	120
2600 (FDD)	70	70	140
2600 (TDD)	50		50
Total			**590**

The quantity of spectrum shown in Table 19 above is well aligned with a study conducted by Plum consulting[178] which found that most of the EU countries had quantities of mobile spectrum assigned, ranging between 250 MHz and above 600 MHz.

However, this amount of spectrum is by far not sufficient to meet future demand growth from users/verticals and support the 5G vision. In order to address future spectrum requirements and demand for mobile broadband, the European Commission, by way of Decision (243/2012/EU)[179], set a target for member states to make available 1200 MHz for mobile broadband by 2015. In contrast, the GSMA's spectrum inventory estimates[180] were higher compared to the Commission as it projected a demand of 1600 – 1800 MHz of Sub-6 GHz spectrum for mobile broadband by 2020 and that there would be a shortfall of 300 MHz to 800 MHz of Sub-6 GHz spectrum across Europe.

It is not yet clear how much spectrum will be needed to support future traffic growth from public users and in particular from the different verticals and their own mix of services and applications (as identified in the 5G vision). This additional spectrum needed to meet the capacity growth will most likely come from bands above 6 GHz, specifically from a number of bands in the range of 24 GHz to 86 GHz as included in the WRC-19 agenda. The propagation characteristics at these frequencies are limited by range, due to atmospheric attenuation, reflections, low penetration through walls and multipath. However, recent studies[181,182,183] have indicated that these bands will be used either indoors or for hotspot cells in 5G, with ranges up to around 200m.

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178 Harmonised spectrum for mobile services in ASEAN and South Asia: an international comparison, Plum Consulting, August 2013, http://www.plumconsulting.co.uk/pdfs/Plum_Jan2014_harmonised_spectrum_for_mobile_asean_south_asia.pdf

179 Decision No 243/2012/EU of the European Parliament and of the Council of 14 March 2012 establishing a multiannual radio spectrum policy programme

180 GSMA Position Paper on the European Commission Spectrum Inventory Report, GSMA, Nov 2014, http://www.gsma.com/spectrum/gsma-responds-to-european-commission-spectrum-inventory-report/

181 A Survey of Millimeter Wave (mmWave) Communications for 5G: Opportunities and Challenges, Yong Niu, Yong Li, Member, IEEE, Depeng Jin, Member, IEEE, Li Su, and Athanasios V. Vasilakos, Senior Member, IEEE, Feb 2015

182 5G Candidate Band Study. Study on the Suitability of Potential Candidate Frequency Bands above 6GHz for Future 5G Mobile Broadband System, Quotient Associates, March 2015, http://stakeholders.ofcom.org.uk/binaries/consultations/above-6ghz/qa-report.pdf

183 Path Loss Models for 5G Millimeter Wave Propagation Channels in Urban Microcells, George R. MacCartney Jr., Junhong Zhang, Shuai Nie, and Theodore S. Rappaport NYU Wireless Polytechnic Institute of New York

Another source of additional spectrum for 5G may come from the public sector within member state countries. In the UK, for example, the Government recently published a report[184] identifying a number of bands used by the public sector (e.g. aeronautical, emergency services) that could either be released to the market or identified for sharing. In the report, UK Government proposes to identify 750 MHz of spectrum for release or sharing below 10 GHz by 2022.

More details on current and future spectrum needs and related considerations can be found in section 3 of the annex.

7.2.2. Spectrum sharing approaches

Mobile spectrum currently deployed by mobile operators is authorised by exclusive licensing mechanisms that are awarded and licensed by the national regulator. The reason for using exclusive licensing as a model is that it ensures there is a sufficient number of spectrum blocks available for the market, creates competition and provides security of tenure and protection of assets between operators.

The 5G vision however includes a network and spectrum sharing element. A common approach to spectrum sharing is access to spectrum on a licence-exempt basis in which devices can freely access the spectrum (within defined operational, technical and compliance limits) and coexist in the same spectrum band at the same time in the same location. There are a number of alternative, more cooperative approaches for spectrum sharing including:

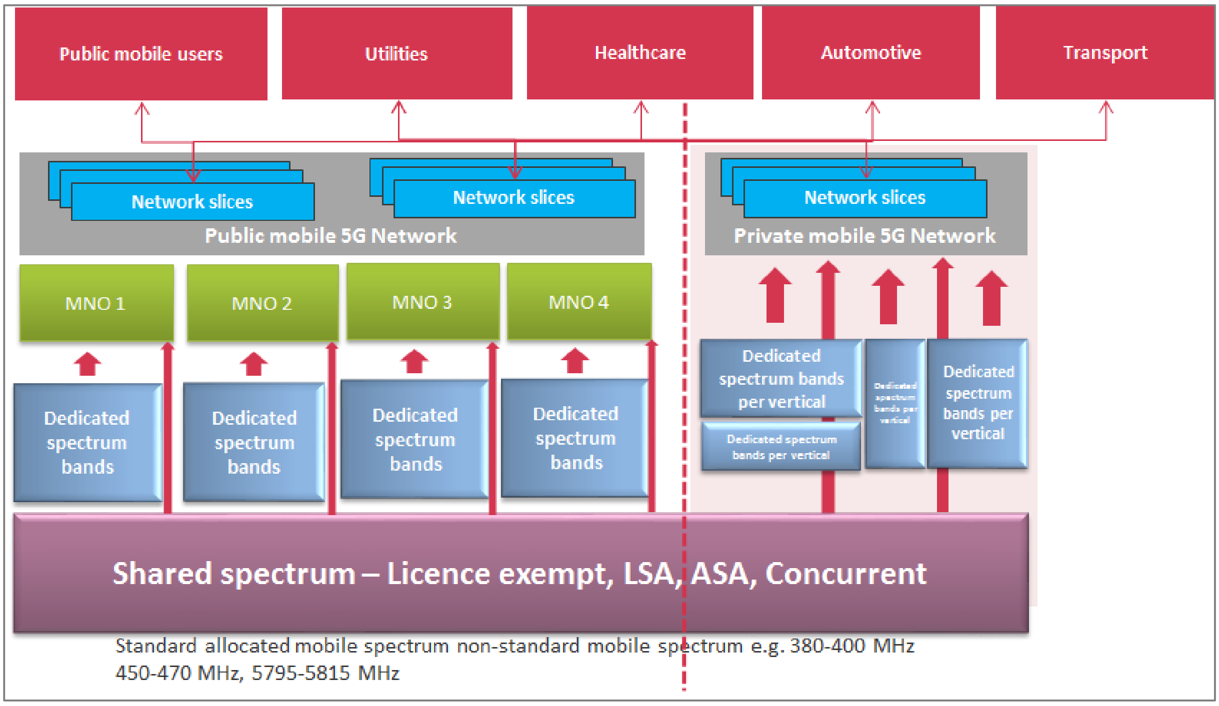
- **Concurrent shared access** – This approach enables multiple operators to share access to the same portion of spectrum but in a coordinated and managed way. This may include geographical access for example.
- **Licensed shared access** – This approach enables incumbent licensed users to permit access to spectrum by way of a sub-licence thus enabling access to licensed spectrum but within a structured sharing framework.
- **Authorised shared access** – This approach enables dynamic use of spectrum at any time and any location where it is unused by the incumbent. The shared user must not cause interference to the incumbent, must be authorised by way of automated or geolocation database access.
- **Licence-exempt access** – This approach enables generally authorised access to spectrum by devices that must be compliant with industry standards for low emissions and types of spectrum access. Devices must all share the same spectrum and are not protected from interference.

We consider each of these sharing approaches to spectrum access for the different use case scenarios to determine the variance in impact to the spectrum estimates.

The diagram below provides an overview of the key elements and players (service providers, networks and spectrum) that demand the services and network access such as public users and the verticals and those that supply the services and access to spectrum such as the mobile operators. It highlights the interactions between the players and where the spectrum challenges and needs may arise within 5G.

University, Dec 2013, http://nyuwireless.com/wp-content/uploads/2013/12/Path-Loss-Models-for-5G-Millimeter-Wave-Propagation-Channels-in-Urban-Microcells.pdf

[184] "Enabling UK growth: Public Sector Spectrum Release Programme", UK Government Investments, April 2016 https://www.gov.uk/government/publications/enabling-uk-growth-public-sector-spectrum-release-programme



Source: Real Wireless

Figure 11: Actors involved in the demand (verticals) and supply (MNOs) for access to spectrum for 5G services

Figure 11 shows the current approach to spectrum access where each of the MNOs have their own spectrum, but in some cases the verticals also hold their own spectrum. The other potential approach that may emerge in future is to share spectrum amongst the operators and verticals, or between public mobile and private mobile networks.

More on current and future spectrum needs and considerations around spectrum can be found in section 3.2 the annex.

7.3. Assumptions and spectrum analysis methodology

We have made a number of general assumptions in order to conduct the spectrum analysis based on use cases, environments and applications that will drive the spectrum requirements in each of the specific situations. Details of the parameter assumptions and associated values can be found in section 3 of the annex.

To create challenging scenarios from a spectrum requirement point of view, we use the ”day in the life of … stories” to characterize the specific demand and traffic aspects that significantly determine the large quantities of spectrum.

In the early days of mobile broadband, mobile data traffic growth forecasts were vastly underestimated such as those from previous ITU[185] and ECC studies. More recently forecasts such as those from Cisco VNI[186] have become more granular and focus on average traffic generated by devices (MB/month) and mobile data CAGR. Given the historic

[185] REPORT ITU-R M.2072, World mobile telecommunication market forecast, 2005

[186] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015–2020 White Paper, Cisco, Feb 2016

trend of underestimated future traffic growth[187], which can lead to underestimated spectrum requirements, we consider a highly demanding use case to drive challenging spectrum.

We have taken a high level approach to the spectrum requirements calculations which considers the main inputs:

- Total number of devices per km$^{2;}$
- Operating data rate/usage rate of the devices;
- Spectral efficiency.

The devices are proportionally assigned to three frequency sub-ranges (Sub-1 GHz, 1 – 6 GHz and above 6 GHz).

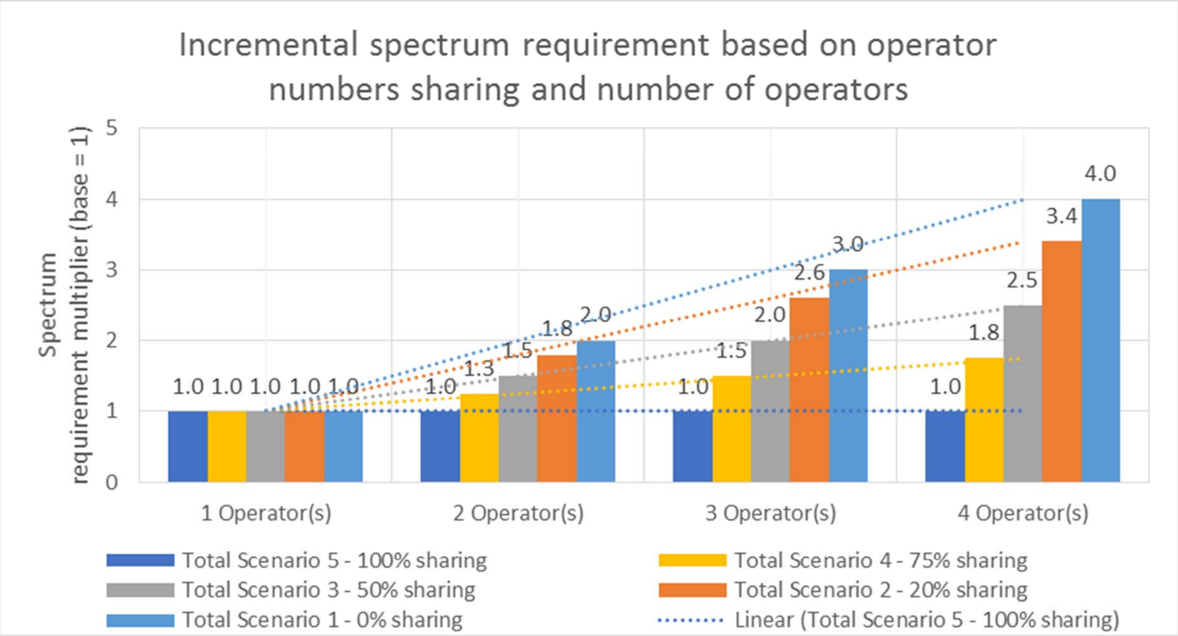
The spectrum estimates within each sub-range are calculated by multiplying the number of devices by their respective occupancy of the spectrum in bps according to the scenario and divided by the assumed spectral efficiency of the technology used for each device type. The results are added across all device types to yield a total spectrum estimate for each use case. Spectrum will be allocated in an appropriate split to the sub-bands (see section 3 of the annex for more detail).

Once we have calculated the theoretical total (user driven) demand estimates, we analyse the spectrum needs based on five different spectrum sharing scenarios assuming 4 operators (networks). The associated proportion of spectrum sharing in each frequency sub-range will be calculated as per the assumptions in Table 7 in the section 3.4.1 of the annex.

The different approaches of 100 per cent sharing (fully shared) versus 0 per cent sharing (exclusive licensing) have a very high impact on the total demand to support either type of operation. In a fully shared (100 per cent sharing) environment, the spectrum needed is equal to the total use case driven demand estimate. In an exclusive licencing environment however, the spectrum needed is equal to the total use case driven demand estimate multiplied by the number of operators in the environment. This approach was taken to understand the minimum and maximum spectrum requirement figures.

Beside the 0 per cent and 100 per cent sharing scenario, spectrum requirement figures are also given for 20 per cent, 50 per cent and 75 per cent spectrum sharing scenarios. The impact of the different sharing scenarios and number of operators in absolute numbers is demonstrated in Figure 12 below.

[187] “CEPT ECC PT1 - Internal Report on Mobile Broadband Landscape”, ECC PT1, 2011



Source: Real Wireless

Figure 12: Sharing scenarios and absolute spectrum number per type of allocation

In an ideal spectrum sharing environment (100 per cent sharing), the incremental spectrum requirement factor would be “1”, representing the total user driven spectrum requirement in an area as per Figure 12. The total spectrum requirement increases with increasing number of operators and decreasing amount of sharing.

It should be noted that there is another approach that is not calculated in detail in this study, but it is worth mentioning. This approach considers a more practical assumption of over-provisioning. Over-provisioning means that operators have a little more spectrum than they really need. In the UK, operators have 29.5 per cent more spectrum than the use in 2015[188]. This means that 29.5 per cent would have to be added to any spectrum requirement calculated as per the methodology demonstrated in Figure 12. More detailed assumptions and methodology can be found in section 3 of the annex.

7.4. Use cases based spectrum requirements analysis

7.4.1. Introduction

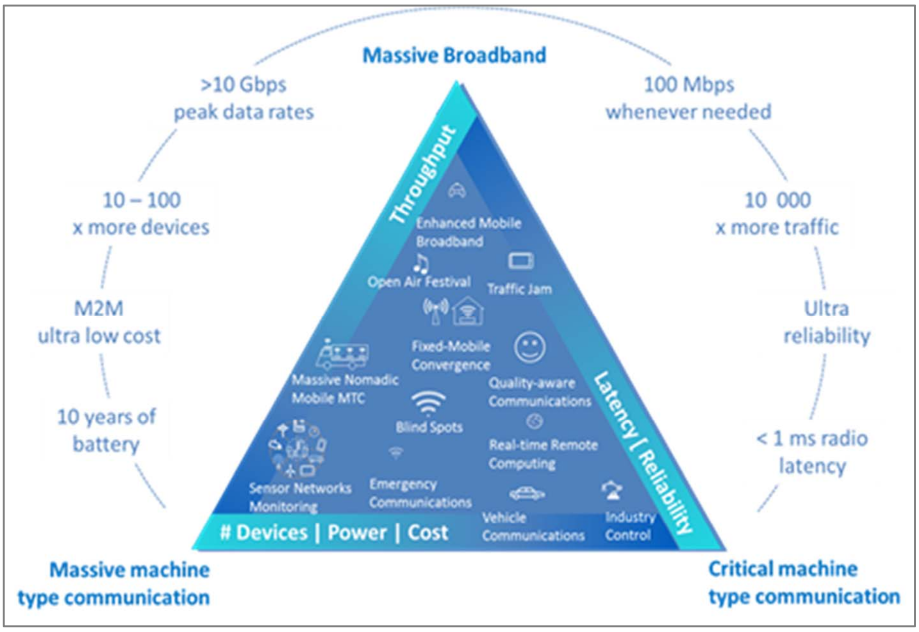
The spectrum requirements estimations are based on the “day in the life” stories developed from the two workshops and public consultation. The specific vertical industry’s that have been assessed - health, utilities, transport and automotive – are seen as key sectors driving the requirements for 5G. The environments - smart city, rural, smart home, smart office – provide a necessary backdrop to describe the operation of devices including the different types, total numbers, user behavior and technical characteristics.

The “day in the life” stories describe in detail how normal day-to-day activities in the future make use of advanced 5G wireless technology. The specific demand values are presented in the Annex in section 3.5 which include number of devices and respective data rates for those

[188] Real Wireless calculations based on 2015 EE report http://www.4g.co.uk/4g-frequencies-uk-need-know/

devices. We provide some example values in each use case that are the main drivers for spectrum needs.

The use cases developed to calculate the spectrum estimates take into account numerous, standard routines such as waking up, driving your car to the station and taking a train or bus to work and in each instance technology has created a completely hassle free, highly efficient, low carbon and cost effective environment to live and work. Figure 13 below shows the high level approach for the alignment of the spectrum estimation with the ITU use case categories. The three main use case categories consist of enhanced mobile broadband, massive machine type communication and critical, ultra-reliable and low latency communications.



Source: 5G PPP NORMA Project[189]

Figure 13: The broad scope of 5G use cases

7.4.2. Use Case 1: Transport and automotive driven spectrum on a motorway

The following environment use case is based on two very high data rate use types within the transport and automotive verticals. The case is taken from the transport “day in the life” story which can be found in section 1 of the annex and was derived from the workshop outputs. This use case is intended to drive the spectrum requirements to an extreme level to understand the impact on spectrum in a very challenging environment.

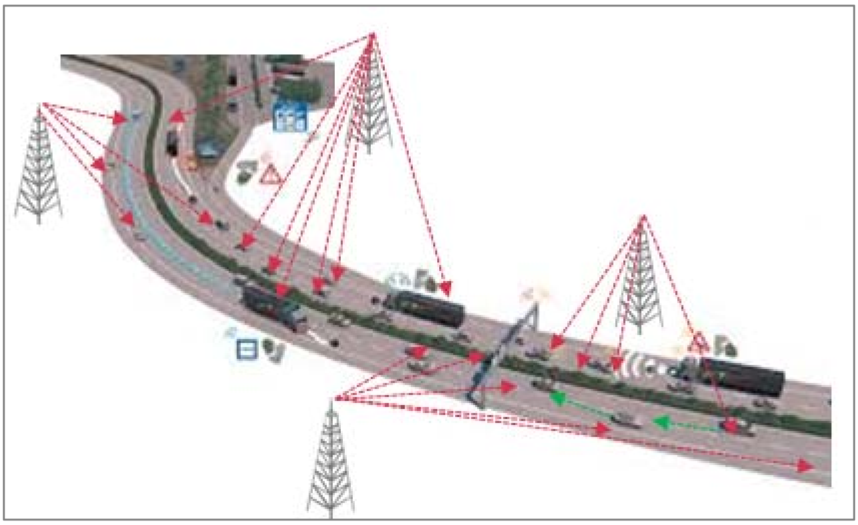
In particular, the general integration of pervasive video and new user interface methods into everyday transport experience in which users have an immersed video experience wearing augmented reality (AR) glasses, head up display on the windscreen and on board video. These devices all support the different media experiences such as entertainment, car video mode and virtual meetings.

There is also consistently very high data rates experienced in all environments and modes of travel which occurs on the train, bus and in vehicle and thus across urban, suburban and rural areas.

[189] 5G PPP Project NORMA https://5gnorma.5g-ppp.eu/dissemination/conference-papers-and-presentations/

This specific scenario considers 1000 vehicles along a 1km stretch of motorway, most of which (75%) are using high rate (4K/UHD) and pervasive video applications and devices operating simultaneously in vehicles. The usage in vehicles on a busy motorway within a Smart City with traffic building up due to an accident, is estimated to be 215 Mbps per vehicle as described in the transport 'day in the life of' story. The other part of this use case incorporates the automotive applications such as the in vehicle monitoring sensors for inter vehicle and vehicle to vehicle communications. Vehicles will become personalized, offering predictive and accurate information and services to occupants which requires continuous, secure, reliable and real time connectivity to the infrastructure.

Figure 14 below provides a high level overview of the connectivity between the communication infrastructure and the vehicles and between the vehicles themselves. This highlights the challenges based on the number of communications links that would need to be supported for such a scenario.



Source: Real Wireless

Figure 14: Incident on a motorway with vehicle communications in a smart city

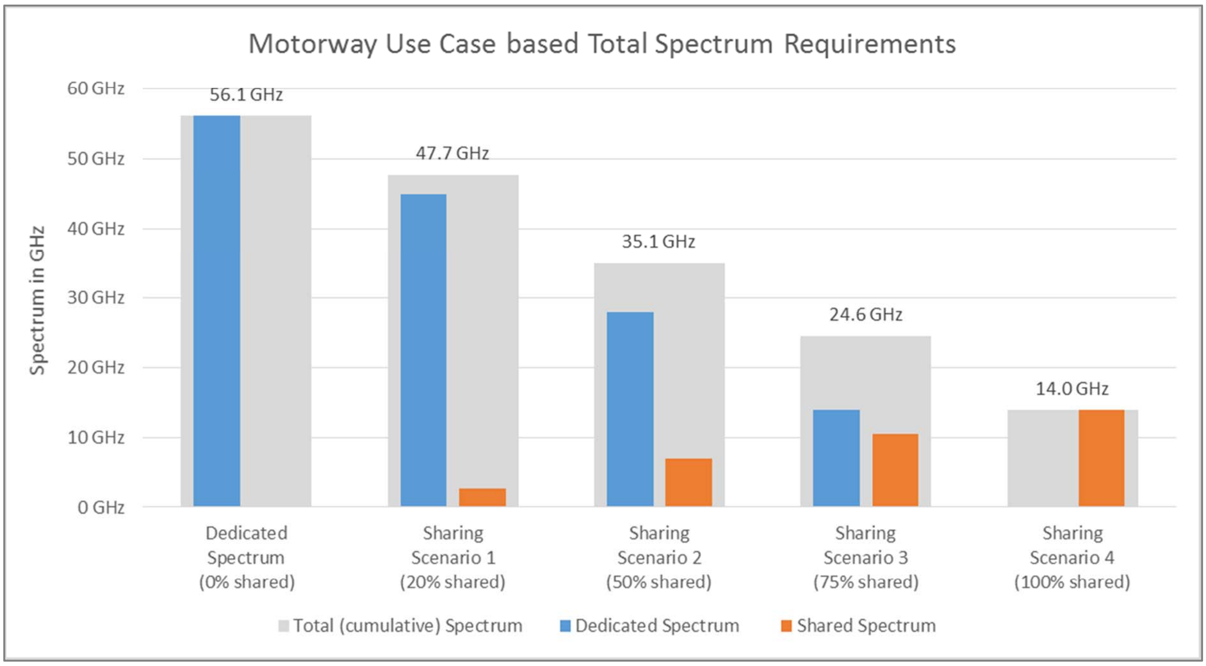
The spectrum requirement was calculated as per the assumptions and parameters applicable to this environment as well as the assumptions and methodology explained in section 7.3. Table 20 below shows how the total quantity of spectrum varies depending on the different sharing scenarios that may emerge by 2025.

Table 20: Total spectrum requirements relative to percentage of spectrum sharing scenarios based on theoretical model

Spectrum sharing scenario	Total spectrum needed (GHz)
Scenario 1: 0% sharing	56.1
Scenario 2: 20% sharing	47.7

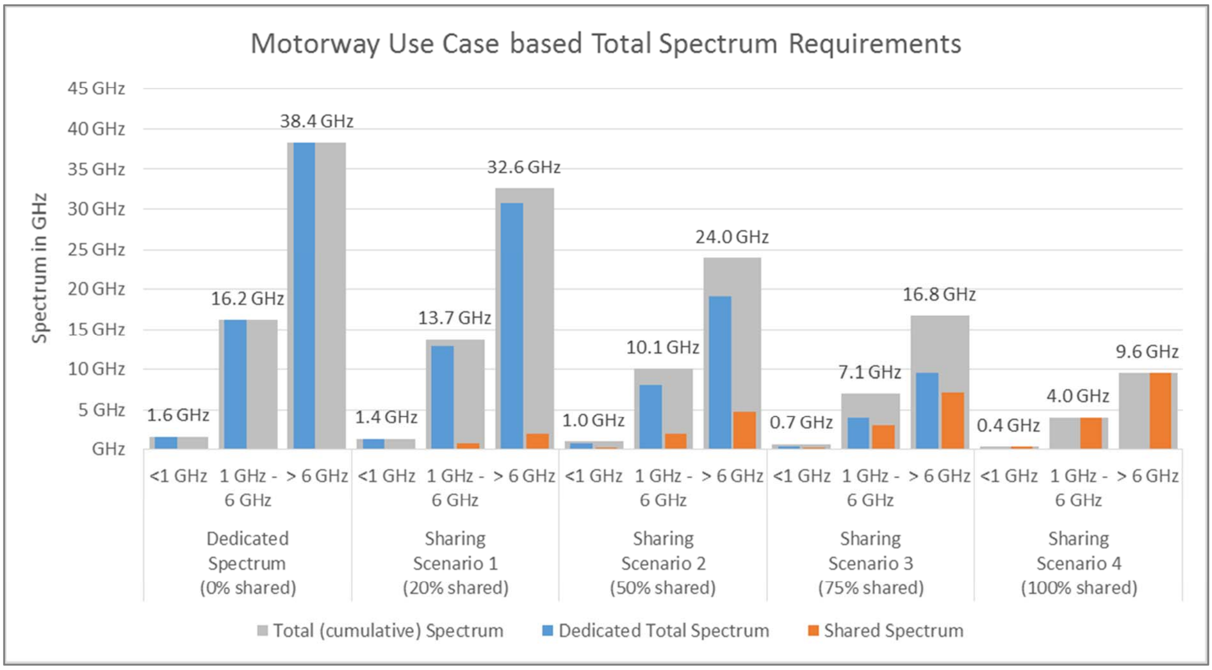
Scenario 3: 50% sharing	35.1
Scenario 4: 75% sharing	24.5
Scenario 5: 100% sharing	14.0

In the figures below we show two different graphs representing the quantity of spectrum needed for each sharing scenario for the traffic jam on a motorway use case. In Figure 15, it shows the total spectrum requirements for each scenario split by the quantity of dedicated and shared spectrum in each case. Figure 16 breaks the sharing scenarios down further into the frequency sub-ranges to show the quantity of dedicated and shared spectrum for each sub-range per scenario.



Source: Real Wireless. Please note that figures in the graph above have been rounded to 1 decimal place.

Figure 15: Total spectrum requirements for motorway use case



Source: Real Wireless. Please note that figures in the graph above have been rounded to 1 decimal place.

Figure 16: Total spectrum requirements per frequency range for motorway use case

We calculated the total quantities of shared spectrum based on the approach described in section 3.4 of the annex. We observe that the all-exclusive case requires the largest quantity of spectrum (56.1 GHz) because each individual of the four-service provider (x4) requires approximately the same amount of spectrum estimated for the given scenario. The all (100 per cent) shared case has the lowest spectrum requirement with a total of 14.0 GHz of spectrum. If by 2025 full sharing is not possible then a mix of dedicated and MNO sharing with the Verticals helps to minimise the total quantity of required spectrum compared to the all dedicated case.

The option of sharing spectrum becomes a benefit to service providers as the proportion of shared spectrum increases. Total required spectrum reduces however, for each frequency range where there is a limit to the quantity of available spectrum in each range. Therefore, this result shows that some sharing will be necessary in Sub-1 GHz band because MNOs will likely only have access to no more than 75 per cent of the spectrum in this sub-range by 2025 and therefore sharing with other operators and new MVNOs will be required to serve the users in this transport scenario below 1 GHz.

In the case of the 1-6 GHz range, although more spectrum is available compared to Sub-1 GHz, not all of the spectrum will be available for mobile use (in 2015 there was approximately 700 MHz of spectrum allocated to mobile between 1 GHz and 6 GHz) and therefore sharing will be necessary to meet the demand for this motorway use case. For example, even if 100 per cent of spectrum is shared in this frequency range, there would already be 4 GHz of spectrum in total needed compared to 700 MHz available to mobile operators in 2016.

In the mmWave bands above 6 GHz, the requirement for sharing is reduced assuming the majority of the spectrum proposed at WRC becomes available for 5G. There is also an argument that the existing approach to licensing would not change in future and exclusive licensing would remain adopted in the mmWave bands. In this use case exclusive licensing would significantly increase the quantities of spectrum required to unrealistic levels. Therefore shared spectrum in the mmWave bands will contribute to improved spectrum efficiency, enabling these challenging corner cases to be met and supporting the economic benefits proposed by 5G networks.

7.4.3. Use Case 2: Utility driven spectrum based on a power company

The following environment use case is based on a mix of massive machine type communications, critical and reliable connectivity and wide area coverage to ensure connectivity in remote and rural locations. The case is taken from the utilities “day in the life” story which can be found in section 1 of the annex. This use case is intended to drive the spectrum requirements based on the requirement to support massive machine type communications and wideband applications such as CCTV.

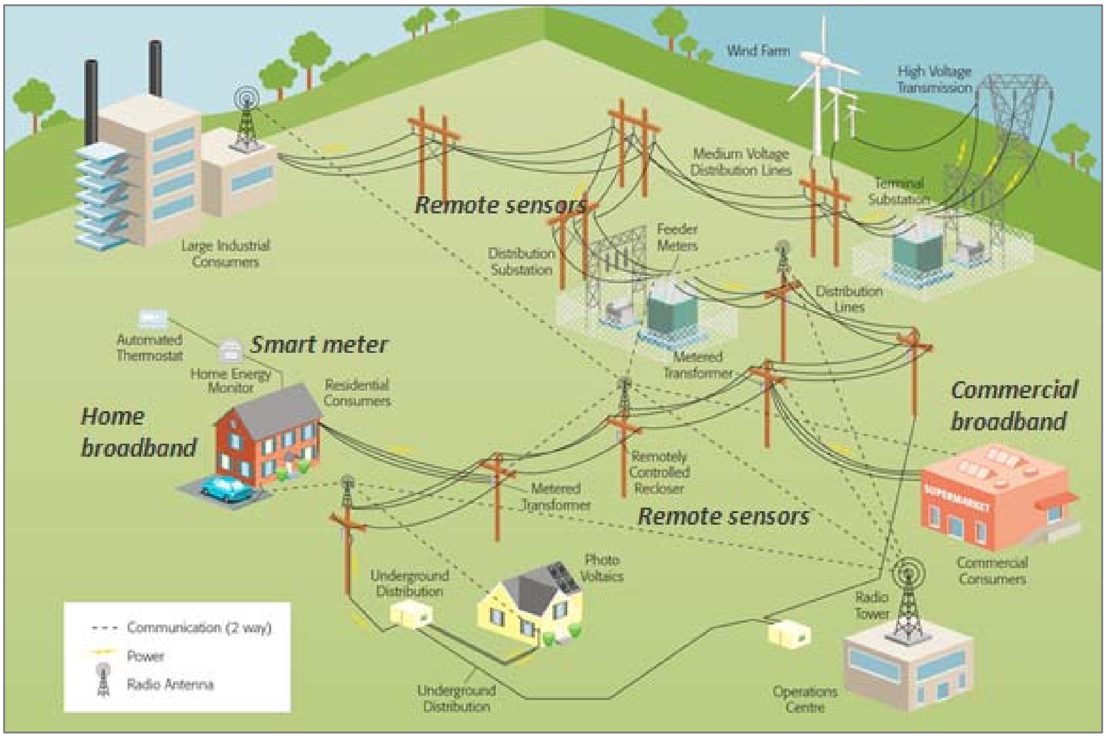
The use case considers the **extensive remote sensor monitoring, smart meter, smart grid and wide area connectivity which enables fast, reliable and real time energy consumption, supply and management.** This application requires network connectivity to a very large number of machine type devices that are located in homes and business premises in a mix of rural, suburban and urban (1 million in the dense urban environment) locations. The operations of the utilities sector depend on large volumes of remote nodes and sensors to monitor status and conditions of equipment, apparatus and energy infrastructure that is critical for the normal operation of power stations and other utility compounds. Such data is processed to give a high level network overview (KPIS) and this data is used for augmented reality displays in the control room of the utility company.

The use case also considers **low latency, highly reliable and available networks** to support the critical national infrastructure requirements within the utilities environment**.**

There is a need for **consistently very high data rates in all environments, which support deployments in smart cities, remote and rural locations.** The specific application is UHD CCTV that provides rich and detailed live video content (utilising speeds of up to 15 Mbps) of some operating assets, although these are currently rare in most utility industries.

This specific scenario considers a range of different applications that operate within a massive machine type network supporting the operations of a utility. A very large number of devices accessing the network as described in the utilities ‘day in the life of’ story. In addition, high demand CCTV cameras strategically located relative to the utilities distributed assets.

Figure 17 below provides a high level overview of the connectivity between the communication infrastructure and the assets and devices used and operated within the utilities environment. This highlights the wide spread nature and the massive machine type communications that would need to be supported for such a scenario. The diagram below highlights the wide spread nature and the variety of different remote sensors, nodes and infrastructure that need to be connected to the 5G network. The diagram also shows that residential, commercial and industrial premises will need broadband connectivity within this rural environment.



Source: Environment Commissioner of Ontario[190]

Figure 17: Smart grid infrastructure in a rural environment

The spectrum requirement was calculated as per the assumptions and parameters applicable to this environment and the assumptions and methodology explained in section 7.3.

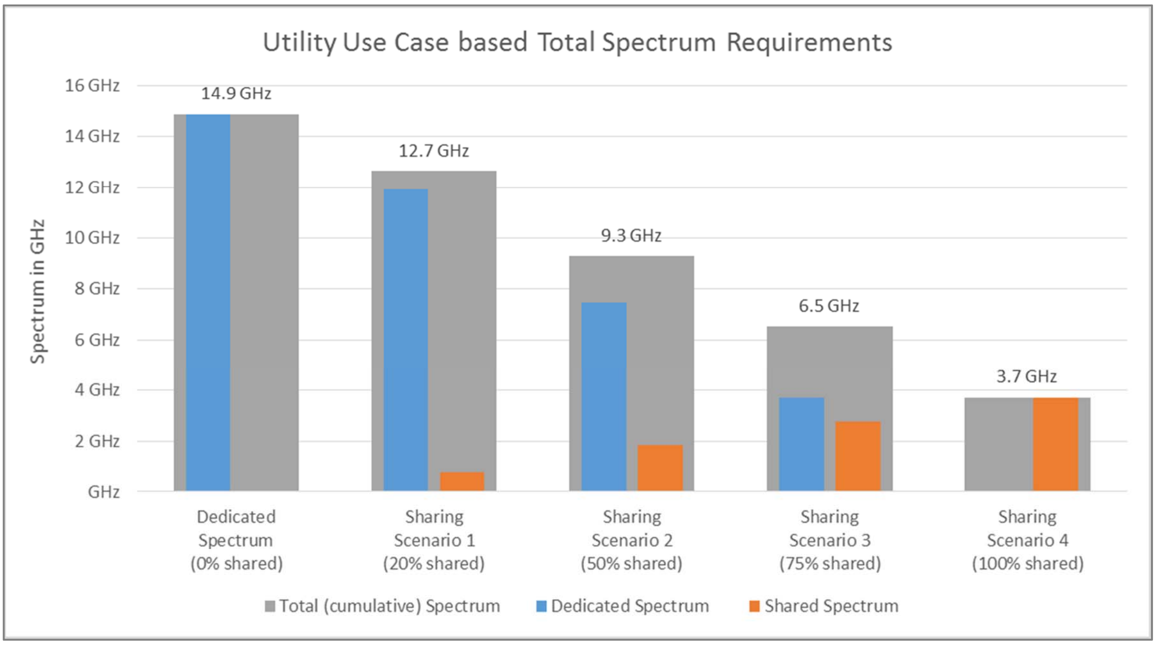
The required spectrum from this use case demonstrates a need for sharing and Table 21 below shows how the quantity of spectrum varies depending on the different sharing scenarios that may emerge by 2025.

Table 21: Total spectrum requirements relative to percentage of spectrum sharing scenarios

Spectrum sharing scenario	Total spectrum needed (GHz)
Scenario 1: 0% sharing	14.9
Scenario 2: 20% sharing	12.7
Scenario 3: 50% sharing	9.3
Scenario 4: 75% sharing	6.5
Scenario 5: 100% sharing	3.7

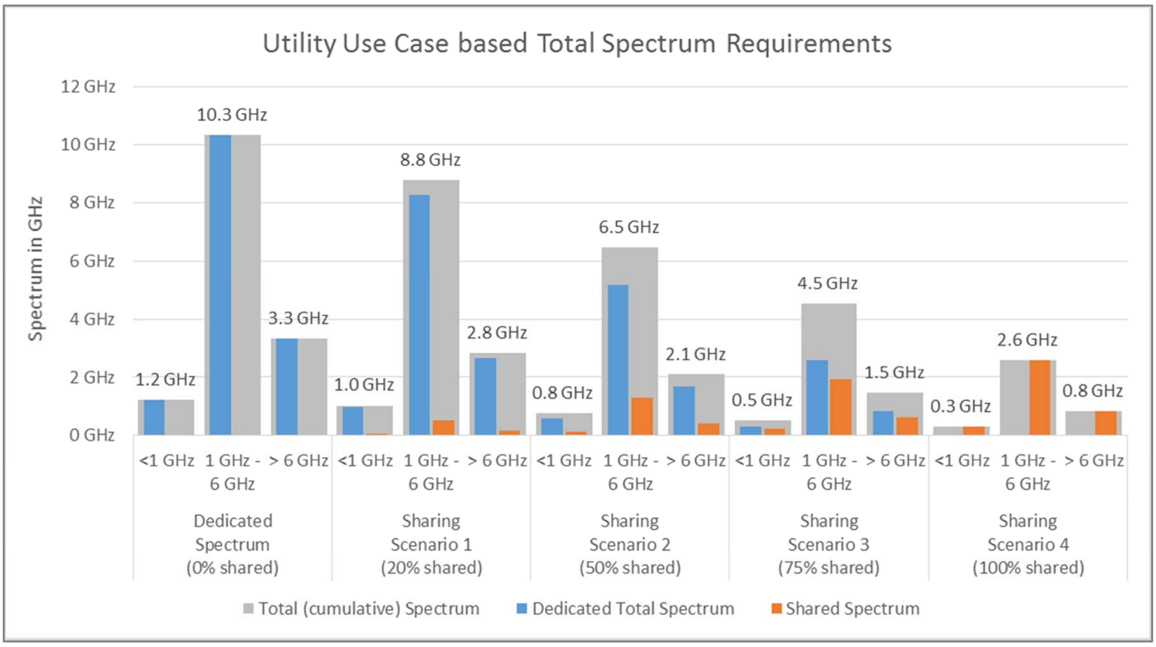
[190] Investing in a Smart Electricity Grid for Ontario, Environment Commissioner of Ontario, Dec 2014 http://www.eco.on.ca/blog/tag/smart-grid/

In the figures below we show two different graphs representing the quantity of spectrum needed for each sharing scenario for utility use case. In the figures below we show three different graphs representing the quantity of spectrum needed for each sharing scenario for the utilities use case. In Figure 18, it shows the total spectrum requirements for each scenario split by the quantity of dedicated and shared spectrum in each case. Figure 19 breaks the sharing scenarios down further into the frequency sub-ranges to show the quantity of dedicated and shared spectrum for each sub-range per scenario.



Source: Real Wireless. Please note that figures in the graph above have been rounded to 1 decimal place

Figure 18: Total spectrum requirements for utilities use case



Source: Real Wireless. Please note that figures in the graph above have been rounded to 1 decimal place

Figure 19: Total spectrum requirements across frequency ranges for utilities use case

We calculated the total quantities of shared spectrum based on the approach described in section 3.4.1 of the annex We observe that the all exclusive case requires the largest quantity of spectrum (14.9 GHz) because each individual service provider (x 4) requires approximately the same amount of spectrum estimated for the given scenario to serve the peak users. The all shared case has the lowest spectrum requirement (3.7 GHz). If by 2025 full sharing is not possible then a mix of dedicated and MNO sharing with the Verticals helps to minimise the total quantity of required spectrum compared to the all dedicated case.

In the utilities use case, dedicated spectrum for operators and verticals is not an option due to the large quantities required to support all the services and devices. Total required spectrum reduces as the proportion of sharing increases. In the Sub-1 GHz and 1- 6 GHz ranges these are the most challenging to meet the requirements without sharing, therefore sharing is strongly advised especially in the Sub-1 GHz but also in the 1 – 6 GHz range. However, even with potentially serving 1 million devices per km^2 in dense urban areas the spectrum requirements for this use case can be readily supported by the bands above 6 GHz given the extensive availability by 2025 (although range limited).

In the Sub-1 GHz band even 100 per cent sharing only goes some way to ease the amount of spectrum needed for the utility applications. This may be a concern because utilities tend to prefer dedicated spectrum for critical type applications and in this case it would mean the spectrum would have to be shared for this frequency sub-range. The situation improves slightly for the 1-6 GHz frequency range such that 75 per cent sharing reduces the total required spectrum to within the quantity available (5 GHz) in the 1 – 6 GHz range. In 2016 many of the applications used in this frequency range do not share because they are used for military, public sector and aeronautical service which have safety of life implications. Therefore, to support the utilities not only increased sharing would need to take place but changes in spectrum allocations and the requirement for adoption of international regulations.

7.4.4. Use Case 3: Healthcare driven spectrum by eHealth and Telemedicine

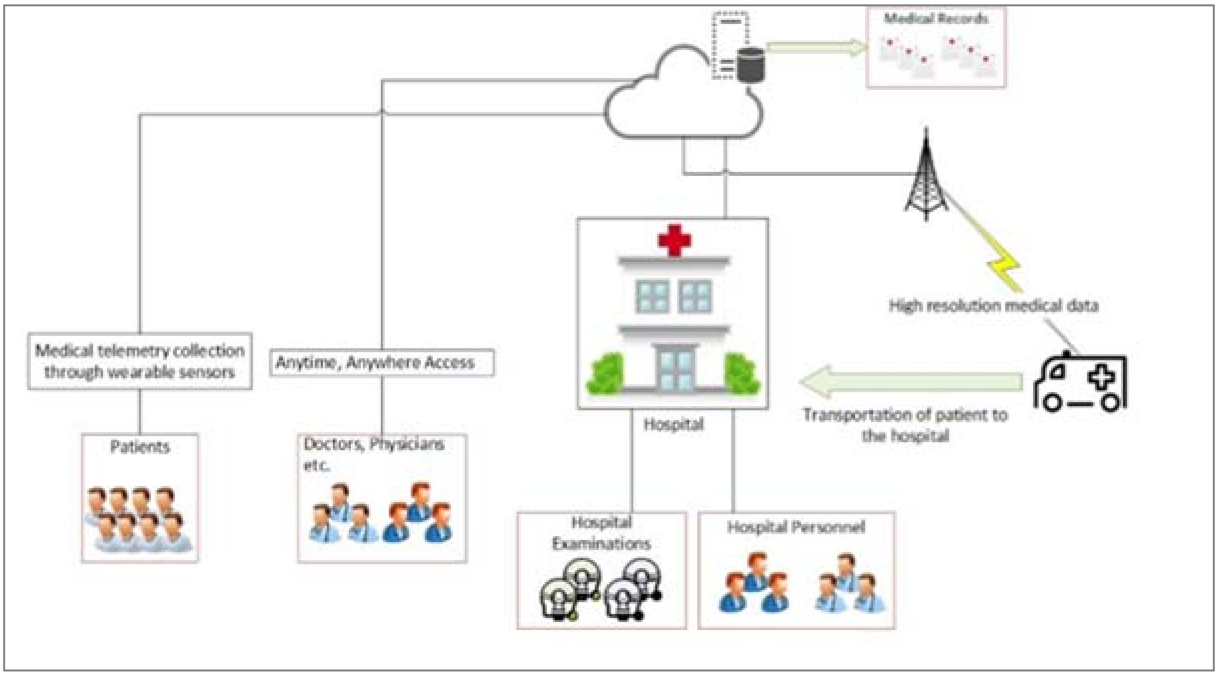
The following environment use case is based on a mix of massive machine type communications, wide spread critical and reliable connectivity and wide area coverage to ensure high speed connectivity in remote and rural locations. The case is taken from the healthcare “day in the life” story. This use case is intended to drive the spectrum requirements based on the requirement to support massive machine type communications and sporadic uses of high intensive bandwidth for smart ambulances and high-resolution endoscopes.

The use case considers the use of mobile ECG monitors, which by 2025 will have become a common integration into smart watches. These devices require ultra-reliable and permanent connectivity to support the critical applications wherever the user is located. These devices will therefore be mobile and worn by tens of thousands of people across many different locations. This means support in the lower frequency bands providing the wide area coverage and given the small form factor of devices also pushes towards lower frequencies. The maximum throughput is low relative to other applications [<10 kbps]. However, in an emergency situation a payload burst is transmitted for up to 10 mins to ensure a consistent and reliable ECG data/trace is delivered to the relevant healthcare centre or health practitioner. There is a presumption of reliability as there is a high risk to safety of life if the trace does not reach its intended destination.

The use case also considers an 8K endoscope (can be used in rural locations and nomadic) link to be supported in spectrum which can be up to 500 Mbps depending on the frame rate, encoding. This applications is for broadcast quality video but can also be throttled back to 100 Mbps. The benefit of utilising 8K resolution is because it makes diagnosis much better due to the high resolution which compensates for variable focus when looking around the body. This application is quite suited to an LSA arrangement due to the nomadic and known location in advance. The density of these devices per km^2 is likely to be low however, but still needs wide area high-speed connectivity for live feeds to healthcare centres and practitioners.

Similar to the transport/automotive applications, the Smart Ambulance is much like a mobile workplace and has similar connectivity requirements. It uses multiple applications with video streaming as a key driver but in this particular use case a three-way video conference is supported on the road to the hospital which would require two separate video feeds to the ambulance and one video feed uplink to the receiving hospitals.

Figure 20 below is an illustration developed by the METIS project, it shows the different constituents that will need to be connected to the 5G network and the types of devices and information that will be used. We observe the mix of medical telemetry data gathered from patients' wearable sensors, similar to our ECG watch and also supporting high-resolution medical data from an ambulance (Smart Ambulance). The spectrum requirements within a local area are likely to be driven by this diverse mix of ultra-reliable communications and enhanced mobile broadband services.



Source: METIS[191]

Figure 20: Example of eHealthcare scenario with connectivity between patients, doctors, hospital and ambulance.

The spectrum requirement was calculated as per the assumptions and parameters applicable to this environment (see section 3 of the annex) and the assumptions and methodology explained in section 7.3. Table 22 below shows how the total quantity of spectrum varies depending on the different sharing scenarios that may emerge by 2025.

Table 22: Total spectrum requirements relative to percentage of spectrum sharing scenarios

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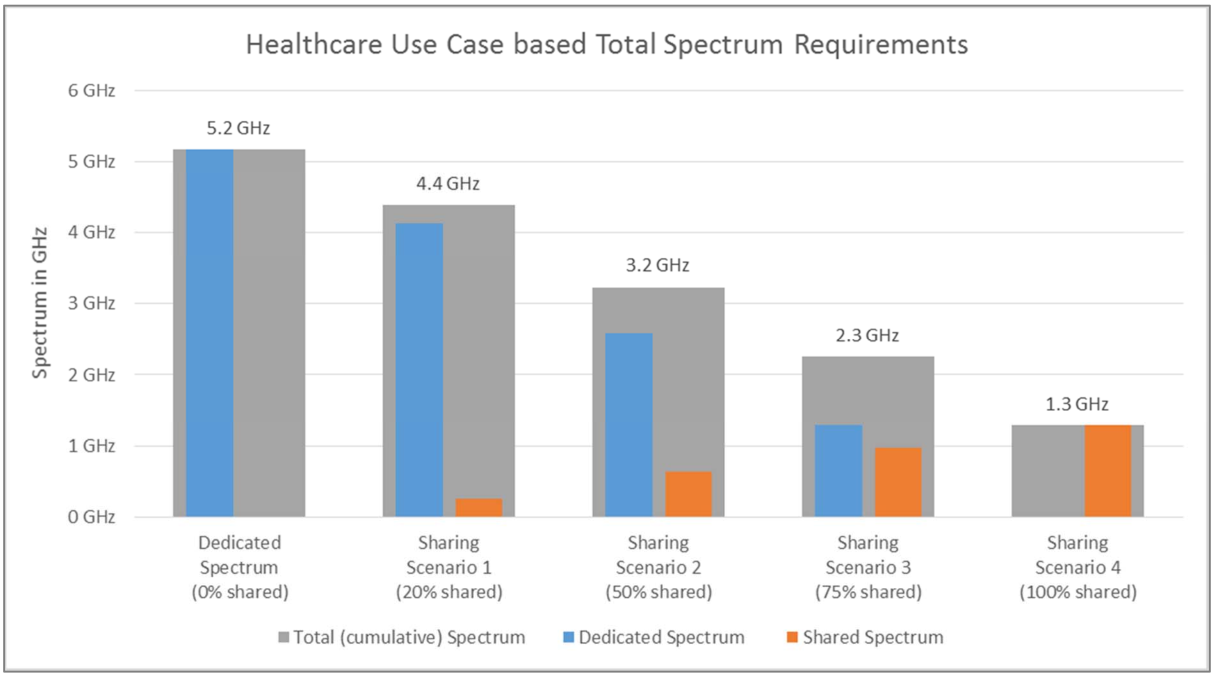
[191] Deliverable D1.5 Updated scenarios, requirements and KPIs for 5G mobile and wireless system with recommendations for future investigations, METIS April 2015, https://www.metis2020.com/wp-content/uploads/deliverables/METIS_D1.5_v1.pdf

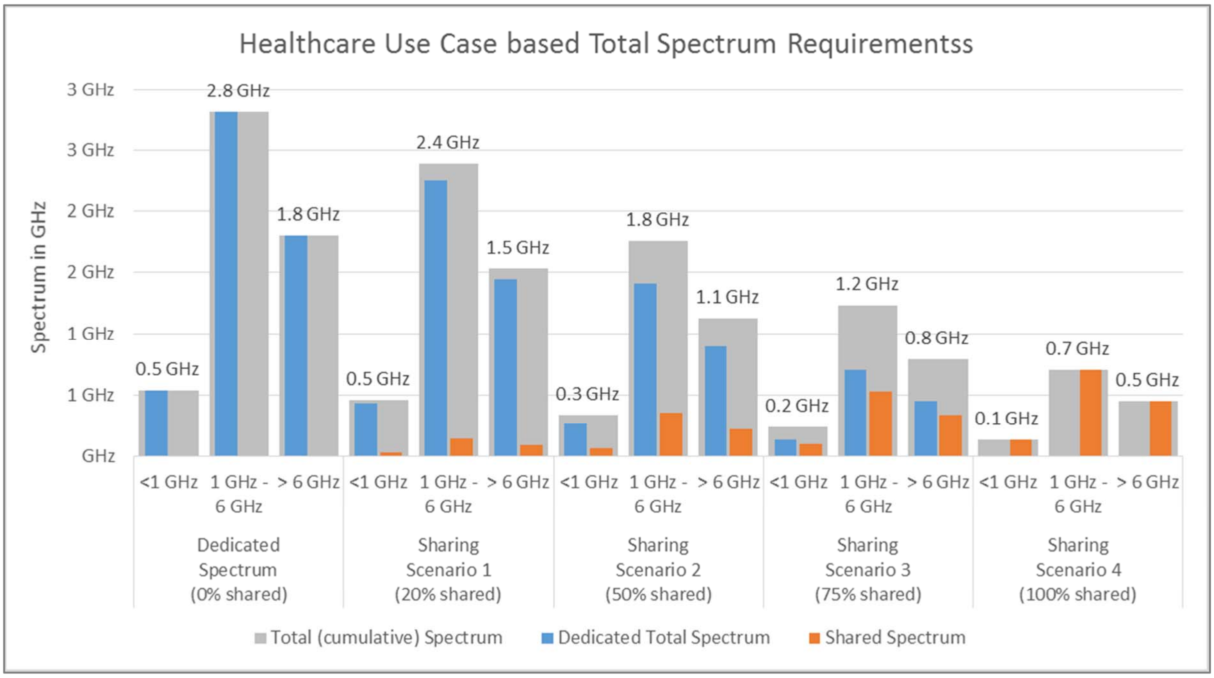
Spectrum sharing scenario	Total spectrum needed (GHz)
Scenario 1: 0% sharing	5.2
Scenario 2: 20% sharing	4.4
Scenario 3: 50% sharing	3.2
Scenario 4: 75% sharing	2.3
Scenario 5: 100% sharing	1.3

In the figures below we show two different graphs representing the quantity of spectrum needed for each sharing scenario for the eHealth (healthcare) use case. In Figure 21, it shows the total spectrum requirements for each scenario split by the quantity of dedicated and shared spectrum in each case. Figure 22 breaks the sharing scenarios down further into the frequency sub-ranges to show the quantity of dedicated and shared spectrum for each sub-range per scenario.



Source: Real Wireless. Please note that figures in the graph above have been rounded to 1 decimal place

Figure 21: Total spectrum requirements for eHealthcare use case



Source: Real Wireless. Please note that figures in the graph above have been rounded to 1 decimal place

Figure 22: Total spectrum requirements across frequency ranges for eHealthcare use case

We calculated the total quantities of shared spectrum based on the approach described in the annex, section 3.4. We observe that the all exclusive case requires the largest quantity of spectrum (5.2 GHz) because each individual service provider (x 4) requires approximately the same amount of spectrum estimated for the given scenario. The all shared case has the lowest spectrum required (1.3 GHz). If by 2025 full sharing is not possible then a mix of dedicated and MNO sharing with the Verticals helps to minimise the total quantity of required spectrum compared to the all dedicated case.

In the eHealth use case some proportion of dedicated spectrum for service providers is an option to support the specific applications across all of the frequency ranges. We observe from Figure 22 that in the Sub-1 GHz range that without sharing a total spectrum requirement of 541 MHz is needed which would use all the available spectrum in that range. Therefore, some sharing is needed if we assume not all the spectrum in this range will be available for use by 5G. However, 20 per cent sharing or 50 per cent sharing reduces the total required spectrum to a level that may support eHealth applications in this spectrum range by 2025. The 1- 6 GHz range is also a challenging sub-range to balance spectrum requirements, spectrum availability and needs of the service providers to meet the demands from the applications. This is because the total spectrum requirements in the dedicated (0 per cent sharing) case equates to over half the available spectrum in the range. This means that sharing will be essential to meet the demands of the eHealth case assuming a significant proportion of the spectrum cannot be shared with mobile applications. The 50 per cent (1.8 GHz) or 75 per cent (1.2 GHz) sharing scenarios provide a reduced overall quantity of required spectrum that would support the traffic demands of the eHealth use case.

Spectrum quantities required above 6 GHz (1.8 GHz) does not rely on any proportion of sharing given the amount of spectrum likely to become available in the mmWave bands. Therefore, in the eHealth case dedicated spectrum can be used by service providers to support the demands of the different applications for eHealth.

7.4.5. Summary of 5G spectrum quantity requirements

Table 23 below summarises the implications of the spectrum requirements and resulting spectrum sharing scenarios for each of the use cases. In each of the three frequency sub-ranges we present the max spectrum requirements, the optimum sharing scenarios that will meet the demands from each use case and explain what spectrum challenges and implications need to be considered if the spectrum requirements are to be met for the use cases.

Table 23: Summary tables of all Use Cases and spectrum need per sub-band

Use Case Type	Max spectrum requirement (MHz)		Balanced sharing and total spectrum quantities (MHz)		Technical and sharing challenges
Motorway Use Case: Transport & Automotive & Public	<1 GHz	404.0	100%	404.0	Potentially not enough available spectrum that can be shared in Sub-1 GHz and 1 – 6 GHz bands. Refarming of 2G and 3G spectrum bands to be concluded by 2025 Highly demanding spectrum limits opportunity for dedicated spectrum for service providers
	1 – 6 GHz	4041.4	100%	4041.4	
	>6 GHz	9587.6	75%	16,778.4	
Utilities Use Case: Power Supplier	<1 GHz	303.4	100%	303.4	Potentially not enough available spectrum that can be shared in Sub-1 GHz and 1 – 6 GHz bands. Refarming of 2G and 3G spectrum bands to be concluded by 2025 Highly demanding spectrum limits opportunity for dedicated spectrum for service providers Above 6 GHz can support dedicated spectrum for service providers
	1 – 6 GHz	2581.2	100%	2,581.2	
	>6 GHz	836.1	0%	3,344.5	
eHealth Use Case: Healthcare	<1 GHz	135.2	50%	338.1	Potentially not enough available spectrum that can be shared in Sub-1 GHz band. Refarming of 2G and 3G spectrum bands to be concluded by 2025 Highly demanding spectrum limits opportunity for dedicated spectrum for service providers Above 6 GHz can support dedicated spectrum for service providers
	1 – 6 GHz	704.2	50%	1,760.4	
	>6 GHz	451.3	0%	1,805.1	

Note: 100% balanced sharing = full sharing / 0% sharing = dedicated exclusive spectrum.

The high level output from these calculations, demonstrating how much spectrum will be needed in each case in 2025, can be found in the section 7.6 - Conclusions.

7.4.6. Factors that could result in lower spectrum requirement

We have assumed a number of highly demanding use cases, one of them being the motorway scenario which is predominantly driven by high resolution video streaming. According to Cisco 75% of mobile traffic will be video by 2020[186]. There are a number of factors that could lead to a reduction in the amount of spectrum required. Below, we highlight just three possible approaches:

1. Dynamic reduction of media resolution (lower streaming codecs) due to congestion allows a dramatic reduction in data rate and often an imperceptible reduction in quality given a small screen is used. Reduction from 4K to Full HD means 77% less pixels, hence Full HD streaming requires only 23% of the throughput needed for 4K. A reduction from Full HD to SD means 83% less pixels, hence SD streaming requires only 17% of the throughput needed for Full HD. There are other factors such as compression and multi-cast that would have substantial impact on traffic needs and the amount of spectrum required. In a real world scenario, non-critical applications may get downgraded to lower resolution which could result in about 61% less spectrum demand (assuming 80% of all data is video/streaming).
2. Spectrum overprovisioning is a concept that relates to the incremental amount of spectrum licensed to an operator beyond its typical needs. The approach taken in the use case analysis was that each operator requires enough spectrum to serve 'all' devices in a non-shared environment. This means 4 x spectrum compared to a single operator environment. It could be argued this is unnecessary given that not all the spectrum will be needed all the time but that some spectrum can be left in reserve to meet peak demand. Another approach to consider for overprovisioning would be to reduce the amount of overprovisioned spectrum to a more realistic level of 30-35% above the usage based (single operator or full shared approach) spectrum forecast. This could result in a 66% reduction of spectrum requirement.
3. Cell sizes are based on industry averages and frequency. Halving the cell size (more sites) = half the spectrum requirement (~ 50% less spectrum needed)

The three approaches described above could contribute to an 86.7% reduction in the amount of required spectrum if both points 2 and 3 are implemented.

There needs to be a balance between the capacity requirements and economic factors. Installing more sites to reduce cell sizes may not be aligned with the operator's business model.

7.5. Policy, regulatory and economic considerations

Recent decisions by the European Commission on mobile sector mergers in Austria, Ireland and Germany suggest that four wholesale or network operators (or three plus an enhanced MVNO sector) are regarded as the minimum for competition in the mobile sector. Each operator also needed a minimum portfolio of licensed, exclusive spectrum to be competitive. This means that an operator with less than the minimum of licenced excusive spectrum will not be able to offer the required set of services necessary to compete in the market cost effectively and would not be able to stay in the market long term. Several different combinations of bands and holdings may meet the minimum requirement as we have seen in 3G and 4G. As long as each operator has the minimum spectrum to be sustainable, spectrum holdings do not need to be equal for competition to work. Indeed, differences in spectrum holdings may be good because operators have to adapt their approaches and thus increase innovation.

Hence the minimum four operators needed for competition multiplied by the minimum spectrum portfolio will be the first driver of spectrum requirements for 5G.

So what might determine the minimum spectrum portfolio need to promote competition in 5G services? In 4G networks, the focus has been on having sufficient spectrum below 1 GHz so that each operator can provide good coverage indoors and outdoors in rural areas and having a sufficient amount of contiguous spectrum (usually in spectrum above 1 GHz) in order to meet customer expectations over quality of experience, particularly download speeds. These will still be important issues in 5G, for enhanced mobile broadband services, however this is only part of the story.

Firstly, 5G is expected to meet new user requirements such as providing connectivity for mass machine type communications (which may not require super high throughput) and providing high reliability services e.g. for real-time communications applications such as remote surgery. Many of the use cases that fall under this involve short range, dense and high capacity networks for which spectrum above 6 GHz may be suitable. This may allow much more concurrent use and greater sharing of spectrum to meet user requirements and this will affect the amount of spectrum required for individual mobile operators. For instance, it may be possible to derive significant economies of scale in the use of spectrum through sharing while maintaining a market structure of four operators (if that is still necessary for competition).

Secondly, because mobile communications services are becoming broader, with M2M communications, the nature of demand and the role of the customer is evolving. In some industries, such as utilities and transport, the customers may be large organisations and may want much more control over service operation than traditional mobile customers. These industrial users (also called verticals) may want shared access to an operator's 5G network capacity or even spectrum. Hence, promoting competition through four wholesale mobile operators (and the associated spectrum requirement for four exclusive allocations) may be less important with regard to vertical users in 5G. For example, fewer mobile network operators may drive greater cost efficiency and vertical customers may be sufficiently large to counteract the effect of higher mobile network concentration.

In summary therefore, exclusive licensed access to some spectrum may still be important, particularly for spectrum below 6 GHz, and it may continue to be necessary to ensure that a suitable number of operators (3 or 4) has access to a basic minimum for competition.

However, there will also be more of an opportunity for sharing of spectrum in higher frequency bands, particularly where user needs may be geographically discrete and /or new technologies may allow users to coexist more easily in the same frequency band. In addition, vertical users may seek more direct access to network capacity than traditional mobile consumers have done in the past – particularly if 5G is used to provide critical business functions such as security – and they could become in effect self-supplying MVNOs.

The findings from this study can be used to inform future EU spectrum policy given the potential spectrum challenges to be faced by member states. In particular, access and availability to spectrum below 1 GHz and 1 – 6 GHz. We identify below the challenges developing spectrum policy and regulations for meeting the 5G vision:

- Timing of spectrum release, including identification of spectrum bands, bandwidths, method of release, the need for any clearance and changes to regulatory policy;
- Timing for operators to reform 2G and 3G spectrum, potential incentives from operators (technology neutrality);
- Studying the options of freeing up spectrum and enabling controlled sharing in the spectrum below 1 GHz to get best and most efficient use of that spectrum;
- Business case analyses will be needed to understand the cost and benefits between sharing and dedicated spectrum in each of the key 5G bands and the ability to deliver against the challenging use cases;

- The needs and requirements of access to virtual networks, networks sharing and APIs in relation to policy and regulation;
- Enabling control of their own virtual network by the vertical sectors;
- Provisions will need to be in place to support the requirements of multi-tenant MVNO;
- Regulatory challenges of rural coverage and achieving the minimum 50 Mbps everywhere which may not just include population but also remote areas where vertical sector infrastructure is located such as remote monitoring stations sharing and the potential need for a single network infrastructure that can support multiple operators (e.g. in light of new public cellular networks being procured to support emergency services);
- Common framework enabling cross industry cooperation to allow sharing of networks that will facilitate the economic growth across each of the verticals

Given the challenges mentioned above and results of the spectrum requirements analysis, we found that spectrum sharing will be key to the access, availability and efficient use of spectrum to ease demanding requirements. It is expected that further developments in spectrum policy and regulations will lead to increased spectrum sharing and new sharing mechanisms. There is one particular example we can highlight that has taken place during the period of this study; An agreement was reached in France between the French Interior Ministry and a verticals association group called Agurre, to share access to prime 700 MHz spectrum blocks with the Public Protection and the Disaster Relief (PPDR) community.

This is the first of its kind in Europe (and possibly the world) where a vertical industry sector, in this case the French transportation industry, has negotiated shared access to sub 1 GHz spectrum. Release and clearance of digital terrestrial television (DTT) in the 700 MHz band is still in the early stages in many member states and France and Germany are leading in awarding this spectrum and making it available for mobile use.

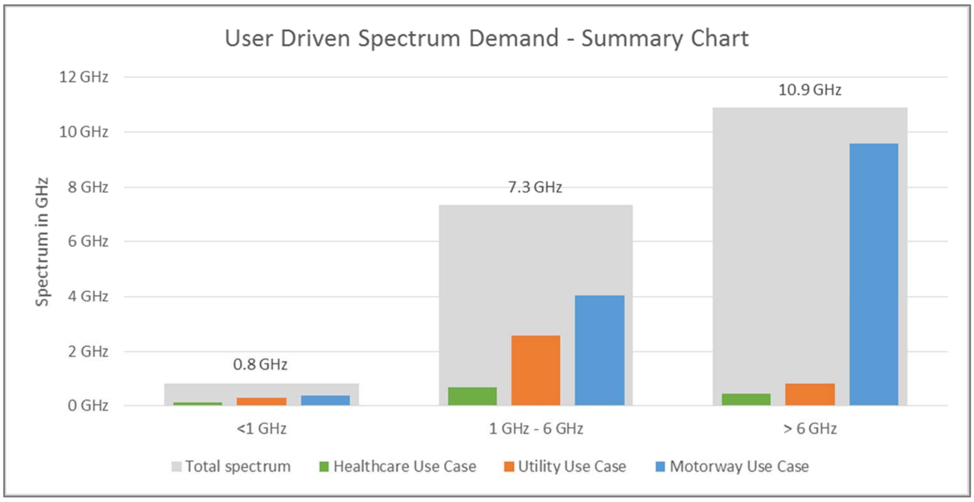
Specific technical and regulatory requirements have been defined to ensure safe use of the bands and that PPDR services are protected from interference by the vertical applications.

This development provides a useful reference point to demonstrate the value that spectrum sharing can bring to the vertical sectors. It also illustrates that in certain use cases access to very large quantities of spectrum may not be necessary.

7.6. Conclusions

This spectrum analysis section explores the targeted question of “how much spectrum will be needed to support the highly demanding 5G applications proposed under the 5G vision and what mechanisms will be needed to make the spectrum available prior to 5G deployment?”.

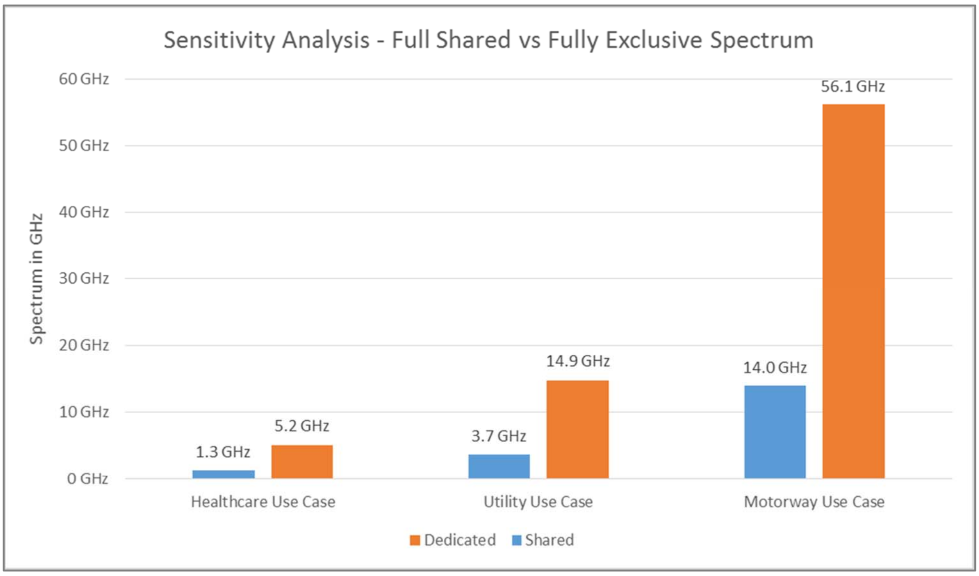
We have examined the amount of spectrum ideally needed to fully satisfy user demand by 2025 to support a number of challenging use cases that would in particular drive the quantities of spectrum to high levels.



Source: Real Wireless. Please note that figures in the graph above have been rounded to 1 decimal place

Figure 23: User driven spectrum needs per sub-band and use case environment in 2025

Figure 23 shows the user driven minimal spectrum requirement calculated based on the challenging use cases built on the "day in the life" stories. This spectrum amount is also the minimal requirement under the assumption that all operators would adopt a 100 per cent spectrum sharing approach. The total spectrum is the sum of all use cases, should they co-exist. It is clear that the < 1 GHz band does not offer enough spectrum and neither does the 1 – 6 GHz band.



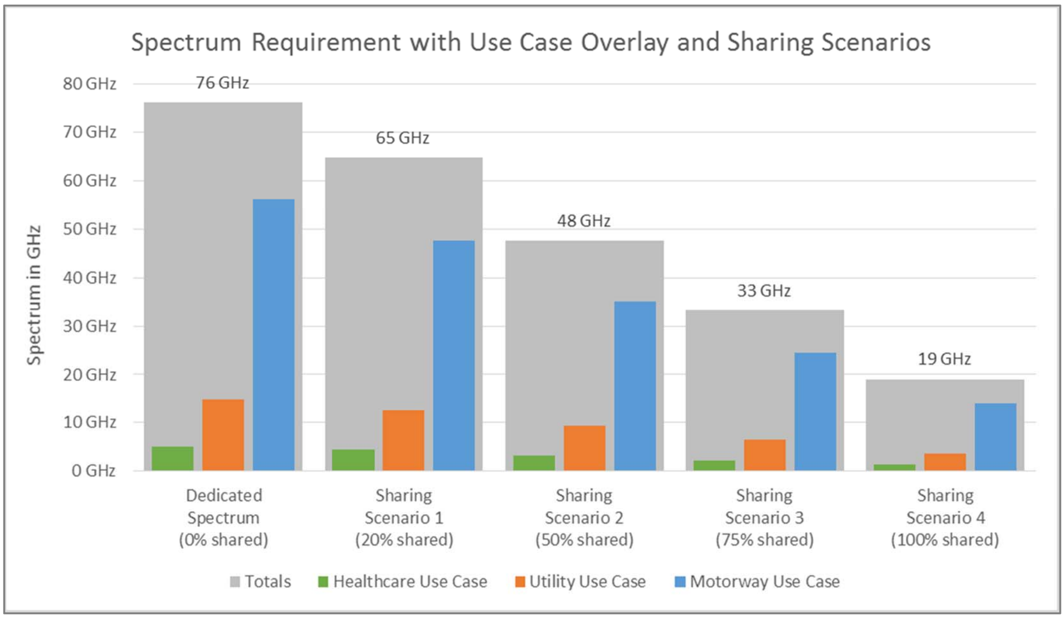
Source: Real Wireless. Please note that figures in the graph above have been rounded to 1 decimal place.

Figure 24: Extreme Sensitivity Analysis for Use Cases with 100% versus 0% Sharing in2025

Our findings from Figure 24 and Figure 25 show that, especially in the multi gigabit connectivity environment of the motorway use case, there is not enough spectrum available in any of the ranges for service providers to hold dedicated spectrum and meet the needs of users.

It shows also clearly that reluctance to share can in the worst case quadruple the total spectrum requirement in any given environment. Figure 25 demonstrates clearly the benefit of sharing versus the unpractical amount of spectrum needed in a dedicated (exclusive) spectrum approach. There is a requirement to share spectrum in all the spectrum ranges, particularly in bands below 6 GHz where it is beneficial to share as much spectrum as possible.

In the utilities environment particularly connectivity to massive machine type devices the spectrum is driven by the expected 1 million smart devices per km^2 that will be deployed in urban and suburban areas. We assume the majority of these devices will be smart meters. The 1 – 6 GHz frequency range is highly utilised in this use case and requires at least 75 per cent sharing in order to support the quantity of available spectrum in this range. The risk in this scenario is the uncertainty of incumbents' ability to share with 5G mobile services. Further examination of specific spectrum sharing opportunities will help yield a better understanding of the scale of deployments by incumbent users in each of the bands.



Source: Real Wireless.

Figure 25: Spectrum for each use case, driven by the sharing scenario in 2025

The eHealthcare use case supports a mix of applications both wideband and narrowband. There is requirement for ultra-reliable connectivity given the safety of life implications. Therefore certainty of access to spectrum will be vital for the service providers to meet the SLAs of the healthcare applications. In terms of the spectrum requirements a degree of sharing is required in each of the frequency sub-ranges. At least 50 per cent sharing is needed in the bands below 1 GHz and 1 – 6 GHz with sufficient dedicated to support the mix of applications for the eHealthcare use case.

The outcome of the analysis suggests that in the challenging spectrum cases there will be a need for sharing in all frequency sub-ranges, in particular the lower sub-ranges. The implications of sharing, particularly for verticals that require ultra reliable and mission critical connectivity, may present potential risks to safety of life or sub-optimal operation if not controlled and managed. The socio economic benefits could be greatly reduced if the challenges of spectrum sharing are not addressed early in the developments of 5G.

Spectrum allocation and sharing principles planning should be investigated by legislators and regulators at an early stage to develop policy tools and strategies that will increase market confidence in the use of spectrum sharing methods to meet the goals and aspirations of the 5G vision.

Another (not spectrum related) factor that is very important for the success of 5G is the impact of MNOs addressing the control, trust, liability and reasonable service level agreements concerns of the verticals. This would go a long way towards the verticals buy-in into 5G and into a sliced, transparent, virtual network. The implications of confidence in a controlled new network, spectrum sharing and infrastructure sharing is a new ecosystem, innovation, interoperability and economies of scale.

8. Conclusions and recommendations

8.1. Conclusion

This study has addressed the hype concerning 5G by investigating what 5G might actually mean for industries, operators, consumers and society. The study, supported by extensive input from more than 150 experts, has provided forecasts of the potential realities that will arise from utilising 5G capabilities in 2025 and 2030. The study provides an insight to the perfect scenario if Europe can maximise the benefits of 5G.

Meta analysis of 5G uses cases and White Papers identified ten key capabilities that are likely to be adopted by 5G standards. Numerous projects, particularly the 19 EC supported 5GPPP projects[192], are focusing on technical developments related to 5G. This study has helped to identify the most important capabilities that will underpin the key development scenarios in Europe.

Workshops, attended by international experts, identified three key capabilities. These were:

- ***50Mbps everywhere*** - Truly ubiquitous coverage (i.e. *everywhere* and with *50Mbps* capacity*)* is a necessary condition for the success of 5G within the context of all verticals and environments;
- ***Scalable solutions for sensor networks*** - Support for large scale M2M/IoT networks was identified as a priority capability for all verticals and environments. Automotive, healthcare, transport and utilities have strong future visions that include a reliance on the IoT. Strategic and operational benefits realisation in verticals is strongly tied to real-time access about date of IoT *things* in the supply chain;
- ***Ultra tactile Internet*** - Ultra tactile Internet allows for a wireless network to be used for control purposes. For real-time sense-respond-actuation cycles that enable both human-device control interactions and device-device interactions. An ultra tactile internet was seen as a step-change capability that would have the potential to unlock more innovative and futuristic applications and services.

The development of these three 5G capabilities has the greatest beneficial impact on the development of optimal scenarios and thus benefits realisation. Evaluation of 5GPPP projects and other initiatives could beneficially focus on ensuring the development of these capabilities to meet user needs and the conditions required to achieve optimal scenarios.

The study focused on verticals/sectors that were most commonly mentioned in 5G use cases and White Papers. In-depth study of these verticals also provides an insight to the potential benefits of 5G capabilities in other verticals.

Second order benefits (or 'knock-on' impacts) arising from the use of goods and/or services in the four verticals and other sectors were investigated by examining four 'environments' where 5G impacts are most likely to arise. The environments focused on two different scales of analysis: Micro level analysis examined households and workplaces. Macro scale analysis investigated smart cities and non-urban environments.

Expert workshops utilised facilitated scenario development techniques to thoroughly investigate opportunities and barriers to the utilisation of 5G to provide optimal benefits in the four verticals and environments. It was notable that the optimistic scenarios were frequently characterised by industries and stakeholders being open to change, with widespread

[192] The Euro 5G PPP project provides an overview of projects, see https://5g-ppp.eu/5g-ppp-phase-1-projects

acceptance of technology enabling data from stakeholders and IoT *things* to flow freely. Increasing acceptance to change by stakeholders in verticals about data sharing will not be easy.

Experts highlighted that enhanced data exchange opportunities provided by 5G will offer significant opportunities for new business models to emerge. Some of these new models might be adopted by incumbents businesses, for example additional income generated from the sale of supply chain or customer data[193]. Other new business models might lead to disruptive change as new entrants; data aggregators and/or data brokers enter existing markets or create new markets. The study has identified a large number of new business models and opportunities in all verticals and environments.

The development of scenarios and identification of key impacts in chapters five and six provide a useful insight to possible futures. Quantifying these benefits is an important element distinguishing this study from others.

Quantitative forecasts have been developed from the best available evidence from previous studies. Assumptions made in forecasts are fully documented to enable readers to easily identify key factors in predictions. Throughout the study quantitative analysis has adopted conservative assumptions. Nonetheless, forecasts describe the maximum attainable benefits and optimal scenarios if Europe can exploit the benefits of 5G.

Greater acceptance of change and data sharing facilitated by 5G is more likely to happen where actors and stakeholders believe benefits will arise to them or their organisation. This report provides an insight to the impact of 5G and magnitude of benefits that might arise. Analysis revealing that more than half of total benefits (51 per cent; €75.2 billion per annum) from 5G will arise for businesses could be a useful catalyst for action by stakeholders in verticals and environments. Further circulation of this report or the distillation of key benefits could assist in enabling stakeholders to identify and work towards potential benefits.

Just under half of the benefits arising from 5G (49 per cent; €71.2 billion per annum) are expected to arise for consumers, householders, society and third parties. It is these benefits that might be harder to achieve without the support of businesses, those developing 5G capabilities and government/administrators and regulators.

It will be important to create the right environment to optimise the benefits of 5G to businesses, citizens and society in Europe. The development, with experts, of optimal scenarios for verticals and environments highlighted the need for effective government frameworks and standardisation, with strong and clear regulations particularly in relation to data exchange and data privacy. Conditions regarding consent and the anonymity of personal data are likely to be included within the forthcoming General Data Protection Regulation[194]. Progress in other areas will also be required, for example capability and technical standards, spectrum needs definition, bands allocation, sharing and regulation.

Estimates of the cost of deploying 5G took a high level approach analysing studies that provide an insight to the costs of 2G, 3G and 4G deployment in Europe. It is evident that each successive generation of mobile infrastructure has cost more than previous generations. Every generation has required more spectrum and cells have got smaller meaning there has generally been a linear increase in base station numbers that have been linearly reduced in cost by more efficient technologies. It is suggested that the €56.6 billion forecast for 5G deployment is probably a conservative estimate because 5G aims to deliver much more than previous generations.

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[193] Within the constraints of the Data Protection Directive 95/46/EC (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31995L0046:en:HTML)

[194] Statement WP218 on the role of a risk-based approach in data protection legal frameworks; see http://ec.europa.eu/justice/data-protection/article-29/documentation/opinion-recommendation/files/2014/wp218_en.pdf

Major investment in an economy has ‘trickle-down’ impacts across the whole of the economy. Input-output analysis of these multiplier effects forecast impacts of €141.8 billion. These effects could create 2.39 million jobs in EU28 Member States.

It was emphasised that it would be unwise to place great significance on any individual forecast in this study. The most significant insights arise from examining the relative differences in benefits within and between forecasts for verticals and environments.

An understanding of 5G spectrum requirements is fundamental to the development of 5G capabilities. This study investigated spectrum challenges and spectrum needs of 5G by examining three challenging use cases scenarios (healthcare, motorway and utility scenarios) developed during expert workshops. The most challenging scenario concerned a congested motorway. In this multi gigabit connectivity environment, there was not enough spectrum available in any of the ranges for service providers to hold dedicated spectrum to meet the needs of users.

Analysis showed there is a requirement to share spectrum in all the spectrum ranges, particularly in bands below 6 GHz.

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