Socio-economic benefits of IMT versus RLAN in the 6425-7125 MHz band in Europe

DSA
DYNAMIC · SPECTRUM · ALLIANCE

LS telcom

VVA
Valdani Vicari & Associati

October 27, 2022

Contents

1 EXECUTIVE SUMMARY

The upper 6 GHz (6425-7125 MHz) band is being studied by the ITU to determine whether the band is suitable for IMT-2020 (5G) use. This band is already in use by other services, which have either recently been introduced such as Wi-Fi, or the satellite, terrestrial and other services whose usage extends over many years. In the case of the use of the band for 5G it is imperative that co-existence between these services is possible otherwise 5G services cannot be established without moving incumbent services out of the band at some expense. To this end, several studies have been started within ITU-R to assess the potential for coexistence and the outcomes are yet to be determined. The expectation is that a Decision will be agreed at the next World Radio Conference in 2023.

This report examines the technical and economic benefits of those IMT and RLAN technologies that could use the upper 6 GHz spectrum band within Europe. In Europe there is continued uncertainty regarding which technology and authorization approach in the upper 6 GHz band will provide maximum benefits to consumers and citizens. This report is intended to help European regulators, and institutions with a spectrum policy remit, to understand the specific benefits of utilizing the upper 6 GHz portion across the candidate technologies, noting:

- the impact of specific technical benefits and challenges (e.g., enabling greater QoS and coexistence with incumbent services); and
- economic benefits and challenges such as enabling more high value applications and the potential for high costs with limited benefits.

There will be a Decision at the World Radio Conference (WRC) in 20231 on whether to adopt an IMT designation for this part of the band (see figure below for current and proposed future allocations of the 6 GHz band). The decision will largely be based on countries supporting the use of IMT in the band and the outcome of studies proving coexistence is possible between IMT and incumbent users such as the Fixed Service and the Fixed Satellite Service. Even if the decision to adopt the 6 GHz band for IMT is agreed by the end of 2023, equipment for use in this band may not be widely available much before 2026/27.

1 WRC-23 agenda item 1.2: to consider identification of the frequency bands 3 300-3 400 MHz, 3 600-3 800 MHZ, 6 425-7 025 MHz, 6 425-7 025 MHz and 10.0-10.5 GHz for International Mobile Telecommunications (IMT), including possible additional allocations to the mobile service on a primary basis, in accordance with Resolution **245 (WRC-19)** https://www.itu.int/en/ITU-R/study-groups/rcpm/Pages/wrc-23-studies.aspx (last accessed June 2022)

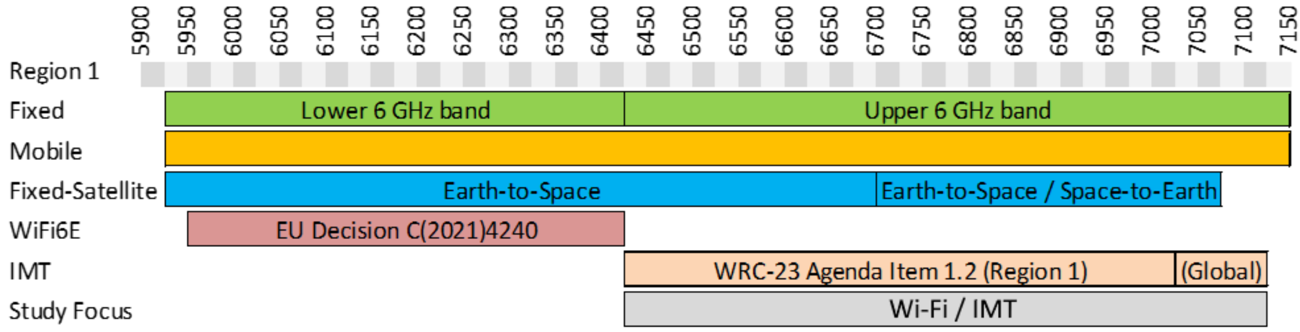

Figure 1: The Region 1 band plan showing existing and proposed usage. Source: LS telcom

Several countries have already adopted the upper 6 GHz portion for the use of Wi-Fi2 and within this context, the study aims to examine the following scenarios that presents the technical and economic benefits of utilizing the upper 6 GHz portion:

- **Scenario 1**: Wide area licensed urban and suburban 5G use of upper 6 GHz
- **Scenario 2**: Local licensed 5G use of upper 6 GHz
- **Scenario 3:** RLAN use of lower 6 GHz vs. All 6 GHz

In each scenario we consider the technical benefits from a counterfactual basis and make a comparison for utilizing the upper 6 GHz band. The specific technical benefits in this case include the Quality of Service (QoS), which is the ability to deliver a certain user throughput and capacity enabling a comparison to be made between use of existing bands used for 5G and the upper 6 GHz portion for Scenarios 1 and 2. In Scenario 3, we specifically examine the difference between capacity benefits of the lower 6 GHz portion versus access to the entire 5925-7125 MHz.

Approach to the study

The study is divided into a technical analysis (Study A) and economic analysis (Study B). The technical analysis identifies the specific technical performance capabilities of utilizing the upper 6 GHz band across the different scenarios. The output from the technical analysis informs the costs and benefits of implementing each technology and authorization approach. In particular, the technical analysis examines the potential benefits, such as improvement in Quality of Service, when deploying the upper 6 GHz for wide area licensed 5G compared to existing 3.4-3.8 GHz services. The analysis includes an assessment of the impact to the incumbent services in the upper 6 GHz band based on standard mobile deployment assumptions when deployed for local licensed 5G and compares the Quality of Service (QoS) of utilizing upper 6 GHz for 5G in a local campus type environment. The final scenario compares the use of the lower 500 MHz block with the entire 1200 MHz for RLAN and the technical benefits that could arise between the different implementations.

The technical analysis has considered the use of both small cells and macrocells for the upper 6 GHz for the nationwide licensed IMT scenario. This is because the network deployment approach remains uncertain but will likely be a mix of both. However, for the purposes of the study we considered the upper 6 GHz band can

2 Wi-Fi Alliance Countries enabling Wi-Fi 6E https://www.Wi-Fi.org/countries-enabling-Wi-Fi-6e (last accessed June 2022)

support coverage and capacity and aligns with the deployment approach used by mobile operators for 3.5 GHz band.

The economic analysis comprises 3 main areas to determine the costs and benefits of using the upper 6 GHz across the different scenarios including:

- **Investment quantification**: investment costs per scenario (cost of implementation using Study A outputs e.g., number of cells, with additional references) for all 3 scenarios and find out what it enables in terms of applications.
- **List of applications triggered per scenario**: based on a combination of technical and market factors, a Multi Criteria Analysis was developed to show the delta benefits of enabled connectivity for each of the scenarios.
- **Investment QoS ratio**: a quantification of the overall investment cost vs. the updated QoS delivered for the three scenarios.

The analysis considered the cost of upgrading existing 5G (3.5 GHz) macrocells across EU cities for a range of scenarios, in which we assumed the number of sites will be fully upgraded over time.

Study findings

The table below presents a summary of the main conclusions per Scenario.

Table 1: Summary overview per Scenario

	Scenario 1	Scenario 2	Scenario 3
Scenario description	Licensed urban and suburban 5G use of upper 6 GHz	Local licensed 5G use of upper 6 GHz	RLAN use of lower 6 GHz vs. All 6 GHz
Deployment costs	Depending on whether macrocells or microcells are deployed, costs can range from **€5.9 billion** to **€7.3 billion** respectively.	€12.35 billion	Ranging from **€9.76 billion**[3] and **€11.68 billion**[4] and could rise to **€13.25 billion**[5]**.**
Economic Sectors[6] most positively impacted by scenario	Agriculture[7]	Construction, Healthcare and Manufacturing	Construction, Manufacturing, Education and Public services

3 Scenario assumption 1: All EU broadband subscribers will be equipped with a WIFI 6 router.

4 Scenario assumption 2: The proportion of people in the EU with a fixed broadband subscription rises to that of South Korea.

5 Scenario assumption 3: Every household, every registered company and every registered NGO would get its own connection.

6 Based on sectors mentioned under the Digital Decade publication, and considered as relevant for the upper 6 GHz band

7 Based on it being the only outdoor application which best ‘fits’ upper 6 GHz use

Socio Economic Benefits	At least twice as many simultaneous users served within a given area as opposed to simply using 3.5 GHz. It will require a large initial investment to deliver its full potential and reach a significant number of EU citizens. In addition, it will only address a limited number of sectors.	No additional users served under this scenario in the upper 6 GHz as opposed to simply using 3.5 GHz. It is thus very likely that no additional benefits will be observed in terms of the number of additional users supported.	From 3 to 4 times more simultaneous users compared to currently deployed Wi-Fi 5 and below. Scenario 3 (RLAN) will require a limited investment, but it will effectively meet user needs from all sectors.

The overall conclusions of this study have found that **it is more beneficial from both a technical and economic perspective to adopt RLAN for use in the upper 6 GHz band**. The Upper 6 GHz band can offer both technical and economic benefits across both IMT and RLAN technologies. However, when considering the technologies in the context of expected additional investment for deployment, notably for IMT and resulting additional benefits, the case for wide area licensed IMT use in the upper 6 GHz band does not look as strong when compared to use for RLAN.

In particular, the two IMT scenarios (Wide area licensed and locally licensed 5G) considered demonstrated pros and cons from a technical perspective, notably:

- The upper 6 GHz band offers a **useful capacity layer in urban densely populated areas** and can support **higher rate applications** over IMT networks, although it is unlikely that the capacity increase, or the cost of providing it, would be compelling outside dense urban areas.
- In the local licensed IMT scenario, **using the upper 6 GHz band would be largely unnecessary**. This is because when compared with operating on the proposed EU harmonized local licensed band (3800-4200 MHz) the additional bandwidth and capacity advantage would not be utilized. There may be some potential specific cases where the upper 6 GHz could be used for 5G indoor deployments, but the benefits are mainly related to ultra-reliable low latency communications characteristics of 5G rather than use of a particular band and could also be deployed in 3800-4200 MHz. Any indoor 5G deployment in the upper 6 GHz band would need to be assigned on a case-by-case basis to protect existing services.

However, in the case of RLAN, we compared the use of the full 1200 MHz with just the lower 500 MHz portion and found that the access to the entire band enables additional capacity and QoS benefits beyond those of access to the lower 6 GHz. Specifically, it enables more wider bandwidth channels (160 / 320 MHz) enabling the full benefits of 1 Gbit/s connectivity, aligning with EU's 2025 target8, and because the technologies enable multi-gigabit connectivity, is future proofed as the EU raises its targets. Access to the full band will ease congestion on 2.4 GHz and 5 GHz networks in densely populated areas resulting in an overall uplift in QoS for Wi-Fi users.

In addition to the technical analysis, we considered the economic benefits across each of the scenarios and found the following:

- **Scenario 1 (National licensed wide area IMT)** will require a large initial investment to reach a significant amount of the EU population, while effectively addressing limited use cases. The economic analysis has highlighted that around 30% of the EU population is living in core urban centers, covering

8 EU 2025 connectivity objectives https://digital-strategy.ec.europa.eu/en/library/connectivity-european-gigabit-society-brochure#Objectives (accessed June 2022)

around 1.2% of EU area. Depending on macrocells or small cells sub-scenarios, providing IMT WAN connectivity in the upper 6 GHz over such area with small cells will require nearly 263,171 small cells, for a total cost of nearly €**7.3 billion**, and regarding macrocells sub-scenario, it will require roughly 65,677 macro sites, at a cost of approximately **€5.9 billion**. When looking at user requirements from downstream sectors mentioned in the Digital Decade9, it was hard to identify strong arguments supporting this scenario. Out of the six sectors, only the agricultural sector seems to have possible outcomes in terms of technical fitness. However, given the nature of this application, which is primarily deployed in rural areas, Agriculture, would not use the higher 6 GHz in practice as this will only be used in urban areas. Few downstream applications using the upper 6 GHz band are expected to take place in an outdoor environment with urban area coverage requirements. When it comes to the effective impact of this scenario, in terms of additional throughput delivered to end-users, deploying such connectivity in the upper 6 GHz band will provide an added value to densely urbanized areas. It will indeed be possible to address the mobile connectivity needs of nearly two times more users within a given area, such as densely urbanized areas, since the deployment and user-demand threshold are expected to be met in such areas, compared to the baseline.

- **Scenario 2 (Local licensed IMT)** is expected to be deployed for sectors requiring localized additional connectivity (Construction, Healthcare, Manufacturing, Ports, Airports, etc.). The study has identified 18,557 potential campus networks for deployment across the EU. Considering a variable number of cells depending on the area (e.g., an average of 8 cells for each campus in the healthcare sector), the study has conservatively estimated that the overall deployment cost will be around €12 Billion. Regarding downstream applications, Scenario 2 enables a wider range of applications across sectors compared to Scenario 1. Local IMT in the 6 GHz band will not meet the requirements of the public sector, however it will offer a reliable solution for three out of six sectors mentioned in the Digital Decade (Construction, Healthcare, Manufacturing). The study has assessed that this scenario will not support additional users under the upper 6 GHz compared to the baseline scenario in 3800-4200 MHz.
- **Scenario 3 (RLAN/Wi-Fi 6E and 7)** has been modelled based on 3 deployment scenarios. These scenarios, ranging from business as usual to extremely dense Wi-Fi penetration rates, has allowed an estimation of different developments in broadband subscriptions. The study has estimated that for domestic users, the cost of deployment will be based on the price of a new router for each subscription (a conservative approach since some routers could potentially be updated with a firmware update). From a downstream point of view, Scenario 3 enables a comparable, but still higher number of applications vis-à-vis Scenario 2 (Local IMT). It is very well suited for five, out of six, sectors mentioned in the Digital Decade. Outdoor use of Wi-Fi in Agriculture scores lowest since most outdoor applications are not expected to rely on RLAN. The study has assessed that Wi-Fi 6E/7 deployment will cover from 3 to 4 times more users compared to currently deployed Wi-Fi. Whilst Agriculture is mainly an outdoor activity, the storage and processing of the crops often takes place indoors and mainly utilizes Wi-Fi. There are many aspects of Agriculture currently being served by Wi-Fi and will continue to be, but the study concentrates mainly on outdoor activities that could conceivably be undertaken by both RLAN and IMT to attain a like-by-like comparison.

Other considerations

The study found that it may be difficult for incumbent services to co-exist with IMT WAN in the upper 6 GHz band, partially due to the potential of interference, such as that predicted to affect the Fixed Service and Fixed Satellite Service across the EU. Studies being conducted in preparation for WRC-23 will ultimately determine to

9 https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en (accessed June 2022)

what extent coexistence is possible. Regardless, it will likely require the deployment of additional mitigation techniques that have not been explored in this study but may limit the deployment of IMT in this band. The use of RLAN in the lower 6 GHz portion has proven coexistence is possible with incumbents and studies within CEPT are exploring similar studies for the upper 6 GHz portion with an expectation that coexistence is possible.

From an economic perspective, drawing a parallel with the C-band migration in the USA, costs could be estimated between €3.2 and €4.7 billion. This cost was not considered for the computation, however deploying IMT WAN introduces a risk that could require such costs to fix.

2 STUDY A: TECHNICAL ANALYSIS OF UPPER 6 GHZ USE

2.1 Introduction

In this part of the report, we look at the technical assessment for the use of various technologies in the upper 6 GHz band, how they impact the existing users, what kind of applications can be implemented, and how useful they will be to the networks implementing them. The report provides a practical and technology-neutral answer to this assessment.

Technical details for the calculations can be found in Annexes 1 and 2.

The background to the introduction and exploitation of the 6 GHz band for IMT or Wi-Fi

In mobile networks, Small Cells are cheaper to buy, cheaper to install and focused on areas of higher customer density. Although the number of users an individual cell can support is relatively small, it is sufficient if they are focused on specific areas where there is a higher density of customers, which makes them economic to run. With such a small range, the targeting is no-longer 'urban' or 'rural', but specific places where people may gather, be that clusters of bus stops, specific parts of railway stations or short sections of road that are prone to traffic congestion. This keeps excessive traffic off the Macro network.

The alternative is to simply backfill the 3.5 GHz urban macro network with 6 GHz. For mobile operators we believe is the likely initial scenario, saving on the cost of establishing new sites although the existing sites would need some reconfiguration to make space on the mounting structures for the new antennas. The proposed use of AAS implies this is likely initially to result in monoband 6 GHz antennas installed above the existing 3.5 GHz antennas, which may have been moved down to accommodate them. The inter-site spacing would not be optimal for 6 GHz, so comprehensive 6 GHz coverage is not likely, and infills may be required in some places if 6 GHz is not to be simply a way of delivering capacity close-in. However, from an economic point of view, retrofitting 6 GHz to existing sites is a fast way to get headline service going, although we believe that 6 GHz will eventually be used on Small Cells because it is the most practical match for the propagation characteristics.

In private networks, the deployment of infrastructure is likely to be more like Wi-Fi, with mainly small cells or picocells deployed in densities appropriate to the planned capacity requirements.

Based on the modelling done, 6 GHz is likely to be of use in specific small-radius applications. In all cell sizes, the aim is to service the same number of users per cell, assuming the same basic capacity, so a higher user density requires more cells. The higher the frequency, the more cells can be deployed to maintain the same overall user experience, as the smaller cell sizes mean fewer customers on each cell for a given population density, with a corresponding saving on backhaul capacity. These techniques allow the network planner to find solutions for capacity hotspots that would otherwise degrade the wide-area coverage. This suggests that the application of 6 GHz cells is most likely to be found in urban areas, perhaps co-located with 3.5 GHz sites, but with lower range, and due to higher attenuation by vegetation and less diffraction around obstacles, likely to only be of use in near line-of-sight situations or close to the cell site. Except in isolated cases, high user densities are more likely in urban areas, and it should be borne in mind that the higher the data rate being consumed, the higher the signal to noise (Channel Quality Indicator, CQI) the User Equipment (UE) requires, so cell density needs to be higher for high-speed data. Additionally, Carrier Aggregation (CA) allows UEs to create a high bandwidth connection by making multiple connections to multiple 'nearby' sites rather than simply connecting to the most dominant cell.

This also implies a high cell density, again more suited to Small Cell rather than Macro deployments, although the distance between urban macrocells is not significant (400m: ITU WP 5D).

2.2 The Regulatory Landscape for use of 5G or Wi-Fi at 6 GHz

At the World Radiocommunication Conference in 2023, Agenda Item 1.2 will consider the use of the Upper 6 GHz frequency range (which for the purposes of this study we are considering to be 6425‑7125 MHz):

> "Consider identification of the frequency bands 3 300-3 400 MHz, 3 600-3 800 MHz, 6 425-7 025 MHz (Region 1), 7 025-7 125 MHz (globally) and 10.0-10.5 GHz for International Mobile Telecommunications (IMT), including possible additional allocations to the mobile service on a primary basis, in accordance with Resolution 245 (WRC-19)"

In advance of any decision on this agenda item, several countries have already opened the entire 6 GHz band for RLAN services including the following example countries10:

- Saudi Arabia
- USA[11]
- Canada
- Brazil
- South Korea

The ITU Radio Regulations for Region 1 defines the use of the band as follows.

Table 2: The ITU Radio Regulations for Region 1

Frequency (MHz)	Allocation
5925-6700	FIXED FIXED-SATELLITE (Earth-to-space) MOBILE
6700-7075	FIXED FIXED-SATELLITE (Earth-to-space) (space-to-Earth) MOBILE
7075-7145	FIXED MOBILE

10 Wi-Fi Alliance Countries enabling Wi-Fi 6E https://www.Wi-Fi.org/countries-enabling-Wi-Fi-6e (last accessed June 2022)

11 The USA's Federal Communications Commission developed an extensive record demonstrating that sharing is possible (with the Fixed Service, for example) with certain technical restrictions applicable to Wi-Fi.

2.3 Sharing between 5G or Wi-Fi with other services

In this section we discuss the different services that would need to share with 5G and Wi-Fi in the upper 6 GHz band. The approach taken to guarantee sharing of 5G or Wi-Fi with other services differs due to the way the services are licensed.

- 5G networks would be operated under license obligations on the operator that are intended to guarantee that the network stays within agreed parameters to protect other users.
- Wi-Fi operates within a license-exempt framework to share spectrum with other services, which it is designed to do. There are strict technical limitations applied to the equipment to facilitate sharing.

The two services that are in use across the EU in the upper 6 GHz band are the Fixed Satellite Service and Fixed Service. Use of IMT in the 6 GHz band could potentially cause aggregate interference to space satellite receivers (FSS system uplink) and to the Fixed Service.

There is work ongoing within the ITU and CEPT on coexistence studies to support Agenda Item 1.2 at WRC-23. Proponents of IMT in this band suggest the following mitigations to support coexistence:

- Active Antenna Systems
- Lower power spectral density compared to 4G
- Restricted overall number of base stations in the band
- Restriction of the IMT activity factor (base station not always on, the improved 5G power saving would help here)

The suggested mitigations point to acceptance that 6 GHz is more suited to localized in-clutter deployments compared to the use of high-power macro cells operating above the clutter. The discussion regarding clutter loss implies that sites would be located where terrain or buildings would limit radiation towards the geostationary arc, which naturally fits the utilization of low-tower small cells in urban areas rather than high-tower or building top macrocells. The requirement to limit the number of base stations across a whole continent raises obvious challenges, when mobile network deployments are usually managed at national level and not subject to international agreements.

2.3.1 The Fixed Satellite Service

The upper 6 GHz band is used by the Fixed Satellite Service for earth to space communications, including Inmarsat feeder links in 3550-3700 MHz (downlink) and 6424-6575 MHz (uplink) for the MSS service and for the uplink of RNSS augmentation signals[12].

Sharing with the uplink makes it very difficult for wide-area networks to operate in the band as the EIRP and antenna patterns required would inevitably present a source of aggregated interference to space-borne receivers[13].

Assessing the potential impact of terrestrial transmitters to earth-space links is simplified in part by all the interferers being approximately the same distance from the satellite receiver (approx. 600km path length difference between pole and equator on a 36,000km path). The overall effect is to raise the noise floor, so it is

12 Inmarsat response to Ofcom's call for input: "Strategic review of satellite and space science use of spectrum", June-August 2015. https://www.ofcom.org.uk/__data/assets/pdf_file/0030/49674/inmarsat.pdf

13 RR-20 APAC "Outcome on Key Issues for the Satellite Industry @ WRC-19 Agenda", ESOA, Oct 2020, https://www.itu.int/en/ITU-R/seminars/rrs/2020-Asia-Pacific/Forum/Session%208_WRC-19%20and%2023/ESOA_Session%208%20_WRC19%20Outcome%20and%20Key%20AI%20WRC23_BP.pdf

possible to estimate that by power summing the terrestrial population at the satellite receiver to ascertain that impact on the noise floor.

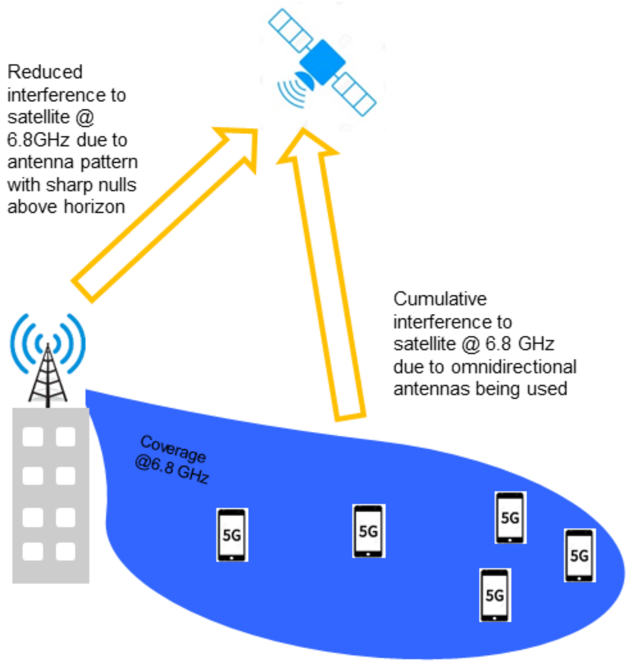

Figure 2: 5G/Satellite interference scenario

Source: LS telcom

Within ITU-R Working Party 5D, technical study conclusions are yet to be drawn on the analysis of 5G co-existence with FSS in the upper 6 GHz range. Countries that have already adopted a decision in the lower 6 GHz for Wi-Fi (based on studies from ECC Report 302) have yet to prove that there can be successful coexistence in practice due to the relatively small numbers of devices currently in use. It can be argued (as indicated by Ofcom[14]) that the use of FSS in the upper 6 GHz band is similar to that of the lower 6 GHz, so the same assumptions and analysis could potentially be applied from ECC Report 302 for studies in the upper 6 GHz portion.

2.3.2 The Fixed Service

Like FSS, sharing between IMT and the Fixed Service is under study as part of preparations for Agenda Item 1.2 at WRC-23. We consider the current circumstances presented from the use of 5G in the upper 6 GHz band and the impact it could have on the fixed service in EU countries.

The table below shows the sub-band frequency usage of the Fixed Service noting the split between the upper and lower blocks of 6 GHz.

Table 3: ITU regulations for the Fixed Service

Band	ITU Reference	Low Block		Upper Block		Raster (MHz)	Separation (MHz)
		Start (MHz)	End (MHz)	Start (MHz)	End (MHz)		
	F.383	5945.2	6152.75	6197.24	6404.79	29.65	252.04

14 Enabling spectrum sharing in the upper 6 GHz band, Ofcom February 2022 https://www.ofcom.org.uk/__data/assets/pdf_file/0022/233194/spectrum-sharing-6 GHz.pdf

Lower 6 GHz		5955	6155	6195	6395	40	240
		5941	6165	6207	6431	28	266
		5945	6145	6205	6405	40	260
Upper 6 GHz	F.384	6460	6740	6800	7080	40	340
		6453	6767	6793	7107	14	340

In the EU, the range of deployed microwave services in the 6 GHz band (5925–6425 MHz and 6425–7125 MHz bands) varies depending on the extent of use for backhaul or core telecommunications network connectivity. This is exemplified by CEPT in ECC Report 173[15] from a survey of Fixed Service usage including the 6 GHz band which includes EU countries. The number of 6 GHz links in CEPT countries since 2011 runs into the tens of thousands.

It is highly likely that IMT base stations and microwave links will need to be coordinated based on real-world deployment conditions. This depends on the extent of FS deployments, such as the locations and heights of antennas, which would significantly impact IMT deployments. In addition, studies with CEPT/ECC (notably within PT1) have shown required separation distances of the order of 100km, thus resulting in a requirement for cross border coordination.

Historically, 6 GHz was used to interconnect the telecommunications networks between urban areas via long-haul fixed links. The usage of the band has declined due to growth in fiber telecommunications although microwave links do get used as redundancy/diversity for fiber connections, which are quite vulnerable to long outages. In addition, 6 GHz microwave links typically support longer distance hops compared to higher bands and many are deployed in suburban/rural areas, this means geographical separation can be a viable solution for coexistence. For instance, the UK's license data shows that Upper 6 GHz is still in use by the oil industry (including Norwegian entities) in UK waters of the North Sea, as well as the UK energy utilities, MNOs, police, coastguard, water industry and broadcasting (unidirectional feeder links) with approximately 500 active unidirectional and bi-directional links (the majority) published in their open license data between 6.5 and 7.1 GHz.

Interference from 5G or Wi-Fi to the Fixed Service is less easy to calculate than the Earth to Space sharing scenario with many variables. Fixed Links will necessarily continue to be operated, and in many cases new links may be deployed. The interferers can be close, or they can be far, they can be in boresight or not. This is very different from the simpler premise of satellite, where the interferers are all essentially at the same distance[16] and where they are deployed on the surface of the earth makes little difference except to the effect of the interferer's radiation pattern and its location WRT the horizon. This means that the amount of interference increases in the mid to high latitudes as the GSO footprint approaches the horizon.

15 Fixed Service in Europe Current use and future trends post 2011, March 2012

16 The geostationary orbit is 36,000km (approx.), the radius of the earth is approximately 6,400km. This means that the distance to the pole from the GSO is approximately 36,600km, actually less than 600km difference, at an angle of 10 degrees from the satellite, so the entire face of the planet is within a close to flat 20 degree arc with the higher latitudes compressed into the edges. The intensity of uplink interference would be such that it would look like most of the noise was coming from the mid to high latitudes.

Specifically, in assessing the potential for interference to Fixed Services, the number of interferers likely to be in or near boresight needs to be calculated. Antenna patterns are important and off-boresight attenuation can be high. This is illustrated in the diagram below.

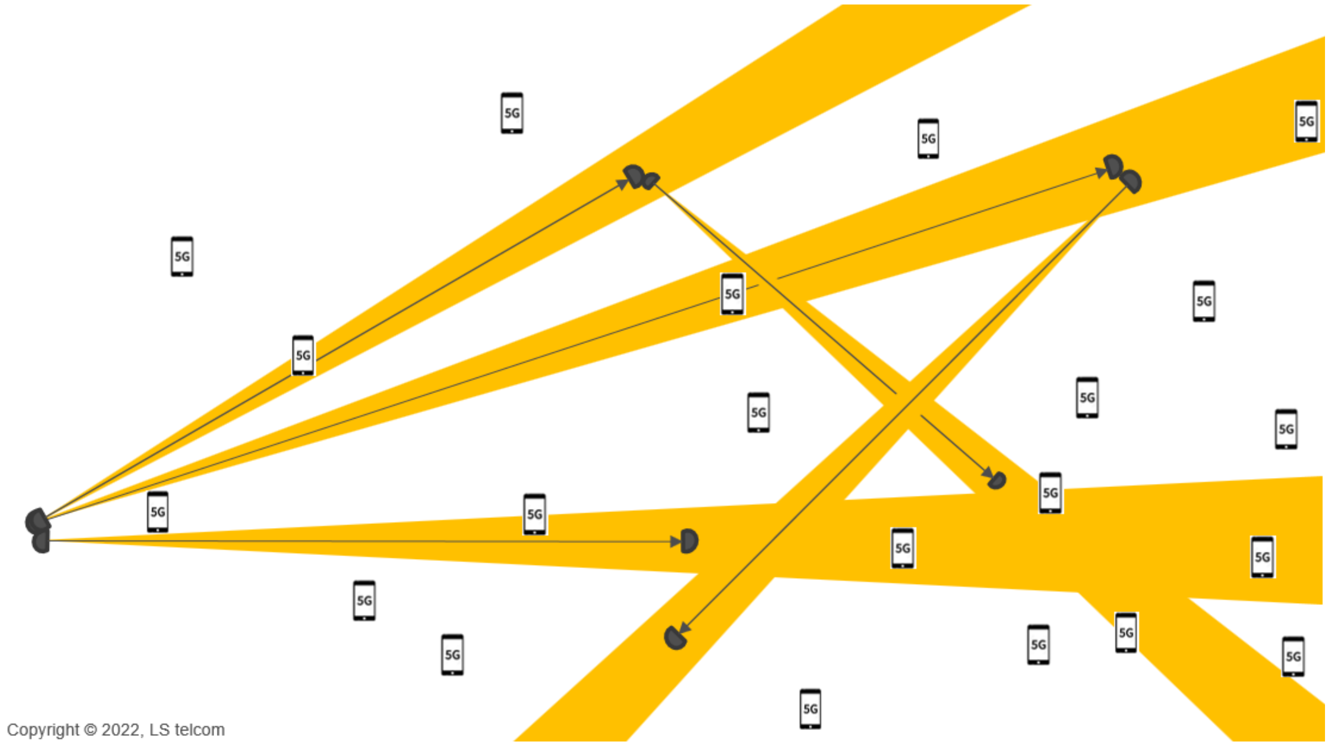

Figure 3: Fixed links interference scenario in plan view showing stylized interference zones (gold)

Source: LS telcom

The number of potential interferers is lower than in the satellite scenario, but they are all going to be closer to the victim and unlike Base Stations, which can be coordinated not to interfere, the location of UEs is not controllable but will generally be outside the interference zone of long-haul fixed links. The side view below shows a highly simplistic interference scenario. The UE on the far right may be receivable by the link end on the far left, but the signal level will be well below the C/I threshold of the link end in boresight as the link being interfered with will have a significantly higher EIRP and is also likely to be running a significant fade margin allowance depending on the required link reliability and it is also not in the clutter, like the UE. It is important to understand that the orange zones are receive and not transmit vulnerable areas, so the UE cannot detect the presence of the link because it is transmitting on another frequency. Whilst the base station may have been coordinated with the fixed link, the UEs around it may not have been and the only way to mitigate is to coordinate not just the base station, but the potential locations of the UEs within the service area as well. This is a little more complicated than simply assessing the antenna-to-antenna paths of the fixed infrastructure and involves uplink-planning the link against the potential UE locations and assessing the impact on the link's reliability.

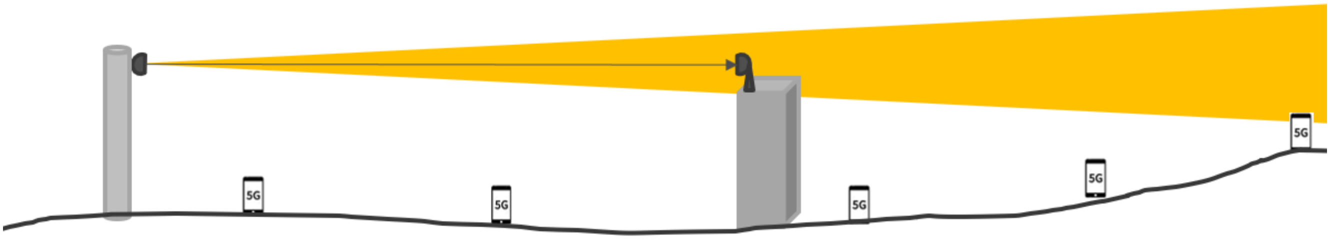

Figure 4: Fixed Links interference scenario-side view showing stylized Interference zone (gold)

Source: LS telcom

Work is ongoing within CEPT and the ITU to determine the impact of IMT on the FS in the 6 GHz band and because of this it is currently uncertain how or whether IMT can share with Fixed Links. In addition, some administrations (i.e., Germany) have indicated the need for large separation distances (high receive gain on boresight, fade margin degradation affecting reliability), while the IMT community has argued for clearing Fixed Links from the band (expensive, for someone).

Sharing of the 6 GHz band between Wi-Fi and the Fixed Service has been modelled by CEPT studies such as ECC Report 302[17] and the results have generally concluded that sharing is possible with caveats. The ECC found that 23dBm terminals (LPI) restricted to indoor operation and outdoor operation (VLP) limited to 14dBm would not interfere with Fixed Services. For example, in the US the FCC found that Wi-Fi use outdoors (Standard Power) will require coordinated efforts and implementation of automated frequency coordination[18] (AFC). Whilst the UK require a license for the use of Wi-Fi in the upper 6 GHz band to protect the Fixed Service.

2.4 Scenario 1: Assessment of wide area licensed 5G in the upper 6 GHz band

The 6 GHz band is, in IMT terminology, a 'Mid' band. It is the highest frequency Mid-band so-far considered and, due to the nature of radio wave propagation (see Model and Assumptions), has a correspondingly lower service radius (about 40% with respect to lower C-Band frequencies comparing like-for-like), the amount of available spectrum is almost twice the size of the 3.5 GHz band, 700 MHz as opposed to 400 MHz, although not all of the 3.5 GHz band is likely to be utilized for 5G. The lower service range would also result in a higher infrastructure density, with some increase in backhaul and supporting infrastructure costs. Because the reuse distance decreases with frequency, but the population density remains the same, the number of users competing for service in any one cell decreases as the service area decreases, increasing the potential share of the cell's offered data capacity each individual user can access. However, the higher the data rate required, the more resource blocks a user needs to access, with a correspondingly higher signal-to-noise required by the user's device. This usually means the user needs to be closer to the serving cell to maintain a CQI above 12 for the higher modulation schemes (see Figure 5), or to use Carrier Aggregation (CA) to take advantage of connections to multiple cells.

2.4.1 Input assumptions for wide area licensed 5G

We assume two different network deployment types for the upper 6 GHz range:

1. Co-located with 3.5 GHz urban macrocells – This scenario is supported by the inputs made by regulators within ITU-R Working Party 5D to conduct compatibility studies between IMT systems and

17 Sharing and compatibility studies related to Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) in the frequency band 5925-6425 MHz, ECC Report 302, May 2019

18 https://www.broadcom.com/blog/open-afc-is-the-key-to-next-generation-6 GHz-Wi-Fi

incumbent services in preparation for WRC ‘23. This assumption demonstrates how mobile operators would seek to deliver equivalent coverage to that of the 3.5 GHz band using the upper 6 GHz band co-located on the macrocell layer

2. Newly deployed urban small cells – This scenario assumes mobile operators using the upper 6 GHz as a dedicated capacity layer using small cell infrastructure on street furniture or monopoles serving very high throughputs to high-density population areas with high mobile data usage levels. It also assumes a high volume of small cells to satisfy the 5G performance targets for individual download and upload speeds of users

The service radius of a 6 GHz cell is approximately 60% of the equivalent 3.5 GHz cell, which equates to approximately 40% of the service area (see Model and Assumptions). This is entirely down to the additional frequency-dependent path loss and, whilst it can be overcome to some extent by using higher gain antennas, 6 GHz doesn’t diffract well, and is much less tolerant of clutter like vegetation. The overall effect of this is that reusing existing 3.5 GHz sites may not be optimal if overlapping coverage at 6 GHz is the aim. However, there may be some improvement in capacity of those sites, so long as there was a convincingly large number of users in close proximity to the site that could be migrated to the higher frequency range, or to simply use CA on 6 GHz to increase throughput for those users.

2.4.2 Assessment of the benefits of wider area deployment of upper 6 GHz

The effect of adding a 6 GHz cell to an existing 3.5 GHz cell would be to add additional data capacity closer to the site (assuming the population density is sufficient to warrant this additional capacity) than the existing 3.5 GHz service provides. The total available bandwidth is 700 MHz from the upper 6 GHz compared to 400 MHz in the 3.5 GHz band. Depending on the number of players in a particular market, for example four player, it would mean each operator could obtain 175 MHz each.

This extra bandwidth would enhance data capacity close-in but do nothing for those not within line-of-sight of the site. To increase data speeds across the whole service area would require a whole new layer of additional sites. Extrapolating to national coverage, or even local area, would require a new cellular plan, but with cells 38% smaller than the 3.5 GHz plan. Logically, a roll-out on existing sites is a likely scenario, with optimization and perhaps additional 6 GHz sites to increase coverage introduced later once customer use and capacity requirements are better understood.

The effects of using a higher frequency band can be seen from the diagram below, which shows high data speeds would be available only in a small area around each site (CQI of 12 and above).

Site coverage is usually quoted out to CQI 1 - a signal level suitable for basic data transfer such as voice calls or text messaging, using only two Resource Blocks.

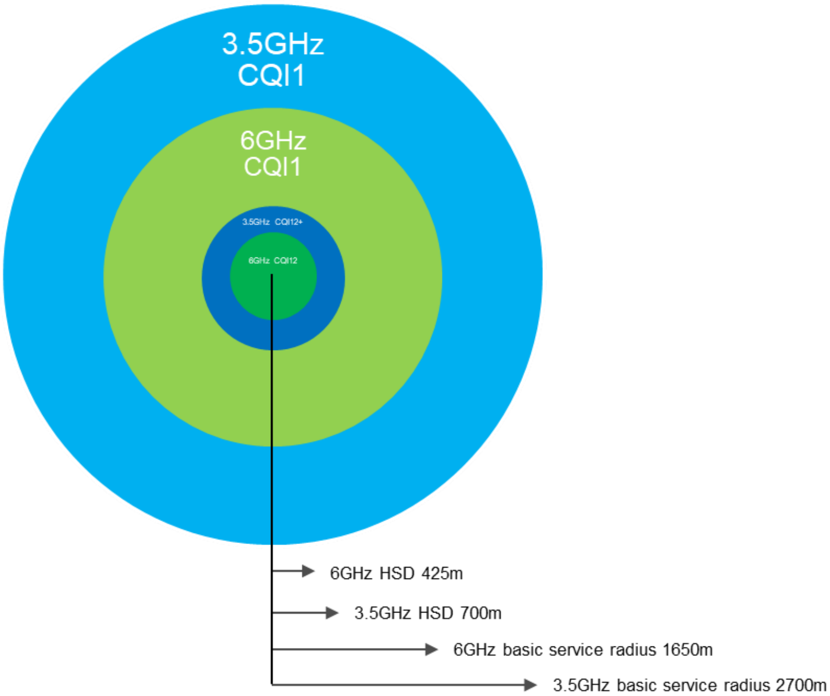

Figure 5: Schematic (to scale) showing effect of introducing co-located 6 GHz service to a 3.5 GHz service cell.

Source: LS telcom

The illustration above is for two co-located macrocells. One on 3.5 GHz and one on 6 GHz. The service radii are estimated using an LS model based on Okumura-Hata and 5G CQI tables. The main service radius shows coverage out to CQI of 1, which is two resource blocks, just about enough signal to maintain a low-speed data or voice connection. To get proper high-speed data using 256QAM, a CQI of 12 or better is required, and this is the smaller circles, assuming the path losses remain constant. It may be possible to assign high-speed data users to phased elements of an active antenna system (AAS), but this would be a small subset of the users.

We calculated the number of sites needed for different cities based on pure coverage and minimum capacity per user (25 Mbit/s). Details of the results for the number of sites required for each of the site types can be found in appendix A1.

2.4.3 Conclusions

The outcome of the analysis has found the following could be the result if either small cells or macrocells are deployed in the upper 6 GHz band for IMT in a wide area licensed environment:

- Deployed to offload demand around existing 3.5 GHz urban macrocells and possibly other congested bands;
- Small cells could be used to add a discrete high-capacity layer over existing coverage without interfering with it or impacting on frequency reuse. Mainly for specific congested outdoor locations in urban areas and thus unlikely to require nationwide licensing;
- Unable to effectively penetrate buildings, it is attenuated by vegetation with very limited diffraction around obstacles, and would only be able to support localized line of sight applications outdoors;
- Wide area licensing of both small cells and macrocells in the upper 6 GHz is unlikely to be economic due to the potential cost of network roll out to fulfil expected 5G target user throughputs, the limited

applicability outside densely populated urban areas, and the cost of mitigating potential interference to other incumbent users.

2.5 Scenario 2: Assessment of local licensed 5G in the upper 6 GHz band

In this scenario we assess whether there is potential to use the upper 6 GHz band for local area 5G deployments. We describe the architecture of a local 5G deployment and determine the difference between 400 MHz of spectrum available in, for example, the 3.8-4.2 GHz range or NR-U in the 5 GHz band versus 700 MHz in the upper 6 GHz range.

The reason for using the 3.5 GHz band as a comparator is because it is growing in popularity in some European countries for local/shared licensing at low power for private mobile networks. This includes Sweden[19], the Netherlands[20] and UK[21] who have identified the band for localized 5G shared use. According to regulators and a position by RSPG[22] this band can be used for sharing between mobile and other services but only in a highly controlled way and predominantly for relatively small areas. Furthermore, it is being harmonized for local networks based on a Radio Spectrum Committee mandate[23] to ECC. Therefore, this approach to spectrum use supports network deployments for a range of different vertical sectors providing applications such as large scale IoT deployments for factory automation, control of vehicles like AGVs at ports and airports, and connecting to a large quantity of remote sensors. There may also be some wideband devices such as video camera or high-speed data transfer for edge cloud computing that could be used.

We discuss in this section whether there is significant utility of the upper 6 GHz band for these local 5G networks and identify any potential technical benefits, over and above the alternatives.

2.5.1 Main input assumptions for Locally Licensed 5G

In order to make our assessment on the technical benefits of the upper 6 GHz band for Local Area 5G we have made the following input assumptions

- Transmit power levels will be in the 31-38dBm range for micro sites and 24dBm for small cells (i.e., following 3GPP 'Medium Range' and 'Local Area' base station definitions)
- Maximum cell ranges in the order of 1- 1.5 km as the cell sites are relatively low power
- 5G sites will mainly be connecting to specific devices, sensors, machinery in industrial settings, health, education, transport, logistics and agricultural settings and not consumer grade smartphones (maybe

19 Consultation regarding conditions for local 5G licenses, PTS, December 2021 https://www.pts.se/en/news/radio/2021/consultation-regarding-conditions-for-local-5g-licenses/

20 Value of the spectrum for local mobile communication networks: Insights into awarding and pricing the 5G spectrum bands, Marja Matinmikko-Blue et al http://jultika.oulu.fi/files/nbnfi-fe2019110737109.pdf

21 Shared access licenses, Ofcom web site accessed April 2022 https://www.ofcom.org.uk/manage-your-license/radiocommunication-licenses/shared-access

22 RADIO SPECTRUM POLICYGROUP

Draft RSPG Opinion on Spectrum Sharing-Pioneer initiatives and bands, RSPG Feb 2021, https://rspg-spectrum.eu/wp-content/uploads/2021/02/RSPG21-006final_Draft_RSPG_Opinion_on_Spectrum_Sharing.pdf

23 Radio Spectrum committee Meeting 13/14 October 2021, agenda Item 6 "Draft mandate to CEPT on the shared use of the 3.8-4.2 GHz band for terrestrial local-area wireless broadband systems"

specialized tablets/smartphones). In some cases, the local areas can be cluttered with large industrial equipment presenting challenging signal propagation environment.

- 5G will be used for critical and secure applications that require unique characteristics of 5G such as massive machine type communications and ultra-reliable low latency communications and mobility
- In many of the industrial or enterprise settings, Wi-Fi and WiGig[24] are likely to be used for very high throughput limited mobility applications such as AR and VR
- Some settings will use 5G for indoor applications namely hospitals and stadia
- As per the description in Scenario 1, the upper 6 GHz provides additional capacity for a high-density/concentration of users and supports very high bit rate applications in the order of 500Mbit/s and above

Table 4 below shows the technical parameters assumed that would be used in a local setting. Particularly important metrics are the EIRP, antenna height/gain and cell radius/coverage, which come from 3GPP as opposed to those adopted for coordination purposes, such as in ITU's WP5D, based on likely installation types and EIRPs, especially assuming that 6 GHz is likely to be initially co-located with suitable existing 3.5 GHz sites in most cases.

Table 4: Detailed parameters schedule from 3GPP (Rel.15)

Band (MHz)	Around 3.5 GHz	Around 3.5 GHz	6.425-7.125 GHz	6.425-7.125 GHz
Technology	5G Micro	5G Small cell	5G Micro	5G Small cell
Antenna height (m)	15	10	15	10
UE height (m)	1.5	1.5	1.5	1.5
Clustering	0.50	0.50	0.50	0.50
Data Req (Mbit/s)	2-200	2-200	2-200	2-200
Tx power (dBm)	31-38	24	31-38	24
Antenna gain (dBi)	10-17	6	10-17	6
EIRP (dBm)	48	30	48	30
Bandwidth (MHz)	400	400	700	700
Cell Radius (m)	1350	350	850	200
Area Covered (km^2)	5.72	0.39	2.27	0.13
MIMO	16	4	16	4

As an illustration, we show below a use case for 5G in a local area environment which enables a high data rate application for deploying a Digital Twin. In this architecture diagram it shows the requirement for 5G connectivity augmented by ethernet and Wi-Fi notably for the end user devices. The 5G connectivity provides the backhaul for a range of different applications. However, it should be noted that there will be some smartphone usage in the local area deployments. These will be for the staff to access necessary business-related data and managing the site, for example viewing live CCTV.

24 https://en.wikipedia.org/wiki/WiGig

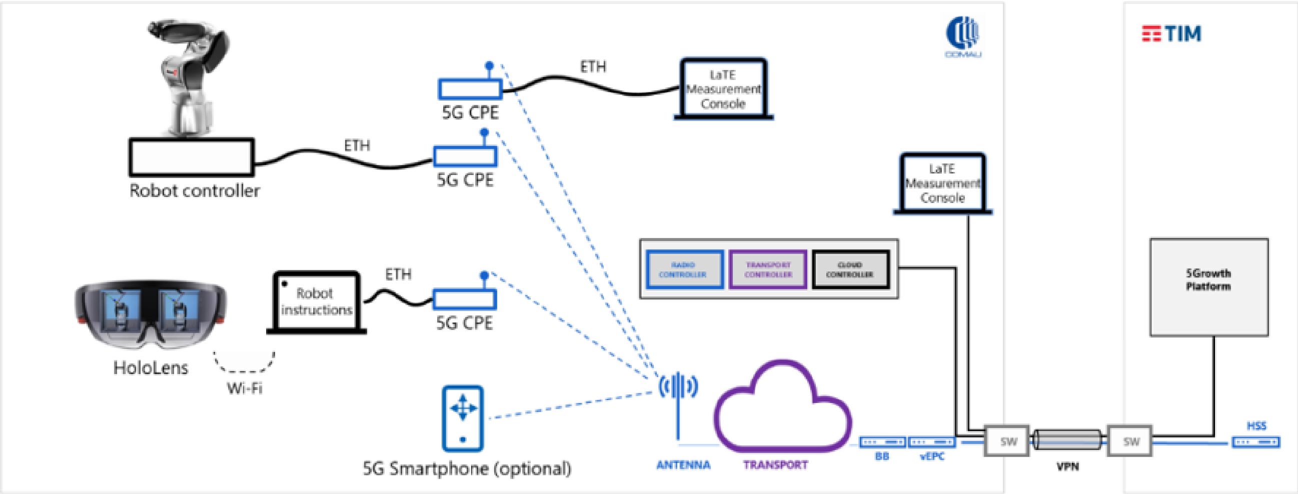

Figure 6: 5G local network architecture for Digital Twin.

Source: 5GPPP[25]

In terms of the type of areas served for campus networks we illustrate below some specific sectors where private 5G networks are being deployed and consider the different applications and the size of the area to determine the number of sites. We also provide an approximation of the number of devices that would be deployed for typical site for each sector.

We have considered the following sectors for local IMT deployment:

- Construction,
- Healthcare,
- Manufacturing,
- *Education*
- *Public service*
- Airports and ports (Transport)
- Sport stadiums

We selected each of the sectors above based on typical local IMT deployments as exemplified by recent vendor deployments by the likes of Ericsson and Nokia (See 5G Observatory for examples) but also private mobile network providers Cellnex and Athonet. All of these sectors are currently addressed by Wi-Fi in many cases. In particular the Education and Public Service sectors, where the use of private 5G may be limited as usage is largely indoor and Wi-Fi is already extensively used for connectivity in these settings. It is unlikely that 5G will be deployed in future as a private network indoors to replace Wi-Fi, mainly due to high replacement cost but also the types of applications not significantly depending on 5G characteristics such as low latency or massive machine type communications.

25 https://5g-ppp.eu/wp-content/uploads/2021/06/Service-performance-measurement-methods-over-5G-experimental-networks, 5GPPP https://5g-ppp.eu/wp-content/uploads/2021/06/Service-performance-measurement-methods-over-5G-experimental-networks_08052021-Final.pdf

Table 5: Local 5G site and user numbers for different vertical sectors

Sector	Application	Area per location (km²)	Approx. number of devices	Estimated number of sites per area 3.8.-4.2 GHz	Estimated number of sites per area 6.425-7.125 GHz
Construction	Remote sensor monitoring of equipment, machines, and materials or UHD surveillance	0.04	50	1	3
Healthcare	Wireless tele-surgery	0.16	250	2	6
Manufacturing	Machinery monitoring for predictive maintenance and remote-control: reduced downtime	0.04	10000- 20000	5	10
Ports[26]	Perhaps real-time inventory and asset tracking UHD surveillance	~2	400-1000	5	10
Airports[27]	Perhaps autonomous airside vehicles and collision avoidance	~2	10000- 20000	5	10
Stadiums	Perhaps highly flexible multiple UHD wireless camera provision and backhaul	0.04	50	1	3

The estimated number of devices is based on wireless IoT devices used for operational purposes at the different locations, such as monitoring, surveillance, control and maintenance. Since 5G is able to connect up to 1 million devices per square kilometer (according to the 3GPP specification), it can support the device numbers indicated for all of the above sector deployments, although this requires a high-density of antennas and frequency reuse.

We note that most 5G devices would need to be powered by the host equipment rather than use an internal battery, so would mainly be used on self-powered platforms such as tugs, cranes, electric transportation, robots, or devices that return to a charging port regularly. High data rate devices such as CCTV for surveillance or AR/VR headsets would also be used in these environments.

2.5.2 Assessment of the benefits of the upper 6 GHz band for local area 5G

The analysis considers the following scenario which compares the QoS/capacity difference for local 5G networks in the 3.5 GHz band versus using 3.5 GHz and 6.425-7.125 GHz within the different settings shown in the table in Section 2.4

26 https://sphere.ckh.com.hk/eng/in-focus/108/5g-ports-2-000-tonnes-of-power-from-your-desk.html

27 https://www.smart-energy.com/industry-sectors/iot/istanbul-airport-connects-10000-sensors-to-smart-monitor-assets/

2.5.2.1 Comparison of data rate

We have assumed that there is sufficient spectrum available in the 3.5 GHz band and other alternatives for four 100 MHz 5G channels. Each channel can deliver peak bit rates in the order of 1- 2 Gbit/s for a single site. In the case of local 5G networks, we assume this data rate will be sufficient to meet the needs of most devices and applications deployed. For example, we show a snapshot of the different use cases and requirements in an automated factory. It shows for each application the reliability, latency, data rate and scalability.

Application	Reliability	Latency / Cycle Time	Data Rate	Scalability
Conventional Industrial Applications				
Monitoring	$\geq$ 99.9%	50 ms – 100 ms	0.1 Mbps – 0.5 Mbps	100 – 1000 nodes
Safety Control	$\geq$ 99.999%	5 ms – 10 ms	0.5 Mbps – 1 Mbps	10 – 20 nodes
Closed-loop Control	$\geq$ 99.999%	2 ms – 10 ms	1 Mbps – 5 Mbps	100 – 150 nodes
Motion Control	$\geq$ 99.9999%	0.5 ms – 2 ms	1 Mbps – 5 Mbps	10 – 50 nodes
Emerging Industrial Applications				
Mobile Workforce	$\geq$ 99.999%	5 ms – 10 ms	10 Mbps – 50 Mbps	50 – 100 nodes
Augmented Reality	$\geq$ 99.99%	5 ms – 10 ms	500 Mbps – 1000 Mbps	10 – 20 nodes
Remote Maintenance	$\geq$ 99.99%	20 ms – 50 ms	1 Mbps – 2 Mbps	500 – 1000 nodes
Remote Operation	$\geq$ 99.999%	2 ms – 10 ms	100 Mbps – 200 Mbps	1 – 5 nodes

Figure 7: Connectivity requirements of key industrial applications.

Source: IEEE[28]

It can be seen from the above table, for the likes of monitoring or remote control, the bit rates are a moderate 0.5 Mbit/s and 5 Mbit/s maximum, respectively. It is also noted that the reliability and requirements are as high as 99.9999% for motion control, clearly indicating the need for reliability. Likewise, for latency a 0.5-2ms which is a demanding requirement. In the case of Augmented Reality and Remote Operation for emerging industrial applications, bit rate demands are higher in comparison to monitoring and control, up to 1 Gbit/s and 200 Mbit/s respectively. In the case of AR, it could be argued that for the higher bit rates these devices can be connected to Wi-Fi.

Introducing an extra 700 MHz from the upper 6 GHz band for private local 5G networks, would provide extensive additional capacity (another seven 100 MHz channels) however, it would not necessarily be required in any of the sectors considered above beyond that which could already be found in alternative frequency bands.

2.5.2.2 Capacity provision

In the case of capacity provision, there is sufficient bandwidth to support a high-density of devices within a local campus environment assuming that 400 MHz of spectrum in other bands was available. In the example table above for the different applications, 5G can scale to thousands of devices with low data rate and also up to 20 devices (nodes) at the maximum 1 Gbit/s data rate (with a 100 MHz channel). The scale of deployment can be handled using alternative bands, with spare capacity to support more concurrent users at the peak rate from a single site.

Based on the scenario above there is sufficient bandwidth alternative bands (such as C-band) to support the most intense usage such as AR and also large volumes of narrowband devices from a single (or more likely multiple) site. This is also because of the characteristics of 5G enable both high throughputs and massive machine connectivity. Thus, like the data throughput case, there would be little use of additional bandwidth in

28 Private 5G: The Future of Industrial Wireless, IEEE Adnan Aijaz, 2020 https://arxiv.org/pdf/2006.01820.pdf

the 6.425 -7.125 GHz band providing extra capacity for the local network environment to support these use cases.

However, we recognize there are/will be some corner cases for local 5G networks that may require the extreme capacity that the upper 6 GHz band can support, such as in hospitals for remote surgery and very high-resolution video cameras for content creation inside stadia. However, these would be indoor deployments that could be accommodated through specific and local measures, such as forbidding Wi-Fi equipment in an operating theatre, without requiring the spectrum to be reserved for such niche cases at national level and potentially not deployed on a wide scale like manufacturing, logistics or construction.

It is also relevant to consider that some professional/industrial users would favor a 5G ecosystem, while some would favor the Wi-Fi ecosystem, since each has its strengths, it therefore makes more sense to open space in the upper 6 GHz band based on the ecosystem available there, i.e., Wi-Fi 6E/7. Any 5G ecosystem would not become available until 2025 at the earliest.

2.5.3 Conclusions

In conclusion, the upper 6 GHz band would generally not be utilized for most of the sectors we have considered for local 5G networks. This is because:

- The main applications for industrial sites, agriculture and other large campuses depend on the URLLC and mMTC characteristics for 5G rather than the high-capacity provisions of the upper 6 GHz band
- The amount of spectrum that is becoming available in other bands (such as those in mid band below 4.5 GHz) should be sufficient to handle the number of devices at the different locations and even for high data rate applications such as concentration of video cameras for live streaming (body worn cameras, or camera mounted on vehicles) in localized environments
- The upper 6 GHz band provides a smaller coverage area (depending on the type of deployment and equipment used) compared to, for example, the 3.5 GHz band and does not propagate as well in cluttered environments, resulting in more sites being required.
- Other bands, such as those already used at lower frequencies in mid band, have a first mover advantage costs, such that equipment will start/has started to support the band (plus the other 5G bands) and once deployed in the identified sectors, the equipment is unlikely be upgraded for years to come.
- There is not yet an established ecosystem of devices in the 6 GHz band.
- The upper 6 GHz would be useful for indoor campus systems, and ultra-high capacity or density scenarios where 5G data rates, together with ultra-reliable low latency is required such as hospitals and stadia. However, users would struggle to source adequate terminals, and we consider these use cases may be too narrow or limited for any decision by regulators to be made for the allocation of the upper 6 GHz band.

2.6 Scenario 3: Assessment of RLAN (Wi-Fi) in the upper 6 GHz band

Historically, Wi-Fi was designed for providing the wireless link between a wired network via an Access Point (AP), and end devices, such as in offices or providing internet access from fixed broadband connections in domestic situations. In recent years the wireless connectivity model for Wi-Fi has expanded significantly providing a range of flexible wireless connectivity solutions between devices, in addition to connectivity to APs. Although, Wi-Fi still offers a small service range mobility between Access Points (APs) it has evolved from developments such as Hotspot 2.0 meaning low speed mobility is no longer a barrier for Wi-Fi deployments, including for public networks. Similarly, earlier iterations of Wi-Fi standards did not use multiplexing techniques such as OFDMA[29] and had limited scope for the use of multiple antennas to support higher levels of MIMO (Multiple Input Multiple Output) for further capacity performance improvements. However, Wi-Fi 5, Wave 2 can support Multi-User-MIMO (MU-MIMO), but only four data streams per AP at any instant. Wi-Fi 6 extends this to eight simultaneous MU-MIMO streams.

Until recently, spectrum for Wi-Fi included the 2.4 GHz, parts of the 5 GHz band and 60 GHz which are available globally for license-exempt use. Access to the lower 6 GHz band for Wi-Fi is the first significant amount of spectrum made available in the last 20 years or so and will provide much needed capacity in networks and settings where there is persistent congestion. The spectrum will be used, at least in the short-term, to increase the number of APs that can operate, to ease congestion rather than to deliver increasingly high data rates. This is mainly due to the fact that most APs are simply delivering wired broadband speed to homes, offices, and other properties and unless these speeds are increased significantly, any Wi-Fi speed over that supplied by the incoming pipe will be wasted except for connections inside the LAN. Enterprise and commercial settings may benefit from the increased number of unrestricted 160 MHz channels and the new 320 MHz additions, however. Given the EU goals to ensure gigabit internet is available to all premises by 2025, Wi-Fi would become the connectivity bottleneck unless Wi-Fi 6E/7 is fully leveraged.

The second use case is the increase of personal area connectivity, corresponding to VLP. Wi-Fi is the connectivity link between AR/VR glasses and smartphones/APs, for instance.

MU-MIMO and bandwidth constraints aside, there is also a hard limit to the number of clients that can affiliate to an AP radio[30]. This number, which can vary between manufacturers, has crept up through the Wi-Fi versions, but is unlikely to be reached in practice due to the noise caused by that number of clients on the channel. The table below shows the max number of clients per radio and maximum number of simultaneous transmissions for the latest Wi-Fi generations.

29 This multiplexing technique Orthogonal Frequency Division Multiple Access has been recently introduced into new Wi-Fi standards to improve performance

30 Approximating_Maximum_Clients_per_Access_Point, Meraki Jan 2021, https://documentation.meraki.com/MR/WiFi_Basics_and_Best_Practices/Approximating_Maximum_Clients_per_Access_Point

Table 6: Hard limit numbers of clients per access point

Technology	Max clients per radio	Max simultaneous MU-MIMO transmissions
Wi-Fi 5 Wave 1 and earlier	128	n/a
Wi-Fi 5 Wave 2	256	4
Wi-Fi 6	512	8

Source: Meraki.com

2.6.1 Peak throughput performance per user

Wi-Fi, until recently, passed data to one user at a time, splitting the users into timeslots. This meant that the download data rate remained the same, but the user's data rate over time depended upon what share of the available timeslots was being allocated. More than one user downloading meant, inevitably, latency, which grew with the number of users attempting to use the AP.

With MIMO, this means that only a small number of users could potentially use the AP concurrently, perhaps eight at a time (Wi-Fi6E), with the available data rate split between then, but with lower latency.

We show in the table below the peak theoretical throughputs that can be achieved for the different Wi-Fi technologies.

Table 7: Wi-Fi performance parameters

	Wi-Fi 4	Wi-Fi 5	Wi-Fi 6	Wi-Fi 6E	Wi-Fi 7
Launch date	2007	2013	2019	2021	2024
IEEE Standard	802.11n	802.11ac	802.11ax		802.11be
Max data rate	1.2 Gbit/s	3.5 Gbit/s	9.6 Gbit/s		46 Gbit/s
Bands	2.4 GHz and 5 GHz	5 GHz	2.4 and 5 GHz	6 GHz	1-7.25 GHz (incl 2.4, 5, 6 GHz bands)
Channel size	20, 40 MHz	20, 40, 80, 80+ 80, 160 MHz	20, 40, 80, 80+ 80, 160 MHz	20, 40, 80, 80+ 80, 160 MHz	Up to 320 MHz
Modulation	64 QAM OFDM	256-QAM OFDM	1024-QAM OFDMA		4096-QAM OFDMA (with extensions
MIMO	4 x 4 MIMO	4x4 MIMO, DL MU-MIMO	8x8 UL/DL MU-MIMO		16x16 MU-MIMO

It can be seen from the table that Wi-Fi 5 and above can support 160 MHz channels, which are the widest channels available, but it is Wi-Fi 7 that will support 320 MHz channels. Essentially, however, the throughput per user is the total data rate of the AP divided by the number of users attempting to pass traffic on the AP at the same time. A 1Gbit/s AP will supply 1Gbit/s to one user, but 500Mbit/s to two, and the latency could double, although Wi-Fi6 and above can share timeslots between clients, so the latency should remain unchanged in that case.

As a license-exempt technology, the regulatory restrictions are limited to low power (e.g., 23dBm) to not cause interference to other users but also means other Wi-Fi users will experience interference/congestion between themselves.

Table 8: Detailed parameters schedule from IEE 802.11

Band	2400	5500	5925-6425	5925-7125	MHz
802.11 EIRP	20	23/27	23	23	dBm
Available spectrum	83.5	455	500	1200	MHz
Max Cell Radius	200	200	200	variable	M
Area Covered	0.145	0.126	0.126	indoors	sq km
MIMO	4	8	8	8	

Source: IEE 802.11

Wi-Fi offers 'best efforts' quality of service but continues to deliver high data rates for many applications that have become reliant on Wi-Fi connectivity, namely video streaming and gaming, where latency also plays an important role on quality of experience for users.

Access to new 6 GHz spectrum will change this perception, as it will bring an overall improvement in quality of experience, which we discuss further below.

2.7 Access to 6 GHz-Low Power Indoors

Below, we examine the use of Wi-Fi 6E indoors which covers two basic scenarios, indoor public places (e.g., shopping malls, railways stations, other public venues, and homes (households and apartments) and offices.

2.7.1 Lower 6 GHz (5925-6425 MHz) vs the full 6 GHz band (5925-7125 MHz)

Shopping malls, railway stations, industrial sites and public venues are usually a mixture of indoor and outdoor areas, some only qualify as being indoor by virtue of them having a roof, but the area enclosed is vast and would require either higher power Wi-Fi or a significant number of Low Power APs to cover it effectively and support the number of clients likely to be active in that space.

These indoor public areas would be a good use of 6 GHz to ease congestion on existing 2.4 GHz and 5 GHz bands. In Europe, 500 MHz in the lower 6 GHz part has been permitted for use indoors at low power,[31] which means easing of Wi-Fi traffic in dense areas and individual devices able to take advantage of increased peak throughputs. Early versions of Wi-Fi would typically support 20 MHz and 40 MHz channels, which supports many of today's applications such as browsing, streaming and casting between devices. More recently bandwidths to achieve better performance and higher data rates have increased to 80 MHz and 160 MHz leading to a theoretical peak bit rate of around 1-2.5 Gbit/s.

31 Commission Implementing Decision (EU) 2021/1067 of 17 June 2021 on the harmonized use of radio spectrum in the 5 945-6425 MHz frequency band for the implementation of wireless access systems including radio local area networks (WAS/RLANs), European Commission, June 2021 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2021:232:FULL&from=EN

In addition, the 500 MHz of spectrum available for Wi-Fi provides more of the wider bandwidths compared to 5 GHz, namely:

- 6 x 80 MHz channels
- 3 x 160 MHz channels
- 1 x 320 MHz channels

However, if the full 1200 MHz was available at 6 GHz this would provide:

- 15 x 80 MHz channels
- 7 x 160 MHz channels
- 3 x 320 MHz channels

We note the peak data rate is the maximum rate that is possible with the highest modulation level and MIMO available on an access point. For many users, this is unlikely to be achieved, for several reasons:

- **Incoming data rate from broadband may be lower than the peak Wi-Fi data rate**: this is quite common in households with ADSL or lower-rate fiber that cannot produce sustained download speeds approaching that of the Wi-Fi. The fastest average download speed for home broadband is Singapore, with around 200 Mbit/s. In the EU, the average broadband download speed is still around 100-170 Mbit/s [32]
- **Wi-Fi access point is not optimally placed for data throughput:** often located on a convenient (for the broadband installer) table or ledge in a single room in the house/apartment, this non-optimal location results in lower or interrupted signal caused by intervening walls, clutter, or people moving about the vicinity of the AP. The impact on channel quality results in lower modulation levels and results in a lower than optimal data throughput. Additionally, multipath affects the ability of the client device to discriminate between spatial streams, rendering MIMO useful only in line-of-sight applications[33]
- **Multiple users sharing the throughput:** The available incoming data rate is divided between the number of users, and limited by their capabilities and the signal environment they are in. Even under ideal conditions, two users will only get half the peak data throughput each. Wi-Fi is also a Time division Multiple Access (TDMA) system, so airtime is divided into slots for downlinks and slots for clients to use to uplink packet responses and data This is not denying that 1Gbit/s and faster domestic connections are available, but they are still far from ubiquitous and domestic Wi-Fi 6e will be more common than connections that support it all the way up to Wi-Fi 7 and beyond.

In addition, the ASSIA report[34] explains that Wi-Fi can be the bottleneck of connectivity which was found in more than 15%/50% of the connections for the 5 GHz/2.4 GHz bands respectively.

The table below shows the minimum technology requirement for certain domestic applications and the minimum sustain data required for those applications.

---

32 https://www.speedtest.net/global-index

33 In telecoms, MIMO has a reputation for enhancing path resilience in multipath environments, but this is ‘spatial diversity’ mode, which is not used in Wi-Fi. Wi-Fi and 5G uses ‘spatial multiplexing’ mode, which they would refer to simply as ‘MIMO’, where each stream is an independent data conduit, relying on the modulation scheme to achieve a channel quality suitable to sustain it;

34 The State of Wi-Fi: Will it Meet Future Demand? ASSIA, Sept 21, https://assia-inc.com/the-state-of-Wi-Fi-will-it-meet-future-demand/

Table 9: Minimum technology requirement for certain domestic applications

Application	Minimum sustained data rate	Minimum Wi-Fi generation
HD TV (720p)	2.5 Mbit/s	802.11b
HD TV (1080p)	5 Mbit/s	802.11b
UHD/4k/2160p TV	20-25 Mbit/s	802.11g can support two UHD TVs (just)
Gaming	3-5 Mbit/s	802.11b
Videoconferencing	1.5 Mbit/s	802.11b
Telnet (FTP/HTTP/SMTP, etc)	Unlimited	Managed by prioritisation in the router, which should prioritise 'streaming' protocols such as those used for TV and Videoconferencing

This example of a conventional house with two adults watching TV, three kids gaming or streaming TV/Music in their rooms, would require the following:

Table 10: Data requirement: conventional house with children using devices

UHDTV	HDTV	Streaming	Casual Gaming	Total
1x25	1x5	3x5	3x5	60 Mbit/s

There used to be a physical networking rule of thumb to avoid *congestive collapse*[35] in TCP/IP (although protocols have improved since then) that the channel needs to be no more than 1/3 occupied under peak circumstances, then the minimum bandwidth available for a generic busy house (Table 10) should be 180 Mbit/s. This equates to 802.11n, although as the numbers of devices in use increases, so does latency, which is worse in pre-Wi-Fi 5 Wave 2 installations (the current majority).

Because Wi-Fi is not a wired connection, data can be lost due to transient breaks in the path caused by interference or rapid changes in propagation such as people moving about the house (Rayleigh/Rician Fading). This poor performance is often identified by congestion management software (and the users) as packet loss due to congestion, but the real cause is different. Loading a Wi-Fi channel beyond 30% risks rapid throughput collapse caused by retries and other congestion mitigation effects. The situation has improved a lot in recent years but is still a common networking metric.

Additionally, channel quality degradation will force the AP to lower the modulation level to attempt a better signal path, which will slow down the individual user's link and perhaps lead to a lower experience. In modern Wi-Fi systems, this experience is user-specific, but in older systems the degradation is across the AP's client base.

So, placement of the AP is key to ensuring optimal data rates, and in a domestic environment, this is unlikely to be the case. Uninterrupted line-of-sight and a high signal level are essential to obtain the headline 'maximum data rates' and most users will experience less than this, but we have already shown that the maximum data rate is not required for most applications and even 802.11g can happily serve the bandwidth needs of a conventional residence, with a comfortable overhead, albeit with an increased latency.

Latency is the main reason for requiring higher data rates. Not so much for the amount of data that can be sent, but the lower time necessary for each packet to be sent and received. This might appear to be an inefficient use of bandwidth, but with modern transmission protocols APs will consume less power and occupy

35 https://en.wikipedia.org/wiki/Network_congestion#Congestive_collapse

less spectrum when not actually sending traffic. Systems that consume wide bandwidths but may only occupy that bandwidth for a relatively small amount of time can share in a different way to older protocols. This requires a different regulatory approach, especially regarding calculating cumulative interference levels when assessing sharing between services.

Clearly, more available channels enabling extra capacity in both public indoor networks and also home and office deployments will be beneficial to users seeking to use to new and innovative devices and applications (as discussed in Study B). The additional spectrum will be particularly valuable in the most densely populated areas where there is congestion on existing networks.

Additional technical benefits of using the whole of the 6 GHz band

Access to the full 6 GHz band compared to the lower 6 GHz portion provides other technical benefits in addition to extra channels and peak throughputs for users including:

- Largely unencumbered access to the whole spectrum compared to current 5 GHz networks which must avoid radars and implement DFS.
- Flexibility to access wide (160 MHz) channels and narrower (40 MHz) channels to support a full range of different applications. This includes new devices (e.g., AR/VR) that require wider bandwidths separate to 'normal' Wi-Fi access networks for lower bit rate applications in both public indoor spaces, offices, and homes.
- Channels could be reused in densely populated locations, giving a high latent capacity to such a network, and would probably be supplemented by other Wi-Fi bands as well.
- Although shorter range compared to 2.4 GHz and 5 GHz, the 6 GHz band is more self-contained when indoors and in many premises throughout Europe would need a single AP to deliver coverage around the home (assuming the intervening walls are not made of concrete or steel). However, in larger homes or those with thicker walls, it is likely more than one AP would be needed for full coverage.

There is an opportunity to deliver an overall improvement in user experience with access to the full 6 GHz band. This can be achieved by assuming each household has a single AP running (likely to be more than one in an office or larger house) with a single 160MHz channel (possibly two channels in an office), with the neighboring households on different 160 MHz channels minimizing interference and congestion between households. There are many arguments in favor or not of the use of 160MHz channels, whether they make a great difference, or whether the additional bandwidth is more efficient that running an 80MHz channel, and this argument is the same for IMT services and 100MHz channels. In reality, whilst the use of 160MHz channels is mooted here, the reality is that most non-domestic users will use 80MHz channels for better signal to noise and frequency flexibility.

Furthermore, the improved modulation technique of Wi-Fi 6 helps with channel re-use between houses/apartments and would add further capacity and latency benefits.

2.7.2 Access to 6 GHz-Outdoor use

In the 6 GHz band, the technical restrictions set out by, for example, the FCC in the US[36] , and ISED in Canada[37] have enabled two device class options for outdoor use of the 6 GHz band:

- Very Low Power (VLP) in which the device EIRP is limited to 14dBm indoors and outdoors
- Standard Power Access Point with Automated Frequency Coordination (AFC) with EIRP limit of 36dBm and client device EIRP limit of 30dBm

Very Low Power (VLP) Wi-Fi concentrates on the use of 160/320 MHz channels connecting peripherals such as a VR headset to a smartphone or other device which can operate *outside* but at very low power. This technology is expected to be the next generation of Personal Area Networks (PAN) technology replacing Bluetooth which is bandwidth limited and could not support the bitrate of streaming anticipated for future AR/VR or metaverse applications.

2.7.3 Conclusions

Overall, there are clear benefits to RLAN users for accessing the entire 6 GHz band compared to the lower 6 GHz portion this is because:

- Access to the full 1200 MHz in the 6 GHz band provides additional capacity, does not require equipment to support additional complexities, unlike in the 5 GHz band, which has to avoid radar in some channels, and ensures future proof access to spectrum for innovative applications that will start to use multiple 160 MHz and also 320 MHz channels.
- Moving users to 160/320 MHz channels will deliver the additional benefits needed from the EU fiber infrastructure roll out to meet Digital Decade 2025 targets. Domestic APs tend to be integrated in the broadband router, so are the only source of a Wi-Fi connection to the broadband, meaning that the widest possible channel width is required to be effective.
- Full 6 GHz band access enables flexibility of usage and ease congestion on existing 2.4 GHz and 5 GHz networks. This in turn may allow other applications within IoT and other networks be used which could potentially unlock further value and uplifting overall QoS to users
- The regulatory conditions imposed by countries that have unlocked access to the full 6 GHz band are based on coexistence studies which prove sharing with incumbent services FS and FSS is possible meaning there is no need for reframing or reallocating incumbent users which can be inconvenient and costly

36 FCC Opens 6 GHz Band to Wi-Fi and Other Unlicensed Uses, FCC, April 2020 https://www.fcc.gov/document/fcc-opens-6-ghz-band-Wi-Fi-and-other-unlicensed-uses-0

37 Decision on the Technical and Policy Framework for License-Exempt Use in the 6 GHz Band, IZED, May 2021, https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11698.html

3 STUDY B: ECONOMIC ANALYSIS OF 6 GHZ USE

The DSA has outlined that the second part of the project (Study B) will focus on the Economic benefits of IMT WAN vs IMT local networks vs RLANs in 6425-7125 MHz. Based on review sessions with the DSA contact group a common understanding of outputs and ways to achieve this by the study team has been structured in 3 main points:

- **Investment quantification:** investment costs per scenario (cost of implementation using Study A outputs, e.g. number of cells, with additional references[38]) for all 3 scenarios and find out what it enables in terms of applications (item 2 below). The investment quantification will be done for the 3 scenarios regardless of the potential benefits.
- **List of applications triggered per scenario:** based on a combination of technical and market factors, a Multi-criteria analysis (MCA) has been developed to show the delta benefits of enabled connectivity for each of the scenarios. The estimation of benefits will be performed regardless of the “preferred” deployment strategy highlighted under the section about investment quantification.
- **Investment Quality of Service (QoS) ratio:** a quantification of the overall investment cost vs. the updated QoS delivered for the three scenarios.

3.1 Investment costs

This section presents the results of the economic analysis on investment costs for the three scenarios.

3.1.1 Investment Quantification

This section presents the methodology for the quantification of investments needed for the three scenarios.

3.1.1.1 IMT WAN (Scenario 1)

In the absence of information on data volume usage in urban areas, we use population figures as a proxy variable. The assumption behind this is that population determines data consumption and that over a large population the data consumption per capita is on average equally distributed. Therefore, we assume that the technology will be most useful where many people live close together. Deployment in areas of high user density, not specifically urban city centers, but the user density is more likely to be high over a wider area in cities.

For this calculation we have considered every metropolitan area where the functional urban area has more than 250,000 inhabitants. A functional urban area is composed of a city at its core and on daily people’s movements. This classification aims at providing a functional definition of an urban area, by maximizing cross border equivalence and overcoming the restriction of using administrative borders.

A functional urban area consists of a core and the hinterland (a region lying beyond major metropolitan or cultural centers). We generally do not consider the hinterland here, even though this area is still populated densely but for our purposes not densely enough. The OECD defines urban cores as contiguous municipalities with population that live to more than 50% in urban high-density clusters. These clusters are formed by contiguous high-density 1 km² grid cells with a density of at least 1,500 inhabitants per km². The urban core itself needs to have at least 50,000 inhabitants.

Across the EU 228,032,606 people or 50.95% of the EU population live within urban cores. Combined, these cores stretch across an area of 134,422 km² or 3.26% of the EU area within Europe. Not all of this area is

38 including information from ESOA on cost of satellite spectrum clearing (not received to date)

considered for the deployment of the technology. However, the model is flexible, therefore depending on the density requirements and the population size of the metropolitan areas, this level of deployment can be adapted.

Regarding the macrocells sub-scenario the approach would be similar and based on the methodological explanation included in the previous technical sections. Hence, the number of macro sites required will be calculated, assuming the entire band is available, to support 100% of the population at 25 Mbit/s or 100 Mbit/s. These estimations will be based on the number of Macro sites needed to cover the city area (75 major European cities will be considered across all EU27 Member States) assuming three base stations per site (i.e. 10 base stations per square km). However, the study does not foresee any economy of scale benefiting more ambitious scenarios.

In the quantification section the criteria for which urban cores should be considered for deployment will be defined. The resulting size of the area is then used to calculate how many sites are needed. If it is known how many sites are needed, the material and labor costs for the installation can be calculated. The material costs are the same in every country. The labor costs, however, must be adjusted to the respective wage levels in the countries.

3.1.1.2 Local IMT (Scenario 2)

For this scenario we estimate the possible deployment locations, number of base stations sites needed for each of the sectors and then multiply them with the costs per cell. Vertical industries concerned have been narrowed down to the sectors prioritized in our Multicriteria Analysis (MCA introduced later in this section) and a relevant proxy was identified to estimate the number of possible campus networks. We have considered the following sectors for local IMT deployment:

- Construction,
- Healthcare,
- Manufacturing,
- *Education*
- *Public service*
- Airports and ports (Transport)
- Sport stadiums

For each of the sectors above we selected the most relevant applications identified as most relevant for this specific scenario.[39] In the Education and Public Service sectors, the use of private 5G solutions may be limited, as usage is largely indoor, and Wi-Fi is already extensively used for connectivity in these settings[40]. It is unlikely in the future that 5G will be deployed as a private network indoors to replace Wi-Fi, mainly due to high replacement cost but also the types of applications not depending greatly on 5G characteristics such as low

39 For agriculture this is precision farming /smart farming (sensors and cameras). For the construction sector we consider remote sensor monitoring of equipment, machines and materials or UHD surveillance. For healthcare this is wireless tele-surgery and for manufacturing machinery monitoring for predictive maintenance and remote-control. In the transport sector we have included instalments in both ports and airports.

40 Based on the 5G Americas white paper, outdoor 5G systems could complement existing Wi-Fi deployments..

latency or massive machine type communications. Additionally, "vertical use cases" including sport stadiums, ports and airports were included for local IMT deployment.

3.1.1.3 RLAN/Wi-Fi 6E (Scenario 3)

To calculate the costs of deploying RLAN/Wi-Fi 6E we will multiply the costs for a new router with the number of fixed broadband subscriptions. The assumption is that all fixed broadband connections will eventually use Wi-Fi 6E/7. We assume the deployment of routers in today's lower price segment. There might be future economics of scale effects that would lead to a general overall price reduction in the market which justifies the assumption that routers will become cheaper in the long term. The assumption will be that one router costs on average €60, like for example the HONOR router 3.[41] Three possible scenarios are considered:

- In the first scenario, we assume that every currently existing broadband subscription will be equipped with a Wi-Fi 6E router. This would mean 162.7 million new routers are needed.
- In the second scenario, we expect a further increase in fixed broadband subscriptions. We assume that the proportion of the population in the EU with a fixed broadband subscription rises to that of South Korea, the country with the highest proportion of people with such a subscription with 48.55%[42]. This would mean an increase of 32 million fixed broadband subscription and therefore 194.7 million Wi-Fi 6E routers would be needed.
- The third scenario tries to make assumptions about the maximum number of new fixed broadband subscriptions. For this purpose, we assume that every household, every registered company and every registered NGO would get its own connection. In this scenario there would be 220.8 million subscriptions.

Considering that many Wi-Fi 6E routers could be updated thanks to a firmware update, the study will thus compute the upper limit on the cost (i.e. conservative approach).

3.1.2 IMT WAN (Scenario 1)

The economic analysis on investment costs for this scenario considers the costs for the installation of the microcells and macrocells in the EU. Regarding microcells, we considered that every member state will deploy this technology at least in one of its metropolitan areas. Therefore, we have assessed at least 27 deployment countries. However, if we assume that the technology would be deployed in urban cores with at least 1,000,000 inhabitants and/or a population density of at least 1,500 people per km² this would mean that the technology would likely be implemented in only 75 core urban areas across the EU.

Regarding macrocells, we determine the number of sites that would be needed to support 100% of the population in these areas at 25 Mbit/s or 100 Mbit/s, assuming the whole band is available. We made estimations based on the number of Macro sites needed to cover the city area (e.g. major cities, like Paris, Barcelona, Berlin, etc.) assuming three base stations per site (i.e. 10 base stations per km), therefore, the number of sites we assume to cover the population at 25 Mbit/s is calculated.

41https://www.amazon.de/dp/B08F25S6C1/

42 https://ec.europa.eu/EURtat/statistics-explained/index.php?title=The_EU_in_the_world_-_digital_society&oldid=484210#Broadband_subscriptions

Table 11: High-density urban cores in EU countries

Country	Population in urban cores	Population Density in urban cores	Urban Area km²	Share of population covered	Share of country area covered	Number of areas included
AT	1,911,191	4,835	395.25	21%	0.47%	1
BE	1,731,790	10,000.3	366.91	15%	1.2%	2
BG	1,589,461	5,927.1	593.98	23%	0.54%	2
CZ	1,335,084	2,691.7	496	12%	0.63%	1
DE	14,694,611	43,847.7	5,154.5	18%	1.4%	16
DK	805,420	4,479.5	179.8	13.8%	0.42%	1
ES	8,742,785	59,506.4	3,324.6	18%	0.67%	10
EE	437,811	2750	159.2	32.9%	0.35%	1
FI	658,864	920.8	715.48	11.9%	0.21%	1
FR	4,658,376	48,724.7	640.99	6.9%	0.12%	6
EL	1,438,225	42,789.5	108.69	13.5%	0,08%	3
HR	790,017	1,232.5	641	19.6%	1.13%	1
HU	1,752,286	3336,4	525.2	18.0%	0.56%	1
IE	554,554	4,707.6	117.8	11.1%	0.17%	1
IT	7,335,375	31,268.8	2,115.14	12.4%	0.70%	6
LT	592,389	1,477.3	401	21.2%	0.61%	1
LU	128,512	2,497.3	51.46	20.2%	1.98%	1
LV	614,618	2,021.6	304.03	32.5%	0.47%	1
MT	480,134	1,875,5	256	93%	81.01%	1
NL	2,073,000	14,918.4	465.76	11.9%	1.25%	3
PL	4,890,926	14,167.3	1,954.06	12.9%	0.63%	6
PT	832,442	12,389.1	141.47	8.1%	0.16%	2
RO	2,155,240	9,452.8	228	11.2%	0.10%	1
SK	666,000	1,811.8	367.584	12.2%	0.75%	1
SI	295,504	1,804.1	163.8	14%	0.81%	1
SE	1,871,688	10,592.6	712.82	18%	0.16%	3
CY	116,392	2279.5	108.69	13%	0.55%	1
EU	**63,152,695**	**342,305.8**	**20,631.5**	**14%**	**0.5%**	**75**

This would mean that the technology would have to cover 20,632km² and it would reach 63.2 million people in the EU or 14% of the total population. The average population density in these areas would be 4,564 people per km². The distribution of areas included per country strongly reflects the country's population density and its population size.

Therefore, it is not surprising that the country with the most deployment areas is Germany even if countries such as Malta and Luxembourg have a higher proportion of the population in their urban core.

As mentioned in study A, the effect of adding a 6 GHz macrocell to an existing 3.5 GHz macrocell site would be to add additional data capacity closer to the site than the existing 3.5 GHz service provides. This would improve data capacity close-in but do little for those not within Line of Sight.

Furthermore, we assume, as described in Study A, that each user of the cell should receive at least 100 Mbit/s performance. A cell has a maximum capacity of 2000 users and a maximum throughput of 24 Gbit/s using a 100 MHz carrier, 64xMIMO, resulting in 12 Mbit/s for each user. Therefore, at 25 Mbit/s, it can handle 960 simultaneous users, and at 100 Mbit/s it can handle 240 simultaneous users.

If the previously presented calculations for the number of required sites are now applied, the following values result. Overall, 2,428,987 microcells are needed, as illustrated in the table below.

Table 12: Estimation of urban microcells 25 Mbit/s required per EU country

Country	Estimation of urban microcells 25 Mbit/s required per EU country
AT	7,964
BE	7217
BG	6,624
CZ	5,563
DE	61,235
DK	3,356
ES	36,434
EE	1,825
FI	2,746
FR	19,412
EL	5,993
HR	3,292
HU	7,302
IE	2,311
IT	30,567
LT	2,469
LU	536
LV	2,561
MT	2,001
NL	8,640
PL	20380
PT	3,470
RO	8,981

SK	2,775
SI	1,232
SE	7,800
CY	485
EU	**263,171**

In the next step, the costs for the installation of the microcells are calculated. These costs are made up of two components, the material costs, and the labor costs for the installation. Based on consortium knowledge, we can assume material costs of €12,100 and labor costs of €15,567 per site. The material costs always remain the same so we can charge the same cost per unit for each country. The cost of departure varies from country to country depending on wage levels and other influencing factors. Through exchanges with the industry, we know the labor costs in the United Kingdom. With data for the average hourly labor cost across EU countries we can convert these costs across the EU. This calculation results in the following cost:

Table 13: Costs of microcell deployment per EU country

Country	Material costs microcells	Civil costs microcells	Total
AT	€96.364.400	€123.978.380	€220.342.780
BE	€87.325.700	€112.349.569	€199.675.269
BG	€80.150.400	€103.118.130	€183.268.530
CZ	€67.312.300	€86.601.171	€153.913.471
DE	€740.943.500	€953.266.711	€1.694.210.211
DK	€40.607.600	€52.244.028	€92.851.628
ES	€440.851.400	€567.180.850	€1.008.032.250
EE	€22.082.500	€28.410.415	€50.492.915
FI	€33.226.600	€42.747.945	€75.974.545
FR	€234.885.200	€302.193.409	€537.078.609
EL	€72.515.300	€93.295.132	€165.810.432
HR	€39.833.200	€51.247.718	€91.080.918
HU	€88.354.200	€113.672.794	€202.026.994
IE	€27.963.100	€35.976.147	€63.939.247
IT	€369.860.700	€475.847.204	€845.707.904
LT	€29.874.900	€38.435.788	€68.310.688
LU	€6.485.600	€8.344.100	€14.829.700
LV	€30.988.100	€39.867.985	€70.856.085
MT	€24.212.100	€31.150.268	€55.362.368
NL	€104.544.000	€134.501.909	€239.045.909
PL	€246.598.000	€317.262.604	€563.860.604

PT	€41.987.000	€54.018.706	€96.005.706
RO	€108.670.100	€139.810.375	€248.480.475
SK	€33.577.500	€43.199.398	€76.776.898
SI	€14.907.200	€19.178.976	€34.086.176
SE	€94.380.000	€121.425.334	€215.805.334
CY	€5.868.500	€7.550.165	€13.418.665
EU	**€3.184.369.100**	**€4.096.875.210**	**€7.281.244.310**

As a result, we get around €7.37B costs for the installation of microcells[43] for 63.2M people across the EU.[44]

Based on inputs from stakeholders to the technical study, where it was pointed out that the estimated investment costs for scenario 1 should also include costs related to the upgrade of existing macrocells for the EU, the estimated minimum numbers of sites at 3500 MHz for each member state are presented in the table below. Overall, 65,677 macro sites are needed, as illustrated in the table below.

Table 14: Estimation of urban macro sites required at 25 Mbit/s per EU country

Country	Estimation of urban macro sites required and 25 Mbit/s
AT	1,988
BE	1,801
BG	1,653
CZ	1,389
DE	15,282
DK	838
ES	9,093
EE	455
FI	685
FR	4,844
EL	1,496
HR	822
HU	1,822
IE	577
IT	7,628
LT	616
LU	134

43 That offer consistent service at least 100 Mbit/s

44 As highlighted in the methodology, another relevant “investment” to take into account for the IMT WAN scenario is the cost of satellite spectrum clearing

LV	639
MT	499
NL	2,156
PL	5,086
PT	866
RO	2,241
SK	693
SI	307
SE	1,946
CY	121
EU	**65,677**

The cost of upgrading the macrocells is estimated in the following step. Likewise, the material costs and the labor costs for the installation make up the two elements of these expenses. Based on consortium knowledge, and previous studies, we can assume material costs of €73,290 per Macrocell[45] and labor costs of around €50,000 per site[46].

Table 15: Estimated costs for deployment of macrocells

Country	Material costs macrocells	Civil costs macro sites	Total investment costs for macrocell deployment
AT	€145.700.520	€33.133.333	€178.833.853
BE	€131.995.290	€30.016.667	€162.011.957
BG	€121.148.370	€27.550.000	€148.698.370
CZ	€101.799.810	€23.150.000	€124.949.810
DE	€1.120.017.780	€254.700.000	€1.374.717.780
DK	€61.417.020	€13.966.667	€75.383.687
ES	€666.425.970	€151.550.000	€817.975.970
EE	€33.346.950	€7.583.333	€40.930.283
FI	€50.203.650	€11.416.667	€61.620.317
FR	€355.016.760	€80.733.333	€435.750.093
EL	€109.641.840	€24.933.333	€134.575.173
HR	€60.244.380	€13.700.000	€73.944.380
HU	€133.534.380	€30.366.667	€163.901.047
IE	€42.288.330	€9.616.667	€51.904.997
IT	€559.056.120	€127.133.333	€686.189.453

45 Material costs required for one macrocell (data from Real Wireless and Ofcom)

46 Civil costs required for one macro site (data from Real Wireless study on future use cases)

LT	€45.146.640	€10.266.667	€55.413.307
LU	€9.820.860	€2.233.333	€12.054.193
LV	€46.832.310	€10.650.000	€57.482.310
MT	€36.571.710	€8.316.667	€44.888.377
NL	€158.013.240	€35.933.333	€193.946.573
PL	€372.752.940	€84.766.667	€457.519.607
PT	€63.469.140	€14.433.333	€77.902.473
RO	€164.242.890	€37.350.000	€201.592.890
SK	€50.789.970	€11.550.000	€62.339.970
SI	€22.500.030	€5.116.667	€27.616.697
SE	€142.622.340	€32.433.333	€175.055.673
CY	€8.868.090	€2.016.667	€10.884.757
EU	**€4.813.467.330**	**€1.094.616.667**	**€5.908.083.997**

Source: consortium expertise, 2022

Based on these costs, the following overall **investment required of macrocells will approximately cost around €5.9B**.

The table below presents the overall costs for Scenario 1, including both sub-scenarios, thus costs for the installation of microcells and macrocells.

Table 16: Estimated costs for Scenario 1

Country	Total estimated costs for microcell deployment	Total estimated costs for macrocell deployment
AT	€ 220,342,780	€ 178.833.853
BE	€ 199.675.269	€ 162.011.957
BG	€ 183.268.530	€ 148.698.370
CZ	€ 153.913.471	€ 124.949.810
DE	€ 1.694.210.211	€ 1.374.717.780
DK	€ 92.851.628	€ 75.383.687
ES	€ 1.008.032.250	€ 817.975.970
EE	€ 50.492.915	€ 40.930.283
FI	€ 75.974.545	€ 61.620.317
FR	€ 537.078.609	€ 435.750.093
EL	€ 165.810.432	€ 134.575.173
HR	€ 91.080.918	€ 73.944.380
HU	€ 202.026.994	€ 163.901.047
IE	€ 63.939.247	€ 51.904.997
IT	€ 845.707.904	€ 686.189.453

LT	€ 68.310.688	€ 55.413.307
LU	€ 14.829.700	€ 12.054.193
LV	€ 70.856.085	€ 57.482.310
MT	€ 55.362.368	€ 44.888.377
NL	€ 239.045.909	€ 193.946.573
PL	€ 563.860.604	€ 457.519.607
PT	€ 96.005.706	€ 77.902.473
RO	€ 248.480.475	€ 201.592.890
SK	€ 76.776.898	€ 62.339.970
SI	€ 34.086.176	€ 27.616.697
SE	€ 215.805.334	€ 175.055.673
CY	€ 13.418.665	€ 10.884.757
EU	**€ 7.281.244.310**	**€ 5.908.083.997**

Source: consortium expertise, 2022

According to the table above, **installation costs for sub-scenario microcells will approximately cost €7.3B, whereas €5.9B for sub-scenario macrocells**.

3.1.3 Local IMT (Scenario 2)

In a first step, the number of sites that could become campus networks and their average size are quantified.

Table 17: Quantification of campus networks

Sector	Application	Number of campus networks	Area per location
Construction	Remote sensor monitoring of equipment, machines and materials or UHD surveillance	1,85947	0.04 km²
Healthcare	Wireless tele-surgery	24,21748	0.16 km²
Manufacturing	Machinery monitoring for predictive maintenance and remote-control: reduced downtime	15,80049	0.04 km²
Ports	e.g. Real-time inventory and asset tracking UHD surveillance	25650	c. 2km²
Airports	e.g. Autonomous airside vehicles and collision avoidance	23951	c. 2km²
Stadiums	e.g. New immersive experiences (e.g. multi-view AR/VR)	16152	0.04 km²

Source: Consortium based on multiple sources

In a second step, we quantify the cells required per campus network and the resulting costs per campus network. To get the total cost, we multiply the number of cells needed per campus network by the number of networks and the cost per cell. As in Scenario 1, the costs of a cell consist of the material costs and the civil costs (including labor costs).

47 Number of large enterprises in the EU (latest EURtat data)

48 Estimation based on projected number of hospitals in the EU

49 Number of large enterprises in the EU (latest EURtat data)

50 Number of ports with over 2m tonnes of gross weight of goods transported per annum in (latest EURtat data)

51 Number of main airports (latest EURtat data)

52 Number of stadiums with capacity over 30,000

Table 18: Quantification of campus networks

Sector	Number of cells per campus network	Number of campus networks	Overall cost (million €)
Construction	4 (1 Pico 3 GHz, 3 Pico 6 GHz)	1,859	205.7
Healthcare	8 (2 Pico 3 GHz, 6 Pico 6 GHz)	24,217	5,360.1
Manufacturing	15 (5 Pico 3 GHz, 10 Pico 6 GHz)	15,800	6,557.2
Ports	15 (5 Pico 3 GHz, 10 Pico 6 GHz)	256	106.2
Airports	15 (5 Pico 3 GHz, 10 Pico 6 GHz)	239	99.2
Stadiums	4 (1 Pico 3 GHz, 4 Pico 6 GHz)	161	22.3
	Overall	**42,532**	**12,350.7**

Source: Consortium analysis

This results in a total cost of 12.351 billion for Scenario 2 the local IMT.

3.1.4 RLAN/Wi-Fi 6E (Scenario 3)

As described in the methodology part, three scenarios are assumed. In the first, the number of current broadband subscriptions in the EU is multiplied by the cost of a Wi-Fi 6E router. However, it can be assumed that the number of broadband subscriptions will continue to rise in the next few years as they have done in the past.

For this reason, two further scenarios are considered that try to explain this increase.

In the second scenario, it is assumed that the EU will achieve the same number of broadband subscriptions per capita as South Korea, the country with the highest share of broadband subscriptions per capita.

The third scenario tries to make assumptions about the maximum number of new fixed broadband subscriptions. For this purpose, it assumes that every household, every registered company, and every registered NGO would get its own connection.

Table 19: Subscriptions and deployment costs across scenarios

Scenario	Number of subscriptions (millions)	Deployment costs (billion €)
Scenario 1	162.7	9.76
Scenario 2	194.7	11.68
Scenario 3	220.8	13.25

As a result, we see costs of between €9.76 billion and €11.68 billion for the expansion of this technology. In the upper bound Scenario 3, the costs could rise to €13.25 billion.

3.2 Qualitative assessment of the impact on applications

The objective of this specific section is to discriminate between the outcomes of the different deployment scenarios in the upper 6 GHz (i.e. IMT WAN, local IMT and RLAN), based on MCA revolving around a qualitative assessment of application developments (triggered by additional bandwidth/connectivity in a number of reviewed sectors).

Technical and market developments have been used to compare each scenario proposed, discriminating between outcomes in terms of benefits of (delta) connectivity per sector based on applications triggered/in scope.

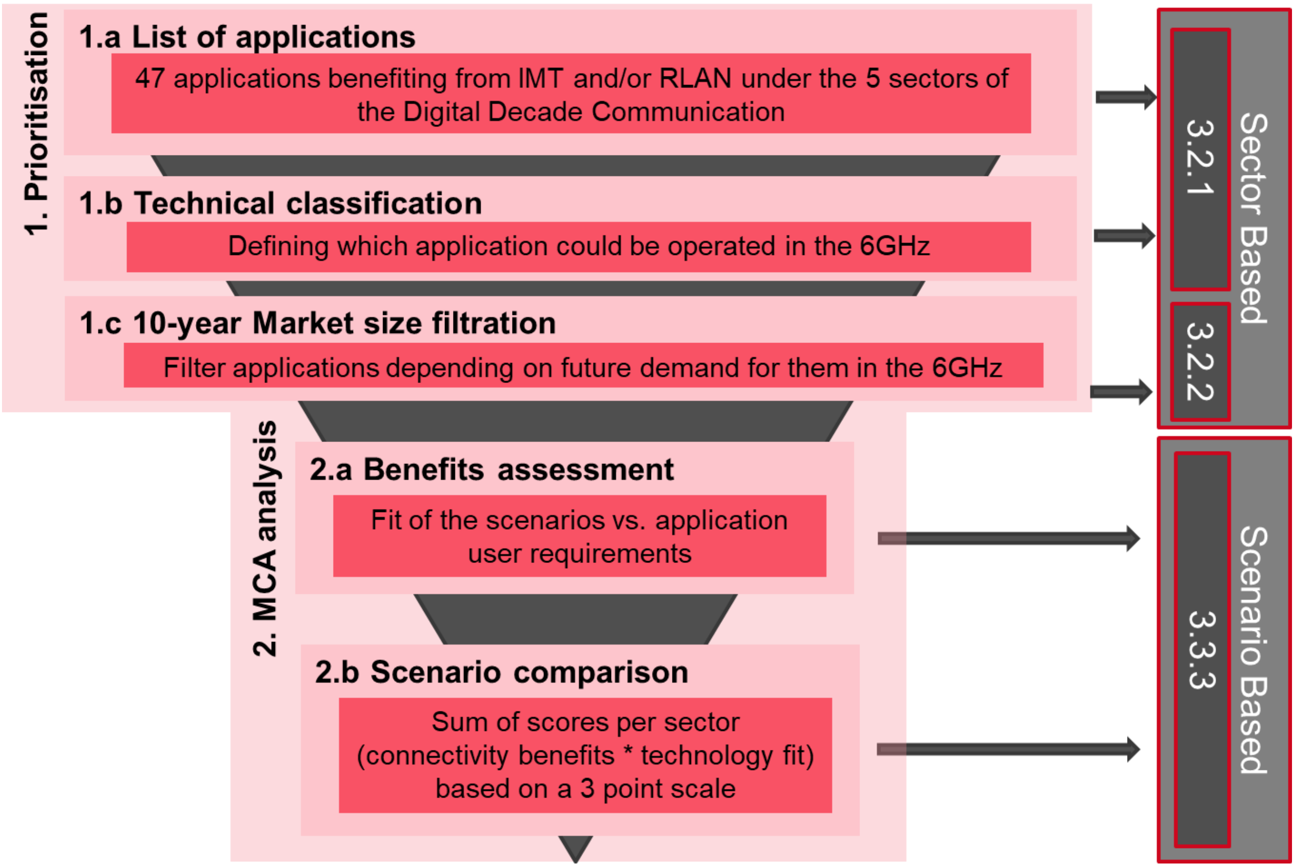

Figure 8: Overview of the Logic for the analysis and relevant sub-sections

Source: Consortium, 2021

The first two sub-sections (i.e. 3.2.3and 3.2.4) cover the assessment based on sectors from the Digital Decade. Then, the MCA assesses the fitness of applications, under each sector, based on the three scenarios, to then compare the relevance of scenario for supporting downstream applications.

3.2.1 Qualitative assessment of applications: Multi-Criteria Analysis

Multi-Criteria Analysis (MCA) is a technique for making a comparative assessment of alternative projects, options, or heterogeneous measures. With this technique, several criteria can be considered simultaneously in a complex situation. Essentially, it applies cost benefit thinking to cases where there is a need to present impacts that are a mixture of qualitative, quantitative, and monetary data, and where there are varying degrees of certainty.

MCA can be used in a variety of settings to structure and combine the different assessments to be considered in decision-making. Its major advantage is that, unlike Cost Benefits Analysis (CBA) and Cost-effectiveness analysis (CEA), MCA does not require all the relevant factors / impacts to be quantified or monetized. Instead, it recognizes the importance of and can consider qualitative data (including stakeholder views and opinions), thus providing a transparent presentation of the key issues at stake and allowing trade- offs to be outlined clearly. Typically, MCA is undertaken in the following key steps:

- **Identify alternative options:** List the alternative interventions, services, or projects that you want to assess and compare.
- **Define judgment criteria**: These might include benefits (e.g. extent to which the options contribute to achieving the objectives) as well as costs (e.g. financial costs, difficulty of implementation).
- **Prioritise the criteria by assigning different rankings or weights:** The weights can be assigned by the analyst, the decision maker, or they can be based on the views of the stakeholders. In some instances, one should consider having different sets of weights, reflecting the views of different stakeholder groups.
- **Score the alternatives in relation to each criterion:** The available qualitative, quantitative and/or monetized data regarding the impacts of each option against the pre-defined criteria needs to be translated into a coherent system (scores, checkmarks, ‘smiley’ faces, etc.).
- **Produce a ranking on which to make a recommendation:** By calculating a combined score based on the different criteria and their weighting, the most favorable option can be identified in a systematic and transparent way.

Table 20: Example of a multi-criteria analysis ‘scorecard’ with three alternative options

Weight	Criteria	Option 1	Option 2	Option 3
3	Achievement of objective 1	+	0	++
2	Achievement of objective 2	++	-	+++
1	Achievement of objective 3	0	++	++++
2	Universal coverage	-	0	++
1	Difficulty of implementation	-	0	+
3	Financial costs	0	--	-
	Total weighted score	**9**	**0**	**4**

MCA will be used whenever CBA nor CEA is feasible or appropriate.

For this study, the MCA approach has been used to assess which scenario will be the most relevant for the uptake of downstream applications. The approach is presented in Figure 7 (below):

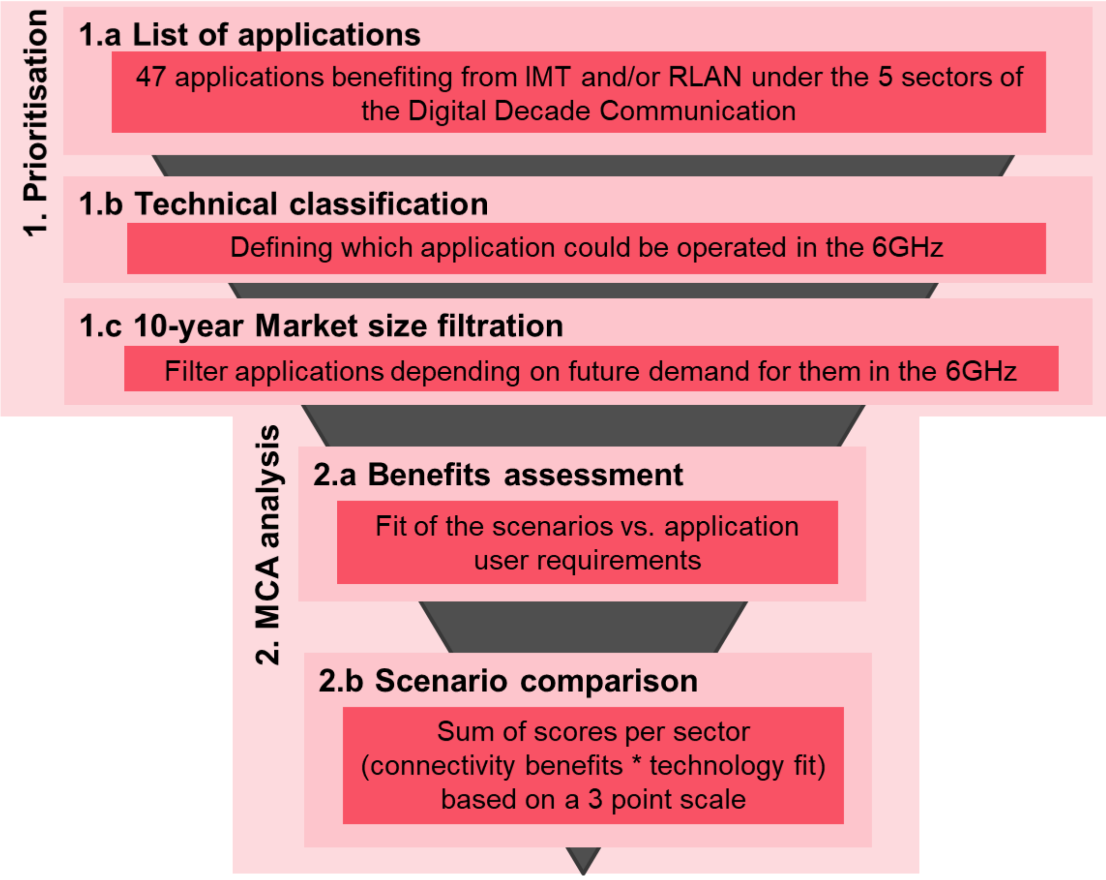

Figure 9: Logic for the Qualitative Assessment of Applications

Source: Consortium, 2021

As highlighted in **¡Error! No se encuentra el origen de la referencia.** above, the MCA analysis will be i ntroduced by a prioritization step. The idea is to first filter and prioritize applications relevant in regard of the Digital Decade, to then identify which of these applications might be operated in the upper 6 GHz, and finally which of these applications might have a growing demand in the future. The second part is a two-step MCA approach where the benefit of each scenario is compared vis-à-vis user/performance requirements of the different applications.

The connectivity requirements of applications are “matched” with scenarios based on the following scale:

Score 0: Deployment scenario/technology will not satisfy application requirements.

Score 1: Deployment scenario/technology will partially satisfy application requirements (requiring complementary technologies).

Score 2: Deployment scenario/technology will satisfy most application requirements)

Score 3: 100% fit deployment scenario/technology vs. application requirements.

Finally, scenarios are compared based on connectivity benefits and the technology fit.

3.2.2 Snapshot of results

Table 21 below highlights the impact of each scenario for each application domain/sector, also demonstrates results from Sector ponderation & connectivity requirements (3.2.5.1). It summarizes the finding from prioritization assessments in section 3.2.3 below.

Table 21: Snapshot of results

Sectors	Sector ponderation based on magnitude of potential impacts	Need for connectivity	Best fit scenario to meet the user needs
Agriculture (3.2.3.13.2.3.1)	3	3	Scenario 1
Construction (3.2.3.2)	12	5	Scenario 2 & 3
Education (3.2.3.3)	6	5	Scenario 3
Public services (3.2.3.43.2.3.4)	6	5	Scenario 3
Healthcare (3.2.3.5)	16	4	Scenario 2
Manufacturing (3.2.3.63.2.3.6)	25	4	Scenario 2 & 3

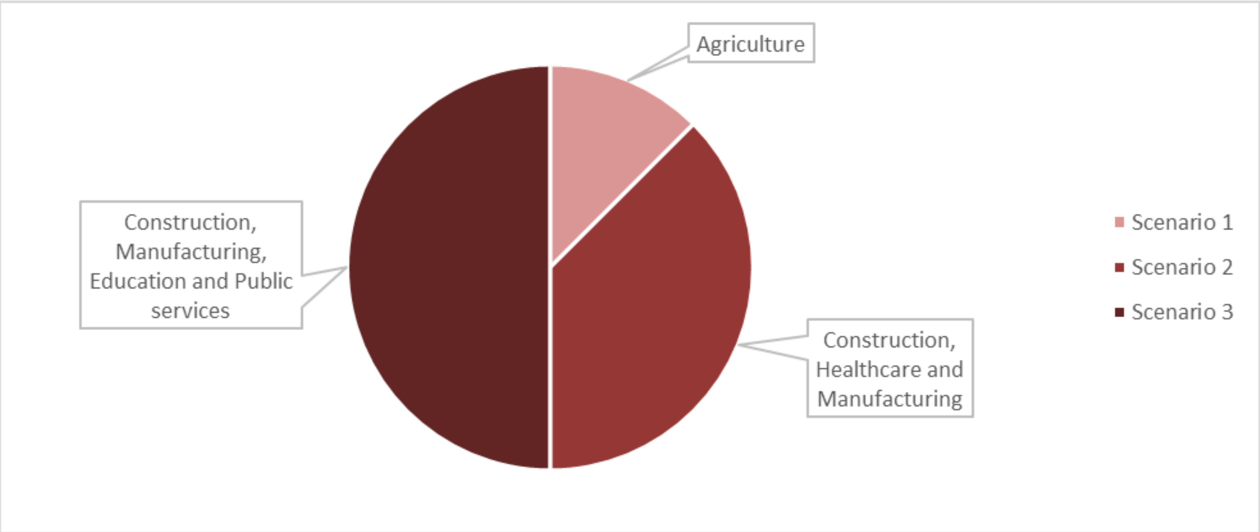

Figure 10: The share scenarios across prioritized sectors

As shown in the figure above, **RLAN (Scenario 3) represents the most fitting scenario for 4 prioritized sectors out of 6**, notably for construction, manufacturing, education, and public services, followed by local IMT (Scenario 2) which is best fitted for healthcare, but also construction and only agriculture is best suited for Scenario 1.

3.2.3 Prioritization

The first step in the qualitative assessment consisted of reviewing emerging applications in the sector and collecting market data on the expected evolution in the upcoming medium-long term (up to 10 years), focusing on connectivity demand. All the applications in prioritized sectors (6 identified below), are subject to an MCA which compares the relevance of each deployment scenario (i.e. WAN IMT, local IMT and RLAN) in terms of their capability to support the identified “downstream” applications. This assessment (presented in Table 22 below) was set in the context of Europe’s future technological direction roadmap i.e. the Digital Decade, which was used as a final criterion to define the relevant sectors (and where applicable, use cases) to be included in the analysis:

- Column “Sector”: includes all the reviewed areas/domains (either from the literature review) or Digital Decade Communication)
- Columns applications:
  - “Applications (Digital Decade)”: lists the use cases/applications (if any) mentioned in the Digital Decade Communication
  - “Sample applications (literature review)”: includes examples of use cases identified through literature review
- Column “Count of applications”: linked to the preceding column, shows the total number of applications linked to a given sector (of the applications identified through literature review, as explained above)
- Column “Market size”: presents a snapshot/indication of the future development of a specific sector in terms of market value closely linked to digitization (and/or promising use case requiring connectivity), based on screened market data and predictions
- Column “Reasoning for analysis”: justification to include a given sector in the assessment

The outcome of this screening consists of a final selection/prioritized sectors (highlighted in green) analyzed more in detail in dedicated sub-sections:

a) Agriculture (3.2.3.1)
b) Construction (3.2.3.2)
c) Education (3.2.3.3)
d) Government/Public Services (3.2.3.4)
e) Healthcare (3.2.3.5)
f) Manufacturing (3.2.3.6)

In addition, a set of horizontal areas have been highlighted as part of the analysis (i.e. Digitalization of SMEs, Remote work/collaboration, Smart villages, digitization of rural areas) given their strategic importance flagged in the Digital Communication. To manage the overlap in terms of “impacts” between these cross-cutting areas and the final selection of sectors, developments in these areas have been treated separately from the MCA.

Table 22: Prioritization and the qualitative assessment of emerging applications across sectors

Sector	Applications (Digital Decade)	Sample applications (literature review-indicative)	Market size	Reasoning for analysis
Agriculture	Smart Farming/ Digital farming technologies	Precision farming (e.g. crops and livestock), autonomous machinery.	The precision agriculture market is expected to reach € 3.7 billion worldwide in 2025 while the autonomous farm equipment will reach 150 billion USD in market value by 2031.[53]	Sector prioritized by the Digital Decade.
Construction	N/A	Remote sensor monitoring of equipment, machines and materials	The global Architecture Engineering and Construction (AEC) market is projected to reach 15.8 billion USD by 2028.[54]	Sector prioritized by the Digital Decade.
Education	eEducation/ Connected Schools	Remote/home-based teaching via interactive platforms	The global E-learning Market to surpass 409 billion USD by 2030.[55]	Application/Sector prioritized by the Digital Decade.
Government/ Public Services	eGovernment/Connected Public Administration	N/A	E-Governance Market expected to reach 45.76 billion USD by 2026.[56]	Application/Sector prioritized by the Digital Decade.

53 Source: Fact.MR

54 Source: Allied market Research

55 Sources: Fatpos global

56 Source: Global news wire

Healthcare	Innovative telemedicine & remote care (monitoring health status), including connected hospitals, robotics solutions	Remote monitoring of patients/early warning of changes in vital signs, video, medicine and 'tactile internet	The Digital Health Market size exceeded 141.8 billion USD in 2020 and is estimated to grow at over 17.4% between 2021 and 2027.[57] According to the Business Research Company data, by 2030, the size of the global telemedicine market will reach about 460 billion USD.	Application/Sector prioritized by the Digital Decade.
Manufacturing	Smart factories: Robotics, Predictive maintenance, Digital twins, Manufacturing-as-a-service	Machinery monitoring for predictive maintenance and remote-control: reduced downtime	The Digital manufacturing market size was $276.5 billion in 2020 and is projected to reach 1,370.3 billion USD in 2028, growing at a CAGR of 16.5% from 2021 to 2030.[58]	Application/Sector prioritized by the Digital Decade.
Energy	N/A	Enhanced smart meters and smart grids	Revenue in the Smart Home market is projected to reach 207.8 million USD by 2026.[59]	Not identified as a priority sector by the Digital Decade.
Entertainment	N/A	Cooperative/off-site media production	VR and AR have the potential to deliver a $1.5 trillion boost to the global economy by 2030.[60]	Not identified as a priority sector by the Digital Decade.

57 Source: GMInsights

58 Source: Allied Market Research

59 Source: Statista

60 Sectors use cases: Product and service development ,Healthcare, Development and training, Process improvements, Retail and consumer

Source: PWC

Financial and insurance	N/A	Enhanced fraud algorithm	Revenue in the Smart Finance Connectivity segment is projected to reach 206 million USD in 2026[61]	Not identified as a priority sector by the Digital Decade.
Mining	N/A	Drone-based video inspections	Mining industry forecasted spend to embrace digitalization amounts to 9.3 billion USD in 2030[62]	Not identified as a priority sector by the Digital Decade.
Tourism	N/A	Enhancement of tourism experiences through VR/AR	The personalized travel and experiences market is estimated to reach 447.3 billion USD by 2030.[63]	Not identified as a priority sector by the Digital Decade.
Transportation	Autonomous vehicles	Improvements in Vehicle-to-everything communications	The Global Autonomous Vehicles Market is expected to reach 325.9 billion USD by the end of 2030.[64]	Autonomous vehicles and related applications (in scope of the Digital Decade) will not be supported by the 6 GHz band.

61 Source: Statista

62 Source: ABI

Sources: Statista Industry Outlook 2021, OECD 2021, EURtat 2021 via Statista

63 Source: Business wire

64 Source: Global News wire

Utilities	N/A	Better waste management and reduced solid waste.	The global IoT utilities market is expected to reach 55 billion USD in 2026.[65]	Not identified as a priority sector by the Digital Decade
Wholesale and retail trade	N/A	Autonomous delivery, in-store customer experience	Global retail e-commerce sales are expected to reach 6,388 billion USD in 2024[66]	Not identified as a priority sector by the Digital Decade.
Horizontal	*Digitalization of SMEs*	*N/A*	Based on McKinsey Global Institute analysis[67], The Digital Single Market could add €375 billion–415 billion per year to annual GDP by 2022, and by 2025, digitization of companies and industries could add €2.5 trillion to European GDP. A more recent report by Deloitte suggests that a 10% increase in the Digital Economy and Society Index (DESI) score is associated with a 0.65% higher GDP per capita. As a result, the study finds that if all EU countries were to invest in digitalization to achieve a score of 90 by 2027, this would result in a 7.2% increase in GDP per capita [68]	*SMEs will play a key role in Europe's digital transformation (highlighted by the Digital decade communication). Nevertheless, this impact is expected to be cross-cutting for a number of sectors. For instance, the expected horizontal impact: more than 90% of European SMEs reach at least a basic level of digital intensity in the Digital Decade communication.*

65 Source: Market Data forecast

66 Source: Statista

67 Source: McKinsey Global Institute analysis

68 Source: Deloitte 2021

Horizontal	*Remote work/collaboration*	*N/A*	For example, a study by the Carbon Trust estimated the emissions savings of homeworking, in a number of European countries estimating that annual GHG savings from homeworking could amount to 12.2 Mt CO2e in Germany and 8.7 Mt CO2e in Italy, equivalent to 83 million and 60 million London to Berlin passenger flights.[69]	*Access to affordable, secure and high-quality connectivity is one of the prerequisites enabling "Digital Citizenship" i.e. all Europeans to make full use of digital opportunities and technologies.* *Expected horizontal impact (for sectors where remote working is possible): substitution of business travel.*
Horizontal	*Smart villages (digitization of rural areas)*	*N/A*	*Digitalization (covered above "Digitalization of SMEs") and enhanced connectivity in remote locations will affect 3.4 billion people living in rural areas globally[70]; Rural areas represent 83% of the total EU area where 30.6% of the EU population lives.[71]*	*Expected horizontal impact: innovative solutions to improve resilience of rural areas, building on local strengths and opportunities according to the Digital Decade communication.*

69 Source: Carbon Trusthttps://www.greenpeace.de/publikationen/homeoffice-and-climate-change

70 Source: UN

71 Source: EC

The following sub-sections analyze each of the prioritized sectors in more in detail in terms of:

- market digitalization and main applications/ technology trends;
- overview of the benefits of digitalization and connectivity for the sector;
- technical classification of applications in the 6 GHz vs. user needs.

3.2.3.1 Agriculture

3.2.3.1.1 Agriculture digitization

The digital transformation of agriculture accelerates collaboration along the value chain, supports farmers and offers opportunities for innovative SMEs. At the farm level, we can achieve more and better with less effort through innovation.[72]

Europe's future technological direction roadmap (i.e., the Digital Decade 2030) recognizes agriculture as a strategic sector where digitalization can contribute to a reduction in global greenhouse gas emissions and pesticide use. The use of various digital agricultural technologies is portrayed as an opportunity for the sector to become more competitive and sustainable.[73]

The use of digital tools in agriculture which ranges from smartphones, computers, to sensors in the field, drones, and satellites, is becoming more prominent among EU farmers.[74] Among techniques used in agriculture, precision farming is a management approach that focuses on observing (in near real time), measuring, and responding to variations in crops, fields, and animals, is employed most widely.[75]

Precision farming relies on the use of smart farming (SF) that uses data generated by different technologies while managing the farm activities[76]. Furthermore, a key component of this innovative approach to land management is the use of hardware and software (e.g. sensor nodes, control systems, robotics, satellites), for imaging and positioning, data storage and analysis, advisory systems, and drones.

The digitalization of agriculture is a key component of the EU's recovery plan post Covid-19, stressing that it offers an opportunity to kick off a **digital revolution in agriculture**.

In particular, the focus is on sustainable agriculture, which includes innovative agricultural tools and effective agronomic techniques to meet consumer demand for healthy, safe, diverse, and affordable food.[77]. For

---

72 Source: Agricultural productivity and innovation, OECD, [Agricultural productivity and innovation-OECD]

73 2030 Digital Compass: the European way for the Digital Decade, European commission, 2021 https://ec.europa.eu/info/sites/default/files/communication-digital-compass-2030_en.pdf

74 Source: European Commission, Developing digital technologies, [Developing digital technologies | EIP-AGRI (europa.eu)]

75 Source: Ibid

76 Source: European Commission, The Digitization of the European Agricultural Sector, [Digitization of Agriculture | Shaping Europe's digital future (europa.eu)]

77 Source: Sustainable agriculture, OECD, [Sustainable agriculture-OECD]

instance, those offering growers with integrated and innovative pest management solutions, also known as IPM[78].

Internet of Things (IoT) is being used in various applications, especially in precision agriculture where real-time IoT data is combined with accurate geospatial data. To make better decisions, farmers are using IoT sensors to collect environmental and machine data and improve various aspects of their work, such as monitoring livestock and crop production.[79]

The World Economic Forum estimates that if only 15-20% of the world's farms switched to precision agriculture by 2030, yields could increase by 10-15%, while greenhouse gas emissions and water use would be reduced by 10% and 20% respectively.[80]

Among the many benefits, the digitalization of agriculture contributes to higher economic and environmental performance, but also improves farmers' working conditions. It also creates environmental sustainability by helping to make agriculture greener. For example, through the virtual representation of physical assets such as equipment and fields, which relies on the use of data generated by sensors using artificial intelligence and the cloud to optimize water consumption, apply seeds and fertilizers correctly or reduce the use of pesticides.[81] Furthermore, digitalization for agriculture accelerates the competitiveness of the EU digital supply industry.[82] For instance, in 2017, smart farms enabled by digital connectivity, have led to productivity gains and cost reductions of €8,700 per farm[83].

Table 23 below summarizes the list of major technologies used in the agriculture industry and their potentials.

78 Source: European Commission, Integrated Pest Management (IPM), Integrated Pest Management (IPM) (europa.eu)

79 Jinyuan Xu, Baoxing Gu, Guangzhao Tian, Review of agricultural IoT technology, Artificial Intelligence in Agriculture, Volume 6, 2022, Pages 10-22.

80 Source : System Initiative on Shaping the Future of Food Security and Agriculture, The World Economic Forum, 2018, WEF_Innovation_with_a_Purpose_VF-reduced.pdf (weforum.org)

81 Source: Ibid. European Commission, The Digitization of the European Agricultural Sector.

82 Source: Ibid

83 Source: Improving farm returns. Enhancing the environment. Smart Farming, PROGRESS REPORT, 2017, SFRF.pdf (smartfarming.ie)

Table 23: Major technologies used for the agriculture industry

Technologies	Technology potential for the agriculture industry
Precision Agriculture	New precision agriculture companies are developing technologies that enable farmers to maximize yields by controlling all variables of cultivation such as moisture, pest infestation, soil conditions and microclimate. By providing more accurate techniques for planting and growing crops, precision agriculture enables farmers to increase efficiency and reduce costs.
Indoor Vertical Farming	Indoor Vertical Farming involves growing racks vertically on top of each other in an enclosed and monitored environment. This technology improves crop yields, saves land area, and reduces the distance travelled in the supply chain, reducing farmers' impact on the environment. In addition, farmers using this technology use about 70% less water than conventional farms.
Farm Automation	Farm automation is often referred to as a practice of 'smart farming' and is used to make farms more efficient by automating the production cycle (livestock or crop production). For example, crop automation, autonomous tractors, seeding and weeding, and drones. Farm automation technology is a response to important issues such as the rising global population, the shortage of agricultural labor and changing consumer preferences.
Livestock Farming Technology	Livestock management is the management of poultry farms, dairy farms, cattle farms or other agribusinesses related to livestock production. Livestock managers must keep accurate financial records, supervise workers and ensure proper care and feeding of the animals.
Modern Greenhouses	The greenhouse industry has transformed from small facilities used primarily for research and aesthetic purposes (e.g. botanical gardens) to much larger facilities that compete directly with conventional food production on land. Modern greenhouses are becoming increasingly technology-heavy, using LED lights and automatic control systems to make the growing environment perfect.
Blockchain	Blockchain's ability to track proof of ownership and tamper evidence can be used to address pressing issues such as food fraud, safety recalls, supply chain inefficiencies and food traceability in the current food system. Blockchain's unique decentralized structure ensures verified products and practices to create a market for premium products with transparency.
Artificial Intelligence	The goal is for farmers to use artificial intelligence and data collection with remote sensors, satellites, and drones to achieve their objective of a better harvest through better decisions in the field. These can monitor plant health, soil condition, temperature, humidity, etc. Remote sensors allow algorithms to interpret a field's environment as statistical data that is understandable to farmers and useful for decision-making.

Source: Consortium elaboration (2022)

The table below provides an overview of applications identified via literature review

3.2.3.1.2 Technical classification-6 GHz: Applications & user needs-Agriculture

According to the FCC Precision Agriculture Connectivity task force[84], the Agriculture Community requires both broadband and narrowband connectivity. The two initial types of broadband coverage necessary to increase the adoption of precision agriculture equipment and practices are identified as:

1) low-speed, broad coverage (for in-field operations) and

2) high speed, high throughput, and targeted coverage (for farm management systems).

For indoor smart farming, Wi-Fi is likely the only service that would be used while outdoor farming and sensors mostly relies on low band wide-area IMT and/or LoRaWAN or conventional Business Radio IoT.

Table 24: Application Requirement: Agriculture

Application	Connectivity requirements			Ranking fitness		
	Static/ dynamic	Indoor/ outdoor	Low latency (Y/N)	Scenario 1	Scenario 2	Scenario 3
Precision farming /smart farming (sensors and cameras)	Static	Indoor & outdoor	No	2	1	0.5
Autonomous machinery	Dynamic	Indoor	No	2	2	1
VR/AR (training)	Static & dynamic	Mostly indoor	Yes	1	1	2
			Total score	5	4	3.5
			Average score	1.66	1.33	1.16

Source: Consortium Analysis

Nonetheless, agriculture does not appear to be a suitable fit for 6 GHz, primarily because it is expected based on the investment quantification that MNOs will largely deploy cells in urban areas, while agriculture is primarily performed in rural areas, even if there are some exceptions[85]. Thus, allocating the upper 6 GHz band to scenario 1 will most likely not necessarily benefit agriculture, however it might greatly benefits use cases not covered under the Digital Decade (e.g. video streaming, gaming, etc.)[86]. In fact, there are other spectrum

84 Source: Task Force for Reviewing the Connectivity and Technology Needs of Precision Agriculture in the United States, the Federal Communications Commission, 2021, Task Force for Reviewing the Connectivity and Technology Needs of Precision Agriculture in the United States | Federal Communications Commission (fcc.gov)

85 FAO, Transforming the livestock sector through the Sustainable Development Goals, 2018. Available on: https://www.fao.org/3/CA1201EN/ca1201en.pdf?eloutlink=imf2fao

86 GSMA, Estimating the mid-band spectrum needs in the 2025-2030 time frame, 2021. https://www.gsma.com/spectrum/wp-content/uploads/2021/07/Estimating-Mid-Band-Spectrum-Needs.pdf

options available today, such as the mmWave technology/band that is being developed and made available by a number of governments for usage in agricultural settings[87].

3.2.3.1.3 Impact of connectivity (2030)-Agriculture

According to McKinsey[88], increasing the autonomy of machines through better connectivity could add $50-60 billion in value by 2030. The same source concludes that **using faster and more reliable connectivity between soils, farm equipment and farm managers could unlock $130-175 billion in value by 2030**. This latter figure will be referenced as a proxy to "weigh" the potential impact of connectivity in the sector for the MCA (3.2.5).

3.2.3.2 Construction

3.2.3.2.1 Construction digitization

Whilst other industries have already adopted digital processes and methods, such as e-commerce, e-health, etc., construction has so far remained an industry characterized by manual processes and traditional methods. According to research by McKinsey, productivity in construction has increased by only 1% over the past two decades[89], making it the sector with the lowest productivity growth compared to all other major sectors over the last 20 years[90].

In contrast, 70% of construction executives said that new and innovative construction technologies and digitalization are potentially the most important drivers of change in the industry.[91]

The digitalization of construction offers the opportunity to meet market demand and improve construction projects. For example, it allows builders to easily connect different aspects of the construction industry, such as facilities and suppliers. It also enables processes to be automated, construction tools to be connected and labor and supply chains to be managed efficiently. According to a 2019 study by Deloitte[92], connected construction companies have many advantages over traditional companies. These include their ability to optimize time and resources and improve the performance of construction projects by tracking the various stages of the construction cycle in near real-time, while effectively managing construction assets and resources in a timely manner and improving the overall execution of construction and infrastructure projects.

---

87 Source: Rural Dorset to test 5G mmWave technology for next generation agriculture, 5G RuralDorset, 2022, Rural Dorset to test 5G mmWave technology for next generation agriculture - 5G RuralDorset

88 Source: *Agriculture's connected future: How technology can yield new growth*, McKinsey, 2020, Article, https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth

89 Source: Reinventing construction: a route to higher productivity, McKinsey, 2017, MGI-Reinventing-Construction-Executive-summary.pdf (mckinsey.com)

90 Source: Shaping the digital transformation in Europe, McKinsey, 2020, Report, mgi_connected-world_discussion-paper_february-2020.pdf (mckinsey.com)

91 Source: Ibid

92 Source: Winning with connected construction, Deloitte, 2019, https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/digital-opportunities-in-engineering-and-construction.pdf

Consequently, networked construction companies could generate profits at various stages of project development. This study estimates that construction hours can be reduced by 10-30%, construction costs and shutdown hours by 5-10%, and operating costs by 10-20%.

As illustrated in Table 26, networked and connected construction tools such as virtual and augmented reality (AR/VR) and automation create intelligent networked construction sites. For example, they make equipment work smarter and help reduce downtime through proactive equipment monitoring and enable actionable insights and predictions to be gathered about construction projects.[93]

Table 25 below summarizes the list of major technologies used in the construction industry and their potential applications.

93 Source: Ibid.

Table 25: Major technologies used/for the construction industry

Technologies	Technology potential for the construction industry
Robotics	From autonomous rovers and drones that can increase the efficiency of construction site inspections to mechanical arms that automate highly repetitive tasks such as bricklaying and tying rebar, the robotics revolution is expected to gain significant momentum.
Automation	The rise of artificial intelligence (AI) is beginning to have an impact on construction, from the big leaps in concepts like predictive design in the project planning phase, to the emergence of smart buildings that learn how to best function themselves and serve their users over time.
3D printing	Precise digital design information enables the use of 3D printing for everything from rapid prototyping, component manufacturing and scale modelling to full-size printing of project components.
Autonomous vehicles	Construction site automation, the combined use of autonomous technology and electrical power, makes it possible to work around the clock without having to take breaks and without the disruptive noise levels that traditionally prevent such work.
Unmanned aerial vehicles (UAVs)	From conducting inspections to ensure workers are not put in harm's way to surveying vast swathes of land in just minutes, the continued rise of UAVs will greatly improve safety and productivity in the construction industry.
Virtual and augmented reality (VR/AR)	VR/AR will allow not only project teams and stakeholders to see proposed plans before construction begins but also walking through complex site logistics plans as well as support health and safety training.

Source: Consortium elaboration (2022)

In addition, the World Economic Forum reported that the significant impact of widespread digitization could help the engineering and construction industry overcome its decades-long lack of productivity advances and generate an estimated $1.0 trillion to $1.7 trillion in annual cost savings[94].

94 Source: Building the Future of Construction, World Economic Forum, 2018, Building the Future of Construction > Press releases | World Economic Forum (weforum.org)

In the table below we summarize the list of applications identified via literature review and their relevance for the upper 6 GHz band:

Table 26: Applications-Construction

Application	Need for additional bandwidth satisfied by 6 GHz (Y/N)	Comment
UHD surveillance	Yes	5G or Wi-Fi depending on required reliability and resilience. Wi-Fi is cheaper to deploy and better for flexibility.
Remote sensor monitoring of equipment, machines and materials	Yes	As above: construction is cost sensitive so would either have Wi-Fi or use MNO networks not necessarily 5G

Source: Consortium Analysis

3.2.3.2.2 Technical classification-6 GHz Applications & user needs-Construction

To take advantage of new technologies, construction companies will need high-quality, reliable, on-site connectivity.[95]The following table provides an overview of connectivity requirements for the selected Construction applications:

Table 27: Application requirements - Construction

Application	Connectivity requirements			Ranking fitness		
	Static/ dynamic	Indoor/ outdoor	Low latency (Y/N)	Scenario 1	Scenario 2	Scenario 3
UHD surveillance	Static	Indoor & outdoor	No	1	2	2
Remote sensor monitoring of equipment, machines, and materials	Static & Dynamic	Outdoor	No	1	2	1
VR/AR (training & collaboration)[96]	Static	Mostly indoor	Yes	1	1	2
			Total score	**3**	**5**	**5**
			Average score	**1**	**1.66**	**1.66**

Source: Consortium Analysis

95 Source: The Future of Construction is Digital, Thanks to Wireless Onsite Connectivity, IoT For All, 2021, https://www.iotforall.com/the-future-of-construction-is-digital-thanks-to-wireless-onsite-connectivity

96Source: *The Power of Augmented Reality (AR) in Construction*, Grace Ellis, Autodesk, Blog, 2021, https://constructionblog.autodesk.com/augmented-reality-ar-construction/

Based on the above table it is worth noting that both Scenario 2 and Scenario 3 are the most adapted to answer the demand for connectivity from Construction applications. It can be explained by the fact that applications are mostly expected to be static in a very localized area, with limited need for low latency.

3.2.3.2.3 Impact of connectivity (2030) - Construction

Based on a BCG study for WEF, the significant impact of widespread digitization of the sector could help the construction industry improve its slow pace of development and productivity progress, offering the possibility of saving an estimated amount between $1.0 trillion and $1.7 trillion in annual costs[97]. Preliminary studies have linked the use of IoT in construction projects to an estimated average cost saving of around 22-29% of total project costs[98]. If connectivity is assumed to account for 20%, this would mean an impact of $200-340 billion. This latter figure will be referenced as a proxy to "weigh" the potential impact of connectivity in the sector for the MCA.

3.2.3.3 Education

3.2.3.3.1 Education: digitization

In the last two decades, digital technologies in education have spread to schools and educational institutions worldwide. In short, digitalization in education refers to the use of digital technologies to teach students. This is explained by the so-called "digital pedagogy", which refers to a new way of learning that uses digital technologies as a direct effect of rapid technological change and aims to ultimately improve student learning[99]. In summary, the European Commission states that "digital literacy" comprises two main components, firstly the development of digital competences for learners and secondly the pedagogical use of digital technologies[100].

Digital education includes the use of desktop computers, mobile devices, the Internet and software applications, and other types of digital technologies. The new digitized learning methods in the era of "digital pedagogy" include online exams, online courses including e-books, and overall, the rise of online universities. Eventually, the education sector is expected to be fully digital, supported by artificial intelligence and virtual reality.

In the EU, the COVID-19 pandemic led to the widespread use of digital learning methods in education and training. In this context, the European Commission has published an Action Plan 2021-2027 on Digital Education, which includes measures to ensure adequate investment in connectivity, equipment and

---

97 Source: Ibid. Building the Future of Construction, World Economic Forum.

98 Source: Ghosh, Edwards, and Hosseini, M.R. (2020). "Patterns and trends in Internet of Things (IoT) research: future applications in the construction industry", Engineering, Construction and Architectural Management.

99 Source: New trends in online learning: the impact of disruptive technologies, EFMD Global, 2021, https://blog.efmdglobal.org/2021/11/22/new-trends-in-online-learning-the-impact-of-disruptive-technologies2/

100 Digital Education at School in Europe, European Commission, 2019, Eurydice Brief, https://eacea.ec.europa.eu/national-policies/eurydice/sites/default/files/eurydice_brief_digital_education_n.pdf

organizational capacity and skills, and ensure that everyone has access to digital education by 2027. Furthermore, digital literacy should be a core competence for all educators and teachers.[101] On the other hand, European Broadband Targets assume that all schools and educational institutions will have access to gigabit internet connections by 2025. In the EU, most schools are increasingly demanding high- bandwidth applications such as video streaming or video conferencing[102].

However, according to a 2019 survey conducted by Deloitte and IPSOS on behalf of the European Commission, information and communication technology (ICT) infrastructure in education varies widely across European countries, with fewer than 1 in 5 students attending a European school with access to high-speed internet of more than 100Mbit/s.[103]

While the acquisition of digital competences by all pupils in the EU is envisaged as an ambitious goal by 2027, the majority of European education systems have already included some aspects of five digital competence areas in the DigComp framework (DigComp)[104] in 2019, either as a cross-curricular topic or as a compulsory subject. This includes[105]:

- Information and data literacy,
- Digital content creation,
- Communication and collaboration,
- Safety, and:
- Problem solving.

Table 28 below presents each of the five digital competence areas under the DigComp 2.0 framework.

Table 28: The five digital competence areas under the DigComp 2.0 framework

Competence areas	Competences
Information & data literacy	• Browsing, searching, and filtering data, information and digital content • Evaluating data, information, and digital content • Managing data, information, and digital content

101Source: Action plan 2021-2027 on digital education, EC, 2020 https://education.ec.europa.eu/sites/default/files/document-library-docs/deap-communication-sept2020_en.pdf

102 Source: The Communication on the Digital Education Action Plan, EC, 2018 https://eur-lex.europa.eu/legal-content/EL/TXT/?uri=CELEX%3A52018SC0012

103 Source: 2nd Survey of Schools: ICT in Education, Deloitte and IPSOS, on behalf of the European Commission, 2019, Report, Study, 2nd Survey of Schools: ICT in Education | Shaping Europe's digital future (europa.eu)

104 The EU has developed the Digital Competence Framework for Citizens-known as DigComp-and a related self-assessment tool. These resources provide people with the opportunity to assess their **digital competence** and identify gaps in their knowledge, skills and attitudes.

105 European Commission, The Digital Competence Framework 2.0, https://joint-research-center.ec.europa.eu/digcomp/digital-competence-framework-20_en

Communication & collaboration	• Interacting through digital technologies • Sharing through digital technologies • Engaging in citizenship through digital technologies • Collaborating through digital technologies • Netiquette • Managing digital identity
Digital content creation	• Developing digital content • Integrating and re-elaborating digital content • Copyright and licenses • Programming
Safety	• Protecting devices • Protecting personal data and privacy • Protecting health and well-being • Protecting the environment
Problem solving	• Solving technical problems • Identifying needs and technological responses • Creatively using digital technologies • Identifying digital competence gaps

Source: European Commission, The Digital Competence Framework 2.0

As highlighted in the table above, to be able to speed up the acquisition of digital competences by all students in the EU, European education systems will need a high level of connectivity to achieve the five digital literacy areas listed in the DigComp framework by 2027.

Table 29 below provides an overview of the digital competence theme in European education systems and other selected countries and how this theme is considered across countries.

Table 29: Digital competence theme in European education systems, by country [106]

A cross-curricular theme	A compulsory separate subject	Integrated into other compulsory subjects	Combine two approaches (cross-curricular theme and compulsory theme)	All three exist at the same time
More than half of the European education systems	Bulgaria, Czechia, Greece, Poland, Portugal, UK (ENG & WAL), Iceland, Liechtenstein,	Czechia, Ireland, Spain, France, Italy, Cyprus, Lithuania, Slovenia,	Ireland, Greece, Spain, France, Italy, Poland, Portugal, Slovenia,	Czechia Liechtenstein

106 Source: European Commission, Digital Education at School in Europe, Eurydice Brief, 2019, https://eacea.ec.europa.eu/national-policies/eurydice/sites/default/files/eurydice_brief_digital_education_n.pdf

	Montenegro North Macedonia	Sweden Liechtenstein	Sweden, UK (Wales) Iceland	

Source: European Commission, Digital Education at School in Europe, Eurydice Brief, 2019

As can be seen from the table above, almost all European education systems have integrated digital literacy as part of their pedagogy, although this teaching approach varies from country to country, placing it either as a cross-curricular topic or as a compulsory subject. This indicates that countries provide different digital tools to their students and have different levels of school connectivity.

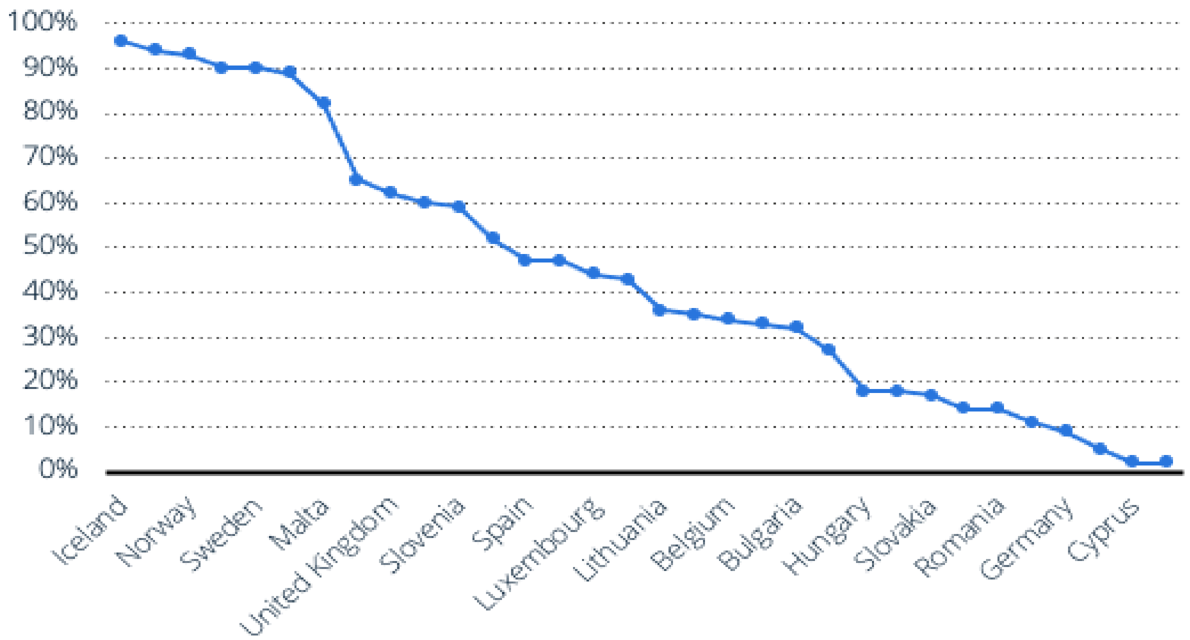

Figure 11: Share of highly digitally equipped and connected primary schools in European countries in 2017/18[107]

Source: European Commission, 2019

As demonstrated in Table 29 and Figure 11, countries where digital literacy is an integral part of their systems, both as a cross-curricular topic and as a compulsory subject, have demonstrably the best digitally equipped and connected primary schools. Iceland, Norway, and Sweden in particular.

107 Source: *New trends in online learning: the impact of disruptive technologies*, EFMD global, 2021, https://blog.efmdglobal.org/2021/11/22/new-trends-in-online-learning-the-impact-of-disruptive-technologies2/

Table 30 below summarizes the list of major technologies used in the education and their potentials.

Table 30: Major technologies in education

Technologies	Technology potential for education
Digital readers and tablets	Digital readers and tablets save students from carrying around a heavy backpack full of books. They provide a central, easily accessible location for all reading material. Regular updates of digital content eliminate the cost of buying new textbook editions every few years. Apps installed on tablets can meet students' educational needs and provide more personalized learning opportunities.
Cloud technology	The cloud hosts applications and services on the internet rather than on the user's computer. It allows information to be stored, shared and accessed on any device connected to the internet. In education, the cloud is used to shop and share digital textbooks, lesson plans, videos and assignments.
Mobile Apps	Some schools are integrating mobile technology into the learning process through educational apps. The wide variety of apps available offers students the opportunity to engage in their own learning process. Educational apps offer the opportunity to personalize learning for each student.
3D printing	In the classroom, 3D printing can create hands-on models that students can examine and interact with. For example, students can learn about the geography of an area by looking at a 3D map of it. 3D printing appeals to both visual and kinesthetic learners. It engages students and makes them curious. It reduces the time teachers have to spend on creating their own models (e.g. for a science lesson).
Virtual reality	The technology for virtual reality, augmented reality and mixed reality is developing rapidly. One of the most important applications of these technologies in the classroom is to take students on virtual field trips to places that are otherwise inaccessible. It provides engaging, real-world experiences that would otherwise be harmful or inaccessible. It appeals to visual learners who like to see and experience things rather than just read about them.
Gamification	Gamification is increasingly being used in education for a number of reasons. In short, it "makes strenuous lessons more fun" and helps motivate students and get them excited about the subject matter. It creates enthusiasm for the lesson and gives immediate feedback.
Artificial intelligence	AI is making its way into education by automating grading and feedback and providing personalized learning opportunities. It can save teachers time by doing the grading and feedback on their behalf. It provides better insight into student learning.

Source: Consortium elaboration (2022)

As presented in the table above, many of the applications mentioned require a high level of connectivity.

This explains why many of these technologies, such as artificial intelligence and virtual reality, are not yet available to the majority of students, as the number of networked schools worldwide is small and there are high connectivity requirements to enable them in modern teaching methods.

The table below provides an overview of applications identified via literature review as well as the Digital Decade communication and their relevance for the upper 6 GHz band:

Table 31: Applications-Education

Application	Need for additional bandwidth satisfied by 6 GHz (Y/N)	Comment
Remote/home-based teaching via interactive platforms	Yes	Wi-Fi use case
Connected schools	Yes	Wi-Fi use case
high-performing digital education system	Yes	Wi-Fi use case

Source: Consortium Analysis

The demand driven by all applications identified in the sector is expected to be met by the upper 6 GHz band.

3.2.3.3.2 Technical classification-6 GHz Applications & user needs-Education

For university campuses, both outdoor and indoor coverage is required with high levels of bandwidth. Large campuses can be found with as many as 10-17K access points.[108] Among the Digital Decade targets, schools are expected to have access to **gigabit connectivity** by 2025 to accommodate video streaming or video conferencing applications.[109]The table below first introduces the relevant connectivity requirements and then ranks their fitness for each scenario:

Table 32: Application Requirements-Education

Application	Connectivity requirements			Ranking fitness		
	Static/ dynamic	Indoor/ outdoor	Low latency (Y/N)	Scenario 1	Scenario 2	Scenario 3
Remote/home-based teaching via interactive platforms	Static	Indoor	No	0	0	2
Connected schools	Static	Indoor	No	0	1	2
High-performing digital education system[110]	Static	Indoor	No	1	0	2
AR/VR (training)	Static	Indoor	Yes	0.5	1	2
			Total score	**1.5**	**2**	**8**

108 Source: Cisco

109 Source: EC

110 Based on the Digital Decade Communication, High-performing digital education ecosystem is understood as a combination of connectivity at home and at school

Average score	**0.4**	**0.6**	**2**

Source: Consortium Analysis

As most applications in the Education sector take place indoors, Scenario 3 (RLAN) is best positioned to meet the user needs compared to both WAN (Scenario 1) and local (Scenario 2) IMT.

3.2.3.3.3 Impact of connectivity (2030)-Education

Economist Intelligence Unit (EIU) analysis shows that for every 10 percent increase in school connectivity in a country, GDP per capita could increase by 1.1 percent.[111] A rough computation using current GDP levels shows that increasing the scores of 13 of the EU 27 countries to the score of Finland (WEF global competitiveness index, ranking economies based on internet access in schools) , would result in 90 billion USD GDP impact. The outcome of this computation will be referenced as a proxy to "weigh" the potential impact of connectivity in the sector for the MCA (3.2.5).

3.2.3.4 Public services

3.2.3.4.1 Public services digitization

Against the backdrop of the Digital Decade, countries around the world are aware of the potential of various digital technologies to improve the efficiency of their public services. Evidence shows that digitization of public services meets the needs of citizens in a timely manner, reduces administrative burden, including costs, while ensuring a high level of transparency.

The Covid 19 pandemic has highlighted the importance of having so-called GovTech, also known as e-government or smart public services, and has highlighted the costs, both economic and social, of delaying the process of creating a functioning GovTech.

GovTech refers to a government approach to public sector modernization which includes three main pillars[112]:

- Citizen-centric public services that are universally accessible,
- A whole-of-government approach to digital government transformation, and simple, efficient and
- Transparent government systems.

In the EU, the approach to e-government presented in the EU Action Plan 2016-2020[113] is based on the use of digital technologies to deliver public services to all European citizens. For example, a citizen can apply for and receive legal documents online, or access various platforms online at any time, such as bank accounts, school enrolment, tax files, etc.

During the Digital Decade, the EU has reaffirmed its strong commitment to ensuring that all EU citizens have access to smart public services and increased its funding for large-scale eParticipation projects[114].

---

111 Source: EIU

112 Worldbank, 2022, GovTech (worldbank.org)

113 EU eGovernment Action Plan 2016-2020, EC, 2016 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52016DC0179

114 Digital public services and environments, EC, 2022, https://digital-strategy.ec.europa.eu/en/policies/digital-public-services

Figure 12 below shows the regional distribution of countries by E-Government Development Index (EGDI) level, 2016, 2018 and 2020.

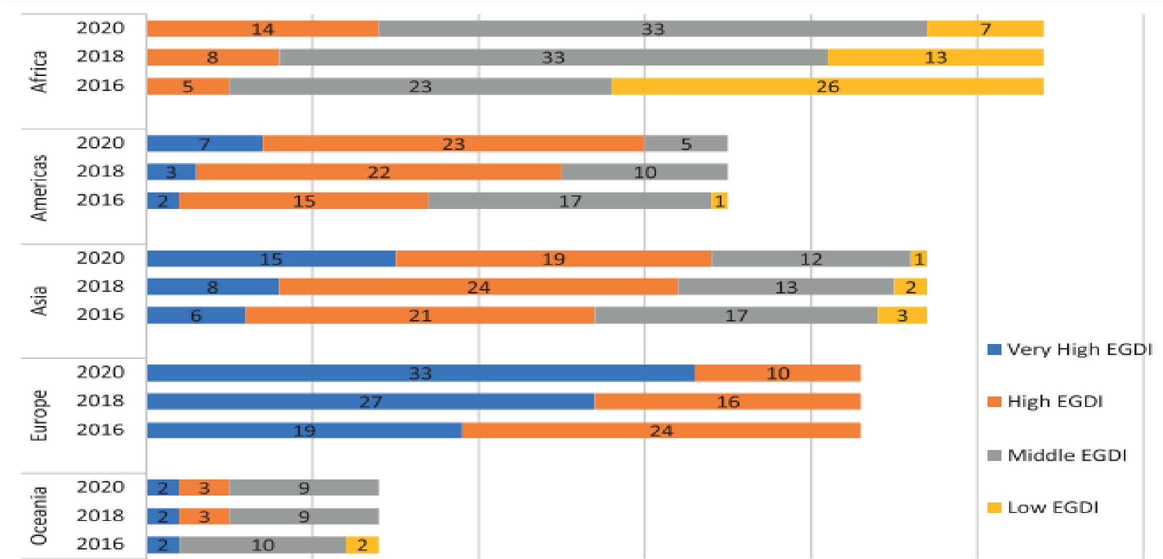

Figure 12: Regional distribution of countries by E-Government Development Index (EGDI) level, 2016, 2018 and 2020

Source: 2016, 2018 and 2020 United Nations E-Government Surveys

At the global level, the United Nations has reported good progress in e-government development across all regions in 2020. As shown in Figure 12, Europe remains the region with the highest average EGDI values since 2016, followed by Asia.[115] Overall, for all 43 countries surveyed in Europe, the results show that all countries have high or very high EGDI values. Table 33 below indicates the EGDI of EU member states.

Table 33: Top 10 leading countries in e-government development in 2020

World ranking	Country	EGDI value (2020)	EGDI value (2018)
1	Denmark	0.9758	0.9150
2	Republic of Korea	0.9560	0.9010
3	Estonia	0.9473	0.8486
4	Finland	0.9452	0.8815
5	Australia	0.9432	0.9053
6	Sweden	0.9365	0.8882
7	United Kingdom	0.9358	0.8999
8	New Zealand	0.9339	0.8806
9	United States of America	0.9297	0.8769
10	Netherlands	0.9228	0.8757

115 Ibid.

Source: United Nations, 2020

Overall, as shown in Table 34, Denmark has had the highest EGDI rate in the world since 2018. One of this country's best practices is the e-invoicing system, which saves taxpayers and businesses €150 million and €50 million respectively every year.[116] Another EU member state in the highest rating category is Estonia, which is also referred to as the most advanced digital society in the world. According to the e-Estonia guide[117], Estonia is perhaps the only country, but certainly the first in the world, to offer 99% of public services online 24/7. In addition, Estonia uses many best practices, such as the use of digital signatures, which result in an immediate saving of 2% of its GDP. In addition, an estimated 44% of citizens cast their vote online via an e-voting platform, where it costs about €20 to process a normal vote, while only €2 is required to process an e-vote. [118]

At the beginning of 2021, 14 Member States have implemented national eID systems, 7 of which are mobile based.[119]

In 2019, 44% of European citizens reported having obtained information or documents from online sources from public authorities in 2018, against 33% in 2008, including 89% of citizens in Denmark and 84% of citizens in Finland, with Romania having the lowest figure at just 9%.[120]

Table 34 below provides an overview of the applications identified via literature review as well as the Digital Decade communication and their relevance for the upper 6 GHz band:

Table 34: Applications-Public services

Application	Need for additional bandwidth satisfied by 6 GHz (Y/N)	Comment
e-voting	Yes	Wi-Fi or 5G whilst on the move
e-government	Yes	Wi-Fi or 5G whilst on the move

Source: Consortium Analysis

Like the education sector, the upper 6 GHz band is expected to be critical to meet the demand of identified applications in the public sector.

116 Source: European Commission, eGovernment and digital public services, https://digital-strategy.ec.europa.eu/en/policies/egovernment

117 Source: e-Estonia guide, Invest in Estonia, https://investinestonia.com/wp-content/uploads/eestonia-guide-veeb.pdf

118 Source: *E-governance saves money and working hours*, e-Estonia, Blog, 2020, https://e-estonia.com/e-governance-saves-money-and-working-hours/

119 Source: Digital Identity: Digital Citizenship & e-Government, European Internet Forum, 2021, https://www.internetforum.eu/events/reports/322-digital-identity-digital-citizenship-e-government.html

120 Source: e-Government-more citizens consult information online, EURtat, 2019, https://ec.europa.eu/EURtat/web/products-EURtat-news/-/edn-20200307-1

3.2.3.4.2 Technical classification-6 GHz Applications & user needs-Public services

The adoption of innovative ICTs to provide digital public services with optimal quality and efficiency is essential to reach the "100% online provision of key public services available for European citizens and businesses" target set by the Digital Decade.

Table 35: Application requirements-public services

Application	Connectivity requirements			Ranking fitness		
	Static/ dynamic	Indoor/ outdoor	Low latency (Y/N)	Scenario 1	Scenario 2	Scenario 3
e-voting	Mostly static	Indoor	No	1	0	2
e-government	Mostly static	Indoor	No	1	0	2
			Total score	**2**	**0**	**4**
			Average score	**1**	**0**	**2**

Source: Consortium Analysis

Consistent with the assessment of applications in the Education sector, as all applications are expected to be mostly static and taking place indoors, Scenario 3 (RLAN) is best positioned to meet the user needs.

3.2.3.4.3 Impact of connectivity (2030)-Public services

Annual savings if electronic invoicing is introduced across the EU (based on the Danish example) would amount to approximately 65 billion USD. [121] The outcome of this specific case study will be referenced as a proxy to "weigh" the potential impact of connectivity in the sector for the MCA.

3.2.3.5 Healthcare

3.2.3.5.1 Healthcare digitization

Digital Health is an umbrella term often associated with e-health, which relies on the use of various digital systems, e.g. advanced computer science such as "Big Data" and artificial intelligence. In the health sector, advanced technologies are crucial in improving the delivery and performance of the sector and thus public health.

The Covid-19 pandemic has underscored the importance of effective digital tools to address urgent situations and the need to introduce, with unprecedented pressure, digitized health platforms and eHealth services, such as online doctor consultation services, including telemedicine services and telehealth consultations. In Europe, many precautionary measures have been taken since the beginning of the pandemic. For example, 58% of countries have started using telemedicine to replace face-to-face consultations, and 50% of European citizens search for health information online for private purposes.[122]

121 Source: Ibid. European Commission, eGovernment and digital public services.

122 Source: Internet activities, EURtat, 2022, Statistics | EURtat (europa.eu)

In the EU, 3 priorities were identified in the European Commission's communication on the digital transformation of health and care:[123]

1. Secure citizens' access to their health data, including across borders;
2. Personalized medicine through a common European data infrastructure;
3. Empowering citizens through digital tools for user feedback and person-centered care.

Table 36 below highlights several promising medical technologies being used on a large scale, especially during the pandemic.

Table 36: Major technologies used for the health industry

Technologies	Technology potential for the health industry
Remote patient monitoring	Physicians use remote patient monitoring (RPM), to diagnose a patient without physically being close, thus, the use of e-prescriptions. RPM has many benefits, such as improved patient outcomes, quicker response time and access to electronic health records, and substantial cost reductions over time.
Artificial intelligence	In healthcare, Artificial intelligence (AI) is used in many applications mainly applying machine learning to evaluate substantial amounts of patients' data and analyzing healthcare data in a comprehensive means and therefore, using the findings to improve patients' outcomes and to reduce costs.
Digital therapeutics	Digital therapeutics are sophisticated software programs accessed through apps used by patients on their smartphone or a computer to have access to information about their wellbeing from their physician. Enabling doctors to monitor their patients without seeing them regularly and diagnose problems in early stages without an appointment.
Internet of medical things	Internet of medical things refers to new technologies such as remote patient monitoring, 5G-enabled devices, and wearable sensors: hundreds of thousands of web-enabled medical devices are gradually more interconnected to provide the most precise and up-to-date patients' data.

Source: Consortium elaboration (2022)

Among clinicians, based on a survey by Deloitte, the most frequently used technologies across the EU are electronic health records (EHRs) utilized by 81% of respondents, and e-prescriptions (62%).[124]

Figure 13 below summarizes the share of clinicians using different types of digital technologies in Europe in 2020, by technology. Remote patient monitoring

---

123 Source: European Commission, COMMUNICATION on enabling the digital transformation of health and care in the Digital Single Market; empowering citizens and building a healthier society, file:///C:/Users/AyoubMahi/Downloads/com2018233_DB104CD3-02A2-749E-3A00B92A16D0D061_51628.pdf

124 Source: Digital transformation Shaping the future of European healthcare, Deloitte, 2020 deloitte-uk-shaping-the-future-of-european-healthcare.pdf

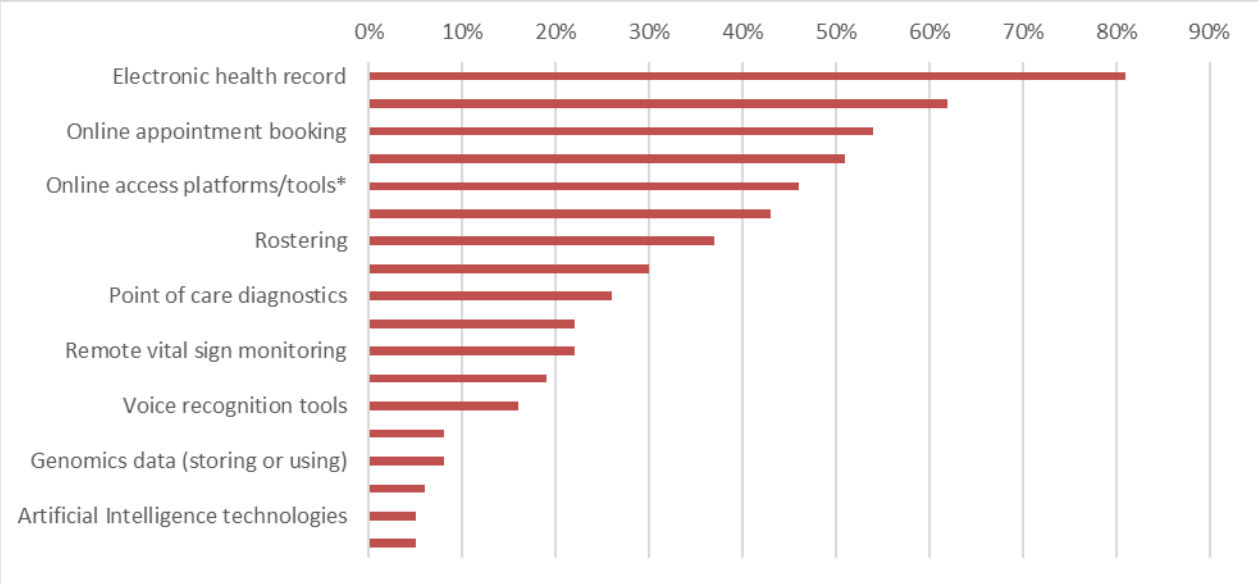

Figure 13: Share of clinicians using different types of health digital technologies in Europe in 2020, by technology [125]

Source: Deloitte, 2020

The table above shows that most clinics rely on different technologies to monitor patients remotely (RPM) using the latest advances in information technology to collect patient data outside traditional health care settings. For instance, more than 80% of clinicians in Europe used electronic health record in 2020.

Several studies, including those authored by the OECD, highlight the impact of digital technologies as a significant opportunity to improve the quality and performance of healthcare. For example, the direct financial impact due to lack of data and knowledge sharing in OECD countries is estimated to be up to 15% of hospital spending, while the overall economic cost losses are estimated to be trillions of dollars.[126]

According to recent OECD estimates, the combined economic benefits of the use of data and digital technology in the health sector could account for 8% of total health spending across all OECD countries.[127] Juniper Research studies have revealed that telemedicine will save the healthcare industry 21 billion USD in costs by 2025.[128]

Similarly, the Digital Decade Communication estimates that the impact of introducing more online interaction, paperless services, electronic transmission and access to data instead of paper documents and automation

---

125 Source: Ibid. Digital transformation Shaping the future of European healthcare, Deloitte.

126 Slawomirski, L., A. Auraaen and N. Klazinga (2017), The economics of patient safety: Strengthening a value-based approach to reducing patient harm at national level, OECD Publishing, Paris, https://dx.doi.org/10.1787/5a9858cd-en

127 "Bringing health into the 21st century", OECD, 2019, Paris, https://doi.org/10.1787/e130fcc2-en

128 Source: Juniper Research, 2021, Telemedicine to Save Healthcare Industry $21bn Globally by 2025 (juniperresearch.com)

could lead to cost savings of up to €120 billion per year in Europe.[129] According to a McKinsey study, e-health practices could generate around €55 billion in France and Germany alone, with only three use cases, namely remote monitoring of patients with chronic diseases, a unified electronic health record/exchange and teleconsultation, accounting for 40% of the value.[130]

Table 37 below summarizes the list of applications identified via literature review and their relevance for the upper 6 GHz band.

Table 37: Selection of applications 6 GHz-Healthcare

Application	Need for additional bandwidth satisfied by 6 GHz (Y/N)	Comment
Remote monitoring of patients/early warning of changes in vital signs, video, medicine and 'tactile internet (IoT+video)	No	If there is good indoor 5G this can offer stable and better reliability than Wi-Fi assuming no access to 6 GHz
Wireless tele-surgery	Yes	Low latency 5G would be needed at a local level. (not a service offered by MNOs).
Connected hospitals (digitalization)	Yes	Some hospitals already looking at indoor 5G as a stable/reliable connectivity to a range of devices.
Innovative Telemedicine/ Telemedicine consultation (video)	No	Wi-Fi use case especially if using HD video. Grouping under "innovative telemedicine"
Remote care (IoT)	Yes	As above.
Robotic solutions	Yes	5G in hospitals could be required for reliable connectivity
Support independent living (IoT)	No	Connectivity could be required on premises (e.g. elderly homes) or on the go (e.g. visually impaired people)
Smarter medication (IoT)	No	Monitoring is narrowband so no need for 5G but wide area coverage from 4G will suffice
Drone-transported medical equipment and therapies	No	Lower bands are most likely to be used for control (but will need access to more bandwidth for live feeds).

129 Source: European Commission, 2030 Digital Compass: the European way for the Digital Decade, 2021, communication-digital-compass-2030_en.pdf (europa.eu)

130 Source: Shaping the digital transformation in Europe, McKinsey, 2020, https://www.ospi.es/export/sites/ospi/documents/documentos/Sstudy_Shaping_the_digital_transformation_in_Europe_Final_report_202009.pdf

Source: Consortium Analysis

Based on reference use cases identified, applications above (Remote care, Innovative Telemedicine/ Telemedicine consultation and Remote monitoring of patients/early warning of changes in vital signs, video, medicine and 'tactile internet (IoT+video) have been grouped under "innovative telemedicine & remote care (monitoring health status)". This grouping corresponds to telehealth service solutions providing on-demand access to care for patients e.g. itransition. Main use cases for connected hospitals can be linked to Electronic Medical and Health Records (EMR and EHR), including eAppointments for booking online consultations and ePrescribing. Automation use cases in healthcare (robotics solutions) include care robots providing support to elderly and disabled patients (e.g. Toyota's Human Support Robot (HSR) robotics platform) and robotic surgical systems (e.g. Johnson & Johnson's Monarch platform for bronchoscopic procedures). X-reality (AR/VR) application examples include augmented reality headsets with layered digital images (e.g. SyncAR projects augmented scans onto the surgeon's microscope display).

3.2.3.5.2 *Technical classification-6 GHz Applications & user needs-Healthcare*

Most eHealth applications are not expected to require very high data rates, (apart from urgent healthcare and remote surgery robotics-assisted surgery)[131]. Among the Digital Decade targets, hospitals are expected to have access to **gigabit connectivity** by 2025.[132] Table 38 below first introduces the relevant connectivity requirements and then ranks their fitness for each scenario.

Table 38: Application connectivity requirements-Healthcare

Application	Connectivity requirements			Ranking fitness		
	Static/ dynamic	Indoor/ outdoor	Low latency (Y/N)	Scenario 1	Scenario 2	Scenario 3
"innovative telemedicine & remote care (monitoring health status)"	Static & dynamic	Indoor & outdoor	No	1	0.5[133]	1
Connected hospitals	Static	Indoor	No	0	2	2
Wireless surgery	Static	Indoor	Yes	0	2	0
Robotics solutions	Dynamic	Indoor	Yes	0	1	1
VR/AR	Static & dynamic	Mostly indoor	Yes	0	1	2
			Total score	**1**	**6.5**	**6**
			Average score	**0.2**	**1.3**	**1.2**

131 Source: European Commission, Directorate-General for Communications Networks, Content and Technology, Manero, C., Jervis, V., Ropert, S., et al., Study on using millimetre waves bands for the deployment of the 5G ecosystem in the Union : final report, Publications Office, 2019, https://data.europa.eu/doi/10.2759/703052

132 Source: Ibid, European Commission, 2030 Digital Compass: the European way for the Digital Decade.

133 Half score reflects relevance of local IMT networks to support video applications.

Source: Consortium Analysis

According to the analysis presented above, local IMT (Scenario 2) and RLAN (Scenario 3) are well positioned to respond to the sector's requirements. Nevertheless, the ultra-low latency requirement associated with wireless surgery places Local IMT as "best fit".

3.2.3.5.3 Impact of connectivity (2030)-Healthcare

Technologies such as advanced analytics, AI-powered diagnostics and population health analytics, connected medical devices and wearables all depend on enhanced connectivity. McKinsey estimates that improved connectivity in healthcare could enable efficiencies that would impact GDP by **$250 billion to $420 billion by 2030**. Advanced connectivity can deliver about 80 per cent of the value at stake, while frontier connectivity accounts for the rest.[134] This figure will be referenced as a proxy to "weigh" the potential impact of connectivity in the sector for the MCA (3.2.5)3.2.5.

In the case of Europe, promoting paperless health services and automation while establishing virtual procedures with patients instead of face-to-face ones could lead to benefits of up to € 120 billion per year.[135]

3.2.3.6 Manufacturing

3.2.3.6.1 Manufacturing digitization

Manufacturing is a sector with rapid productivity growth and is undergoing a rapid digital transformation characterized by the massive use of smart technologies and connected devices.

The digitization of manufacturing has revolutionized the methods for designing, producing, and developing products. According to Deloitte, the term Industry 4.0 stands for "the promise of a new industrial revolution"[136]. The goal of Industry 4.0 is to use the Internet of Things (IoT) to create an ecosystem of connected manufacturing systems that can communicate with each other and perform data analytics that enable manufacturers to significantly improve efficiency, productivity and precision.

According to the report published by Allied Market Research, the global digital manufacturing market generated $276.5 billion in 2020 and is estimated to earn $1.37 trillion by 2030, growing at a compound annual growth rate (CAGR) of 16.5% from 2021 to 2030. [137]

The Digital Decade roadmap envisages 5G as an enabler of more connected devices in factories collecting industrial data. Artificial intelligence provides robots with real-time information and make them increasingly collaborative, improving jobs, safety, productivity, and worker well-being.

---

134 Source: Ibid, Shaping the digital transformation in Europe, McKinsey,

135 Ibid

136 Source: Industry 4.0, Deloitte, https://www2.deloitte.com/us/en/insights/focus/industry-4-0.html

137 Source: Global digital manufacturing market to garner $1,370.3 billion by 2030: Allied Market Research, Allied Market Research, 2021, https://www.globenewswire.com/en/news-release/2021/07/08/2259815/0/en/Global-digital-manufacturing-market-to-garner-1-370-3-billion-by-2030-Allied-Market-Research.html

Manufacturers will be able to improve predictive maintenance and produce on demand without inventory thanks to digital twins, new materials and 3D printing[138].

Table 39 below provides an overview of applications identified via literature review and their relevance for the upper 6 GHz band:

Table 39: Applications-Manufacturing

Application	Need for additional bandwidth satisfied by 6 GHz (Y/N)	Comment
Machinery monitoring for predictive maintenance and remote-control	Yes	5G proving to be successful in some manufacturing facilities as exemplified in Germany. Currently using 3.7-3.8 GHz.
Cell automation	Yes	As above.
X-reality guided procedures and repairs	Yes	5G for AR/VR inside factories is a potential use case and offers the low latency at a local level. 6 GHz would be a good option but will be competing with Wi-Fi.
Ultra-high definition (UHD) surveillance	Yes	5G could be a use case here and wider bandwidths will support the required speeds similar to Wi-Fi
Manufacture as a service	Yes	Additional bandwidth to accommodate online platforms for manufacturing companies [139]
Real-time supply chain visibility	No	Massive IOT is likely to be mostly handled in lower frequency band/competing with other technologies (not relevant for 6 GHz).

Source: Consortium Analysis

As highlighted in the table above, the majority of the manufacturing applications could be operated in the upper 6 GHz band. Only the Real-time supply chain visibility might not be able to be operated in this band since alternatives are more relevant. The next section looks at the connectivity requirements of these applications in more detail.

3.2.3.6.2 Technical classification-6 GHz Applications & user needs-Manufacturing

Connectivity with high availability and reliability (both indoors and outdoors) is required for sensors and actuators to ensure seamless production and the ability to adapt processes in real-time for maximum flexibility. Additional bandwidth will be required to accommodate video applications as well as automated guided vehicles.[140]

---

138 Ibid. 2030 Digital Compass: the European way for the Digital Decade, European commission

139 Source: *On-Demand Manufacturing: What it is and How it Works*, Xometry Europe, 2021, https://xometry.eu/en/on-demand-manufacturing-what-it-is-and-how-it-works/

140 Bandwidth to accommodate video, automated guided vehicles

Table 40: Application requirements-Manufacturing

Application	Connectivity requirements			Ranking fitness		
	Static/ dynamic	Indoor/ outdoor	Low latency (Y/N)	Scenario 1	Scenario 2	Scenario 3
Machinery monitoring for predictive maintenance and remote-control	Static & dynamic	Indoor	No	0	2	2
Cell automation	Static	Indoor	No	0	2	2
X-reality guided procedures and repairs	Static	Mostly indoor	Yes	0.5	2	2
Ultra-high definition (UHD) surveillance	Static	Indoor	Yes	0	2	2
Manufacture as a service	Static	Indoor	No	0	2	2
			Total score	**0.5**	**10**	**10**
			Average score	**0.1**	**2**	**2**

Source: Consortium Analysis

Based on the analyzed applications above, like the construction environment, local IMT (Scenario 2) and RLAN (Scenario 3) are equally well positioned to respond to the sector's requirements

3.2.3.6.3 Impact of connectivity (2030)-Manufacturing

Based on McKinsey, the business value resulting from use cases running on improved connectivity could generate from \$400 billion to \$650 billion of GDP impact by 2030.[141] This figure will be referenced as a proxy to "weigh" the potential impact of connectivity in the sector for the MCA (3.2.5).

141 Source: Connected world: An evolution in connectivity beyond the 5G revolution, McKinsey, 2020, Discussion paper, [mgi_connected-world_discussion-paper_february-2020.pdf (mckinsey.com)]

3.2.4 Outcomes of the prioritization

Table 41 below summarizes the impact/expected outcome of the digital transformation across sectors (and/or relevant application domains) as envisaged by the Digital Decade roadmap.[142] The predominance of indoor applications has implications for the 6 GHz band and its future usage scenarios explored in the scope of this study:

Table 41: Overview of Digital Decade sectors/applications

Digital decade			
Sector	Area	Applications	Impact/outcome
Agriculture	Agriculture	Smart Farming/Digital farming technologies	Advanced services to farmers like harvest prediction or farm management and optimize food supply chains.
			Improve sector's sustainability and competitiveness: cut global GHG emissions and pesticide use.
Construction			70% of construction executives mentioned new production technologies and digitalization as the drivers of change in the sector
Health	Digitally enabled health solutions	Innovative telemedicine & remote care (monitoring health status)	Support independent living, prevent non-communicable diseases, and bring efficiency to health and care providers and health systems. introducing more online interaction, paperless services, electronic

142 The "transportation" sector covered by the Digital Decade roadmap is not included in this overview/study scope given that autonomous vehicles and related applications (in scope of the Digital Decade) will not be supported by the 6 GHz band.

Digital decade			
Sector	Area	Applications	Impact/outcome
		Robotics solutions	transmission and access to data instead of paper records and automation could lead to benefits of up to € 120 billion per year in Europe.
	Connected Hospitals	eHealth	Connected Hospitals/ access to eHealth
Education	Connected schools	eEducation	Development of a high-performing digital education ecosystem, as well as by an effective policy to promote links with and attract talent from all over the globe.
Government/Public services	Public services	E-Government / GovTech / or smart public services	Modernized public services responding to society’s needs.
Manufacturing	Connected/smart factories	Robotics	Thanks to 5G connectivity, devices in factories will be even more connected and collect industrial data. Artificial Intelligence will instruct robots in real time, making them increasingly collaborative, improving workers’ jobs, safety, productivity, and wellbeing. Manufacturers will be able to enhance predictive maintenance and produce on demand, based on consumers’ needs, with zero stocks, thanks to digital twins, new materials and 3D printing.
		Predictive maintenance	
		Digital twins	
		Manufacturing-as-a-service	Boost visibility of SME production capacity

Digital decade			
Sector	Area	Applications	Impact/outcome
Horizontal	Digitalization	Digitalization of SMEs	More than 90% of European SMEs reach at least a basic level of digital intensity.
Horizontal	Businesses/ Households	Remote collaboration	Access to affordable, secure and high-quality connectivity is one of the prerequisites enabling "Digital Citizenship" i.e. all Europeans to make full use of digital opportunities and technologies. Expected horizontal impact (for sectors where remote working is possible): substitution of business travel.
Horizontal	Smart villages	Digitization of rural areas (connectivity)	Innovative solutions to improve resilience of rural areas, building on local strengths and opportunities.
		Multi-modal intelligent transport systems, rapid emergency assistance in case of accidents, more targeted waste management solutions, traffic management, urban planning, smart energy and lighting solutions, resource optimization	

Source: Consortium based on Digital Decade review

Below is the overview of sectors and use cases/applications in scope of the study, with green boxes subject to MCA elaborated in the next section:

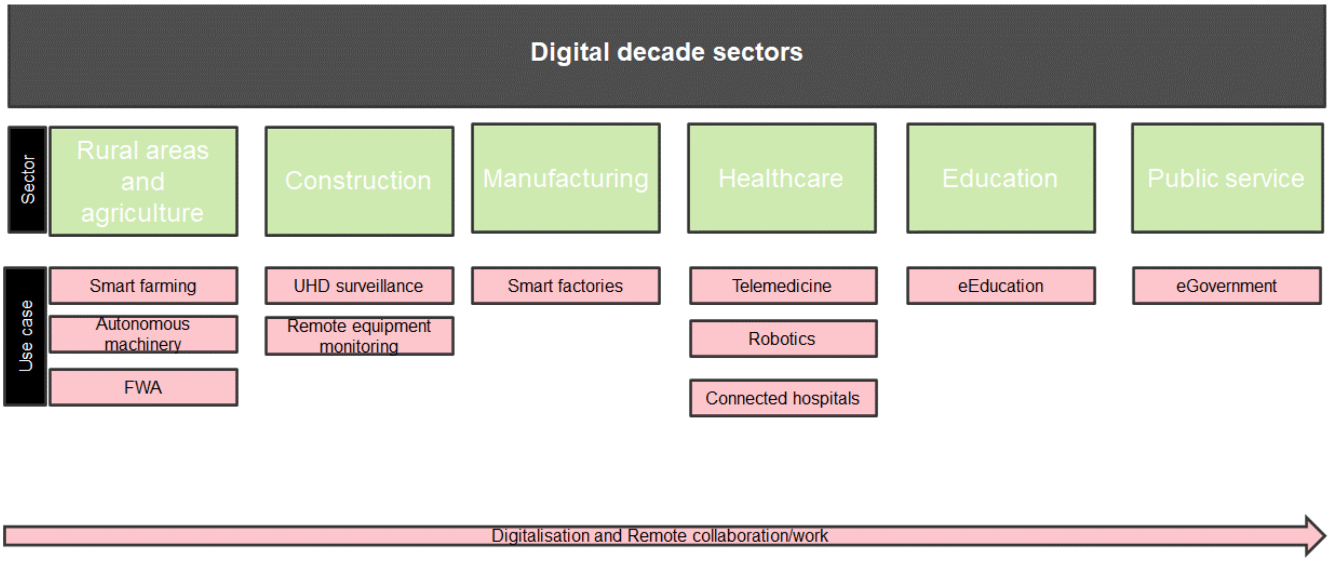

Figure 14: Overview of Digital Decade sectors analyzed in the MCA

Source: Consortium

3.2.5 MCA-Economic benefits of digitization & enhanced connectivity (5G vs Wi-Fi6E)

The second stage of the qualitative assessment of applications consists of a two-step MCA approach where the benefit of each scenario is compared and measured in terms of its ability to satisfy user requirements of individual sectors and applications. As shown in the figure below, the outcome of this assessment will enable a ranking of scenarios based on connectivity benefits and technology fit.

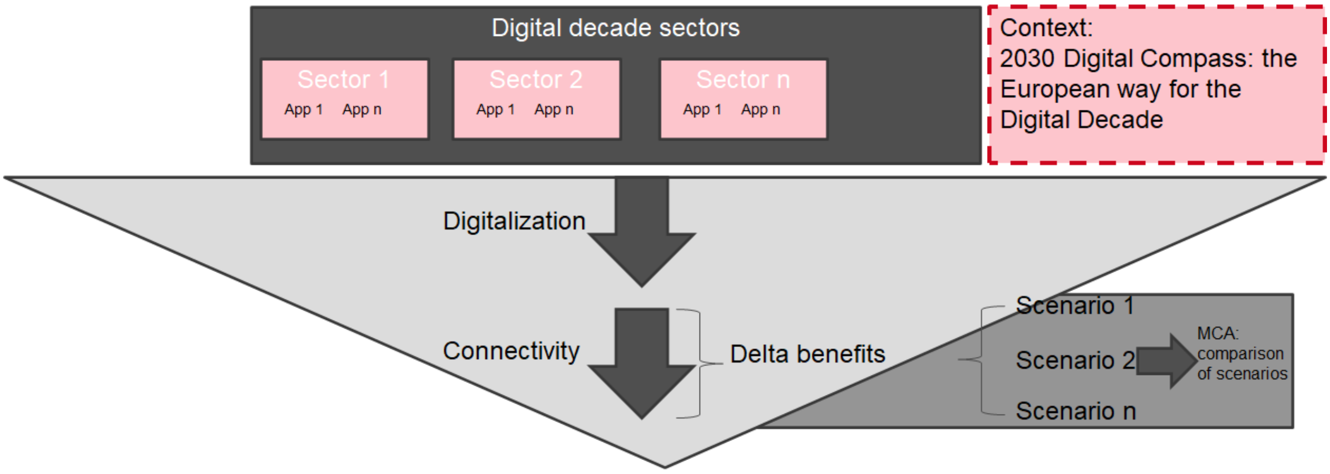

Figure 15: MCA methodological approach

Source: Consortium

In the sections below, the fixed MCA criteria/columns (highlighted in the figure below) will be presented. Then, the intermediary computations per sector and scenario will be assessed, to conclude with the final comparison of scenarios based on average sector scores.

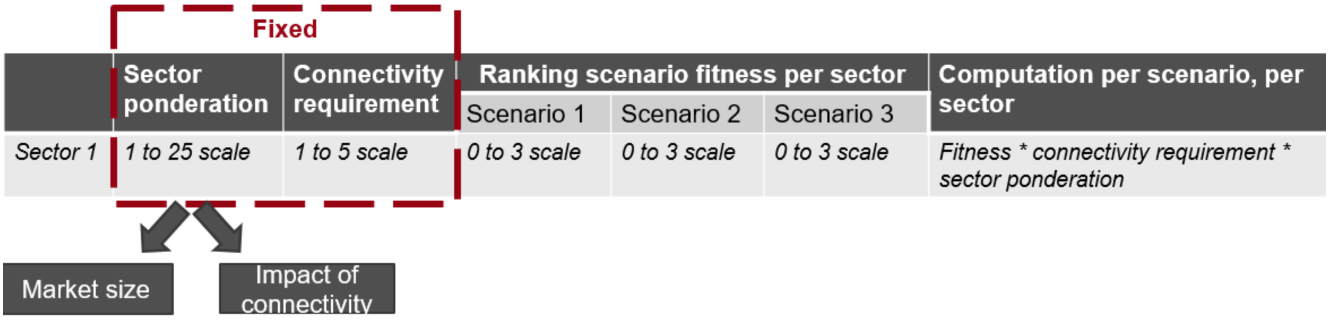

Figure 16: Zoom in MCA approach

Source: Consortium

The purpose of the first two, “fixed” factors related to the market size and expected demand for connectivity is to “scale” each sector in terms of where the biggest impact of connectivity will be achieved. The ranking scenario fitness per sector allows to benchmark scenarios which might have the best fit with user requirements from each application under the selected sectors. The final computation is thus based on technical criteria of the MCA and a ponderation based on socio-economic elements (i.e. in order to provide more weight to segments representing an important share of the EU economy and expected to greatly benefit from additional connectivity in the future). A more detailed breakdown, ranking and link between the criteria is provided in the next section.

3.2.5.1 Sector ponderation & connectivity requirement

“Sector ponderation” is based on the magnitude of potential impacts and computed as the market size multiplied by the expected impact of connectivity (by 2030).

The following scale is used to rank the impact of connectivity:

Table 42: Impact of connectivity scale

Score	Definition
Score 1	<$65 billion
Score 2	$65 billion to $90 billion
Score 3	$130 billion to $175 billion
Score 4	$200 billion to $420 billion
Score 5	$400 billion to $650 billion

Market size is ranked based on the following scale:

Table 43: Market size scale

Score	Definition
Score 1	< €250 billion
Score 2	€250 billion to €500 billion
Score 3	€500 billion to €1000 billion
Score 4	€1000 billion to €1500 billion
Score 5	€1500 billion to €2000 billion

The second “fixed” criterion, the connectivity requirement, is measured based on the following ranking:

Table 44: Connectivity requirement scale

Score	Definition
Score 1	20%-40% of applications identified relevant for the 6 GHz
Score 2	40%-60% of applications identified relevant for the 6 GHz
Score 3	60%-80% of applications identified relevant for the 6 GHz
Score 4	80%-95% of applications identified relevant for the 6 GHz
Score 5	All applications identified relevant for the 6 GHz

Table 45 below summarizes the results of the 2 “fixed” MCA criteria applied per sector (applicable for the analysis of each of the 3 scenarios):

Table 45: MCA overview of "fixed" criteria

Sector	Sector ponderation based on magnitude of potential impacts	Connectivity requirement
Agriculture	3	3
Construction	12	5
Healthcare	16	4
Manufacturing	25	4
Education	6	5
Public Service	6	5

Source: Consortium Analysis

Based on the impact expected from improvements in connectivity combined with the sectors’ Gross Value Added (GVA) contribution in the EU, manufacturing along with Healthcare and Construction emerge as the “most critical” in terms of their weight. Nevertheless, compared to smaller sectors where the majority of the demand from applications is expected to be met by the 6 GHz band (Education, Public Service), alternative technologies and/or bands will to some extent accommodate this extra capacity in 2 of the 3 “high impact sectors” (i.e. Healthcare and Manufacturing).

3.2.5.2 Scenario comparison

In Annex 3 we summarize the average scores per application and end result per scenario, while the purpose of this section is to bring together the outcomes of the 3 scenario assessments for a full comparison.

The final scoring of scenarios clearly shows the benefit of opening the 6 GHz for unlicensed use (LPI/VLP/SP, technologies based on Wi-Fi 6E standards). The following table provides the overall fitness of the three scenarios.

Table 46: Final scoring MCA per scenario

Scenarios	Technical fitness[143]	Overall fitness, including economic impact
Scenario 1 (IMT WAN)	4.3	23.3
Scenario 2 (IMT local)	6.9	68.7
Scenario 3 (RLAN)	10	84.5

Source: Consortium Analysis

Scenario 3 not only enables the highest number of applications relevant for the 6 GHz band and in scope of the Digital Decade, but also aligns better with the sector connectivity requirements given that most of these use cases will take place indoors rather than “on the move”. Wide area coverage requirements are not only less relevant for applications in scope but can also be equally met by alternative (mobile) networks (operating in alternative frequency bands), hence the relatively lower ranking of IMT WAN deployment (Scenario 1). Overall, the ubiquity of Wi-Fi device usage and corresponding applications translates into a benefit of additional bandwidth available indoors on an unlicensed basis is therefore expected which outweighs the value of its alternative, licensed use.

Scenario 1 and Scenario 2 scores rather poorly both in terms of technical fitness and overall fitness considering the economic impact of enabled sectors. However, this assessment is based on sectors from the Digital Decade, which will be able to benefit from additional connectivity in the upper 6 GHz. Additional use cases/applications could however benefits from additional connectivity in the upper 6 GHz band (e.g. video streaming, autonomous vehicles, etc.).

In the next section, demand price/cost will be explored for the competing technologies (measured as fixed and mobile broadband consumption) to finally draw some conclusions and recommendations on the future use of the specific frequency band.

143 Represents the sum of averages of each Scenario

3.3 Investment vs. QoS ratio

This subsection aims to bridge outcomes of Study A and Study B to build a meaningful comparison of results from each scenario. This section will, for each scenario, start by highlighting economic results from the different scenarios (i.e. investment part) and will then discuss elements related to the QoS.

3.3.1 Ratio of Quality of Service and Investment Cost

The objective of this section is to describe the methodology for assessing the ratio of investment cost versus enhanced QoS for the three scenarios. The goal is to define a ratio to illustrate the required level of investment needed to provide a substantial added value to end-users. This computation will be required for the three scenarios.

To be aligned on effective connectivity usage of the upper 6 GHz band, the study has considered that the enhanced QoS will be derived from the increased throughput and capacity added to the baseline with the upper 6 GHz band. The enhanced QoS will be based on the increased throughput and capacity unlocked by each scenario. The figure below provides an overview of the approach:

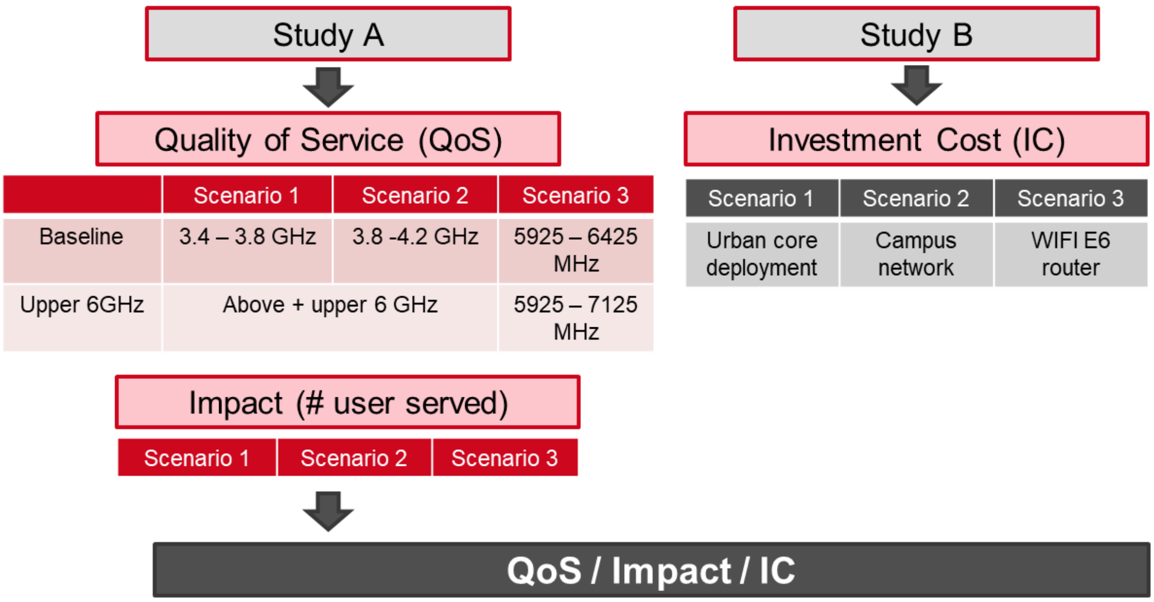

Figure 17: Ratio QoS and Investment Cost

The study will focus on the increased throughput and capacity based on the number of users served by each scenario. It will rely on the percentage of increase in the upper 6 GHz versus the current deployment and connectivity solutions.

3.3.2 IMT WAN (Scenario 1)

In the previous sections, costs related to Scenario 1 have been highlighted. These economic results could be summarized as follows:

- **Market sizing:** 75 urban cores identified across the EU for deployment host 63.2 million people (14% of EU population) across 20,632 km² (1.21% of EU area)
- **Microcells sub-scenario:**
  - **Cells to be deployed**: 263,171 microcells would be required to cover this urban cores
  - **Overall deployment costs microcells: €3.2** billion material costs + **€ 4.1** billion civil costs = €**7.3 billion**
- **Macrocells sub-scenario:**
  - **Sites to be deployed**: 65,677 macro sites would be required
  - **Overall deployment costs macrocells**: €**4.8** billion material costs + €**1.1** billion civil costs = €**5.9 billion**

Regarding the additional QoS delivered under Scenario 1, Study A has stressed that the coverage of microcells deployed for the upper 6 GHz will be more limited compared to the ones currently deployed. A better service will be available to users in a smaller area with **at least 2 times more simultaneous users** served within a given area.

In order to reach a proportion of the EU population equivalent to scenario 3 (see below), scenario 1 (IMT WAN), **in a microcell configuration**, will require an **important initial investment**. This does not align economically as whilst it provides a high user experience this would only be for **a limited number of users in our agriculture application**. In contrast, a **macrocell configuration** will not require a significant initial investment as it will mainly involve rooftop upgrades to existing 3.5 GHz sites. In theory, the macrocell sub-scenario offers economic benefits due to lower costs but in practice, these benefits would only be brought to high-density mobile data usage in urban areas and not agricultural applications. The likely deployment of macrocells in the upper 6 GHz range will be urban areas and not the rural areas where agriculture applications are used making this an intangible benefit.

3.3.3 Local IMT (Scenario 2)

Regarding the economic cost for Scenario 2, the following elements have been highlighted in the previous section:

- Market sizing:
  - Over 5 sectors: Construction Healthcare Manufacturing Ports Airports and Stadiums
  - 18,557 campus networks for deployment identified across the EU
- Cells to be deployed: based on Study A results for the number of cells needed per campus network, for example 8 per hospital
- Overall deployment costs: €12.35 billion.

Regarding the enhanced QoS in Scenario 2, Study A has highlighted that there will be no additional users served under this scenario in the upper 6 GHz. It is thus very likely that no additional benefits will be observed in terms of the number of additional users supported.

Scenario 2 (IMT Local) will require a **significant initial investment** to cover relevant areas. This scenario however **fails to provide enhanced QoS in the upper 6 GHz.**

3.3.4 RLAN/Wi-Fi 6E (Scenario 3)

Regarding the investment cost for Scenario 3, different sub-scenarios have been explored as summarized in the following table:

- Costs = price new router multiplied with the number of fixed broadband subscriptions.
- 3 scenarios estimated the development of broadband subscriptions:

Table 47: Summarizing investment costs for Scenario 3

Scenario assumptions	Subscriptions	Total Costs (Billion €)
Every currently existing broadband subscription will be equipped with a Wi-Fi 6 router.	162.7 million	9.76
The proportion of people in the EU with a fixed broadband subscription rises to that of South Korea, the country with the highest proportion of people with such a subscription with 48.55%.	194.7 million	11.68
Maximum number of new fixed broadband subscriptions: every household, every registered company and every registered NGO would get its own connection.	220.8 million	13.25

Regarding the QoS for this scenario, Study A has estimated that this scenario will cover from 3 to 4 times more simultaneous users compared to currently deployed Wi-Fi 5 and below.

Scenario 3 (RLAN) will require a limited investment to cover the entire population. This scenario has the highest ratio since it is 300 times less expensive than Scenario 1 and it provides and higher QoS.

From an investment cost versus QoS deployed, the Scenario 3 (RLAN) provides the highest ratio since investment costs are lower than the two other scenarios and does provide a higher level of QoS in the upper 6 GHz.

3.4 Risk to satellite, and associated costs

Another problem that needs to be considered is the potential satellite reallocation cost. Drawing a parallel with the C-band migration, in the USA where this process is currently ongoing, the costs are estimated between €3.2 and €4.7 billion.[144]

In general, there are four broad categories of applications relying on C-band that have been considered for the migration cost:

- receive only consumer applications such as satellite TV broadcasting;
- receive only commercial applications such as for cable head ends;
- two-way Very Small Aperture Terminals (VSAT), such as for banking terminals and ATM networks;
- two-way large dishes such as for trunk telephony.

The migration for satellites can be broken down into several parts, that do not concern only the satellites themself. The company SES Americom calculated the costs for their necessary migration in the USA at around

144 https://www.satellitetoday.com/5g/2020/06/22/intelsat-ses-detail-c-band-transition-plans/

1.67 billion USD. Only 74.9 per cent of these costs can be directly linked to the satellites. Technology upgrades and filters and LNBs account for a further 7.8 per cent and 6 per cent respectively. If migration takes place over time and that therefore the cost of new satellites is marginal, the cost of migrating a satellite can be further subdivided. The engineering and execution laboratory costs amounts to USD 150,000-350,000. A single launched C-Band satellite costs $120M-$450M. Furthermore, the cost for managing satellite relocation program is estimated at $200,000-$400,000.[145]

According to ESOA, the 6 GHz band is mostly used for C-band uplinks for geostationary satellites. Specifically in Europe, more common use is for large gateway earth stations.[146] The impact of satellite uplink operations being prevented due to signal interference from high power IMT stations can be estimated based on the amount of earth stations that would need to transition to other bands or locations as a result.

However, this cost was not considered in the computation of overall investment cost under Study B. It is worth noting that deploying IMT WAN introduces a risk that could require such costs to fix.

145 https://docs.fcc.gov/public/attachments/DA-20-802A2.pdf

146 https://www.Wi-Fi.org/beacon/aarti-holla-maini/in-discussion-with-aarti-holla-maini-secretary-general-emea-satellite

4 CONCLUSIONS

The overall conclusions of study have found that it is more beneficial from both a technical and economic perspective to adopt RLAN for use in the upper 6 GHz band. IMT does offer some limited technical benefits across the two scenarios (wide area licensed 5G and local licensed 5G) however, the use of RLAN in the full 6 GHz band (1200 MHz) enables additional capacity and QoS benefits beyond those of access to the lower 6 GHz. Notably, it enables more wider bandwidth channels (160 / 320 MHz) enabling the full benefits of 1 Gbit/s fixed broadband speeds, aligning with EU's 2025 target. In addition, access to the full band will ease congestion on 2.4 GHz and 5 GHz networks in densely populated areas resulting in an overall uplift in QoS for Wi-Fi users.

In addition, **RLAN not only enables the highest number of applications relevant for the 6 GHz band and in scope of the Digital Decade, but also aligns better with the sector connectivity requirements given that most of these use cases will take place indoors rather than "on the move".** Wide area coverage requirements are not only less relevant for applications in scope but can also be equally met by alternative (mobile) networks (operating in alternative frequency bands), hence the relatively lower ranking of IMT WAN deployment (Scenario 1). Overall, the ubiquity of Wi-Fi device usage and corresponding applications translates into a benefit of additional bandwidth available indoors on an unlicensed basis is therefore expected which outweighs the value of its alternative, licensed use.

- Regarding the Demand price/costs, the study has highlighted the fact that consumers will be willing to pay more for additional connectivity. However, since Scenario 3 (RLAN) requires lower investments, it will allow consumers to have a more affordable access to enhanced connectivity.
- The three scenarios will have a very different Investment vs. QoS ratio. Scenario 1 (IMT WAN) will address two times more users than currently deployed technology within a given area (i.e. densely urbanized areas). Scenario 2 (Local IMT) is not expected to increase the number of users compared to what is offered from alternative frequency bands i.e. 3.8-4.2 GHz. Finally, Scenario 3 (RLAN) is expected to increase the number of users served from 3 to 4 times compared to existing technologies.

RLAN also has the biggest impact in regard to the number of suited application domains/sectors (4 prioritized sectors out of 6), notably construction, manufacturing, education and public services, followed by local IMT (Scenario 2) which is compatible for healthcare, but also construction and only agriculture is best suited for Scenario 1. In fact, IMT WAN scores are relatively low in terms of fitness as a small number of applications in the sectors reviewed are expected to take place "on the move" and wide area coverage requirements can be equally met by alternative networks, however, local IMT (Scenario 2) enables a wider range of applications across sectors than IMT WAN which results in an overall higher score when it comes to "fitness" of requirements compared to Scenario 1. **On the other hand, RLAN enables a higher number of applications vis-à-vis local IMT, thus, scoring the highest in regard to "fitness" of requirements compared to IMT WAN and local IMT.**

In the case of IMT wide area nationwide licensed, the upper 6 GHz band offers a **useful capacity layer in urban densely populated areas** and can support **higher rate applications over wider area** IMT networks. However, nationwide licensing would, in practice, be limited to urban areas where operators wish to increase capacity but may also increase the risk of causing interference to incumbent services.

In the local licensed IMT scenario, using the upper 6 GHz band would be largely unnecessary. This is because when compared to alternative local licensed bands such as 3.8-4.2 GHz the coverage is smaller, and the additional bandwidth and capacity advantage would not be utilized. There may be some potential corner cases where the upper 6 GHz could be used for 5G indoor deployments, but the benefits are mainly related to ultra-reliable low latency communications characteristics of 5G rather than use of the particular band. In addition, any indoor 5G deployment in the upper 6 GHz band would need to be technically assigned to protect existing services.

From an economic perspective the study found:

- The investment required to deploy microcells and macrocells sub-scenario 1 and (IMT WAN) in the upper 6 GHz seem economically advantageous than Scenario 2 (Local IMT), however, it will primarily bring benefits to agriculture which does not appear to be a suitable fit for 6 GHz, primarily because it is expected based on the investment quantification that MNOs will largely deploy cells in urban areas. Also, this scenario will only be beneficial for 14% of the population.
- Overall, the most economically relevant (i.e. least resource intensive) will be Scenario 3 (RLAN). It is supported by the fact that RLAN deployment requires a lower amount of initial investment to be deployed and will most likely be able to coexist with incumbent services and it beneficial for the entire EU population.
- **From a downstream point of view, Scenario 3 (RLAN) will be a better fit than the two other scenarios for applications requiring additional connectivity in the upper 6 GHz.**

Based on the impact expected from improvements in connectivity combined with the sectors' GVA contribution in the EU, **manufacturing along with Healthcare and Construction emerge as the "most critical" in terms of their weight**. Yet, compared to smaller sectors where the majority of the demand from applications is expected to be met by the 6 GHz band (Education, Public Service), alternative technologies and/or bands will to some extent accommodate this extra capacity in 2 of the 3 "high impact sectors" (i.e. Healthcare and Manufacturing).

The final scoring across all three scenarios clearly shows the benefit of opening the upper 6 GHz portion for unlicensed use (LPI/VLP/SP, technologies based on Wi-Fi 6E standards).

ANNEXES

ANNEX 1 PRESENTATION OF STUDY A RESULTS

Most of the results of Study A were fed into Study B or were discarded as part of the process of assessing the Scenarios. However, one factor that remains is a predicted level of infrastructure in the 3400 MHz and 6800 MHz bands required to support the population of several cities in Europe, using averaged population data from various sources, illustrating the variation across selected cities using GIS data compiled by the Joint Research Center for the European Union (Joint Research Centre, 2009).

These data illustrate the need for a combined multi-band approach to network deployment, i.e. it is uneconomic to try to use the 6 GHz band to cover an entire city as in many places the population density makes it uneconomic. Obviously, MNOs have access to several bands, and the bands chosen would be appropriate to the expected revenue from the customers in the catchment.

Without prejudicing the results of the economic study in Part B, the higher the frequency the more likely it is that any deployment would be targeted at areas where the number of potential subscribers, or the required sustained data rates, justified it. This tends to concentrate 6 GHz deployments in places such as shopping centers or football stadiums rather than on a dark desert highway, although a village setting for normal service or even FWA would be appropriate if the fiber infrastructure allowed.

From a licensing perspective, it is not unrealistic to conclude that the 6 GHz band would be more suited to Campus-style deployments and not sold off wholesale to MNOs. MNOs could still use the band, but under a Campus license, perhaps held by the site owner. This would allow private LTE/IMT use, but the Regulator’s revenue would not be instantaneous and would be lower than simply auctioning the band off to MNOs. There is, however, the option of auctioning the band off to a management agency, although the economics of this would be extremely difficult to balance. The limited use of the band for wide-area coverage does imply that the auction concept may not result in large revenues for the regulator as the outlay to fully utilize the band would be significant and therefore MNOs may not be keen on spending a lot of money for spectrum in places they could not afford to serve.

A1.1 Assessment of wide area 5G types for several European cities

The model allows calculation of the number of sites required to cover the surface area of the city, based on the site’s service radius and the area to be covered. It also calculates the number of sites required in that area to serve the population, assuming they all wish to use 25Mbit/s or 100Mbit/s at the same time (technology, latency, CQI and other factors notwithstanding).

It is possible to assess the suitability of a particular type of base station for use in the desired band with the desired service radius and full-band capacity.

Table 48: Selected EU27 Cities and the assessment of site numbers for IMT

City	Country	Pop.	Area (km2)	Density (/km2)	6 GHz sites macro	6 GHz sites micro	6 GHz sites pico	6 GHz macro 25Mbit/s	6 GHz micro 25Mbit/s	6 GHz pico 25Mbit/s
Berlin	Germany	3,669,495	891.7	4,115	105	859	9269	32642	15855	5877
Madrid	Spain	3,223,334	604.31	5,334	71	582	6282	28673	13927	5162
Rome	Italy	2,860,009	1,285	2,226	151	1238	13357	25441	12358	4580
Paris	France	2,165,423	105.4	20,545	13	102	1096	19263	9357	3468
Bucharest	Romania	2,155,240	228	9,453	27	220	2370	19172	9313	3452
Vienna	Austria	1,911,191	395.25	4,835	47	381	4109	17001	8258	3061
Hamburg	Germany	1,845,229	755.22	2,443	89	728	7850	16414	7973	2955
Warsaw	Poland	1,794,166	517.24	3,469	61	498	5377	15960	7752	2874
Budapest	Hungary	1,752,286	525.2	3,336	62	506	5459	15588	7572	2807
Barcelona	Spain	1,620,343	101.4	15,980	12	98	1054	14414	7001	2595
Munich	Germany	1,488,202	310.71	4,790	37	300	3230	13238	6431	2384
Milan	Italy	1,399,860	181.76	7,702	22	175	1890	12453	6049	2242
Prague	Czechia	1,335,084	496	2,692	58	478	5156	11876	5769	2138
Sofia	Bulgaria	1,242,568	492	2,526	58	474	5114	11053	5369	1990
Brussels	Belgium	1,208,542	162.4	7,442	19	157	1688	10751	5222	1936
Cologne	Germany	1,084,498	405.15	2,677	48	391	4212	9647	4686	1737
Stockholm	Sweden	975,819	188	5,191	22	181	1955	8681	4217	1563
Naples	Italy	967,068	119.02	8,125	14	115	1238	8603	4179	1549
Amsterdam	Netherlands	872,680	165.76	5,265	20	160	1723	7763	3771	1398
Marseille	France	868,277	240.62	3,608	29	232	2501	7724	3752	1391
Turin	Italy	852,223	130.17	6,547	16	126	1353	7581	3683	1365
Copenhagen	Denmark	805,420	179.8	4,480	22	174	1869	7165	3480	1290

It can be seen from the table that in general, the higher the population density, the smaller the service radius of each base station should be to limit the number of customers accessing it at any one time. The nearer the site count possible within a city's limits to the number of sites required to service the need, the more suitable the site type is, on pure 'busy hour' expected capacity grounds.

Obviously, this figure can be diluted in several ways, and usually by the inclusion of a mix of site types or the use of multiple bands, perhaps Low Band supplying a wide-area coverage with Mid Band sites serving more focused concentrations of population, which in turn takes the heat off the Low Band Macro sites. As this model is only assessing the use of the 6 GHz band for 5G, then it does not go into that level of complexity.

The ranges derived to calculate the service area and therefore the minimum site density is based on the maximum (CQI1) service range, and not the high-speed data service radius, which is considerably smaller and would result in a higher total figure.

One way to modify the total number is to assume that, as is most likely the case, not everyone wants 25Mbit/s all the time, and their needs are spread across a busy period, and that period is not the same for everyone. In many cases, a handheld device would be downloading in a bursty fashion as it updates social media feeds, or simply camped on a cell doing very little. The effect of this is that the number of actual real-world UEs that a cell can support is several orders of magnitude larger than the model presupposes although there are limits on the number of UEs that can be affiliated to particular site.

The LS model assumes absolute peak capacity and not a day-to-day operational capacity. The difference between the two is very much up to the network operator and every operator will have their own ways of approaching that puzzle. It should be noted that FWA usage profiles do not match mobile UE usage profiles, and the amount of data and the much less bursty nature of consumption does mean that supporting FWA requires much higher levels of standing capacity than necessary for handheld devices. People do not 'stream' movies as it is more sensible to download and cache the movie in part or whole to ensure that the experience is seamless and not interrupted by the viewer going into a tunnel. It is only time-sensitive media that would need to be live-streamed, such as virtual reality, sports events, videoconferencing, specific types of machine communications, or a phone call.

ANNEX 2 MODEL AND ASSUMPTIONS

A2.1 Assumptions

The 5G model is kept as uncomplicated as possible. Only factors that could not be applied after the fact were considered. The exception to this is MIMO. Although that could be unwound if required, there were small overheads involved and it was felt that including it in the cell type was necessary at the initial modelling stage. All capacity assumptions are based on the worst-case busy hour, with the only mitigation being a contention ratio used as a way of scaling the number of UEs affiliated to a site but not actually consuming resources. For instance, a 10:1 ratio meaning that for every UE in use, there were 10 others that were passive at any instant rather than actively queuing for a slot (Random Access).

A2.2 5G model parameters

IMT-2020, or 5G, is modelled in center frequencies (3.5 and 6.8 GHz) and three installation types (Macro, Micro and Pico). Although not all types are permitted in both bands, they were included in the modelling for comparison purposes and not to re-assess their suitability for each band. GSMA studies (insert ref) have assessed the utility of both bands with regard to cell deployments and determined that both bands could be used on macro sites and small cells. However, there is work under way in ITU and CEPT on coexistence studies to support WRC-23 Agenda Item 1.2. This study is considering using terrain and clutter to shield 5G installations from the geostationary orbit (GSO), essentially excluding macro sites. See Section 2.3.

A2.2.1 Cell Configuration

In general, the default, or most common likely configuration was used. Sites/Cells were omnidirectional and not sectorized. This, like many configuration variables, can be calculated in after the fact, so was avoided for the initial capacity calculations. A tri-sector cell has 3x the backhaul requirement of an otherwise identical omnidirectional cell, for instance, and the same service radius, although the user density per sector would be

1/3 that of the omnidirectional cell, because it is effectively three cells, albeit occupying 1/3 of the operational area of the omnidirectional cell.

A2.2.2 Cell Types

Three types of cell configuration were considered based on typical deployment scenarios.

- A Macro cell with 64xMIMO;
- a Micro cell with 18xMIMO; and
- a Pico cell with 4xMIMO.

The terminology used is industry specific. A **Macrocell** is the basic component cell of a mobile network and typically divided into three sectors. The design is optimized for relatively low-capacity, wide-area coverage. **Microcells** are not as small as the name suggests but are essentially simplified, lower-power Macro cells with coverage tailored for specific situations, often within clutter rather than above it, and the user capacity is also lower. The term **Small Cell** has started being used concurrently with microcell although the term often includes picocells, but not always. In this document, Small Cell means anything that is not a macrocell or femtocell, i.e., a cell in the clutter intended for localized, specialized coverage not including personal networking. Within that umbrella term is **Picocells,** which are usually not sectorized, and are designed to cover small areas, such as at street level or areas where customers may congregate, such as traffic pinch points or shops, outdoor markets, railway stations. There are three types of Picocell. We have chosen the 'biggest', with a service range of approximately 200m. Below Picocells, and not assessed in this report, is **Femtocells**. These are normally only found in personal hotspots or attached to home broadband routers. The role of Femtocells in this report is mainly covered by Wi-Fi. The role of all network elements besides Macro is to keep traffic off the Macro cells. Macro cells in mid-band are there to keep traffic off the low-band Macro cells, which constitute the basic geographic coverage layer everything else is built upon.

A2.2.3 Cell throughput

A cell's throughput was calculated using the online 5G NR throughput calculator (5G Tools, 2022). This is a peer-reviewed calculator based on 3GPP TS 38.306.

We assumed a 100 MHz channel in all cases and accepted the defaults unless there was a compelling reason to vary them. The parameters were kept the same across cell types if possible. Those changes are shown in Table 49.

It should be noted that UEs don't tend to have more than 4 antennas, so higher levels of MIMO tend to be used for beamforming or addressing multiple users at the same time rather than supplying a single user with 64 individual spatially separate data streams.

Table 49: Basic 5G NR parameters used, and resulting capacity estimate

Cell	MIMO	QAM	Channel Spacing (MHz)	Subcarrier spacing (kHz)	Throughput (Mbit/s)
Macro	64	64	100	30	24038
Micro	16	64	100	30	6010
Pico	4	64	100	30	1502

A2.2.4 Service Radius

The maximum service radius of each type of cell was calculated using an internal LS model, which utilizes the Okumura-Hata method and CQIs for the service being assessed. This gives a realistic generic service radius and can be used to approximate the number of sites necessary to give physical coverage of a geographic area. EIRP is the regulatory maximum for the site and as bandwidth isn't modelled, the limit is what is allowed, be it in 5MHz or overall. The service radius also varies depending on the modulation level required. Maximum service range is usually quoted for a voice call or low speed data at CQI 1 (two Resource Blocks), and range for 256QAM is significantly less. See also the decrease in service radius with MIMO level when using Spatial Multiplexing.

Table 50: Basic Cell type definitions used in the cell service radius calculation

Cell	EIRP (dBm)	Ant AGL (m)	UE height (m)	Maximum CQI1 Service Radius (3GHz/6 GHz) (m)	256QAM Service Radius (3GHz/6 GHz) (m)
Macro	60	30	1.5	**2700/1650**	**700/425**
Micro	48	15	1.5	**945/575**	**265/150**
Pico	30	10	1.5	**275/175**	**80/50**

The amount of MIMO also affects the regulatory EIRP limit (usually measured over 5MHz for wider channel widths) as it is divided between all MIMO chains, although as each chain is spatially unique, is not included in the link budget. So, a macrocell with a regulatory EIRP limit of 60dBm is the total power, and the individual EIRP of each spatial chain is $1/64^{th}$ of that power (42dBm). 5G uses MIMO in a different way to it has been used in the past. ODFMA modulation doesn't usually need help from MIMO in Spatial Diversity mode, so MIMO is used to multiply the number of data streams being emitted, effectively as a rate multiplier. Current user equipment isn't generally capable of more than 8xMIMO and doesn't use it on the uplink, but over the lifetime of IMT-2020 this is expected to change and is allowed for. Cell sites would use MIMO on the uplink in Spatial Diversity mode to increase the receive gain to overcome the limited EIRP of UEs.

Table 51: 3.5 GHz Maximum service radius depending on MIMO level (showing CQI1 and CQI12 distances)

Cell Type	None	4xMIMO	8xMIMO	16xMIMO	64xMIMO
macrocell	2700/700	1825/475	1500/375	1225/325	825/200
microcell	945/265	650/185	540/150	445/125	n/a
picocell	275/80	190/55	160/45	n/a	n/a

Table 52: 6 GHz Maximum service radius depending on MIMO level (showing CQI1 and CQI12 distances)

Cell type	None	4xMIMO	8xMIMO	16xMIMO	64xMIMO
macrocell	1650/425	1100/275	900/225	750/200	500/125
microcell	575/150	400/100	340/95	280/80	n/a
picocell	175/50	123/36	103/30	n/a	n/a

A2.2.5 Optimizations

With a generic value for cell throughput and service area, it is possible to take other action against these values to make the model more realistic. For instance, introducing a contention ratio, to represent the number of UEs that could be affiliated to a particular site but not actually consuming data at the same point in time. We found that a 10:1 ‘user:using’ ratio gave a believable result in deployed infrastructure. To increase the capacity of macro sites it is possible to sectorize them, so in some of the calculations we have tri-sectored macro sites, but only on 3.5 GHz because we are working on the assumption that a 6.8GHz macro site will not be permitted due to the potential for interference to satellite uplinks. See section 2.3.1 for more details.

A2.3 Considering ‘Population served’ calculations

Contemporary reports quote surprisingly high population densities for some European cities. In truth, this is rarely the case, or perhaps it is the result of taking a peak density figure and extrapolating over an entire city center. ITU-R Report M.2290-0[1], for example, uses a value of over 220,000 people per square kilometer in estimating spectrum demand even in a ‘low’ market setting, that’s one person every 2m.

For instance, if one assumes (Joint Research Center, 2009) that Brussels has a peak density of some 40,000 persons per square kilometer, then extrapolates that to model the spectrum requirement for Brussels at xMHz, but in reality, that peak may only be in a very small area, such as a single office tower. The average for Brussels (Population/Area) is nearer 7500 persons per square kilometer (Wikipedia, 2022), which would result in a significantly lower estimate for spectrum than the writers of such a report might wish for, and significantly more effort (engineering & expenditure on infrastructure) required for those small areas where the catchment is higher than that average figure. The answer is in the middle somewhere, and which side of that answer a bid is pitched depends entirely on the motives of the entity producing the report.

Certainly, a residential tower would have a very high population density per square kilometer, but as the tower cannot be covered effectively by a single outdoor IMT site, engineering needs to be applied that effectively averages out or deletes the spike in population density. The building is more likely to be served by an indoor distributed antenna system rather than relying on outdoor coverage elements. External coverage sites would have little impact on the building except to serve customers of MNOs that were not working in the building and the impact of a 6 GHz site outside the building would be limited unless it was specifically designed to serve the building or just happened to be on the roof of a nearby block and illuminating part of the tall building. This pre-supposes that MNOs would be that bothered about a specific building that they would install a network especially for it. Up until now, without sponsorship, occupants of large buildings would have to live with whatever coverage the outdoor service provides, or use ‘Wi-Fi calling’ if available. It is likely that the niche for 6 GHz is indeed as an improvement on Wi‑Fi calling, either on premises or at home. Whether the best technology for exploiting the 6 GHz band is IMT-2020 or RLAN is discussed later.

The dilemma for statistical analysis is how such peaks in population are addressed. The usual method is to slice the building up and distribute the occupants over an equivalent linear area, or average the occupancy over a suitable raster, which may be an average of the total population over the area of the city, the usual method.

Because ‘city’ population densities are averaged over wide areas, so a city (Brussels) may have an average population of 7465 persons per square kilometer, but looking at a more detailed plans, the population is concentrated into small areas of the city and not perhaps as easy to quantify by spreadsheet statistics as first thought. Brussels’ peak occupancy is in Gillon (bright yellow, below) at 48,000 persons per square kilometer, but that covers a few streets, and some nearby parts of the ‘city’ are at 20 persons per square kilometer. One can easily assume that 6 GHz would be useful to add capacity in Gillon but be of very little use where the population is less dense. It is these details that need to be considered when assessing the headline-grabbing statistics in reports/studies promoting the need for more spectrum for 5G networks.

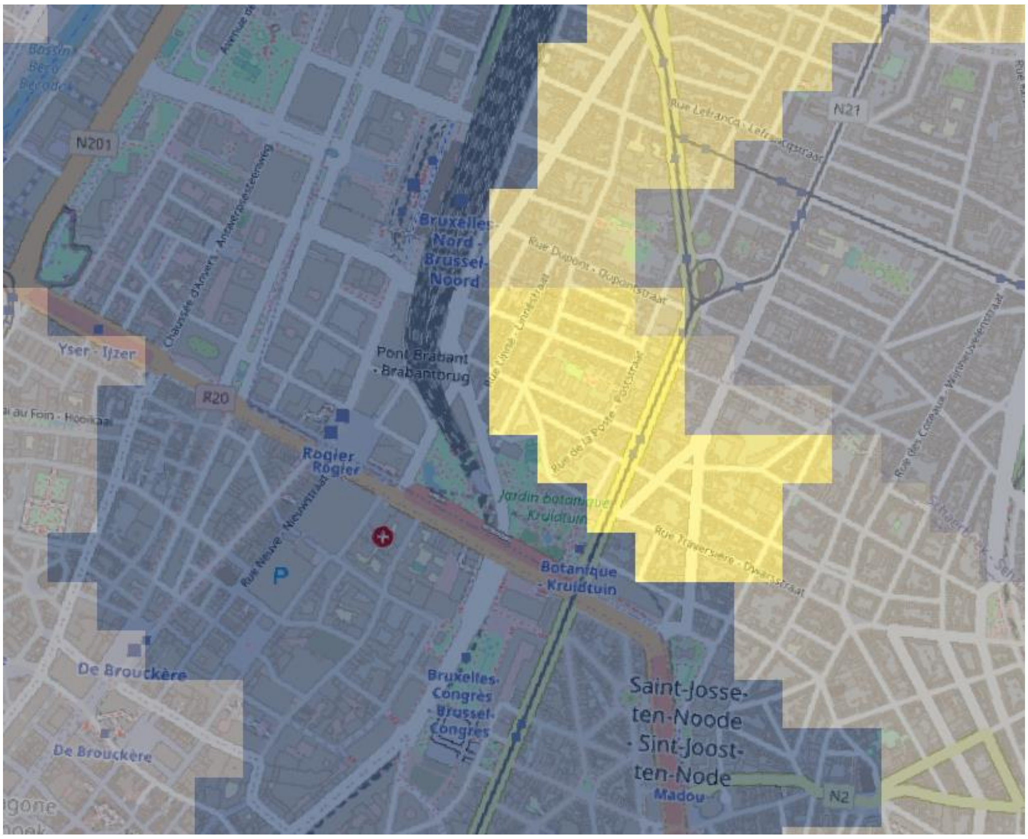

Figure 18: Map of Brussels population density. Bright Yellow area showing 48k persons per km^2, but the dark blue is around 200 persons per km^2.

So, whilst it is possible to produce tables of city population densities vs. the number of sites required to serve that population density, and we have, it is not a precise science, and no mobile operator would apply a single band network to a city if there were other more suitable bands available to press into use. The reality is that most MNOs would apply layers of coverage and capacity depending on the population density, so calculating whether, say, 6 GHz is a good band for covering cities of a certain population density is ultimately pointless: the study needs to identify where in a city or development the 6 GHz band has an advantage over other bands. This is what we attempt to explain in the following sections.

Table 53 below shows the number of sites required at two specific sustained data rates. It includes maximum concurrent UE numbers for site types as described by Telit[147].

Explanation of the derivation of data in this table: Assume a macrocell has a maximum capacity of 2000 users and a maximum throughput of 24000Mbit/s using a 100MHz carrier, 64xMIMO, that's 12Mbit/s for each user. Therefore, at 25Mbit/s, it can handle 960 users, and at 100Mbit/s it can handle 240 users. Sectorizing the cell

147 https://www.telit.com/blog/5g-networks-guide-to-small-cell-technology/

would allow for multiplication of that number over the service area, so a tri-sector cell would be able to serve 720 users at 100Mbit/s (with a hard limit of 240 per sector).

Assuming very rough figures, a simple calculation will allow the planner to scope the capacity of a band, assuming no co-channel interference, or no same cell type frequency reuse. If you include the service radius of the site (from the LS model) you can calculate the no-terrain user density per square km that a macro site can handle (by sectorizing (x3) then dividing the resulting 6000 users served by the area in square km (40km^2 at 3500MHz)), which gives you a total of 150 concurrent users served per square km. For an average EU27 city, with an average user density of 5000 persons per square km, that means 34 sites per square km are required to serve that density. Then add the number of sites required to cover the area of the city (assume 100km^2) that makes 3400 macro sectors at 3 GHz required to serve the population of that city. However, there isn't the bandwidth available to do this, so more focused capacity needs to be employed.

Table 53 illustrates the calculations required to build capacity in a city using both 3 GHz and 6 GHz sites but omitting 6 GHz macro sites due to potential interference to satellite uplinks, discussed in 2.3.1. This table comes from a spreadsheet that calculates capacity. The yellow column shows the number of users left after a single site has taken its maximum capacity in a square km. This table is for a population density of 5000 persons per square km. At 2500 persons per square km, the 3 GHz band takes up all the users and leaves none for the 6 GHz band. Referring again to the picture of the center of Brussels, that means 6 GHz is not necessary in many parts of the town center as the population density is too low.

Table 53: Number of users possible at 25 or 100 Mbit/s under different cell types

Band	Type	User limit (per sector)	users per km^2	hard limit per users sector per sq km	Sectors for pop/km^2	Sectors per city area for pop density	Sectors to cover city area	Users per site 100Mbit/s	Users per site 25Mbit/s	Users unserved per km2
3GHz	tri-sector macro	2000	150	150	34	3400	8	18	72	4400
	monosector micro	200	43	43	117	11700	22	13	51	4228
	monosector pico	64	167	64	79	7900	260	40	157	3972
6 GHz	tri-sector macro	2000	404	404	13	1300	21	49	195	0
	monosector micro	200	114	114	44	4400	57	35	137	3174
	monosector pico	64	403	64	79	7900	629	95	378	2726

The figures in Table 53 are based on simplified power levels used by each type of base station, the user distribution over the service area and the variation in signal quality over that radius. We have included MIMO, but the calculations are for concurrent use, so these are absolute maximum numbers and can be diluted by including busy-hour contention, such as a 5:1 ratio to estimate the number of users possible to be served at the same time under B2B service levels. The true number of users that could be served acceptably by such a site depends on the overall user profile and would be significantly more outside the busy 'hour', to say nothing of the technology being used for the transmission medium and what could be successfully argued constitutes '*at the same time*', or 'concurrently'.

In a real network, there would be a mix/hierarchy of site types deployed, and the Low Bands would also be in use as well as, perhaps the millimeter bands. Network planning usually assumes the users will be outside and to then include an allowance for building penetration, which would be considered in detailed plans or considered incidental coverage if the number of buildings is not great. Generally, dedicated in-building coverage would be low power in the Mid or Millimetric bands, and isn't considered in these calculations. It should be noted that published 'population' data are usually for residents, who would normally be indoors, incidental coverage, or on their own broadband. A significant number would be at work during the 'busy hour', so the subscriber peaks during the day may not map to residential peaks fossilized in the published data. Recent rises in home working due to the Covid-19 pandemic will have moved the daytime figures closer to the published data distributions, although most people would still be using their home ISP data connections and not 5G. 5G remains primarily the domain of nomadic users, although it is ideal for short-term FWA when moving house or operating from premises where fixed lines are not available. It is also a potential technology for persons renting or having lifestyles that preclude contract-style fixed network provision. It is easier to move house with a 5G FWA modem that struggle with ISP provision at the new home when the user may not have rights over telecommunications provision.

The pinch point is when the available spectrum cannot support the number of users requiring data using the best available mix of Low and Middle band sites. This might only happen at specific times, or even only during events such as Carnivals. The available spectrum would at other times not be fully utilized.

ANNEX 3 DEMAND PRICE/COSTS

A3.1 Methodology

The objective of this section is to describe the methodology for analyzing consumer demand for fixed and mobile broadband in the EU, with a specific focus on whether consumer demand for broadband has changed over time. Demand for fixed and mobile broadband will be analyzed using two different indicators. The first indicator is the number of subscriptions of both fixed and mobile broadband. This indicator will inform the analysis about whether consumers purchase broadband internet or not, i.e. the focus here is on the extensive margin. The second indicator is the amount of data used by consumers, measured in gigabytes (GB). This second indicator analyzes how consumers react on the intensive margin. This captures how much data the consumers use when they purchased fixed or mobile broadband.

The focus is on all 27 EU Member States for the period 2008 to 2020. This allows for analyzing cross-country differences and how consumer behavior has evolved over time. In order to capture these aspects, the analysis will rely on panel data techniques.148 The use of panel data techniques also allows for controlling for unobserved country specific characteristics. This could for example be the level of digitization of the country, which is determined by institutional factors. The figure below sows the Digital European and Society Index score of all EU Member States and the number of mobile broadband subscriptions. The firsts can be considered fixed over the time horizon analyzed but it remains important for the demand for broadband

148 Chamberlain, G. (1984): Panel data, Handbook of Econometrics, Volume 2, 1984, Pages 1247-1318.

internet, as shown by the upward sloping trend line. This highlights the importance of unobservable characteristics

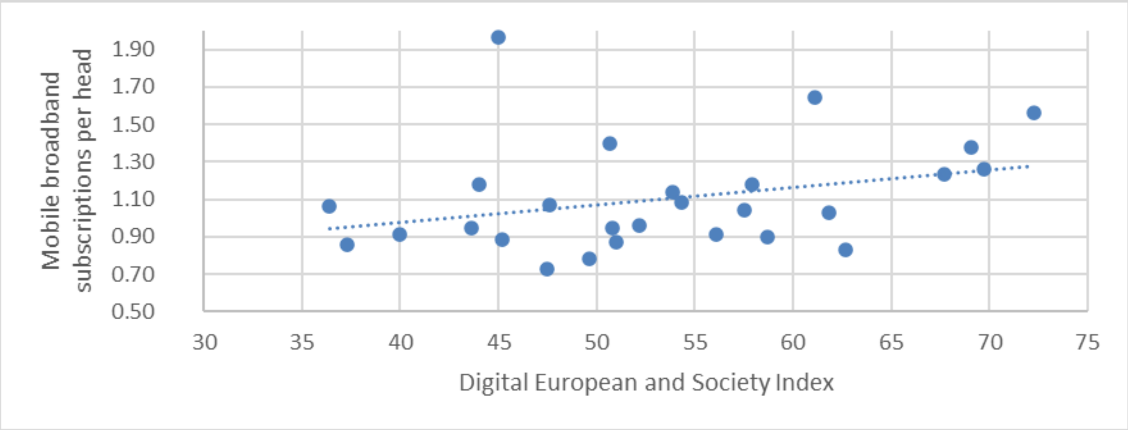

Figure 19: Digital develop and mobile broadband subscriptions

Source: own elaboration based on ITU and European Commission

The model specifications:

The model we estimate follows the traditional way of estimating demand for goods and services. Demand is typically modelled as a function of the price of the product, income of the consumers, price of related goods, and the number of buyers in the market. In this analysis we follow the same approach and use the population as an indicator for the number of buyers in the market. Our model can be specified as follows:

$$(1)\ \ subscriptions_{i,t}^{j} = \beta_0 + \beta_1 \cdot income_{i,t} + \beta_2 \cdot population_{i,t} + \beta_3 \cdot price\ of\ broadband_{i,t}^{j} + \alpha_i + \varepsilon_{i,t}$$

The superscript *j* refers to the type of Broadband, namely fixed or mobile. Demand for each of the type is estimated separately. Subscript *i* refers to the country. As mentioned above, focus of this analysis is on all 27 EU Members States. Subscript *t* refers to the year, and focus is on the period from 2008 to 2020. $\varepsilon_{i,t}$ is an idiosyncratic error term. Since the model relies on country level data in a panel data setting, it also allows for unobservable country specific characteristics. These characteristics are captured by α_i.

The β's are parameters to be estimated. All variables are in natural logs, and this implies that the estimated parameters can be interpreted as elasticities. Elasticities measure, e.g. how many percent subscriptions change when the population goes up by 1%. This elasticity is captured in the parameter, β_2. The parameter of key interest is β_3, which is the price elasticity. In order to analyze consumer behavior over time.

The analysis also makes use of recursive estimation techniques. This will shed light on the stability of the key parameter of the demand equation. It allows an analysis of how consumers have changed behavior over time and in particular how consumers react to changes in the prices for broadband. Specifically, this is done by observing parameter changes over time when the model estimated for 5-year intervals.

A3.2 Data

In order to estimate the model, we rely on data from the International Telecommunication Union (ITU), EURtat and the OECD. From the ITU we collected data on fixed broadband subscriptions, mobile broadband subscriptions, the price of fixed and mobile broadband. From EURtat, we collected data on income, general price development, population and exchange rates. Similar to the traditional approach, income is proxied by GDP since household disposable income is unavailable in some EU Member States. Data is collected at the country level for all 27 EU Member States. From these two sources we have a panel starting in 2008 and ending in 2020, covering all 27 EU Member States. Finally, from the OECD we have collected information on mobile broadband data usage. This data source only covers the period from 2016 onwards and includes only OECD countries.

A3.3 Analysis

The objective of this section is to analyze consumer demand in the EU for fixed and mobile broadband, with a specific focus on whether consumer demand changed over time. We will follow the methodology outlined above in section 2.1.3. The analysis will analyze the demand for both broadband and fixed broadband internet on the extensive as well as the intensive margin. The analysis is done within a panel data framework, allowing analyzes across countries as well as over time. In order to analysis consumer behavior over time, the analysis also makes use of recursive estimation techniques. This will shed light on the stability of the key parameters of the demand equation, how consumers have changed behavior over time and how consumers react to change in prices for broadband.

The starting point of our analysis is equation (1) shown in section 2.1.3. It is repeated here for the sake of clarity:

$$(1)\quad subscriptions_{i,t}^{j} = \beta_0 + \beta_1 \cdot income_{i,t} + \beta_2 \cdot population_{i,t} + \beta_3 \cdot price\ of\ broadband_{i,t}^{j} + \alpha_i + \varepsilon_{i,t}$$

The superscript *j* refers to whether we are analyzing the demand fixed or mobile subscriptions. We estimate them separately. Subscript *i* refers to the country. Our focus here is on all 27 EU Members States. Subscript *t* refers to the year, and our focus is on the time period from 2008 to 2020. $\varepsilon_{i,t}$ is an idiosyncratic error term. Since we are estimating the demand using country level data in a panel data setting, we can also allow for unobservable country specific characteristics. These characteristics are captured by α_i.

Table 54 below shows the estimation results of the model relying on data for all EU Member States and for the period 2008 to 2020. Table 54 below shows results of the demand for both mobile broadband (models 1-3) and for fixed broadband (models 4-6). As commonly done in panel data estimations, we motivate the importance of the unobservable country specific characteristics. We therefore show the estimation results of three variants of equation 1;

i) A pooled regression where we assume that unobservable characteristics are unimportant,

ii) a regression assuming fixed effects; and

iii) a regression assuming random effects.

While the fixed effect model cannot identify the effects of variables that are fixed over time, random effects models can. The intention of showing these models is to show that unobservable characteristics are important, i.e. that we can reject the pooled regression model. Then in the next step, the Hausmann test is used to test whether the data supports a fixed or random effects.

Table 54: Estimation of number of subscriptions

	Mobile broadband			Fixed broadband		
	(1) Pooled regression	(2) Fixed effects	(3) Random effect regression	(4) Pooled regression	(5) Fixed effects	(6) Random effect regression
Price of subscription	0.242*	-0.519**	-0.552**	0.643**	-0.161**	-0.161**
Income per head	0.320**	2.534**	1.418**	0.115	0.280**	0.282**
Constant	15,68**	26,33**	22.03**	0.321*	15,98**	15.98
Unobserved heterogeneity	No	Yes	Yes	No	Yes	Yes
R-squared	0.0777	0.0318	0.034	0,0884	0,0002	0,0002
No. of observations	334	334	334	351	351	351
Time period	2008-2020	2008-2020	2008-2020	2008-2020	2008-2020	2008-2020
Hausmann test	Chi2 = 21,10	Prob > Chi2 = 0.0001		Chi2 = 7,31	Prob > Chi2 = 0.0259	

Note: * indicates that the parameter is significant at a 90% level. ** indicates that the parameter is significant at a 95% level. Source: Own elaboration based on ITU, and EURtat.

The first point to note is that in the pooled regression the price elasticity is estimated to be positive (Model 1 and 4). This appears implausible, and in fact, when accounting for unobservable characteristics (models 2 and 3 for mobile broadband, and models 5 and 6 for fixed broadband), the price elasticity turns negative, which is more intuitive. A negative price elasticity means that when prices go down, then the number of subscriptions go up. This appears intuitive and this supports the hypothesis that unobservable characteristics are important. Another point is that all the parameters to income per head have the expected positive sign. A positive sign means that when prices go up, demand for broadband increases. A second point to note is that all the estimated coefficients in the fixed effects and random effects are significant at a 95% level, which indicates that they are significantly different from zero.

The table above also shows the results of a Hausman Test in the last row. This test essentially looks at whether there are any systematic differences in the coefficients. Rejection of the null-hypothesis is supportive of a fixed effect model. The Hausmann test of the demand for mobile broad strongly supports a fixed effect model. This is also the case for fixed broadband, although it is not as strong as for mobile broadband. In the following the focus is there exclusively on models assuming fixed effects.

Another interesting aspect is how consumer behavior has changed over time. To analyze this, the analysis looks at the stability of the price elasticity, using recursive techniques. That is, instead of making use of all years as in the estimation shown in the table above, the estimations were repeated for periods of five-years intervals. The first model made use of data from 2008 to 2012, the second from the period 2009 and 2013, etc. In total, the model was estimated 9 times. The figure below shows the estimation results.

An interesting result is that the price elasticity is declining over time. In the beginning, the price elasticity is estimated close to -1 for mobile broadband and around -0.17 for fixed broadband. Both parameters are significant at the 95% level, as indicated by the two * in the axis label. When changing the time period and moving the window backward in time, the price elasticity is becoming numerically smaller and eventually becomes insignificant. In other words, consumer demand is becoming less and less price sensitive as time goes by. This is interesting in several aspects and poses several questions, which we discuss in the following section.

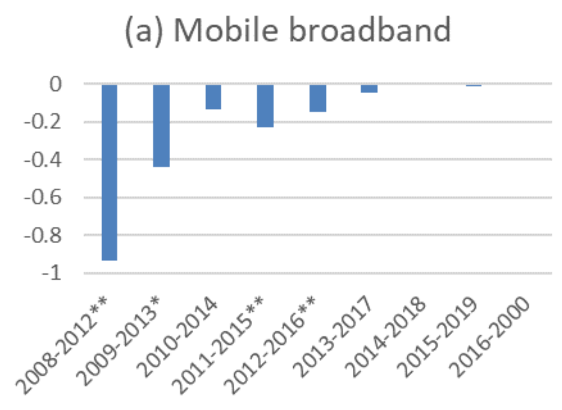

Figure 20: Estimation of price elasticities using recursive for mobile broadband

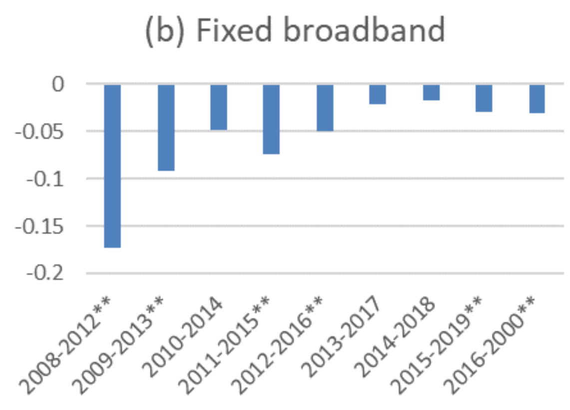

Figure 21: Estimation of price elasticities using recursive for fixed broadband

Notes: * indicates that the parameter is significant at a 90% level. ** indicates that the parameter is significant at a 95% level Source: ITU and EURtat.

Sensitivity and robust checks

The lack of price sensitivity could be due to how the empirical model is specified, as shown in equation (1). The equation measures the number of mobile and fixed broadband subscriptions in each country. The lack of price sensitivity could simply mean that EU inhabitants have all their subscriptions that they need, and for this reason demand no longer react to price changes. One way of testing this, is to re-estimate the model for two sub-samples; one only with countries with the lowest numbers of subscriptions per inhabitant, and another one with countries with the highest number of subscriptions. The figure below shows the estimated price elasticity for each of these subsamples.

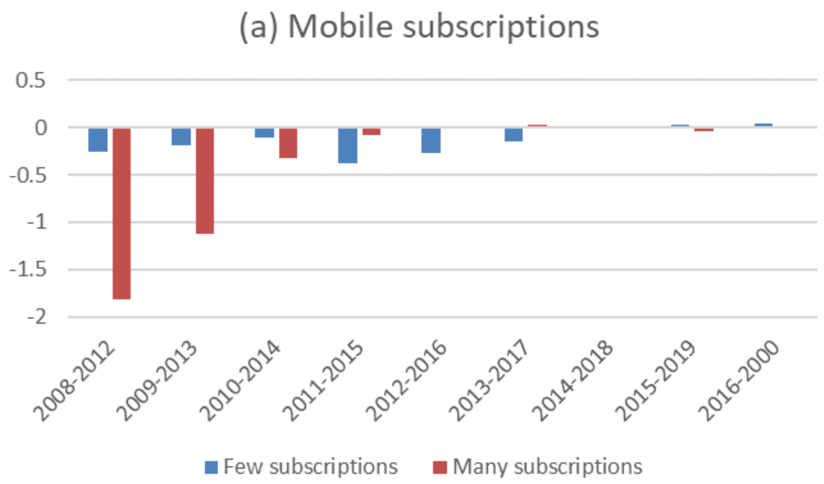

Figure 22: Price elasticity in countries with few and many mobile subscriptions, EU countries

Source: own elaboration based on ITU and EURtat

The results for countries with many subscriptions show the same trend as in the full sample. This could mean that this sample drives the results, and it is likely that demand is becoming saturated in these countries. However, for countries with few mobile subscriptions, the price elasticity remains smaller. However, they also tend to exhibit the same pattern, especially after 2010 where LTE was introduced. The coefficient is also getting smaller and towards the end it becomes insignificant. This means that it is not only in countries with many subscriptions relative to the population that show less and less price sensitivity over time. It applies essentially in all EU countries. This finding is supportive to the hypothesis that demand is not saturated. In addition to this, if demand was saturated, the growth in the number of subscriptions would tend to diminish over time, and approach zero. In other words, the number of subscriptions would stabilize. However, this is not the case as illustrated in the figure below. The data at hand do not indicate that the demand for mobile broadband is saturated. The flip side of this argument is that mobile broadband is becoming an essential good, i.e. that demand is broadly based across all EU countries.

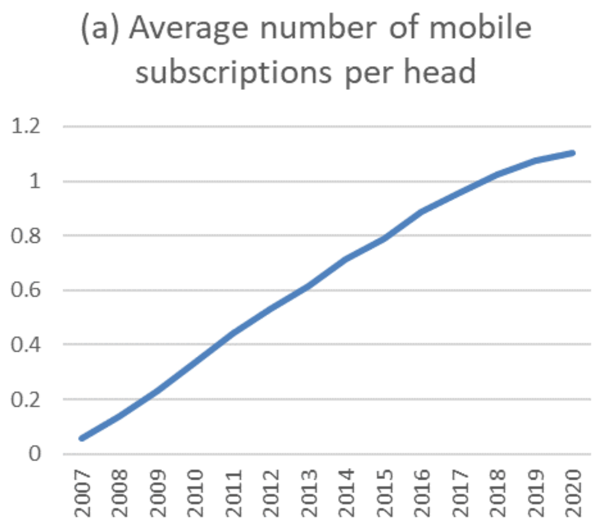

Figure 23: Number of subscriptions per head, unweighted average of EU countries-mobile

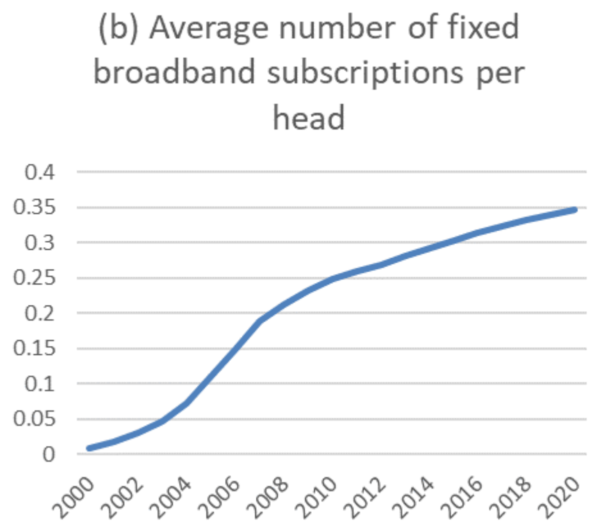

Figure 24: Number of subscriptions per head, unweighted average of EU countries-fixed

Source: own elaboration based on ITU and EURtat

The above analysis is a way of analyzing consumer behavior along the extensive margin, i.e. the decision to buy or not to buy broadband subscriptions. Another aspect is how consumers are behaving along the intensive margin, which is informative about how much data consumers are consuming. To analyze the amount of data consumed, the analysis now turns its focus to another model, yet similar to the one above. Instead of having the number of subscriptions on the left-hand side of the equation, the equation analyzes the mobile broadband data consumed. Focus here is exclusively on mobile broadband.

Data on mobile broadband data used is obtained from the OECD and only covers 5 years (2016-2020). Since there is only five years of data available, the model cannot be estimated recursively, and it is hence not possible to analyze how consumer behavior has changed over time. Table 55 below shows the estimation results.

Table 55: Estimation of number of subscriptions

	Mobile data use (GB)		
	(1) Pooled regression	(2) Fixed effects	(3) Random effect regression
Price of subscription	-0.526**	0.118	0.130
Income per head	0.422**	4.952**	0.269
Constant	4.355**	19.400**	2.166**
Unobserved heterogeneity	No	Yes	Yes
No of observations	110	110	110

Period	2016-2020	2016-2020	2016-2020
R-squared	0.1002	0.0078	0.0001
Hausmann	Chi2= 24.13	Prob > Chi2 =0.0000	

Source: own elaboration based on ITU, OECD and EURtat

The central parameter is again the price elasticity. As before, the table shows the results of a pooled regression, as well as for fixed and random effects models, which allow for unobserved heterogeneity. Again, the price elasticity becomes intuitive when allowing for unobserved heterogeneity, i.e. becomes positive which indicates that consumers are willing to pay more for higher use of data. In other words, consumers consuming more data also pay more. It should be noted that the results are not as robust as the analysis of the extensive margin, since the estimated parameter is only close to being significant a 90% level. Although this casts some uncertainty about the validity of the results, it supports the finding that consumers are willing to pay for the data and that the price is not a key parameter when paying for the services.

To sum up, our empirical analysis shows that EU consumers are demanding more and more broadband internet services. In addition to price and income per capita, country specific (unobservable) characteristics are important determinants of demand. Instant access to internet and the need to be online is shaping the behavior of consumers. Consumers are demanding more and more mobile and fixed broadband subscriptions. The price for a subscription is becoming less important, and what matters is what is included in the subscription and the amount of data. While this could be an indication of consumers being saturated with broadband subscriptions, the analysis argues that this is not the case. Our analysis is supportive of the hypothesis that broadband internet is becoming an essential good and that consumers are willing to pay for these services.

ANNEX 4 LITERATURE CONSULTED (APPLICATIONS)

Authors	Title	Year
STL Partners	The Impact Of 5G On The Manufacturing Industry: A $740bn Opportunity	2019
Omdia	5G Impact 2030: The Impact Of 5G On The Economy, Employment, And Emissions In France, Spain, Poland, Belgium, And Romania In 2030	2021
GSMA	3.5 GHz In The 5G Era	2021
Analysys Mason	5G Action Plan Review For Europe	2020
GSMA	Capacity To Power Innovation 5G In The 6 GHz Band	N/A
Dotecon Ltd and Axon Partners Group	Study On Implications F 5G Deployment On Future Business Models	2018
Ericsson Consumer & Industrylab	5G For Business: A 2030 Market Compass	2020
Policyimpact Partners & DSA	How To Realize The Full Potential Of 6 GHz Spectrum	2021
Pwc	The Global Economic Impact Of 5G.	2021
Ericsson Consumer & Industrylab	Harnessing The 5G Consumer Potential	2020
IHS Markit	The 5G Economy How 5G Will Contribute To The Global Economy	2019
Tech4is	5G Socio-economic Impact In Switzerland	2019

ANNEX 5 ACRONYMS AND ABBREVIATIONS

3GPP: Third Generation Partnership project, a global standardization body for developing mobile standards

ADSL: Asynchronous Digital Subscriber Line

AGV: Automated Guided Vehicle

AP: Access Point in the context of this report this is usually a Wi-Fi/RLAN device.

AR: Augmented Reality

CBA: Cost-benefit analysis

CEA: Cost-effectiveness analysis

CEPT: European Conference of Postal and Telecommunications

C-Band: IEEE designation for a portion of the electromagnetic spectrum ranging from 4.0 to 8.0 GHz. However, the U.S. Federal Communications Commission C band proceeding, and auction additionally designated 3.7-4.2 GHz as C band. In this report, we try to restrict the use of the term C-Band only to satellite systems, recognizing that multiple bands, some contentiously allocated/proposed for IMT-2020 use, are within C-Band, so it is too imprecise to use in any other way.

CQI: Channel Quality Indicator

dBm: Decibels relative to 1 mW

DESI: Digital Economy and Society Index

DFS: Dynamic Frequency Selection

EIRP: Equivalent Isotropic Radiated Power

Femtocell: Consumer-level ‘closed’ (limited access) cell designed for installation in the home or in personal devices. Range about 10m. Not the focus of this report, although could be considered part of the RLAN domain.

FS: Fixed Service

FSS: Fixed Satellite Service

FTP: File Transfer Protocol

GVA: Gross Valued Added

HTTP: Hypertext Transfer Protocol

IMT: International Mobile Telecommunications. Analogous to 5G in this report and when more correctly described as IMT-2020.

IoT: Internet of Things

ITU: International Telecommunications Union

IEEE: Institute of Electrical and Electronics Engineers

LAN: Local Area Network, usually describing a predominantly wired infrastructure with wireless access points in places.

LNB: Low Noise Block

LPI: Low Power Indoor

Macrocell: A high-capacity, wide area coverage base station that can serve many simultaneous users in a mobile network. Usually installed above local clutter. Range of 5-30km normal, depending on data rate or modulation scheme used.

MCA: Multi-Criteria Analysis: MCA provides a systematic approach for supporting complex decisions according to pre-determined criteria and objectives. MCA is particularly suitable for complex decision problems that involve multiple and conflicting objectives and criteria. It allows identifying a single preferred alternative, or to rank or short-list possible alternatives. MCA provides a framework to explore trade-offs between different options.

Microcell: A less-sophisticated, lower power, lower capacity form of Macrocell used to infill areas of poor Macro coverage and soak up smaller areas of higher user density. These cells tend not to be sectored, but this is not always the case. This is an older term than the more modern Small Cell, and specifically excludes Picocells, which are usually included in the term Small Cell, so this document uses both terms, depending on context.

MIMO: Multiple Input Multiple Output a method for increasing capacity in wireless networks

mMTC: Massive Machine Type Communications

MNO: Mobile Network Operator

MU-MIMO: Multi User Multiple Input Multiple Output

OFDMA: Orthogonal Frequency Division Multiple Access

Picocell A very low coverage cell of the smallest type deployed by MNOs for public use. Service range of 200m or less.

QAM: Quadrature Amplitude Modulation

QoS: Quality of Service

RLAN: Radio Local Area Network. Analogous to Wi-Fi.

SFC: Automatic Frequency Control

Small Cell: A rage of base station/cell types of lower coverage and complexity than a Macrocell, often installed within clutter to serve discrete areas of high user density or for specific applications. Also previously known as Microcells, this newer definition also includes Picocells and even Femtocells in some contexts, although they were previously considered separate. Service range of 10m to 2km, less at higher data rates.

SME: Small to Medium Enterprise

SMTP: Simple Mail Transfer Protocol

SP: Standard Power

TCP/IP: Transmission Control Protocol/Internet Protocol

TDMA: Time Division Multiple Access

UAV: Unmanned Aerial Vehicle

UE: User Equipment

UHD: Ultra-High Definition

URLLC: Ultra Reliable Low Latency Communications

VLP: Very Low Power

VR: Virtual Reality

WAN: Wide-Area Network, as opposed to LAN

Wi-Fi: Trademark of the Wi-Fi Alliance, denotes a range of standards produced by IEE 802.11. The term is avoided in regulatory circles and RLAN is used instead. In this report, the terms are used interchangeably, although RLAN is used where appropriate.

WRC: World Radio Conference

DSA

DYNAMIC • SPECTRUM ALLIANCE

2022

FOLLOW US:

@DynamicSpectrumAlliance

Dynamic Spectrum

Dynamic Spectrum Alliance

@DynamicSpectrum