GSMA

Mobile Evolution in 6 GHz

The impact of spectrum assignment options in 6.425–7.125 GHz

September 2024

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Executive summary

THEMES IN THIS REPORT:

Mobile needs space to grow

Data demand is rising

Digital development needs macro-cell 6 GHz

Mid-bands are indoor and outdoor

IN 2023 the **increase** in global mobile data traffic was greater than the **absolute traffic** level in → 2018

32 EB/month
2023 mobile data increase over 2022

27 EB/month
2018 total mobile data

Peak 6 GHz trial speeds: 12 Gbps

IN CITIES STUDIED IN THIS REPORT:

The average economic benefit of **FULL-POWER LICENSED MOBILE IN UPPER 6 GHz** is **7×** **GREATER THAN UNLICENSED**

71% **of mobile data use is indoors and** **29%** **is outdoors**

85% **of indoor connectivity is provided by mid-bands with** **15%** **coming from low bands**

71% **of urban indoor 5G use is provided by 3.5 GHz**

Wi-Fi use:

42%	43%	15%
Wi-Fi 4	Wi-Fi 5	Wi-Fi 6

Technology migration will enhance efficiency

Mid-band 4G download speeds are 3× higher than on low-bands

3.5 GHz 5G download speeds are **7×** times higher than low bands and **2.5×** higher than lower mid-bands

New evidence on traffic growth, network utilisation and efficiency of spectrum use

Considerations on the optimal approach for managing spectrum in the 5.925–7.125 GHz frequency range are at the forefront of global debate. Following the conclusion of the World Radiocommunication Conference 2023 (WRC-23), countries representing 60% of the global population sought inclusion in the identification of the band for licensed mobile. Regulators are now seeking further evidence to inform their decisions on which technology requires additional 6 GHz spectrum, as this represents the largest remaining single block of mid-band spectrum that can be assigned to licensed mobile or unlicensed RLAN.

Debate on the use of the 6 GHz band forms part of a wider discussion on the future of connectivity. The digital needs of industry, businesses and consumers have a clear impact on spectrum management considerations, including the use of licensed and unlicensed spectrum, and macro- and small-cell public mobile networks. To assist policymakers in their decision-making for the evolution of mobile spectrum, including the 6 GHz band, this report provides new evidence on data traffic growth, the utilisation of mobile and Wi-Fi in different scenarios and frequency bands, and how efficiently mobile and Wi-Fi technologies are currently utilising their existing spectrum.

Key findings

- **Mobile and fixed operators will need to manage significant traffic growth on their networks over the next decade.** Global mobile traffic growth in 2023 was the largest of any year to date. The 2023 increase alone was greater than the absolute traffic level in 2018. Looking ahead, growth in traffic per mobile connection during 2023–2030 is expected to be 2–4× greater than over the previous seven years, depending on the region. It is important for regulators and policymakers to consider these absolute increases in network traffic rather than the percentage growth.
- **Most mobile use is indoors and largely delivered over mid-band spectrum.** In the case of indoor 5G, the majority of traffic is delivered in the 3.5 GHz frequency range, which provides high-performance indoor coverage, with data rates up to 16× faster than with 5G low bands. Trials have shown that 6 GHz can deliver comparable indoor coverage to the 3.5 GHz range. Evidence also strongly suggests the upper 6 GHz band can effectively provide an additional capacity layer in urban areas and that it can meet the majority of indoor and outdoor requirements.
- **There is scope to improve the efficiency of unlicensed Wi-Fi spectrum use.** In the cities[1] considered in this study during Q1 2024, data gathered by Ookla shows that between 22% and 78% of Wi-Fi usage was on legacy Wi-Fi 4 technology. The lower 6 GHz band was hardly utilised for Wi-Fi 6. Studies that have assessed Wi-Fi spectrum needs indicate a spectral efficiency range from 1 to 9 bps/Hz.[2] The lower end of this range represents sub-optimal use of the unlicensed frequency bands currently available. Upgrading to the latest Wi-Fi 6 technology would be more efficient, along with optimising indoor deployments (for example, with additional access points, mesh network solutions and using Wi-Fi boosters) and using unlicensed high bands in the 57–71 GHz range, which would all reduce the amount of additional spectrum needed.
- **5G is expected to deliver spectral efficiencies** of around 6 bps/Hz, which is seven times more efficient than 3G,[3] as spectrum licences mean operators face a pricing signal to utilise spectrum efficiently. In addition to improving spectral efficiencies, operators also reuse spectrum where possible by densifying networks. It is important that policymakers avoid assigning spectrum to compensate for inefficient unlicensed use.

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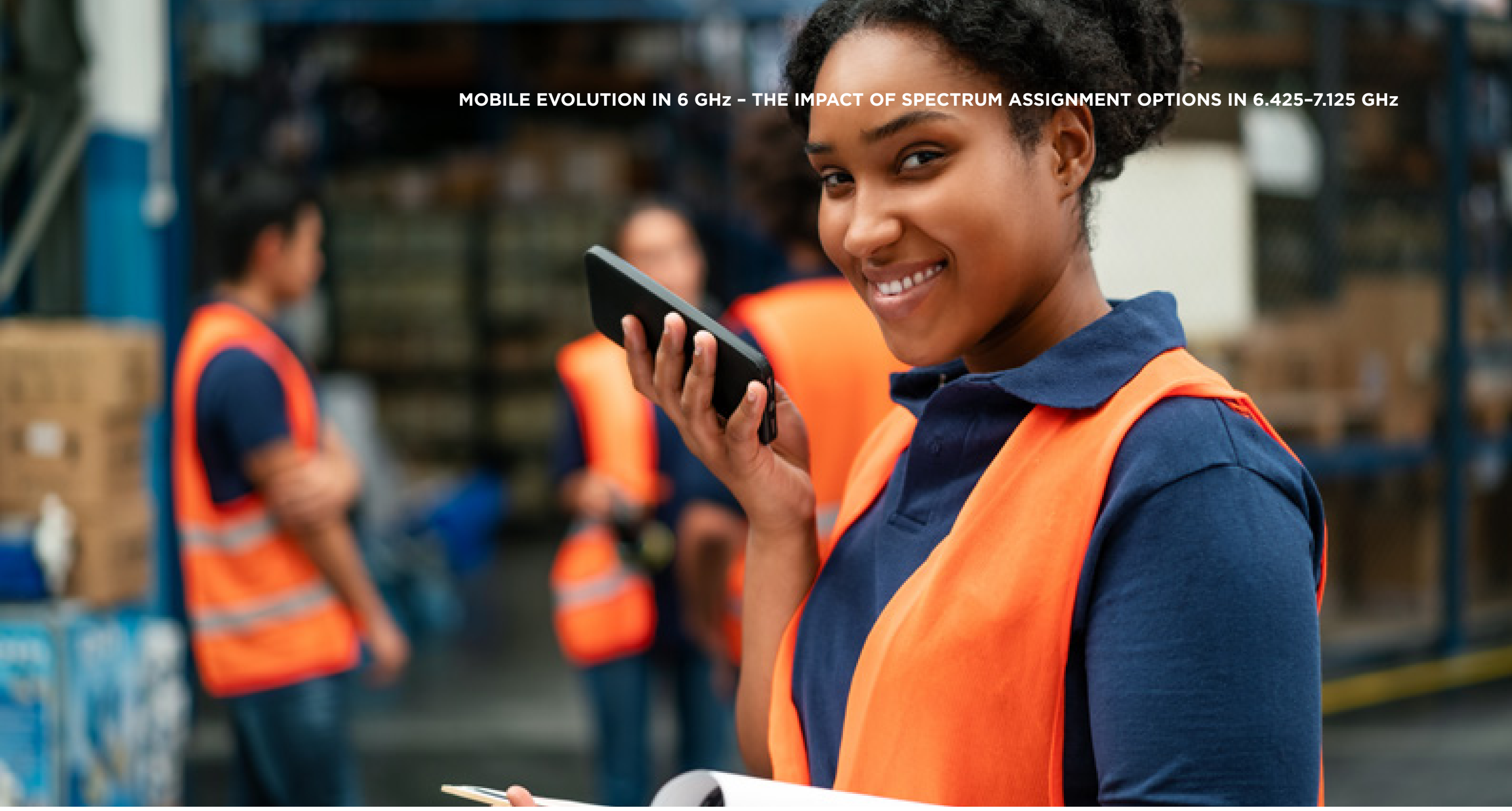
[1] The cities have been selected to ensure one is taken from each region considering options for the upper 6 GHz band.

[2] See A Quantification of 5 GHz Unlicensed Band Spectrum Needs, Qualcomm, 2016; Presentation for the UK Spectrum Policy Forum On Future Demand for Unlicensed Spectrum, Qualcomm, 2023; Impact of additional mid-band spectrum on the carbon footprint of 5G mobile networks: the case of the upper 6 GHz band, Analysys Mason, 2023; Wi-Fi Spectrum Requirements, Plum Consulting, 2024; and https://www.comtelitalia.it/indoor_connectivity_test_en/

[3] See for example Estimating the mid-band spectrum in the 2025-2030 time frame, Coleago, 2021; Technology-Neutral Spectrum and Legacy Network Sunsets: The Evolution of Connectivity in Africa, GSMA, 2023



Policy options for the upper 6 GHz band

Leveraging this new evidence, this study analyses the economic benefits of three different policy options for the upper 6 GHz band:

- licensed mobile use (Scenario 1)
- unlicensed RLAN use (Scenario 2)
- enabling shared use by reducing the power levels of mobile deployments (Scenario 3).

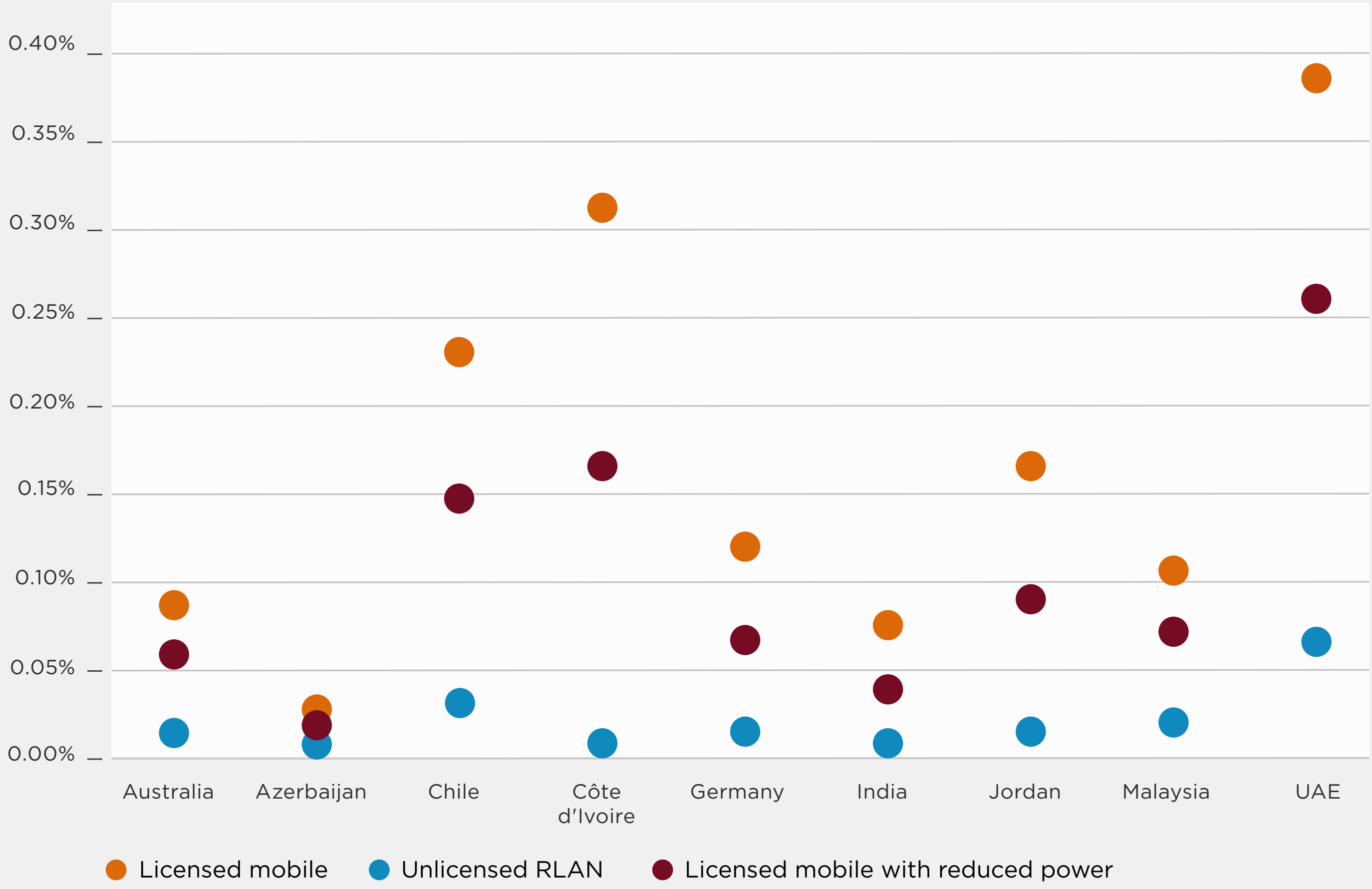
Governments and regulators are invited to consider this analysis, with the report presenting results for nine countries.

Key findings

- The greatest economic benefit in all countries is Scenario 1, where the upper 6 GHz is assigned for licensed, macro-cell mobile with standard power levels.
- This scenario drives the greatest benefit because mobile is much more likely than Wi-Fi to be capacity constrained in each country over the period to 2035. This means additional spectrum in the upper 6 GHz band will drive greater improvements in network quality and user experience, which will in turn drive greater benefits for the wider economy. By assuming efficient utilisation of spectrum, which follows best-practice decision making, the analysis shows that unlicensed assignments in the 2.4, 5 and lower 6 GHz bands are more than sufficient to meet expected demand for Wi-Fi traffic.
- With regard to shared use, the results show that restricting the power levels mobile base stations can emit in the upper 6 GHz band will significantly reduce the additional capacity they can provide. As a result, the economic benefits are lower than having a fully licensed macro-cell band. Furthermore, given that the majority of mobile traffic originates indoors, there is no clear rationale for attempting to enforce an outdoor mobile use of the band and an indoor Wi-Fi use of the band (“indoor/outdoor split”) .
- For regulators wishing to pursue a shared use approach to the upper 6 GHz band, it is vital to incentivise efficient spectrum use by ensuring any requirements and additional costs to share spectrum are not solely imposed on mobile operators, but also place responsibility on Wi-Fi providers. If the technical conditions for sharing are too stringent and costly for one of the technologies, the sharing framework will lose value. As mobile is more likely to be capacity constrained, an approach to sharing should ensure licensed mobile has priority to the band using standard power.

The economic benefits of the three scenarios in nine countries

Proportion of expected GDP in 2035



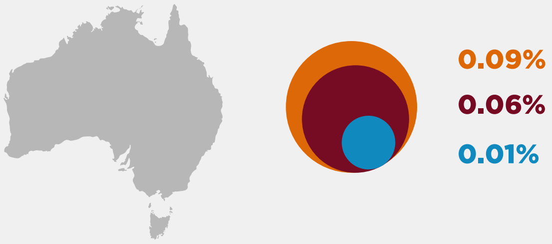
Source: GSMA Intelligence

Note: The results represent the net present value (NPV) of economic benefits during 2023-2035, expressed as a proportion of expected GDP in 2035 for each country.

While the results of this study focus on nine countries, the findings and analytical approach are relevant to other countries considering their options for the upper 6 GHz band; it can serve as a framework to inform decision-making.

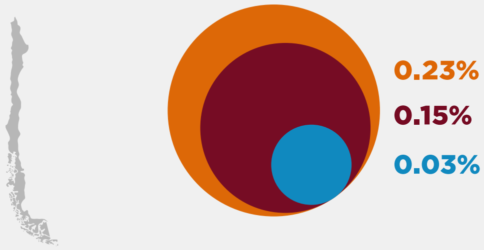
The economic benefits of the three scenarios in nine countries
Proportion of expected GDP in 2035

Australia **GDP impact**

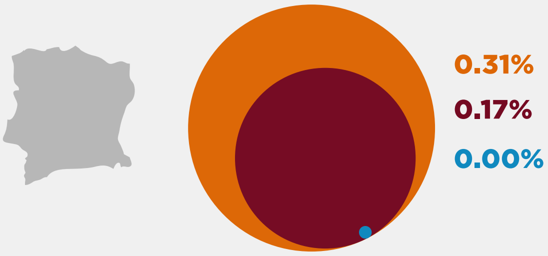


Azerbaijan **GDP impact**

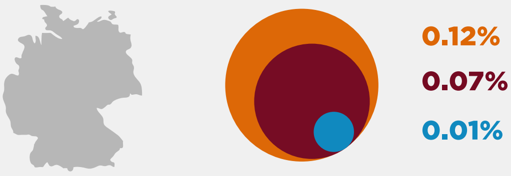
Chile **GDP impact**



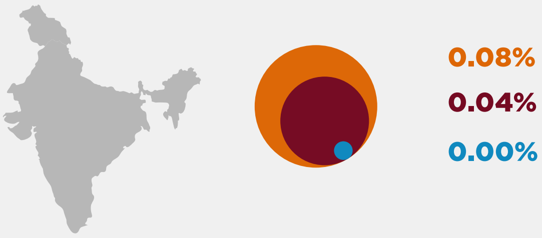
Côte d'Ivoire **GDP impact**



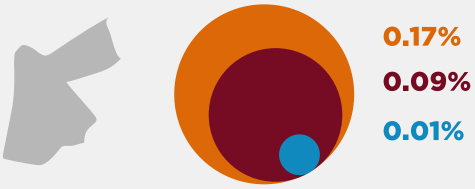
Germany **GDP impact**



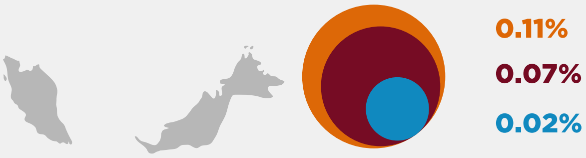
India **GDP impact**



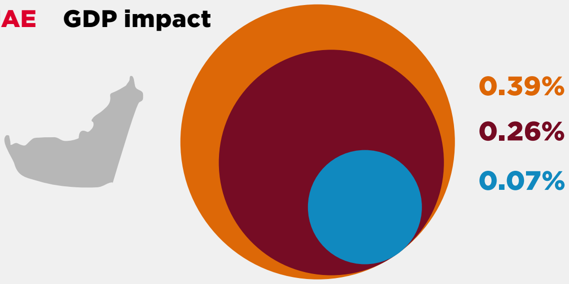
Jordan **GDP impact**



Malaysia **GDP impact**



UAE **GDP impact**



● Licensed mobile

● Licensed mobile with reduced power

● Unlicensed RLAN

Source: GSMA Intelligence

Note: The results represent the net present value (NPV) of economic benefits during 2023-2035, expressed as a proportion of expected GDP in 2035 for each country.

1. Introduction

1.1 The need for an updated assessment

To assist policymakers in assessing their options for the 6 GHz band, this report provides new evidence on data traffic growth, the utilisation of mobile and Wi-Fi on different frequency bands, and how efficiently mobile and Wi-Fi technologies are utilising their existing spectrum.

The report analyses the economic benefits of different policy options for the upper 6 GHz band, including whether to assign it for licensed use, unlicensed use or enabling shared use by reducing the power levels of mobile deployments. It also considers the implications for other approaches to achieve shared use of the band which do not involve reduced mobile base-station power levels.

To illustrate how the economic analysis can be taken into account by governments in practice, the report presents results for nine countries. However, the findings and analytical approach are relevant to other countries yet to make a decision on the upper 6 GHz band and can serve as a framework for considering the costs and benefits of different policies.

The economic analysis builds on a 2022 GSMA Intelligence study on the socioeconomic benefits of options for the whole 6 GHz band[4] (5.925–7.125 GHz). This found that the most economically beneficial approach was to either assign the full band for licensed use, or assign the upper 700 MHz of the band (6.425–7.125 GHz) for licensed use and the lower 500 MHz (5.925–6.425 GHz) for unlicensed use. The optimal policy depended on expected adoption of 5G, fibre and cable broadband adoption, fixed broadband speeds and the availability of licensed and unlicensed spectrum in the given country.

Since that study was published, there have been a number of important developments that require an updated assessment of options for the 6 GHz band. The biggest was the conclusion of the World Radiocommunication Conference 2023 (WRC-23), where countries in the EMEA and Eurasia regions (ITU Region 1) agreed to support IMT in the upper 6 GHz band. There was also support for IMT in upper 6 GHz in Asia Pacific and the Americas, with countries representing 60% of the global population seeking inclusion in the identification of this band for licensed mobile.[5]

Technical conditions for 6 GHz spectrum are now globally harmonised to enable standard power macro mobile deployments, laying the foundation for expanding mobile capacity. Harmonisation of the band may also grow at WRC-27.

The focus of the debate is therefore now on the upper 6 GHz band rather than the full 6 GHz band, as the majority of countries have either allocated the lower 6 GHz band for unlicensed RLAN technologies[6] or are expected to do so.

Other developments in the past two years include China becoming the first country to allocate spectrum in the upper 6 GHz band for licensed mobile,[7] the continued development of trials utilising the upper 6 GHz band for mobile,[8] and the decision by some regulators (especially in Europe) to explore options on the shared use of the upper 6 GHz band by MFCN and Wireless Access Systems, including RLAN.[9] This means new evidence to take into account and new policy options to consider.

Relatedly, governments and regulators have been seeking more evidence to inform their decisions on which technology requires additional 6 GHz spectrum, as this represents the largest remaining single block of mid-band spectrum that can be allocated to licensed or unlicensed use. Both mobile and Wi-Fi experience fast-moving technological changes. The latest technologies – 5G and Wi-Fi 6 and their evolution – are expected to drive continued increases in traffic, with consumers and enterprises using more devices with advanced capabilities and using their existing devices more intensively.

Communication providers typically utilise both licensed and unlicensed spectrum with different deployment architectures to serve different use cases. It is therefore not straightforward to determine which technology has the greatest need for additional spectrum. In theory, a well-designed, market-based assignment process such as an auction should achieve an efficient assignment that will maximise the net benefit to society. This means spectrum will be assigned to users prepared to pay the highest amount for it, therefore valuing it the most. However, when considering unlicensed spectrum, such approaches may not be possible; it is recommended that the relevant national authority conduct a regulatory impact assessment to identify the best policy option for radio spectrum assignments. This study provides evidence and a framework for regulators carrying out such an assessment.

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4. The socioeconomic benefits of the 6 GHz band: Considering licensed and unlicensed options, GSMA Intelligence, 2022
5. See https://www.gsma.com/connectivity-for-good/spectrum/wrc-series/ and https://6ghzopportunity.com/wrc-23/
6. While unlicensed use refers to the broader family of RLAN technology, the main technology used is Wi-Fi. We use Wi-Fi and RLAN interchangeably throughout this report.
7. See China claims world-first 6GHz allocation for 5G, 6G, Mobile World Live, June 2023.
8. See for example "etisalat by e& 5G-advanced network speed trials", e&, August 2023; "Setting the right path to meet growing data consumption", Maxis, September 2023; "Vodafone tests reveal 6GHz spectrum gains in last call to avoid a 5G capacity crunch", Vodafone, October 2023; "Ericsson and MediaTek demo shows global ecosystem support for 6 GHz licensed 5G band", Ericsson, November 2023; "Telekom demonstrates 12 gigabits per second in mobile communications", Deutsche Telekom, November 2023.
9. The Electronic Communications Committee (ECC) has commenced studying sharing options under work item PT1-50.

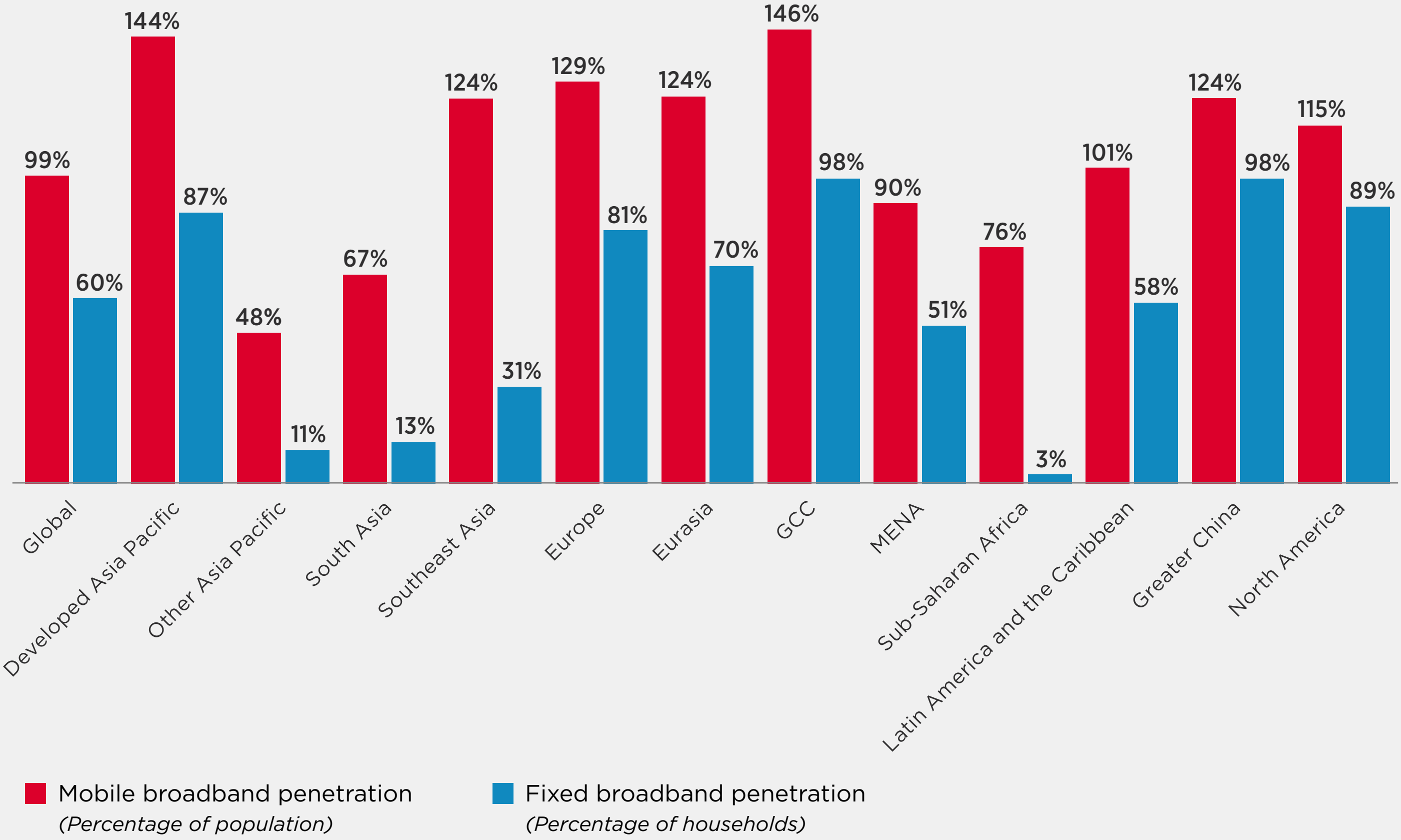
2. Evidence on mobile and Wi-Fi utilisation

The overwhelming majority of internet users rely on at least some form of wireless connectivity. This obviously applies to the 57% of the world's population that uses mobile internet,[10] while Wi-Fi provides the final link between a wireless-enabled device and a router or access point receiving a connection over fibre, cable, copper, fixed wireless or satellite.

The roles of the two types of connectivity vary by market. In countries with widespread fixed broadband infrastructure, mobile and Wi-Fi are complementary, with the latter used in places where a fixed connection is available (especially at home or in an office) and mobile used elsewhere. However, in many countries – especially low- and middle-income countries in Sub-Saharan Africa and South Asia – adoption of fixed broadband remains limited (see Figure 1). In these countries, most internet users rely entirely on mobile rather than Wi-Fi over a fixed connection.

Figure 1

Mobile and fixed broadband penetration, 2023



Source: GSMA Intelligence and ITU

Note: Mobile broadband penetration refers to 3G, 4G and 5G connections as a proportion of the population. A connection is a unique SIM card that has been registered on a mobile network. Connections differ from subscribers in that a unique subscriber can have multiple connections. Fixed broadband penetration refers to residential broadband subscriptions as a proportion of households. Appendix 2 provides the list of countries in each region.

Key findings

- Traffic growth is expected to continue increasing in absolute terms for both mobile and fixed broadband connections (and therefore also Wi-Fi).
- Mobile use is mostly indoors and delivered via mid-band frequencies. In the case of 5G, most indoor use is supported by the 3.5 GHz range.
- Mid-band frequencies provide good quality indoor coverage, with much faster speeds than low-band spectrum.
- While mobile operators have an incentive to be spectrally efficient, Wi-Fi could utilise spectrum more efficiently, including by upgrading legacy Wi-Fi 4 devices which remain in wide use.

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[10] State of Mobile Internet Connectivity Report 2023, GSMA, 2023

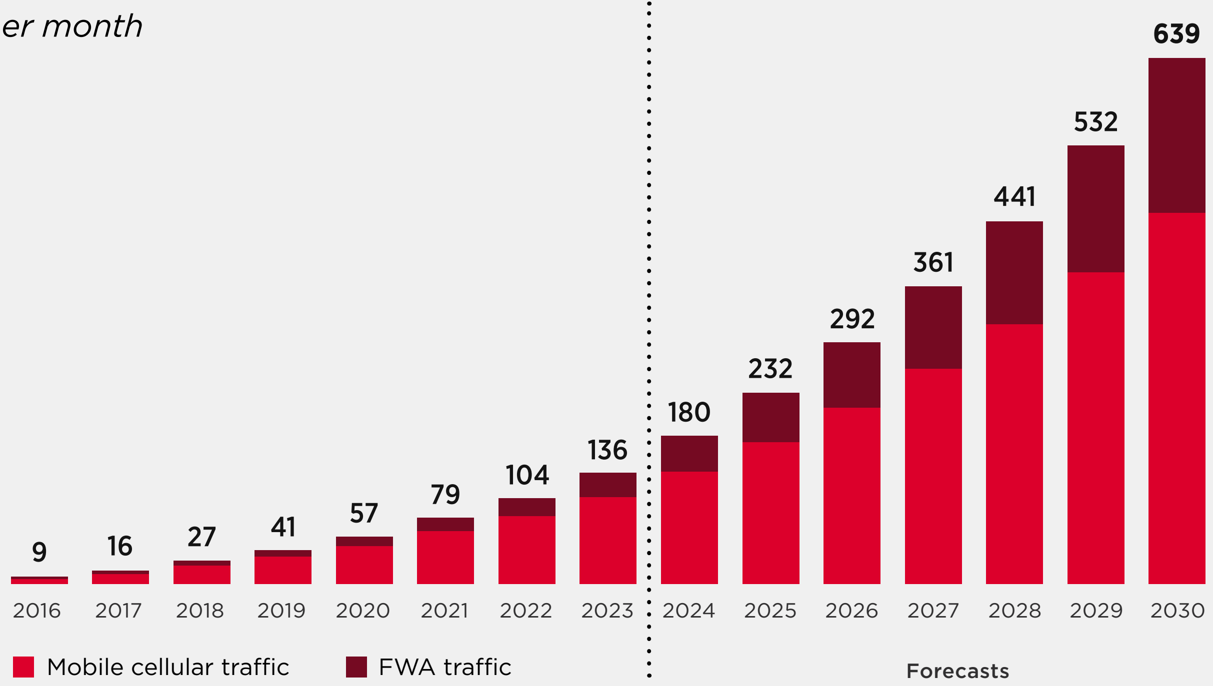
2.1 Traffic growth is expected to increase for both mobile and fixed broadband

Figure 2a shows the global level of mobile traffic (in exabytes, or EB, per month) since 2016. Some industry analysts have noted that growth in percentage terms is expected to decline. For example, between 2016 and 2017, there was a 78% increase in growth (from 9 to 16 EB per month) compared to a 31% increase between 2022 and 2023 (from 104 to 136 EB per month). However, this simply reflects the lower level of traffic in the initial years of 4G growth.

Mobile networks need to manage the absolute increases in traffic. Figure 2b shows this has been increasing over time and is expected to continue to 2030. For example, growth in global traffic in 2023 was greater than absolute traffic levels five years earlier in 2018 – even though the percentage growth in 2023 was lower.

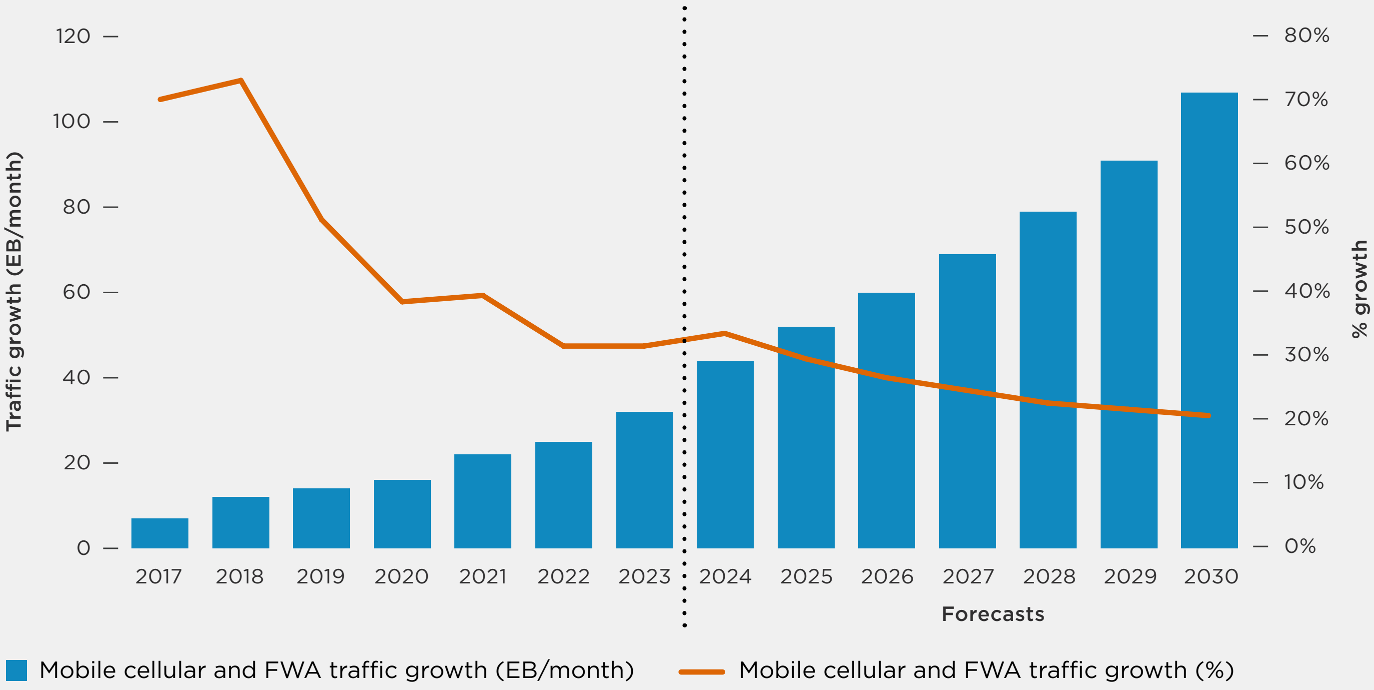
Growth in mobile traffic is expected to occur across all regions. Figure 2c shows that while there are significant differences across regions, growth in traffic per mobile connection during 2023–2030 is expected to be 2–4× greater than in the previous seven years, depending on the region.

Figure 2a
Global mobile cellular and FWA traffic
EB per month



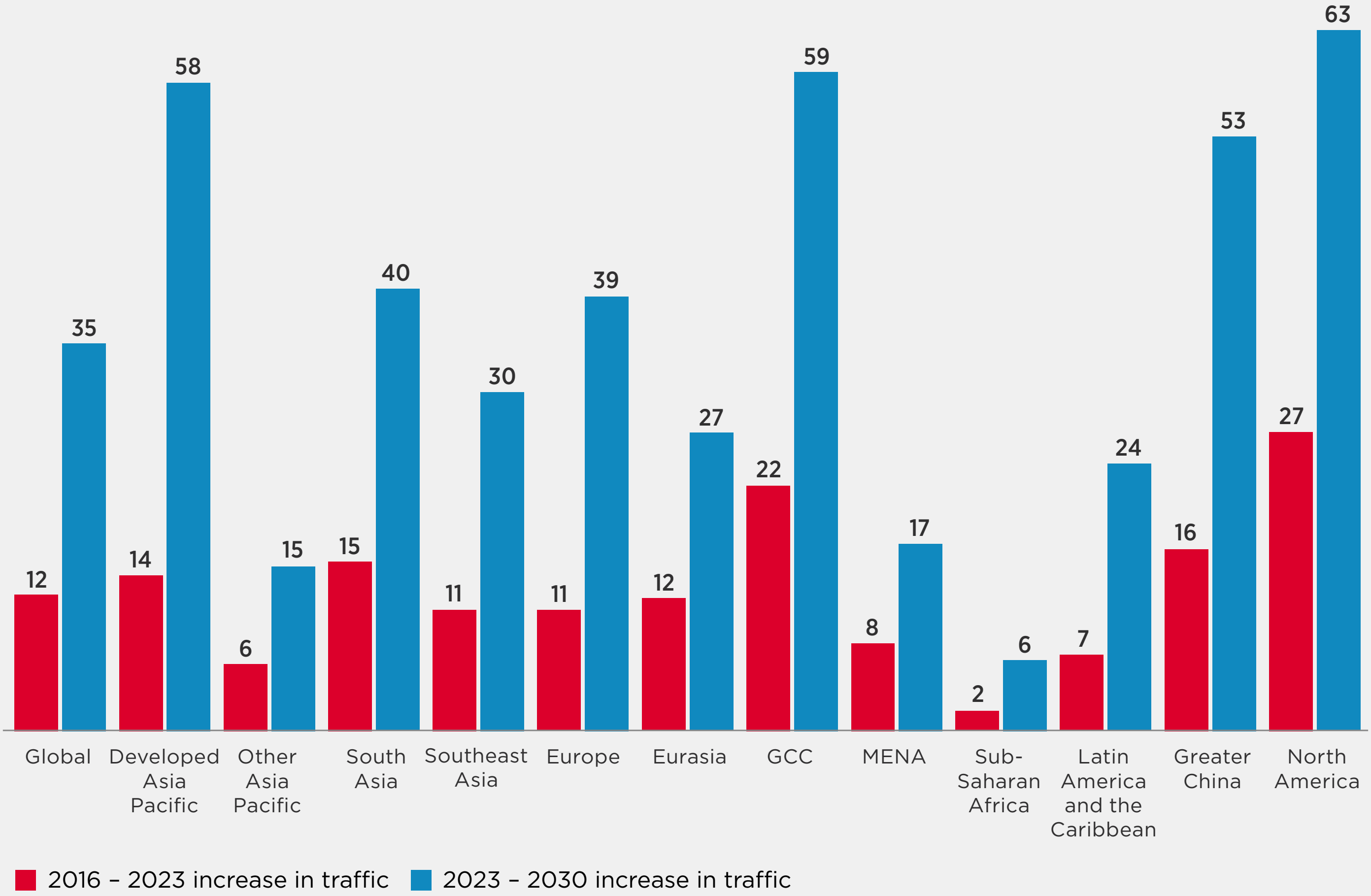
Source: GSMA Intelligence and Ericsson

Figure 2b
Global mobile cellular and FWA traffic year-on-year growth



Source: GSMA Intelligence and Ericsson
Note: Mobile cellular traffic growth is sourced from GSMA Intelligence. FWA traffic growth is sourced from Ericsson Mobility Report, 2024. Cellular IoT traffic is not included in the analysis.

Figure 2c
Increase in traffic per mobile connection
GB per month

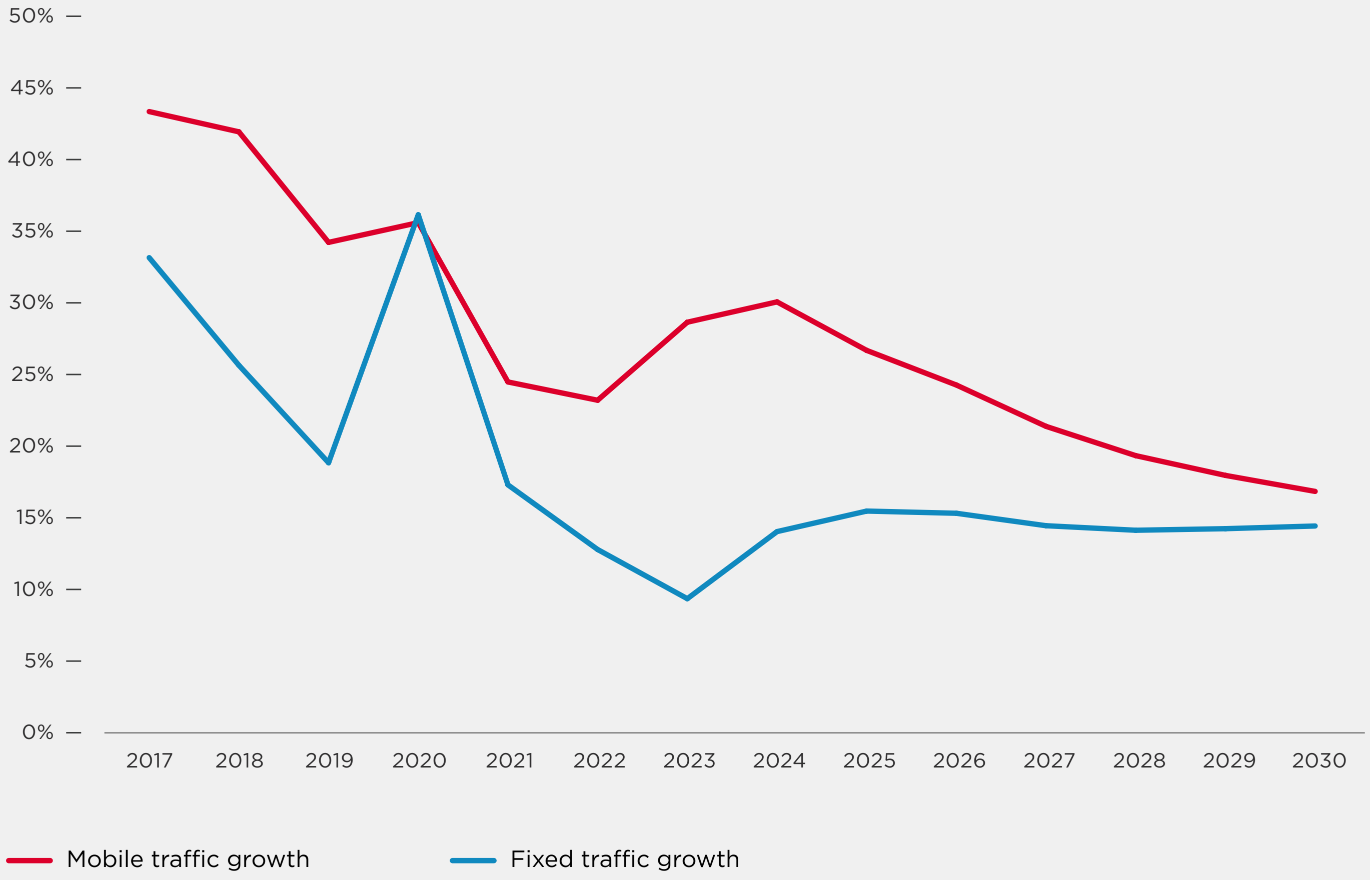


Source: GSMA Intelligence
Note: FWA and cellular IoT traffic are not included in the analysis.

It is therefore important that regulators and policymakers consider the absolute levels and increases in network traffic, rather than the percentage growth. When considering the latter only, we do, in fact, observe similar trends in fixed and mobile traffic. Figure 3 shows historic and forecast annual growth in mobile and fixed traffic in Europe, highlighting that in percentage terms both are declining – though are still significant by 2030, at 15–20%. This means both types of traffic will continue increasing in absolute terms.

Figure 3

Mobile and fixed traffic: percentage growth in Europe

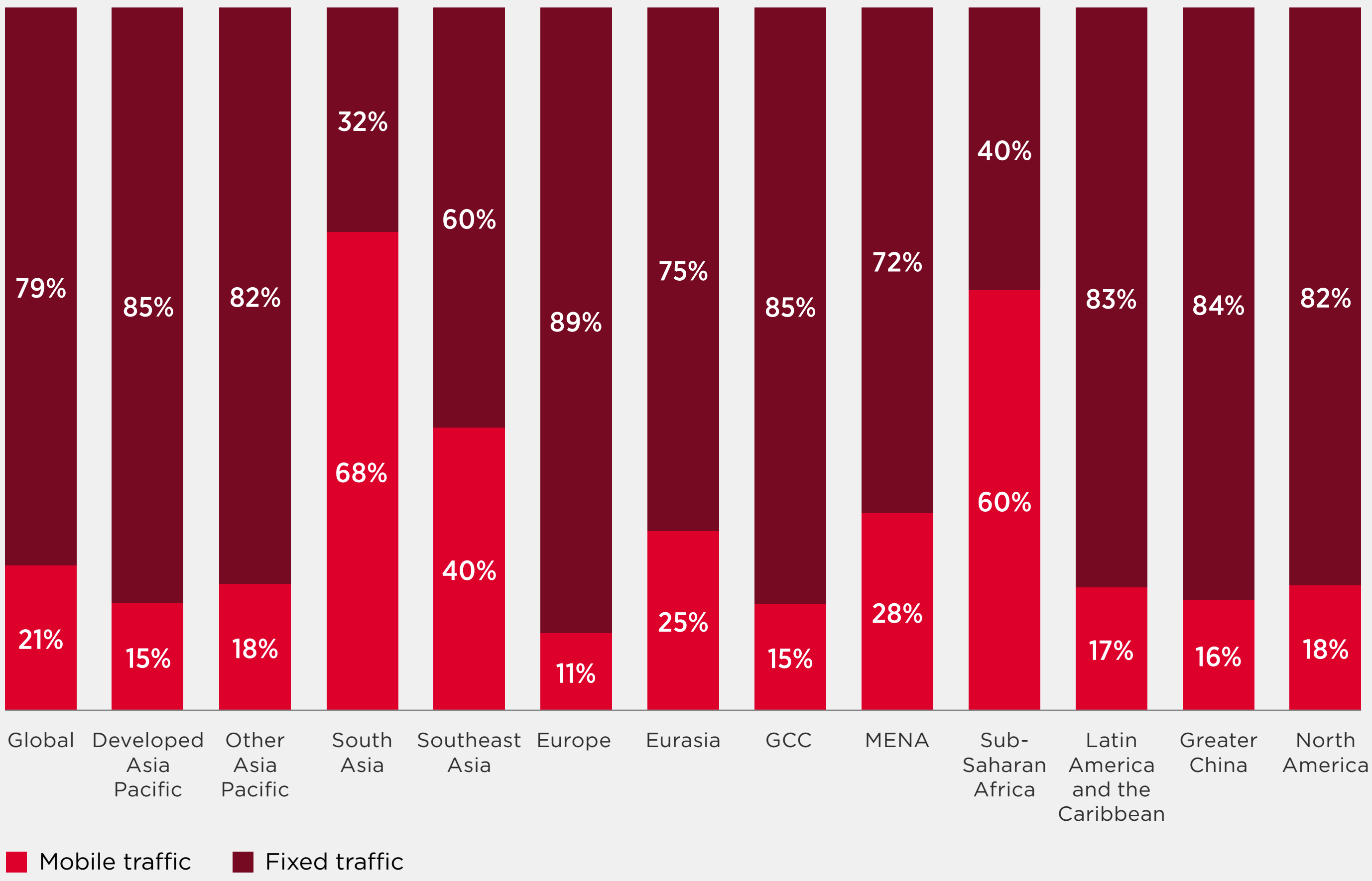


Source: GSMA Intelligence

It is important that regulators do not just take total traffic into consideration when deciding the optimal use of spectrum. Assumptions are sometimes incorrectly made that since global fixed traffic is around four times greater than mobile (see Figure 4), there is a greater need for unlicensed spectrum to support the delivery of fixed traffic via Wi-Fi. However, a simple comparison of traffic delivered over mobile and Wi-Fi is not like-for-like. Mobile technology provides wide area coverage from sites to thousands of end users who can be either indoors or outdoors, and macro cell sites can provide coverage up to 15–20 kilometres. Wi-Fi and other unlicensed RLAN technologies typically provide indoor, short-range coverage (up to 50 metres) to offer best-efforts connectivity for a single household of 1–5 people, with most data delivered by the underlying copper, fibre, wireless or satellite connection.

While most traffic globally is carried by fixed networks, this is not the case in every country and region. In particular, mobile traffic significantly exceeds fixed traffic in South Asia and Sub-Saharan Africa (see Figure 4). The two regions account for almost 40% of the global population. The traffic reflects the low levels of fixed broadband penetration in the two regions.

Figure 4
Distribution of mobile and fixed traffic by region, 2023



Source: GSMA Intelligence and ITU
Note: FWA and cellular IoT traffic are not included in the analysis.

In many countries, mobile operators are converged providers offering fixed and mobile. For example, mobile operators account for more than a third of fixed broadband subscriptions in Brazil and Mexico, around 70% in France and Germany, 80% in Indonesia and Colombia, and more than 90% in China and South Korea.[11] Their customers use both licensed mobile and unlicensed WAS/RLAN connectivity as part of the suite of services offered to them. As such, mobile operators focus on the best means of getting localised connectivity to the end user. This makes them well-placed to determine which technology has the greatest need for additional spectrum.

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[11] Harnessing Spectrum Diversity, GSMA

2.2
Understanding how mobile is used by consumers

The nature of use is a further consideration for the assignment of new mobile spectrum such as 6 GHz. Previous analysis has suggested that 70–90% of mobile traffic is indoors,[12] which has implications for whether 6 GHz frequencies could be used to address this demand.

To understand this in more detail, this study leverages data from Speedtest Intelligence® (sourced from Ookla®). The Speedtest consumer-initiated testing platform allows users to test download speed, upload speed and latency (among other metrics). It also records the location of the test, technology used and spectrum frequency. An average of 11 million consumer-initiated performance tests are run per day, globally. In addition to the consumer-initiated test, Speedtest Android users can allow collection of coverage scans, with hundreds of millions of scans collected per day to provide insight on the availability and quality of coverage.[13]

Covering Q1 2024, the data used in this report encompasses more than 100 million consumer-initiated Speedtest samples and coverage scans in 10 cities, including the following:

- mobile coverage scans, providing data on indoor/outdoor location, connection type (3G/4G/5G), spectrum band and signal strength
- Wi-Fi coverage scans, providing data on connection type (Wi-Fi 4/5/6), spectrum band and signal strength
- mobile speed tests, providing data on indoor/outdoor location, connection type, spectrum band and network quality (e.g. download speed)
- Wi-Fi speed tests, providing data on connection type, spectrum band and network quality.

2.3
Mobile use is mostly indoors and delivered by mid-bands

Figure 5a shows that in 9 of the 10 cities covered in the analysis, the majority of mobile coverage scans are indoors, ranging from around 60% to 90%, depending on the city. This is consistent with the previous indoor traffic estimates highlighted above.

Figure 5b shows that the majority of indoor scans are in mid-bands above 1 GHz, ranging from around 75% to 95%, depending on the city. This is also consistent with analysis suggesting that low bands typically account for 10–20% of total mobile traffic.[14] If 60–90% of mobile traffic is indoor and 10–20% of traffic is delivered by low bands, it mathematically follows that most indoor traffic has to be supported by mid-bands.

Figure 5c also shows that in the cities with sufficient 5G coverage data, the majority of 5G indoor scans are using frequencies in the 3.5 GHz range, with the exception of Sydney. As the data sourced from Ookla is based on periodic scans, the proportion of scans accounted for by low bands (for example, in the 700 MHz band) is likely to be higher than the proportion of traffic delivered by low bands. This is because the connection may default to low band when it is not in active use, but the download and upload of traffic triggers the use of mid-bands. In other countries where there have been no 5G deployments in spectrum bands below 1 GHz to date, all indoor traffic would be supported by mid-bands – primarily in the 3.5 GHz range (for example, in South Korea and Saudi Arabia).

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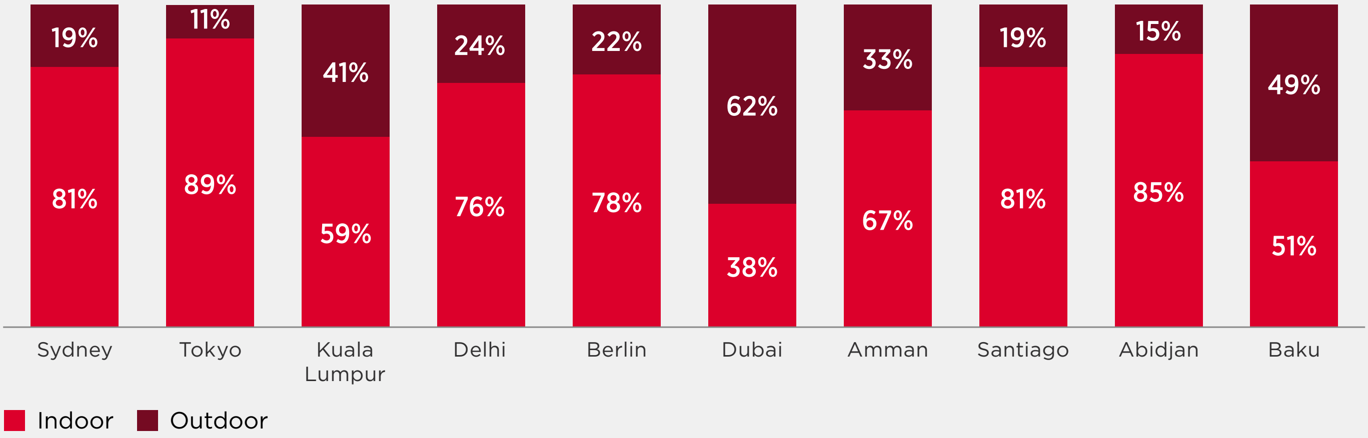
[12] See for example Planning indoor 5G coverage, Ericsson; 5G Thriving indoors, Cisco; and Better Indoor coverage, Better 5G networks, Huawei.

[13] For further details, see https://www.ookla.com/resources/guides/speedtest-methodology

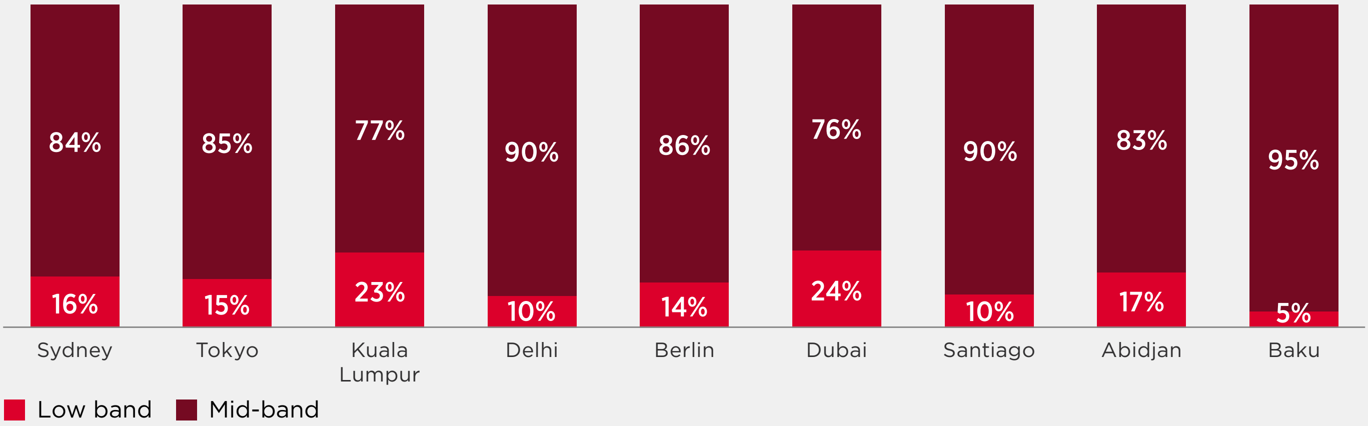
[14] See for example Socio-Economic Benefits of 5G: The importance of low-band spectrum, GSMA, 2023; Low-Band Spectrum for 5G, Coleago, 2022; Decision to make the 700 MHz band available for mobile data – statement, Ofcom, 2014; The 700 MHz radio frequency band, ComReg, 2015.

Figure 5a
Distribution of mobile scans based on indoor/outdoor locations



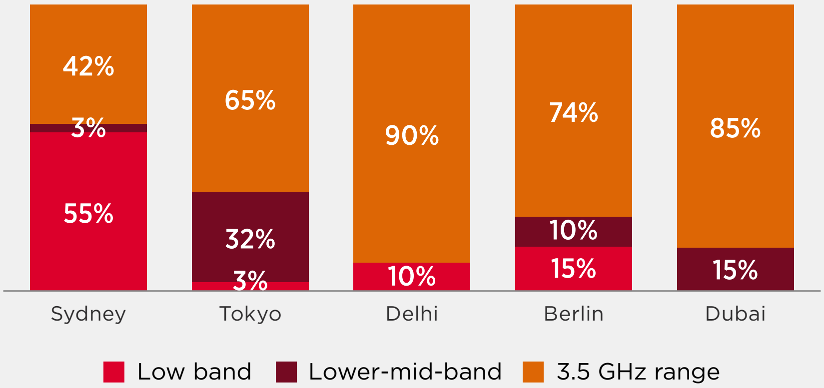
Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

Figure 5b
Distribution of 4G and 5G indoor mobile scans by spectrum band



Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla
Note: Low bands refer to frequencies below 1 GHz, while mid-bands refer to frequencies above 1 GHz excluding mmWave bands. Insufficient data on low bands in Amman.

Figure 5c
Distribution of 5G indoor mobile scans by spectrum band



Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla
Note: Low bands refer to frequencies below 1 GHz, while lower mid-bands refer to frequencies between 1 and 3 GHz. The 3.5 GHz range refers to frequencies in the 3.3–4.2 GHz range and excludes mmWave bands.

2.4 Mid-bands provide high-performance indoor coverage

Given that most indoor mobile traffic is supported by mid-band spectrum, it is important to consider whether this is providing a sufficient quality of service and experience for consumers.

Figure 6a shows the distribution of signal strength, measured by the Reference Signal Received Power (RSRP) for indoor scans on mid-bands for both 4G and 5G. Figure 6b shows the same analysis for the 3.5 GHz range when delivering indoor 5G only, for the cities with available data.

The majority of scans have an RSRP above -100 dBm, which is above the typical signal strengths used to determine whether coverage is available by regulators.[15] This suggests that mid-bands are providing more than sufficient indoor coverage to consumers, including the 3.5 GHz range for indoor 5G.

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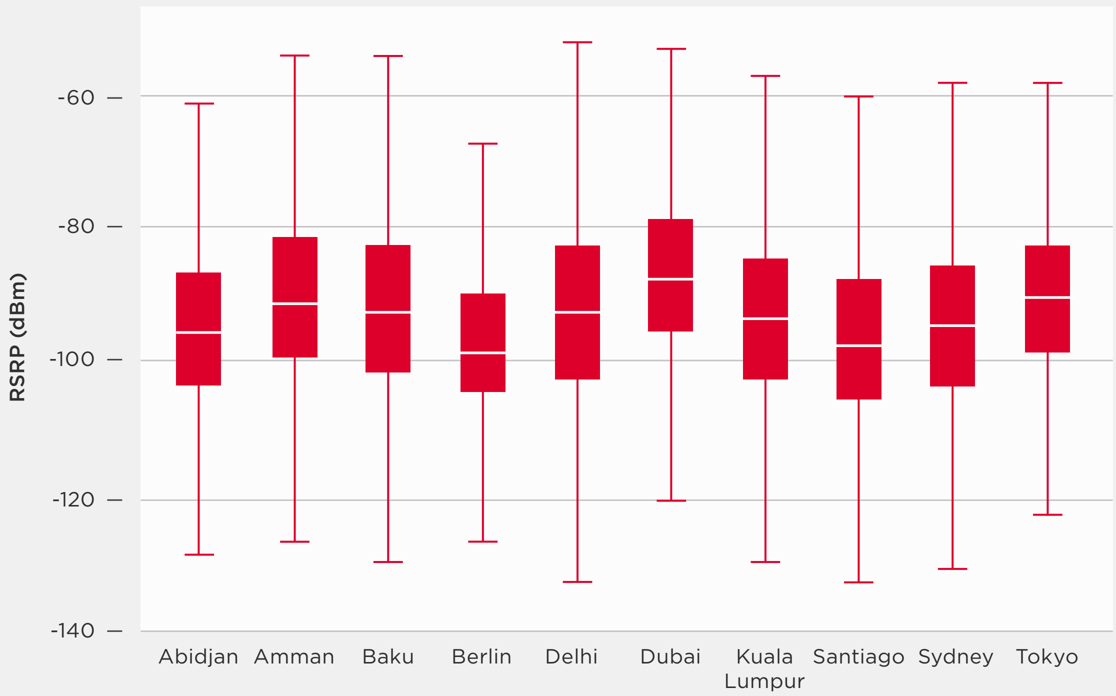
15. The RSRP threshold used to determine whether a user has 4G coverage generally ranges from -115 dBm to -105 dBm. See for example Connected Nations update, Ofcom, 2022.

Figure 6a

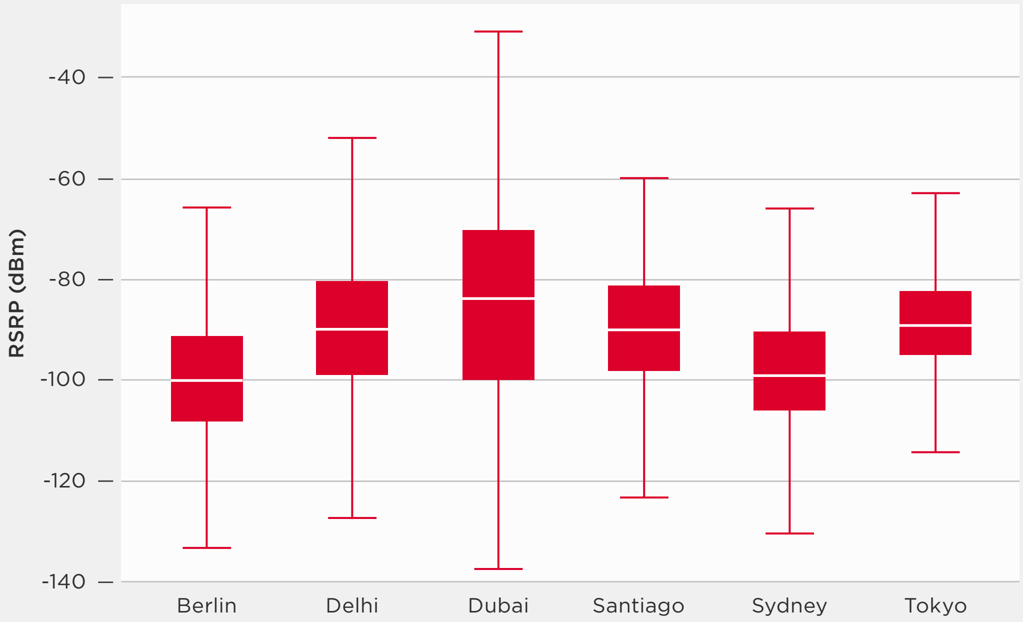
Distribution of 4G/5G indoor signal strength delivered by mid-bands



Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla
Note: Mid-bands refer to frequencies above 1 GHz and exclude mmWave bands.

Figure 6b

Distribution of 5G indoor signal strength delivered by 3.5 GHz range



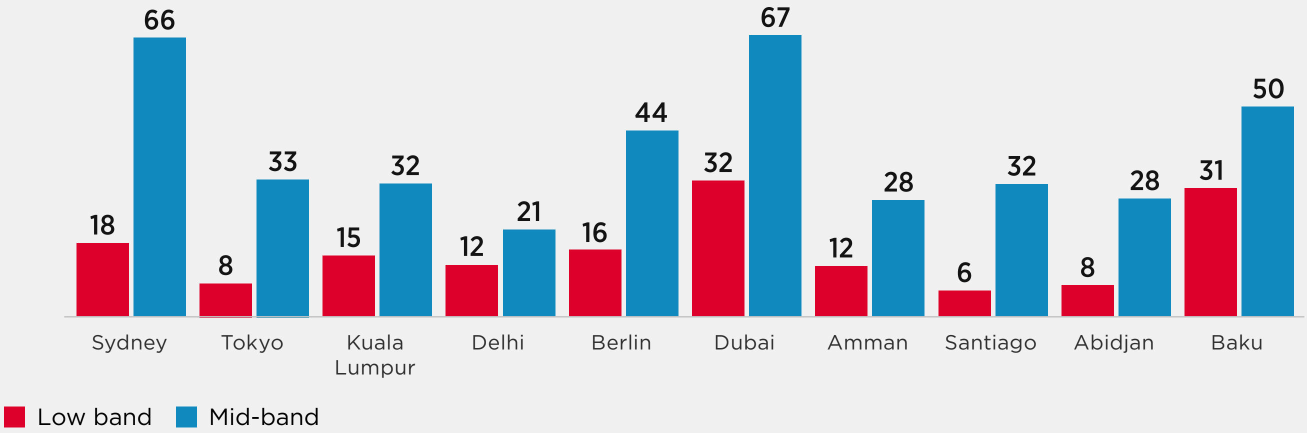
Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla
Note: The 3.5 GHz range refers to frequencies in the 3.3–4.2 GHz range

Looking at the download speeds experienced by consumers, Figures 7a shows that mid-bands provide 2–5× faster data rates than low bands on 4G, while Figure 7b shows that the 3.5 GHz range provides 3–16× faster speeds than low bands on 5G.[16] This is unsurprising given the additional frequencies and wider channels available in mid-bands, but it highlights their importance in providing the quality of service consumers expect from 4G, and especially 5G. While low bands are critical for coverage in rural and remote areas, and providing deep indoor coverage and capacity in urban areas, most traffic in urban areas (both indoor and outdoor) is supported by mid-band spectrum, which also provides much faster speeds.

Furthermore, given the 6 GHz trials carried out to date show it can deliver comparable indoor coverage to the 3.5 GHz range,[17] the 6 GHz band could be effectively used to provide a further capacity layer in urban areas, and can meet the majority of indoor and outdoor requirements.

Figure 7a

Median 4G indoor speeds by spectrum band (Mbps)

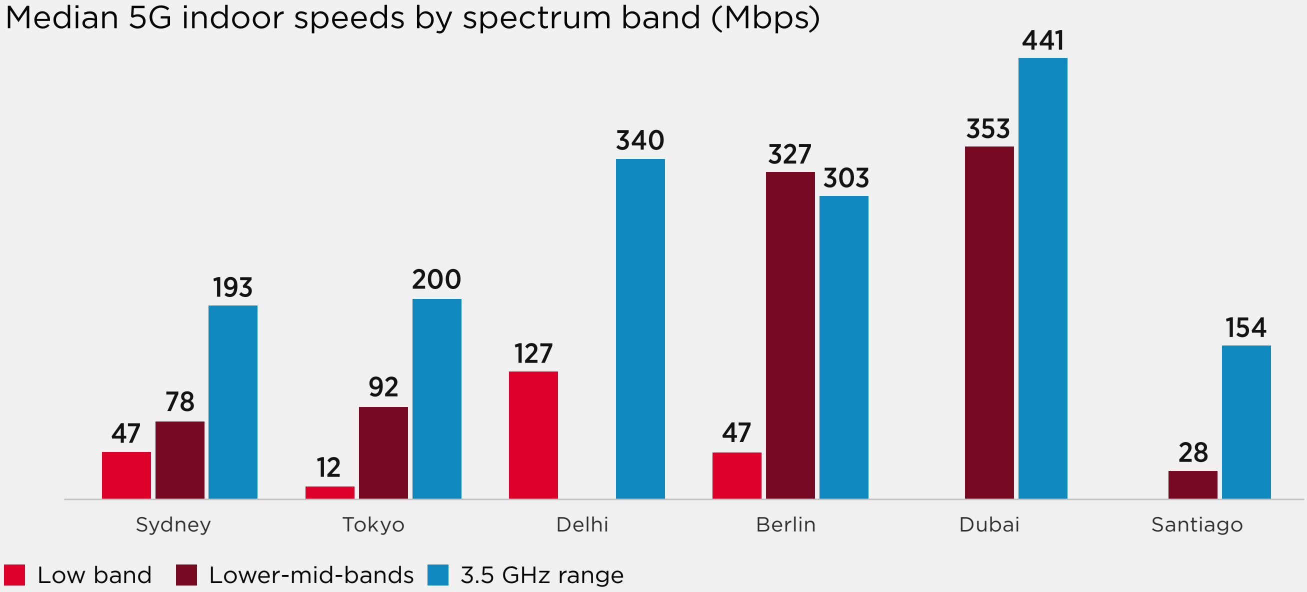


Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

Note: Low bands refer to frequencies below 1 GHz while mid-bands refer to frequencies above 1 GHz and excludes mmWave bands.

Figure 7b

Median 5G indoor speeds by spectrum band (Mbps)



Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

Note: Low bands refer to frequencies below 1 GHz; lower mid-bands refer to frequencies between 1 and 3 GHz; and the 3.5 GHz range refers to frequencies in the 3.3–4.2 GHz range and excludes mmWave bands.

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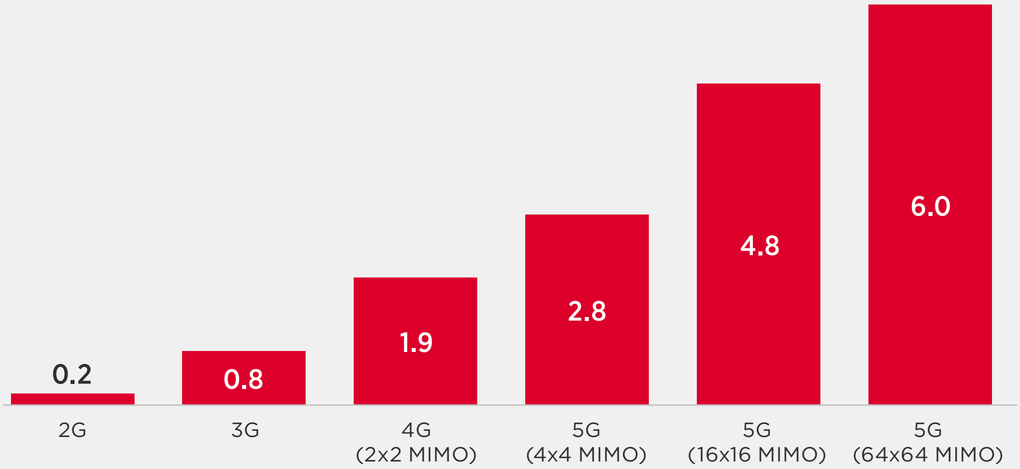
[16] Similar analysis also shows that mid-bands support upload speeds that are 2–4× faster on both 4G and 5G.

[17] See for example the following ECC PT1 submissions: ECC PT1 #77 by Telefonica Germany; "5G on 6 GHz Frequency Test in Chula Sandbox", chula.ac.th, May 2023; "Setting the right path to meet growing data consumption", Maxis, September 2023; "Vodafone tests reveal 6GHz spectrum gains in last call to avoid a 5G capacity crunch", Vodafone, October 2023.

2.5 How efficiently do mobile and Wi-Fi utilise spectrum?

Almost all governments and policymakers aim to ensure spectrum is used efficiently.[18] With each technology cycle, mobile has made more efficient use of spectrum, as shown in Figure 8, with the spectral efficiencies of 5G more than seven times greater than that of 3G. Operators also have an incentive to utilise spectrum efficiently, because in almost all countries they face a pricing signal to do so – whether they purchase spectrum in an auction and/or pay renewal or annual fees (or have a licence obligation). This means that in addition to improving spectral efficiencies, they also reuse spectrum where possible by densifying networks.

Figure 8
Mobile spectral efficiencies by generation
Bps/Hz



Source: GSMA Intelligence

By contrast, where a spectrum user does not face a pricing signal, there is less incentive to deploy it as efficiently as possible. Figure 9a shows how Wi-Fi theoretical spectral efficiencies have evolved by generation, with the spectral efficiencies of Wi-Fi 6 around twice that of Wi-Fi 4. However, these headline rates are rarely achieved due to co-channel and non-co-channel interference, especially in densely populated, urban apartment buildings. Given this challenge, several studies have sought to assess actual Wi-Fi spectrum needs to deliver certain speed requirements (for example, 1 Gbps) in dense urban apartment blocks. This includes analysis by Qualcomm (2016 and 2023),[19] Analysys Mason and Huawei,[20] and Plum Consulting.[21]

More recently, Comtel published the results of a series of field tests on Wi-Fi connectivity in a high-density urban residential environment, with the aim of evaluating the ability of Wi-Fi access points to effectively handle high traffic volumes while subjected to significant interference.[22]

The results of these studies vary considerably according to the following assumptions and inputs:

- frequency bands and channels used
- number of access points
- backhaul between access points (Ethernet or WLAN)
- number of devices (or STAs)
- number of antenna, per access point and per STA
- coverage
- frequency reuse
- access point channels
- use of unlicensed mmWave in the 57–71 GHz range.

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[18] For example, Decision No 676/2002/EC of the European Parliament and of the Council, Article 1 states, *"The aim of this Decision is to establish a policy and legal framework in the Community in order to ensure the coordination of policy approaches and, where appropriate, harmonised conditions with regard to the availability and efficient use of the radio spectrum necessary for the establishment and functioning of the internal market in Community policy areas such as electronic communications, transport and research and development (R&D)".*

[19] A Quantification of 5 GHz Unlicensed Band Spectrum Needs, Qualcomm 2026; Presentation for the UK Spectrum Policy Forum On Future Demand for Unlicensed Spectrum, Qualcomm, 2023

[20] Impact of additional mid-band spectrum on the carbon footprint of 5G mobile networks: the case of the upper 6GHz band, Analysys Mason, 2023

[21] Wi-Fi Spectrum Requirements, Plum Consulting, 2024

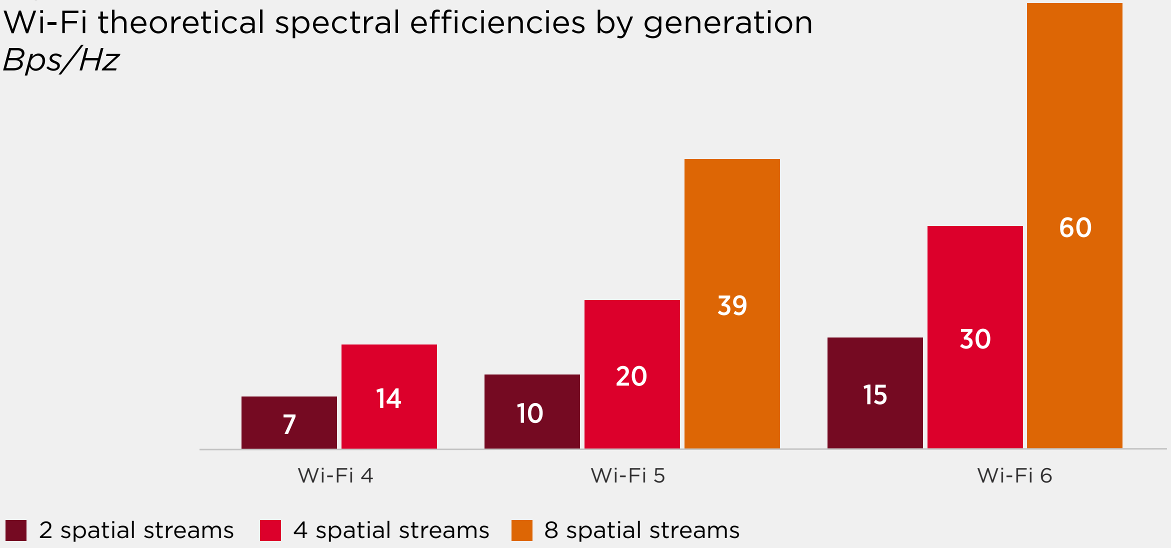
[22] See https://www.comtelitalia.it/indoor_connectivity_test_en/

Figure 9b shows the range of spectral efficiencies implied from each study, based on the spectrum required to deliver 1 Gbps. The lower range typically assumes one access point, one end user device (or STA), 99% coverage, minimal frequency reuse, no utilisation of mmWave and that STAs will have two antennas even in the long term. The upper range adjusts one or two of these assumptions – for example, 2–4 access points, 90% coverage, greater frequency reuse or assuming STAs will have four antennas in the long term. This is important, as when deciding how to assign spectrum outside of a market-based mechanism, policymakers should incentivise the efficient use of spectrum and avoid assigning spectrum to compensate for inefficient use.

Figure 9a

Wi-Fi theoretical spectral efficiencies by generation

Bps/Hz

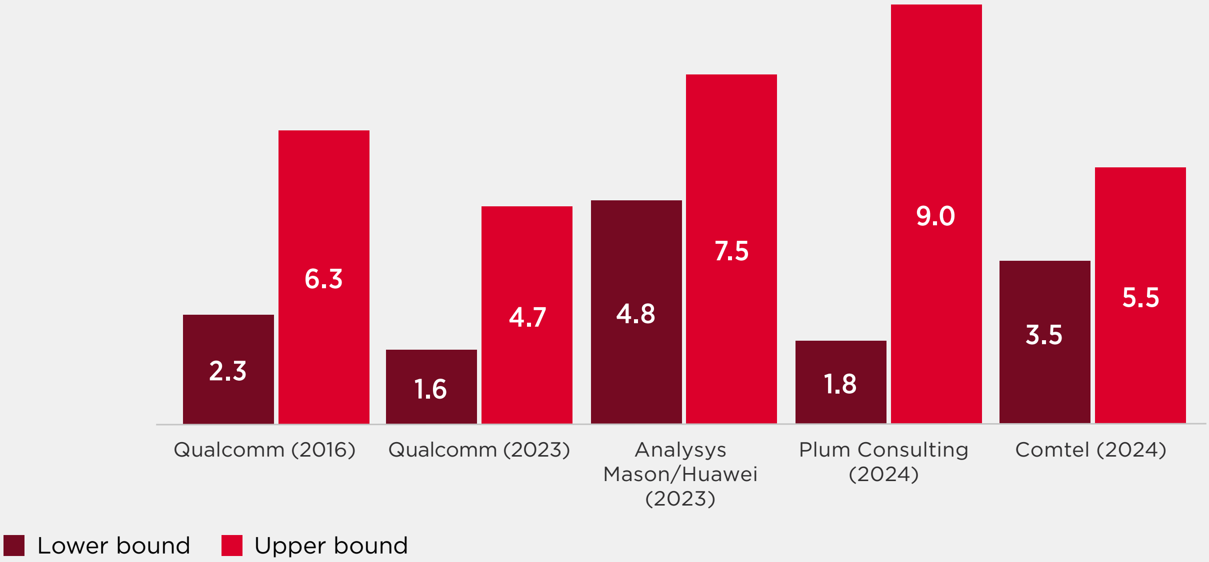


Source: GSMA Intelligence calculations based on the MCS Index table

Figure 9b

Wi-Fi spectral efficiencies to deliver 1 Gbps

Bps/Hz



Source: GSMA Intelligence calculations based on the respective studies

Wi-Fi performance can be significantly improved by upgrading Wi-Fi 4 devices

A related point regarding the efficient deployment of unlicensed networks is whether they utilise the most efficient technology. In the 10 cities considered in this study, Figure 10a shows a significant proportion of Wi-Fi scans were on Wi-Fi 4, ranging from 22% in Santiago to 78% in Abidjan.[23]

As demonstrated in Figure 10b, the type of Wi-Fi technology has a significant impact on user experience. Download speeds on Wi-Fi 6/6E were up to 15× faster than Wi-Fi 4. This shows that Wi-Fi performance could be significantly enhanced by upgrading users to the latest technology, as well as more efficient deployments indoors. It is also worth emphasising that the fast speeds observed on Wi-Fi 6/6E in this analysis have not been dependent on access to the lower 6 GHz band. Figure 10c shows that when looking at Wi-Fi 6/6E scans, less than 1% have utilised the lower 6 GHz band, with the exception of Tokyo. This includes cities such as Berlin, Sydney and Santiago, where the lower 6 GHz band has been available to use for unlicensed RLAN technologies.

Wi-Fi speeds will be constrained by the maximum speed of the underlying copper, fibre or cable connection. Around half or more fixed broadband subscriptions cannot deliver speeds greater than 100 Mbps in Europe, Latin America & the Caribbean, South Asia, Southeast Asia, Sub-Saharan Africa and MENA (outside of the GCC).[24] In such cases, Wi-Fi and the amount of unlicensed spectrum will never be a capacity bottleneck.

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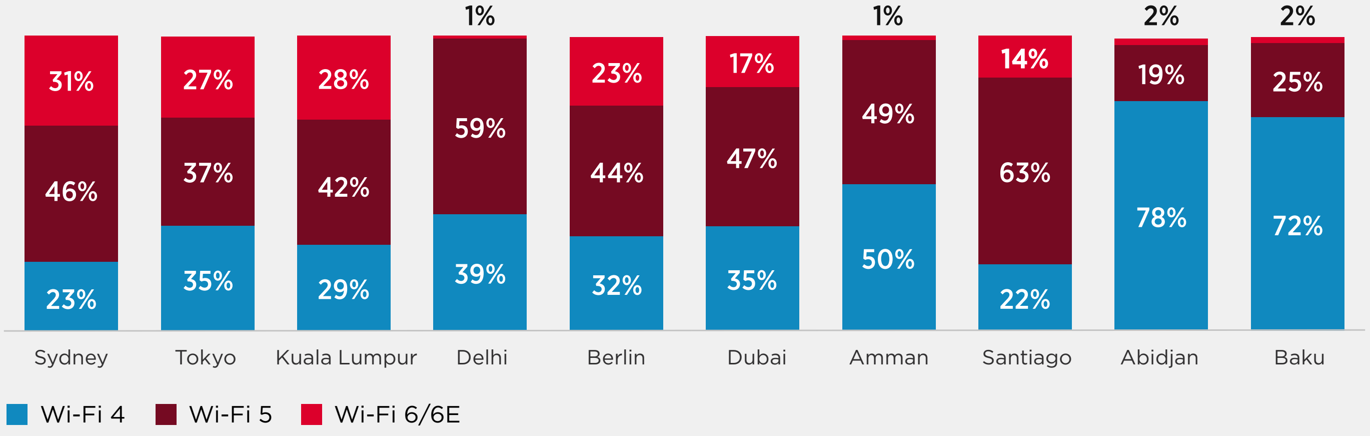
[23] This is further supported by analysis in other cities and countries. See for example "ISPs Need to Do More to Improve Wi-Fi Performance in the Home", Ookla, May 2023; "Gulf ISPs should help fiber customers upgrade and configure their Wi-Fi routers to deliver faster speeds", Ookla, October 2023.

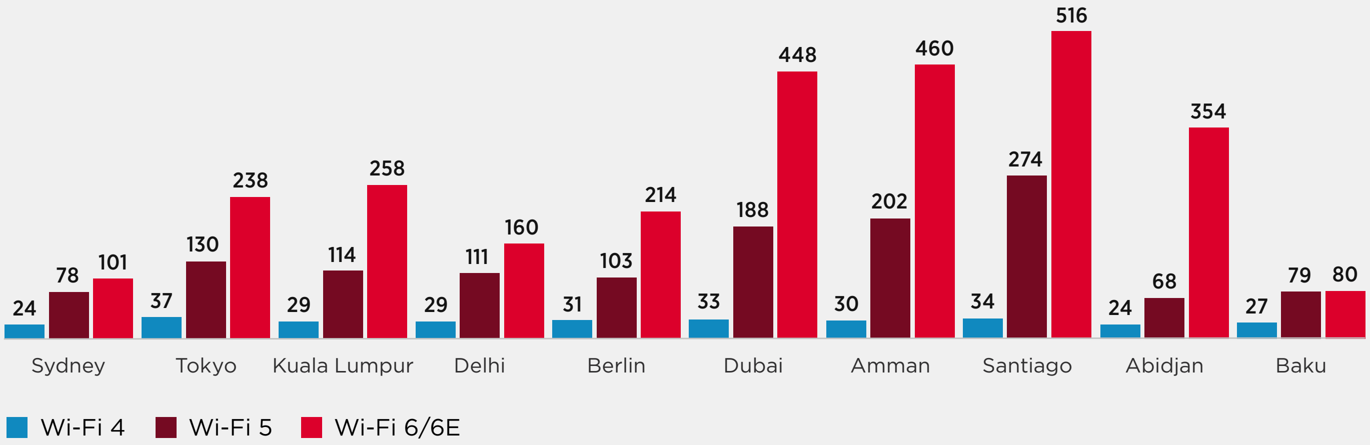
[24] GSMA Intelligence analysis of ITU data

Figure 10a
Distribution of Wi-Fi scans by technology



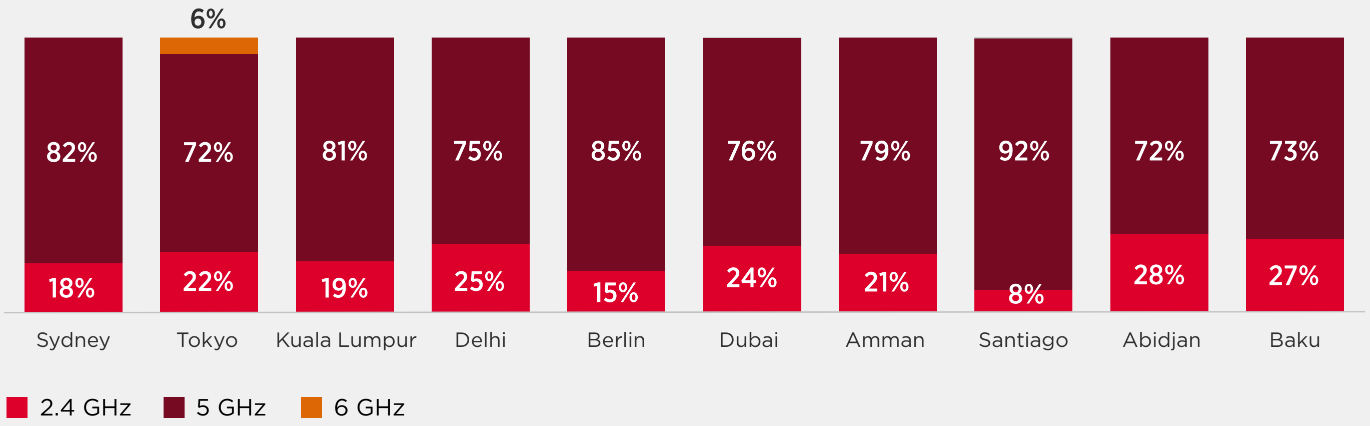
Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

Figure 10b
Median Wi-Fi download speeds by technology (Mbps)



Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

Figure 10c
Distribution of Wi-Fi 6/6E scans by band



Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

3. Economic assessment of policy options in the upper 6 GHz band

3.1 Approaches to cost-benefit analysis

Applying rigorous cost-benefit analysis to spectrum helps ensure its most advantageous use. In a similar way to the 2022 GSMA Intelligence 6 GHz study, we apply a cost-benefit analysis using a supply and demand framework.

The main impacts of assigning 6 GHz spectrum to provide wireless connectivity are that it can make it less costly to provide capacity, and it improves the experience for end users. In economic terms, this results in reduced prices and/or improved service quality, driving a gain in economic welfare.

To understand which spectrum policy will generate the greatest benefit, we consider the demand and supply conditions in each market – in particular, current and expected demand for mobile and Wi-Fi. This shows where upper 6 GHz spectrum will have its most productive use. To estimate the impact of assigning additional spectrum for mobile or Wi-Fi, we develop supply and demand models for network capacity for the period between 2023 and 2035 based on current and expected market growth. Appendix 1 provides details of the methodology and assumptions behind each model.

In summary, we apply the following approach:

- We estimate mobile and Wi-Fi traffic demand during the period 2023–2035 based on expected adoption of mobile and fixed broadband, performance requirements and traffic growth.

- We estimate supply based on the amount of spectrum available (or expected to be available), spectral efficiencies and site densification. This is done across four different policy scenarios (see Figure 11).

- The availability of additional spectrum is expected to drive improved network quality – for example, higher download and upload speeds. This impact will increase as networks become increasingly capacity constrained. Therefore, if demand exceeds supply or if the two are comparable, having more spectrum in the upper 6 GHz band will drive greater improvements for consumers. If supply significantly exceeds demand even without additional spectrum in the upper 6 GHz band, the impact will be more limited.

- Enhanced network quality for mobile broadband or fixed broadband is linked to an increase GDP based on empirical research.

3.2 Modelling scope

When carrying out an economic analysis of policy options, regulators in each country have to consider the costs and benefits for their respective mobile and fixed broadband sectors, and gather the appropriate economic and technical inputs. To illustrate the results of applying the framework, we have implemented the model in nine cities for this study:[25]

- Sydney, Australia (from the developed Asia Pacific region)
- Kuala Lumpur, Malaysia (Southeast Asia)
- Delhi, India (South Asia)
- Berlin, Germany (Europe)
- Abidjan, Côte d'Ivoire (Africa)
- Santiago, Chile (Latin America)
- Dubai, UAE (GCC)
- Amman, Jordan (MENA outside of the GCC)
- Baku, Azerbaijan (Eurasia).

The analysis is focused on urban centres as these are the areas where additional capacity is most likely to be required for both mobile and Wi-Fi, and therefore where the upper 6 GHz band is most likely to be deployed. To illustrate the economic impacts at a country level, we extrapolate the results of each of the above cities to other urban areas in the nine countries.

We consider three policy scenarios for each country, relative to a baseline of no upper 6 GHz spectrum being allocated for either licensed or unlicensed use (shown in Figure 12). Specifically, we look at the economic benefits of allocating the upper 6 GHz band to licensed use (Scenario 1); the upper 6 GHz band to unlicensed use (Scenario 2); and shared use, implemented by reducing the power level of 6 GHz frequencies at mobile base stations (Scenario 3).

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[25] The nine cities have been selected to ensure one is taken from each region that is considering options for the upper 6 GHz band. This does not apply to North America or China, which have already assigned the band for unlicensed and licensed use respectively.

Figure 11
Upper 6 GHz policy scenario analysis

	Licensed	Unlicensed
Baseline	No upper 6 GHz	No upper 6 GHz
Scenario 1	With upper 6 GHz	No upper 6 GHz
Scenario 2	No upper 6 GHz	With upper 6 GHz
Scenario 3	Shared use based on IMT power restrictions	

Source: GSMA Intelligence

3.3 Considerations for sharing the upper 6 GHz band in Scenario 3

The option of sharing the upper 6 GHz band between licensed mobile and unlicensed Wi-Fi has gained increasing attention among regulators and policymakers, especially in Europe.[26] The objective behind a shared approach is to realise the potential benefits of both mobile and Wi-Fi use of the band, rather than selecting one over the other, and allowing greater flexibility for the band to optimise use based on local demand and usage patterns. There are a number of different ways shared use can be implemented, including the following:

- Geographic sharing, with licensed mobile use permitted in busy areas with high traffic demand and Wi-Fi use in other locations (or vice versa). This requires the development of suitable co-existence mechanisms to ensure there is no interference.
- Dynamic sharing, which assigns a priority for one type of use (mobile or Wi-Fi) and allows the other to access the band when it is not being used. This would require the development and coordination of co-existence mechanisms, such as managed databases and/or dynamic sensing to implement 'sense and avoid' techniques. There are also variants of this option. For example, the entire band could be prioritised for one type of use, or there could be a spectrum split (with some frequencies given priority for mobile and some for Wi-Fi). The decision on priority use could also vary depending on location and/or time.
- An 'indoor/outdoor split', with Wi-Fi using the band for indoor connectivity and mobile using it for outdoor. One proposed way of implementing this is to reduce the radiated power limit of upper 6 GHz deployments,[27] so they would not interfere with indoor Wi-Fi use of the band. This is often based on the assumption that Wi-Fi is typically used indoors, while mobile base stations are usually deployed outdoors. However, as shown in Chapter 2, most mobile usage is actually indoor and supported by mid-bands, making the concept of an indoor/outdoor split problematic in real-world conditions. Furthermore, even reduced transmitted power by mobile does not provide a guarantee of low interference if it results in further base station densification.

While the objectives of a shared use approach are understandable, the practicalities involved in implementing the above options are complex.[28] For example, using managed databases for indoor systems is more difficult than for outdoor, while dynamic sharing may require a solution that increases Wi-Fi signal detection thresholds, which are currently higher than the signals emitted by outdoor mobile base stations. Given some of these challenges, additional sensing technologies are being considered by ECC studies that would allow standard mobile power deployments – for example, the use of cross-technology signalling based on IEEE waveform broadcast by mobile networks,[29] or the use of cross-technology signalling based on existing 3GPP pilot signals.[30]

Geographic sharing faces challenges as mobile and Wi-Fi demand may peak in similar areas (i.e. in dense urban clusters). In the case of an indoor/outdoor split, reducing the emission power of mobile base stations in a manner that degrades performance could ultimately result in limited use of the band for mobile, particularly as the majority of mobile use is indoors and currently supported by mid-bands (see Chapter 2).

It will also be important to ensure international harmonisation on any type of sharing mechanism, especially if new equipment features and capabilities are required, but also to avoid the need for multiple certification processes for consumer devices. All the options for shared use would therefore ultimately add cost and complexity to network deployments and user devices.

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26. See for example: Mobile and Wi-Fi in Upper 6 GHz: Why hybrid sharing matters, Ofcom, 2024; Future use of the upper 6 GHz band Options paper, ACMA, 2024; Hybrid sharing: enabling both licensed mobile and Wi-Fi users to access the upper 6 GHz band, Ofcom, 2023. The Electronic Communications Committee (ECC) has also commenced studying sharing options under work item PT1-50.
27. See for example some of the studies undertaken by the ECC that explore the impact of restricting the equivalent isotropic radiated power (EIRP) of base stations for upper 6 GHz deployments.
28. See for example ongoing CEPT work in ECC PT1 and Hybrid sharing: enabling both licensed mobile and Wi-Fi users to access the upper 6 GHz band – Summary of responses and next steps, Ofcom 2023.
29. See Qualcomm submission, ECC PT1(24)113.
30. See Huawei submission ECC PT1(24)098, and Ericsson submission ECC PT1(24)111.

For this study, it has not been feasible to assess each option being discussed in relation to sharing the upper 6 GHz band between licensed and unlicensed use, as there is not yet sufficient clarity on how each approach would be implemented. For example, geographic sharing would depend on how the relevant geographic segments for shared use are defined (i.e. where are mobile and Wi-Fi permitted to use the band?). Dynamic sharing would depend on which parts of the band are prioritised for each use (and whether this varies based on the time or location) as well as the sharing mechanism used (for example, managed databases, spectrum sensing or a combination of both). It is also currently unclear what the costs of these solutions would be, and their impact on mobile and Wi-Fi deployments in the upper 6 GHz band (in terms of capacity loss, for example).

However, using the framework developed for Scenarios 1 and 2, we can consider the impact of reducing the power of mobile deployments, as there is initial evidence on the implications for mobile spectral efficiency and capacity[31] (though there may still also be a requirement for additional mitigation to ensure no interference with Wi-Fi, which is not captured). While the impact depends on the level of power restriction put in place, we have modelled one scenario based on a 50% reduction in capacity offered by the upper 6 GHz band for mobile (see Appendix 1 for further details). As more details are developed on other sharing approaches and further analysis and evidence is gathered, the framework developed in this study can be applied to carry out an economic assessment of those options.

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[31] See Ericsson submission, ECC PT1(24)110, Vodafone submission, ECC PT1(23)033 and Huawei submission ECC PT1(24)_CG6GHz022.

4. Economic assessment: results and key findings

4.1 Scenario 1 – the greatest economic benefit in all countries studied

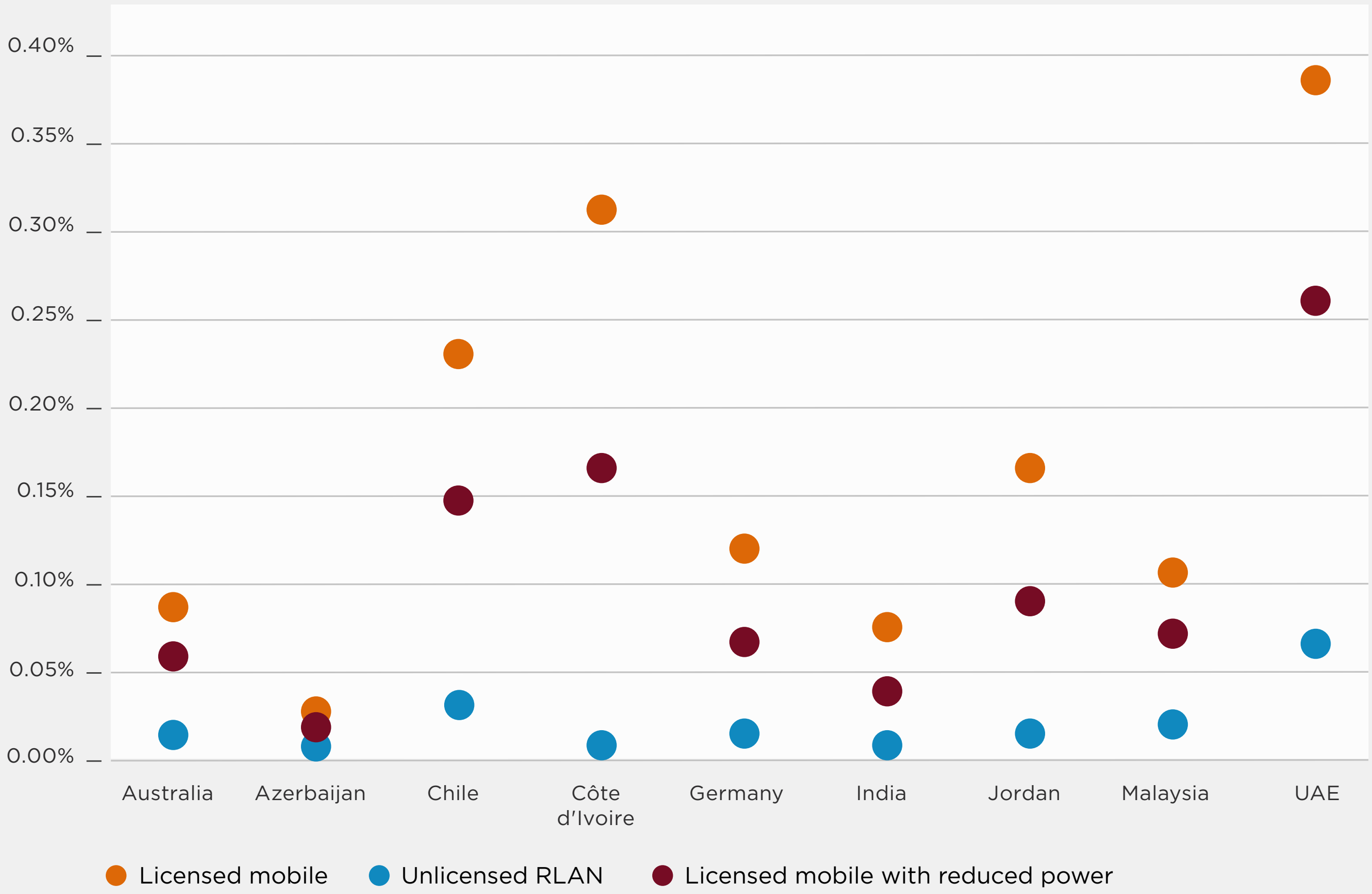
The results of our assessment, presented in Figure 12, show that across the nine countries studied, the greatest economic benefit in all countries is for Scenario 1, where the upper 6 GHz is assigned for full-power, macro-cell licensed use. This is followed by Scenario 3, enabling shared use via lower IMT power levels, and then Scenario 2 (assigning the band for unlicensed use).

The benefits of Scenario 1 are 3–20× greater than Scenario 2, with the exception of India and Côte d'Ivoire, where they are even greater due to the limited adoption of FTTH/B and cable broadband compared to mobile broadband. The benefits for Scenario 3 represent an upper bound as they do not include potential mitigation costs to manage interference between low-power mobile deployments and Wi-Fi.

The main reasons for these consistent results are as follows:

1. Mobile is more likely to be capacity-constrained than Wi-Fi in each country.
2. There remains scope to increase Wi-Fi capacity by improving Wi-Fi spectral efficiency.
3. In lower income countries, mobile broadband adoption is generally higher than fixed broadband adoption, and there is limited use of FTTH/B and cable broadband.

Figure 12
Economic benefits of the three scenarios in nine countries
Proportion of expected GDP in 2035



Source: GSMA Intelligence

Note: The results represent the net present value (NPV) of economic benefits over 2023–2035, expressed as a proportion of expected GDP in 2035 for each country. Appendix 1 includes details of the methodology and key assumptions, as well as a sensitivity analysis based on a data traffic approach to measuring demand.

Scenario 1 drives the greatest benefit because mobile is much more likely than Wi-Fi to be capacity constrained in each country over the period to 2035. This either means demand exceeds supply, or the extent of excess capacity is much lower for mobile than for Wi-Fi. Our assessment is based on mobile operators and Wi-Fi providers being efficient in the long term, which is the best-practice approach when deciding how to allocate spectrum because it ensures it is not assigned for a service being delivered inefficiently or using older technologies, or because the existing bands that have been assigned are not being fully utilised.

By assuming that, in the long term, all licensed spectrum uses 5G technology and all unlicensed spectrum uses Wi-Fi 6 technology[32] and by assuming efficient utilisation of spectrum, the analysis shows that unlicensed assignments in the 2.4, 5 and lower 6 GHz bands are more than sufficient to meet expected demand for fixed traffic. This is the case whether we assume that all fixed broadband connections should provide speeds of 1 Gbps (shown in Figure 12) or if we consider the expected growth in fixed traffic (see Appendix 1 for these results).

The analysis also does not assume any use of unlicensed high-band spectrum in the 57–71 GHz range, but does assume mmWave bands will be used by mobile operators. These unlicensed high-band frequencies provide propagation properties that allow short-range coverage (e.g. within a room) while easing coordination in terms of interference between adjacent access points. High bands can therefore be used for Wi-Fi to support connectivity for certain high-capacity use cases, such as AR/VR, and a variety of short-range devices.

With regard to Scenario 3, the benefits are subject to some uncertainty. The main modification was to reduce the capacity that mobile networks can provide when transmitting in the upper 6 GHz frequency range at a lower power limit (see Appendix 1). It is possible that operators do not utilise the band at lower power levels if they do not provide the necessary capacity and coverage, especially for indoor use.

In Scenario 3, we also assume that, with lower IMT power levels, Wi-Fi would be able to utilise the upper 6 GHz band without interference indoors. In practice, this may not be the case depending on the power restriction, especially in 'shallow' indoor locations. This would potentially involve additional mitigation costs, as well as potential impacts on how the upper 6 GHz band is used by Wi-Fi. The benefits in Scenario 3 should therefore be considered as an upper bound.

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[32] Over the next 12 years, it is expected that new standards will be developed for RLAN (Wi-Fi 7) and mobile (6G). However, given the uncertainty over timing and the specifications, we only model Wi-Fi 6 and 5G in this study.

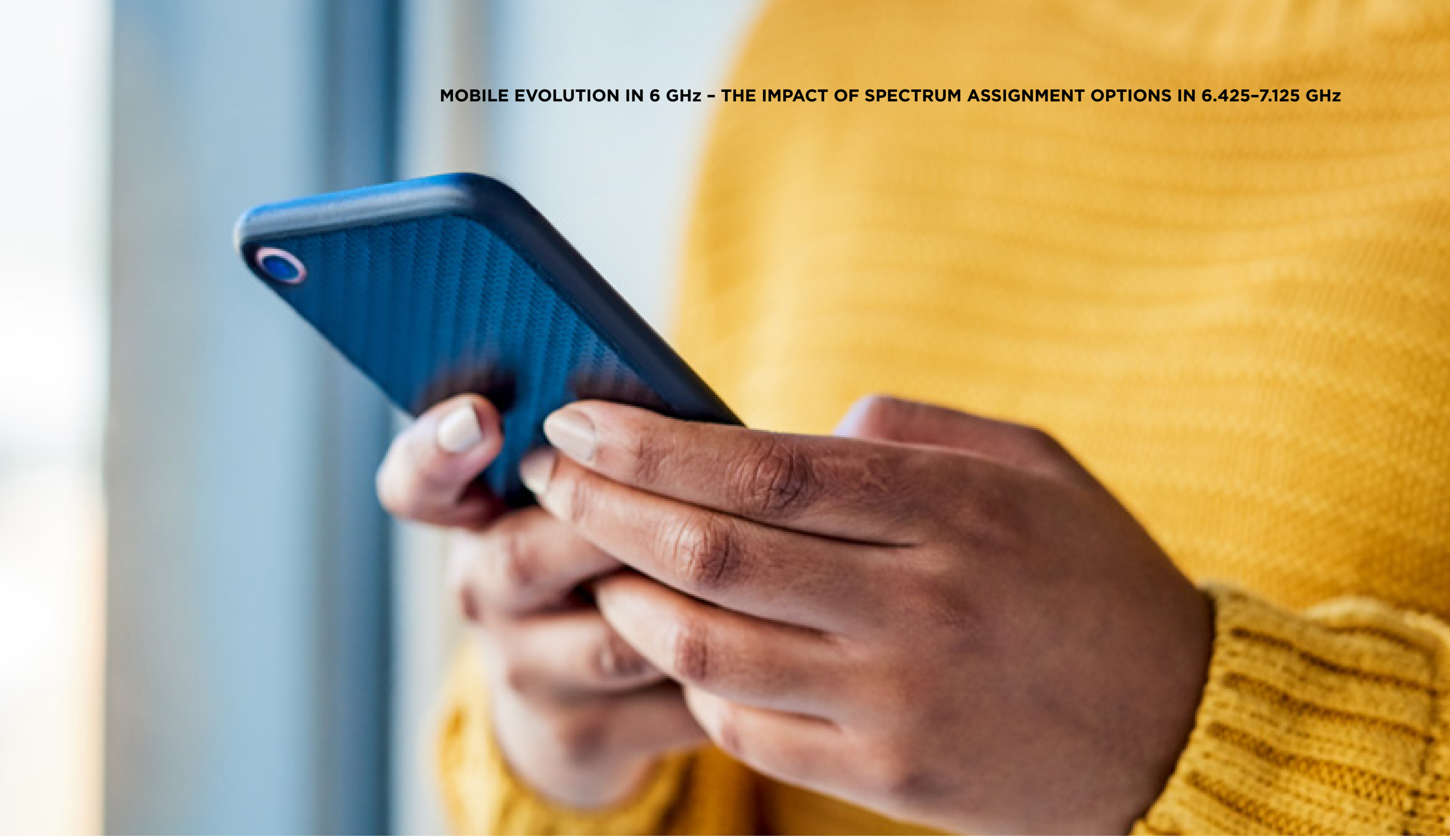
4.2 Shared use of upper 6 GHz

With regard to the options for shared use, while it has not been possible to carry out an assessment of all approaches in the upper 6 GHz band, there are some important implications from the analysis.

First, restricting the power levels that mobile base stations can emit in the band will significantly reduce the additional capacity that can be provided, meaning the economic benefits are lower than a policy of having a fully licensed band. Furthermore, given that the majority of mobile traffic originates indoors, there is no clear rationale for attempting to enforce an indoor/outdoor split of the band, and it is unlikely that a reduction in mobile power levels would achieve that. More generally, if the technical conditions for sharing are too stringent and costly for one of the technologies, the sharing framework will lose value.

Second, the results of the economic analysis show that if Wi-Fi is deployed in an efficient manner, there is no capacity constraint in the cities considered. By contrast, demand is much more likely to exceed capacity for mobile. Mobile operators also have an incentive to utilise spectrum efficiently as they face a pricing signal, whereas Wi-Fi deployments do not have such an incentive. Any approach to spectrum sharing should incentivise efficient spectrum use by both technologies. This means the burden of sharing and limitations on use should not be entirely placed on mobile operators.

Any approach to sharing the band should reflect these considerations by ensuring licensed mobile has priority to the band using standard power where (and when) needed and that any requirements and additional costs to share spectrum are not just solely imposed on mobile operators but also place responsibility on Wi-Fi providers. Such solutions are currently being explored in Europe – around cross-technology signalling, for example. This will allow fixed ISPs to determine the most suitable option to increase capacity where needed, rather than relying on additional spectrum to compensate for inefficient spectrum utilisation. This could involve upgrading to the latest technologies, optimising indoor deployments (for example, with additional access points, mesh network solutions, using Wi-Fi boosters, utilising unlicensed mmWave bands) or accessing the upper 6 GHz band when not being used by mobile.



Policymakers need to ensure that the upper 6 GHz band is utilised efficiently

Spectrum policymakers face an important decision in the coming years as they look to decide the optimal approach for managing spectrum in the 6.425–7.125 GHz frequency range. The results of an economic cost-benefit analysis will be specific to the circumstances of each market, depending on the level of expected 5G and FTTH/B and cable adoption, the expected traffic growth, spectrum availability in other bands and network deployments. Governments should pursue the spectrum policies that generate the most economic and social value for their populations.

In each of the countries considered in this study, the benefits from assigning the upper 6 GHz band for licensed mobile significantly exceed the benefits from assigning it for unlicensed use or sharing the band based on reduced IMT power levels. This is because the evidence on how mobile and Wi-Fi are currently utilised strongly suggests Wi-Fi has sufficient spectrum, if used efficiently, in the 2.4, 5 and lower 6 GHz frequencies (as well as unlicensed high bands) to meet expected traffic demand to 2035.

While mobile operators already have an incentive to be efficient in their spectrum use, they are more likely to face a capacity constraint across the countries considered, which is why the most economically beneficial policy is currently the assignment of the upper 6 GHz for licensed mobile.

The suggestion that the 6 GHz band could not support mobile use indoors, where most traffic originates, is not consistent with the evidence currently available. A shared use approach to the band can be considered if it helps address localised capacity constraints for Wi-Fi, but it should not be done in a manner that incentivises inefficient spectrum use and should not impose significant costs or restrictions. In particular, it should not reduce mobile network power levels such that it reduces the benefits that could be driven by increasing the capacity of 5G networks.

Appendix 1: Methodology

To estimate the economic impact of different policy options for the upper 6 GHz band, we develop two traffic demand and supply models for the period between 2023 and 2035. This is applied in the following nine cities:

We focus on cities and urban areas as this is where capacity is most needed and where 6 GHz is most likely to be used for wide-area cellular networks and Wi-Fi.

A1.1 Mobile demand and supply model

Figure A1 illustrates the structure of the mobile model. It works as follows:

- Demand is based on either a 'traffic approach' or 'speed approach'. The traffic approach takes the latest GSMA Intelligence mobile traffic forecasts[33] and adjusts them to reflect traffic in each city, which is higher than the country average due to higher mobile broadband adoption and greater use per consumer.[34] We assume a certain proportion of traffic is delivered over low bands and mmWave bands, and the remaining demand for mid-bands is then converted into Mbps units based on the proportion of traffic delivered during the peak hour.

- The speed approach assumes that operators must deliver the minimum ITU-R performance requirements of IMT-2020[35] (100 Mbps download and 50 Mbps upload[36]), based on expected 5G adoption in each city and the share of connected users active.[37]

- Mobile supply (or capacity) is driven by the amount of spectrum available; the number of sites deployed (both macro- and small sites); spectral efficiencies; and a network loading factor.

- We then compare the baseline where no additional upper 6 GHz spectrum is available and where 700 MHz in the upper 6 GHz band is made available in Scenario 1 (with a fully licensed approach to the band). For Scenario 3, we model the impact of reduced IMT power levels by assuming a lower spectral efficiency for the upper 6 GHz frequencies. Studies carried out for the ECC work item PT1-50 have shown that a reduction in base station EIRP would result in a degradation in median and cell-edge spectral efficiency. The impact depends on the power restriction applied. One input by Ericsson[38] shows the capacity loss could range from 15% to 90%, depending on the final EIRP. For this analysis, we assume the power restriction would reduce the spectral efficiencies for 6 GHz frequencies by 50%.

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[33] This includes cellular and FWA traffic but not IoT, due to lack of available data.

[34] From a modelling perspective, this has the equivalent effect of applying a uniform data usage assumption but adjusting for the fact that the majority of traffic is concentrated in a small proportion of sites.

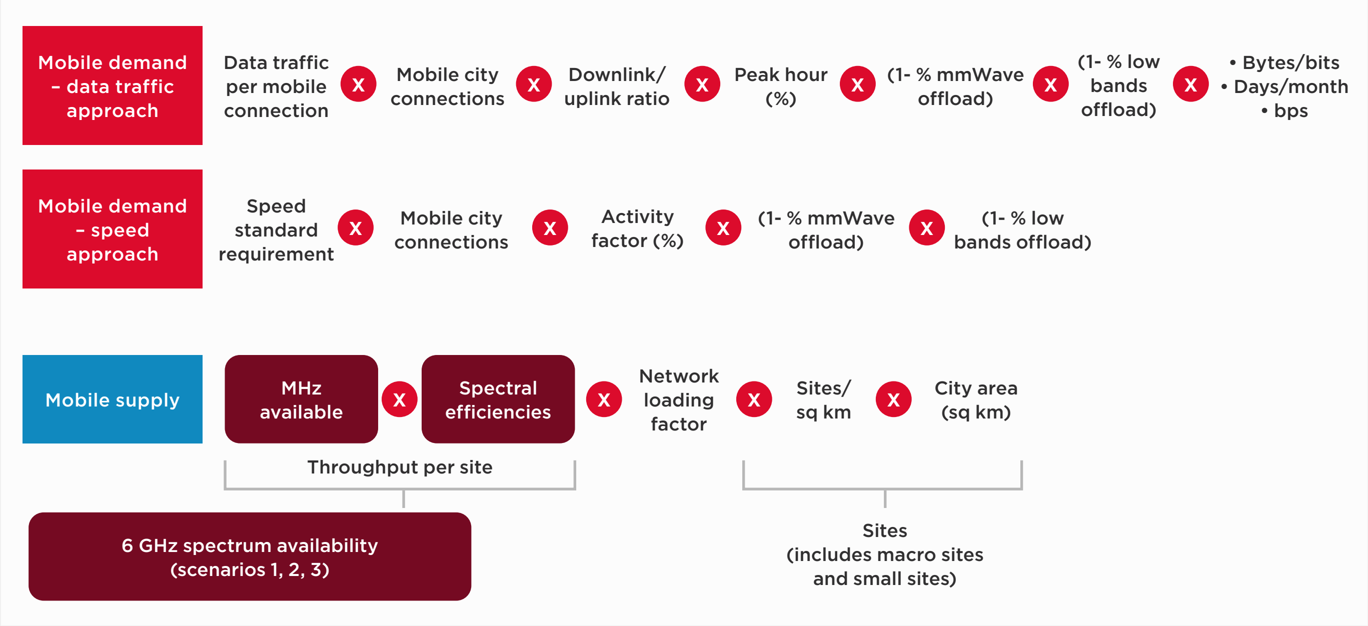
[35] Report ITU-R M.2410-0.

[36] Such performance requirements are applied for the whole period (2021–2035). This represents a conservative assumption since, over time, administrations could set national targets that go beyond those minimum requirements and considering that new generations for the IMT systems will become available before 2035.

[37] This share refers to concurrent demand from connected 5G users during the busy period. For example, a share of 5% means that up to 5% of all 5G users will be using their devices simultaneously in the busiest hour.

[38] Ericsson submission, ECC PT1(24)110

Figure A1
Mobile traffic demand and capacity supply model



Source: GSMA Intelligence

Table A1
Mobile model data inputs

Input	Data	Source
5G spectral efficiencies DL/UL (bps/Hz)	Lower mid-band: 2.2/2.5 for macro sites Upper mid-band: 6.0/4.1 for macro sites 3.7/2.6 for small sites	Coleago (2021)[39]
Number of sites	City-specific assumptions The number of sites is calculated based on: – city square kilometres – an inter-site distance of 400 metres – three small sites installed for each macro site	City square km: GHS Urban Centre Database Inter-site distance: Coleago (2021) Small sites per macro site: Coleago (2021)
Spectrum available	Country-specific assumptions Existing and planned mid-band spectrum assignments by country	GSMA Intelligence and national regulators
mmWave offload	30%	GSMA Intelligence
Low-bands offload	15%	GSMA Intelligence
DL/UL ratio	Downlink traffic: 75% Uplink traffic: 25% This refers to the amount of data or traffic downloaded/uploaded by the user	GSMA Intelligence
Peak hour	Mobile peak hour: 8.5% FWA peak hour: 20% This refers to proportion of daily traffic delivered in the hour when the demand for data usage is at its highest	GSMA Intelligence
Network loading factor	85%	GSMA Intelligence
Mobile connections in the city and other urban areas	Country- and city-specific assumptions Expected take-up of 4G and 5G services combined with urban adoption produces the number of mobile city connections over time	GSMA Intelligence and Gallup World Poll
Data traffic per connection (traffic approach)	Country- and city-specific assumptions	GSMA Intelligence
Performance requirements (speed approach)	100 Mbps download speeds 50 Mbps upload speeds	IMT-2020 requirements. Report ITU-R M.2441-0 (11/2018)
Activity factor (speed approach)	5% This reflects the concurrent demand from connected 5G users during the busy period. For example, a share of 5% means that up to 5% of all 5G users will be using their devices simultaneously.	GSMA Intelligence

Source: GSMA Intelligence

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39. Estimating the mid-band spectrum in the 2025–2030 time frame, Coleago, 2021

A1.2 Wi-Fi demand and supply model

Figure A2 shows the structure of the Wi-Fi model. It is based on demand in residential premises and works as follows:

— In a similar way to mobile, demand is based on either a 'traffic approach' or 'speed approach'. The traffic approach takes the latest ITU fixed broadband traffic data and applies forecasts to 2035.[40] As with mobile, we adjust demand to reflect traffic in each city, which is higher than the country average due to higher fixed broadband adoption and greater use per consumer. Demand is then converted into Mbps units based on the proportion of traffic delivered during the busy hour.

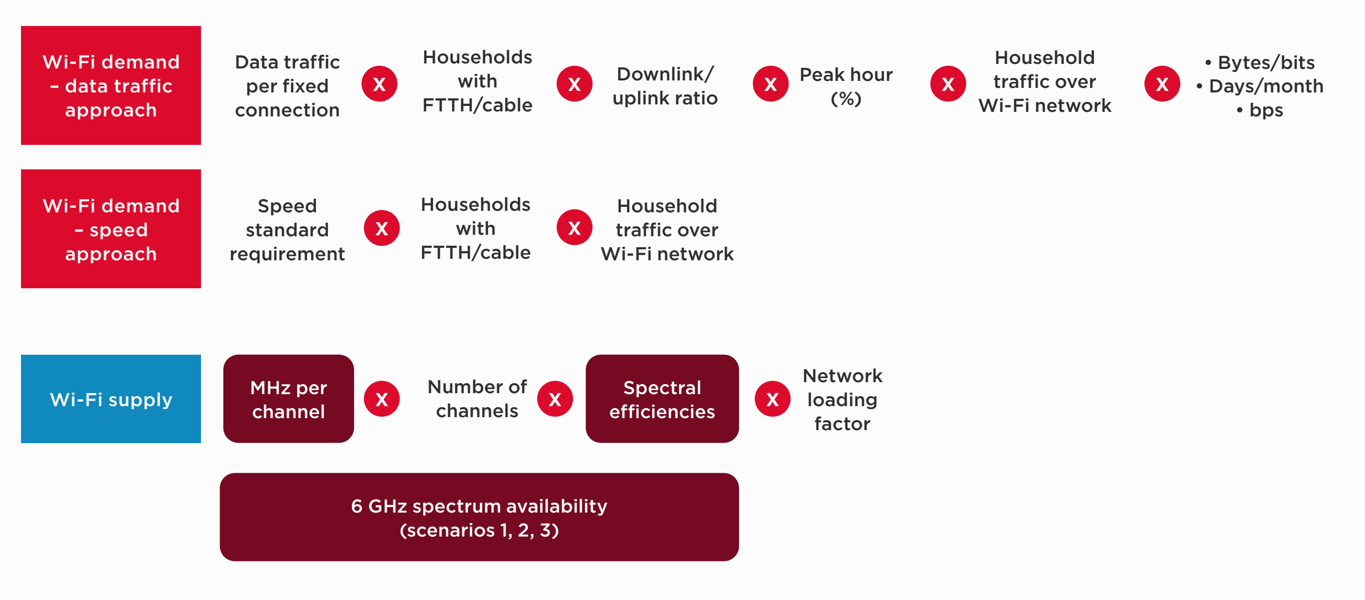
— The speed approach assumes operators must deliver 1 Gbps of connectivity to each household that has a broadband connection to support those speeds (i.e. FTTH/B and cable), which is in line with targets set by some governments and policymakers.[41]

— Wi-Fi supply (or capacity) is driven by the amount of spectrum available, spectral efficiencies and a network loading factor. We include 2.4, 5 and lower 6 GHz frequencies but not unlicensed high bands. However, the latter represents a solution to address potential Wi-Fi capacity constraints within households.[42]

— We then compare the baseline where no additional upper 6 GHz spectrum is available and where 700 MHz in the upper 6 GHz band is made available in Scenarios 2 and 3. In the case of Scenario 3, we assume that with lower IMT power levels, Wi-Fi would be able to utilise the upper 6 GHz band without interference indoors. In practice, this may not be the case depending on the power restriction, especially in 'shallow' indoor locations. This would potentially involve additional mitigation costs, as well as potential impacts on how the upper 6 GHz band is used by Wi-Fi. The benefits in Scenario 3 should therefore be considered as an upper bound.

Figure A2

Wi-Fi traffic demand and capacity supply model



Source: GSMA Intelligence

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40. Traffic forecasts for fixed broadband are based on The Evolution of Data Growth in Europe, Arthur D Little, 2023.
41. For example, the European Commission's Digital Decade 2030 Strategy aims to deliver gigabit coverage to all EU households by 2030.
42. For example, see Broadband India Forum (2021), The Economic Value of Wi-Fi Spectrum for India. The study highlights WiGig as one of the key use cases of V-Band spectrum. This can link devices at up to 7 Gbps over a distance of up to 12 metres.

Table A2
Wi-Fi model data inputs

Input	Data	Remarks and source
Wi-Fi spectral efficiencies (bps/Hz)	3.5 bps/Hz in 2023–2030 5.5 bps/Hz in 2031–2035	Comtel (2024). These assumptions are conservative, as they assume every household faces high levels of interference in an apartment block setting. Spectral efficiencies will be much higher in a house and will also be higher in apartments not at the centre of a building. These spectral efficiencies also do not reflect devices having more antennas in the long term.
Spectrum available	Country-specific assumptions on existing unlicensed spectrum assignments by country in the 2.4 and 5 GHz bands. We also assume 500 MHz is available in the lower 6 GHz band. For DFS channels in the 5 GHz band, we assume 50% utilisation (equivalent to assuming the capacity is halved).	Linux wireless regulatory database and national regulators
DL/UL ratio	Downlink traffic: 75% Uplink traffic: 25%	GSMA Intelligence
Peak hour	20%	GSMA Intelligence
Network loading factor	85%	GSMA Intelligence
Household traffic over Wi-Fi network	95% This refers to the proportion of fixed traffic delivered over Wi-Fi. It excludes any fixed data traffic transmitted to a device via a cable or wired connection from the access point.	GSMA Intelligence
FTTH/B and cable adoption in the city and other urban areas	Country-specific assumptions	GSMA Intelligence, ITU and Gallup World Poll
Data traffic per fixed connection (traffic approach)	Country-specific assumptions	Data to 2023 is sourced from the ITU. Traffic forecasts are sourced from Arthur D Little (2023)
Performance requirements (speed approach)	Speed requirement of 1 Gbps	GSMA Intelligence

Source: GSMA Intelligence

A1.3 Timing of 6 GHz use

In most countries, spectrum in the 6 GHz band is currently used for fixed services (including mobile backhaul and fixed satellite services in some countries). Studies to ensure co-existence with these services, and in particular with FSS UL (Earth to space direction), were completed prior to WRC-23. It is likely that 6 GHz will be available for large-scale 5G commercial deployments after WRC-27 has concluded. We therefore assume that 6 GHz will be available for licensed use from 2029 in our model. In terms of using 6 GHz for unlicensed use, we assume it can be used immediately, given the availability of Wi-Fi 6E equipment.

A1.4 Modelling the impact on mobile and fixed broadband users

When modelling the impacts of 6 GHz spectrum assignment on mobile and Wi-Fi, we focus on capacity rather than coverage – the assumption being that assigning additional upper mid-band spectrum will primarily allow operators to improve wide-area capacity and Wi-Fi providers to deliver faster speeds. Expanding wireless coverage, particularly in rural areas, generally requires low-band spectrum (below 1 GHz), and it is unlikely that the propagation characteristics of the 6 GHz band will enable the expansion of mobile and Wi-Fi coverage in rural or underserved areas.

To determine the impact of supply and demand on end-user experience, we model this in two ways:

1. Where demand exceeds supply in a given year, we assume a proportionate reduction in 5G mobile or FTTH/B and cable adoption. For example, if there is a capacity gap of 20% with no upper 6 GHz spectrum allocated for unlicensed (or licensed) use, we assume FTTH/B and cable (or 5G) adoption falls by 20% in that scenario. The rationale is that users do not get the full benefits of the service they require and which was purchased.

   An alternative approach would be to assume that operators increase capacity by densifying the network with less spectrum at higher cost. This would be passed on to consumers, which would reduce demand and therefore mobile broadband or FTTH/B and cable adoption. However, it is possible that the required densification may not be feasible from an interference perspective (i.e. requiring too many sites in a given area). We therefore model the economic impacts based on a reduction in quality of service. When applying the network densification methodology in the GSMA Intelligence 2022 study, we found the impacts on 5G adoption were comparable to using a quality-of-service based approach.

2. We also model the impact of additional spectrum on user experience, proxied by increased download speeds. Even if supply exceeds demand, the additional spectrum for licensed or unlicensed could result in faster speeds that allow users to realise additional benefits from fixed or mobile broadband connectivity. We assume that the increase in spectrum drives a proportionate increase in speeds (for example, a 10% increase in spectrum increases speeds by 10%[43]), which we then scale based on excess capacity where it exists. The latter means that if supply only just exceeds demand by a small amount, we assume a larger increase on speeds than if supply greatly exceeds demand. This is because if there is a lot of excess capacity, the impact on consumer experience will be less than if the network is capacity constrained.

This analysis is carried out in each of the nine cities included in the model. We then extrapolate the supply and demand analysis to other urban populations in the country. Regulators would ideally carry out separate analysis in each city and urban area, but we extrapolate in this study to illustrate the results at a country level.

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[43] This results from assuming a linear relationship determined by spectral efficiencies.

A1.5 Modelling the socioeconomic impacts of mobile and Wi-Fi

Having estimated the impact of each of the scenarios on adoption and speeds for mobile and FTTH/B & cable, the next step is to estimate the wider socioeconomic impacts of each policy. Both mobile and fixed broadband are digital technologies widely regarded as general purpose. They drive economic growth because they enable tools and processes for quicker, cheaper and more convenient production, which improves the productivity of firms and workers. They also lower information search and knowledge costs of consumers and producers, enabling new transactions and improving existing ones, thereby stimulating more trade and competition.

A number of studies have found a causal link between the adoption of mobile and fixed internet and GDP, suggesting a 10% increase in mobile or fixed internet adoption can increase a country's GDP by between 0.5% and 2.5%.[44] The impact of introducing 5G or faster fixed broadband is unlikely to deliver the same benefit as connecting an individual or business for the first time. Rather, the impact will reflect an improvement or 'upgrade' to the technologies people are already using – for example, by offering faster data rates, lower latencies and higher reliability.

A study by GSMA Intelligence[45] found that upgrading connections from 2G to 3G, and 3G to 4G, increased the economic impact of mobile by around 15%.[46] We therefore assume a similar uplift when estimating the impact of upgrading from 4G to 5G. As this reflects the overall impact of a technology upgrade on GDP growth, it will capture both direct and indirect impacts. Direct economic impacts include the value-add of firms in the mobile ecosystem, including operators, handset manufacturers, equipment and infrastructure vendors, and content providers. The indirect economic impacts include wider productivity benefits that mobile drives in other sectors.

The benefit at the country level is calculated as a function of 5G penetration rate, as follows:

t = time

i = country

α = 5G adoption rate[47]

β = 5G productivity impact

$$Total\_Benefit_{it} = GDP_{it} * (\alpha_{it} - \alpha_{it-1}) * \beta$$

The α parameter is based on the 5G forecasts for each country and the impact of each scenario. For the β parameter, the model assumes a value of 0.0195 for low-income countries, 0.0150 for middle-income countries and 0.0075 for high-income countries. This reflects the fact that mobile broadband has been found to have greater impacts in lower-income countries.

When modelling the economic impact of speeds, there are a number of studies that demonstrate faster broadband speeds (fixed and mobile) can drive improved macroeconomic outcomes.[48] For this study, we assume that a doubling of broadband speeds drives a 0.3% increase in GDP, and apply the same assumption for both mobile and fixed.

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[44] For example, see How broadband, digitization and ICT regulation impact the global economy, ITU, 2020; and Briglauer, Wolfgang; Krämer, Jan; Palan, Nicole (2023) : Socioeconomic benefits of high-speed broadband availability and service adoption: A survey, Research Paper, No. 24, EcoAustria – Institute for Economic Research, Vienna

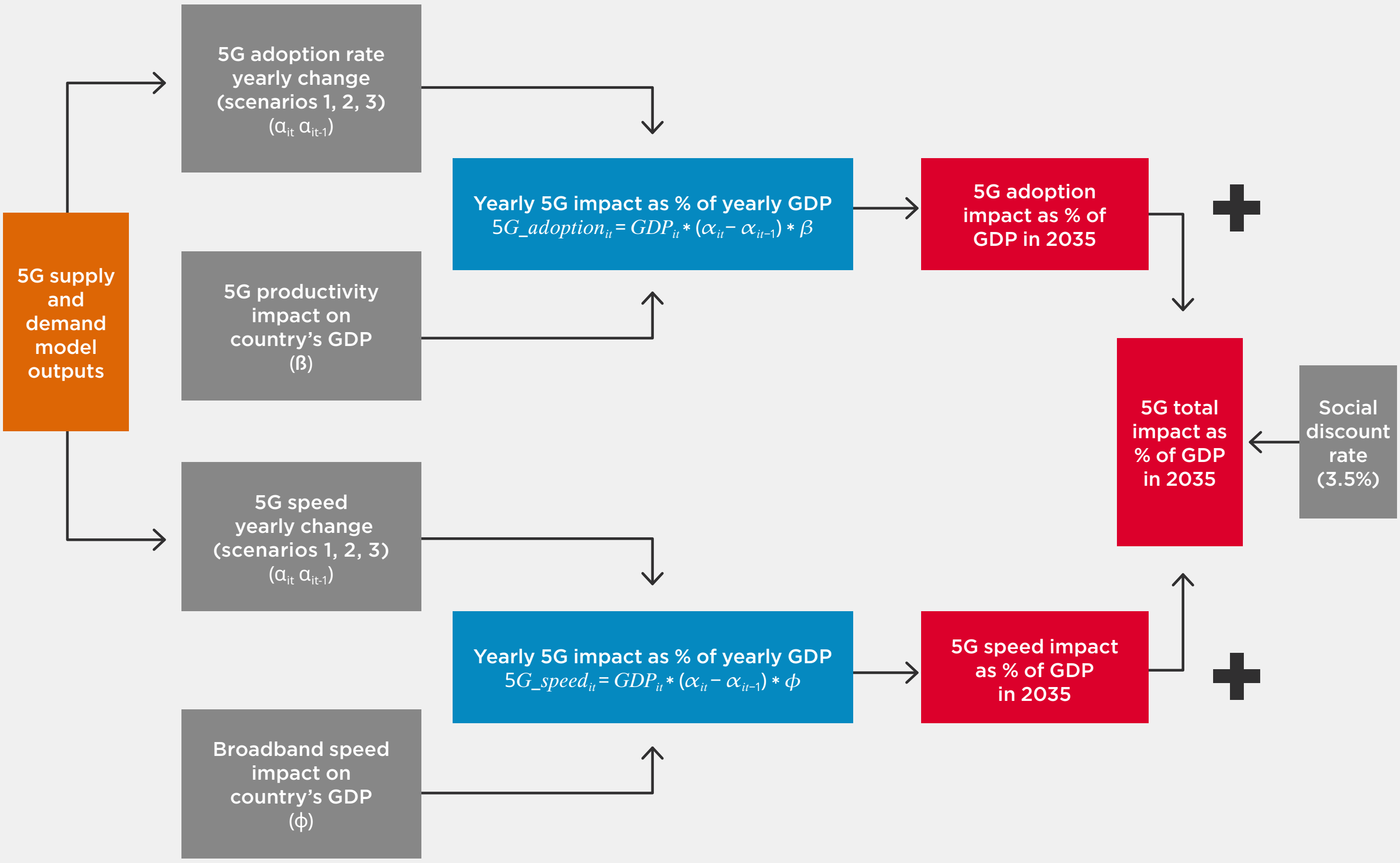
[45] Mobile technology: two decades driving economic growth, Working Paper, GSMA Intelligence, 2020

[46] For example, if a 10% increase in 2G adoption increases GDP by 1%, then a 10% increase in 2G-to-3G adoption increases GDP by an additional 1% * 15% = 0.15%.

[47] This reflects the expected level of 5G adoption (number of 5G users relative to population) in each country over time.

[48] See for example: Rohman, Ibrahim Kholilul, and Erik Bohlin. "Does broadband speed really matter as a driver of economic growth? Investigating OECD countries." International Journal of Management and Network Economics 5 2, no. 4 (2012): 336-356; Edquist, Harald. "The economic impact of mobile broadband speed." Telecommunications Policy 46, no. 5 (2022): 102351, and; Acosta, Camilo, and Luis Baldomero-Quintana. "Quality of communications infrastructure, local structural transformation, and inequality." Journal of Economic Geography 24, no. 1 (2024): 117-144.
A full list of papers is provided in Briglauer, Wolfgang; Krämer, Jan; Palan, Nicole (2023) : Socioeconomic benefits of high-speed broadband availability and service adoption: A survey, Research Paper, No. 24, EcoAustria – Institute for Economic Research, Vienna.

Figure A3
Modelling the socioeconomic impacts of 5G

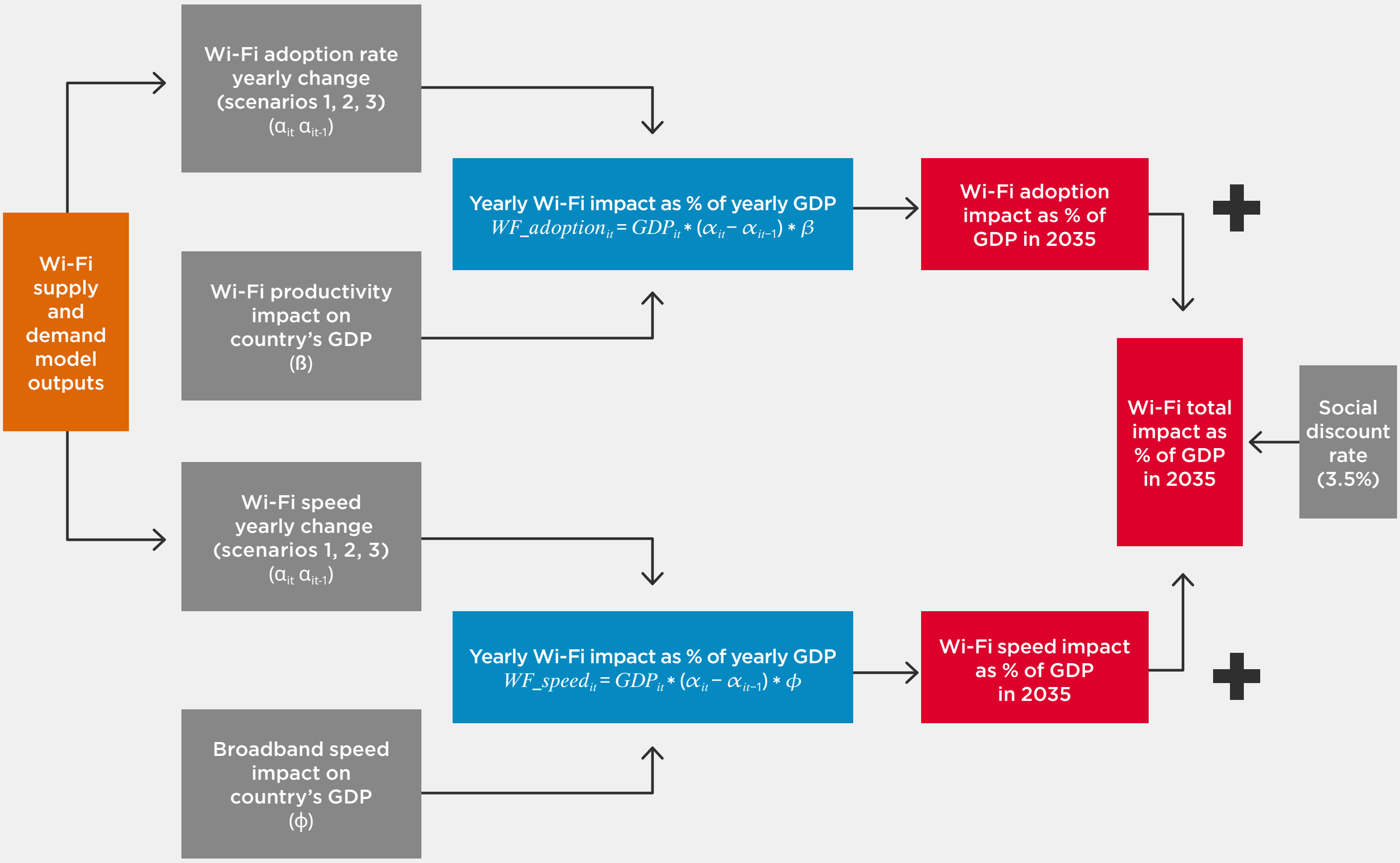


Source: GSMA Intelligence

This allows us to calculate the overall contribution of 5G technology to a country's economy in each year. We then aggregate the overall economic benefit in the 2023–2035 period by taking the net present value of economic benefits, using a social discount rate of 3.5%. In our presentation of results, we express this as a proportion of expected GDP in 2035.

The incremental economic impact of more or less FTTH/B and cable adoption is assumed to be the same as the impact of 5G. For example, if a 10% increase in 5G penetration drives a 0.15% increase in GDP, we assume that a 10% increase in FTTH/B and cable penetration also drives a 0.15% increase in GDP. This ensures we apply a consistent approach to both technologies. It also means the results between scenarios are not sensitive to the specific impact assumption (as it is applied in the same way to mobile and Wi-Fi). The same applies to the impact of faster speeds, where we assume that a doubling of broadband speeds drives a 0.3% increase in GDP.

Figure A4
Modelling the socioeconomic impacts of Wi-Fi



Source: GSMA Intelligence

Both models of mobile and Wi-Fi are based on urban demand and urban residential requirements respectively. We then apply the economic impact analysis based on overall 5G and FTTH/B & cable adoption (and overall mobile and fixed broadband speeds).[49] This captures the economic impacts consistent with existing evidence, as the empirical literature demonstrating the impact of mobile and fixed broadband on GDP is based almost entirely on broadband adoption at the national level by individuals or households.

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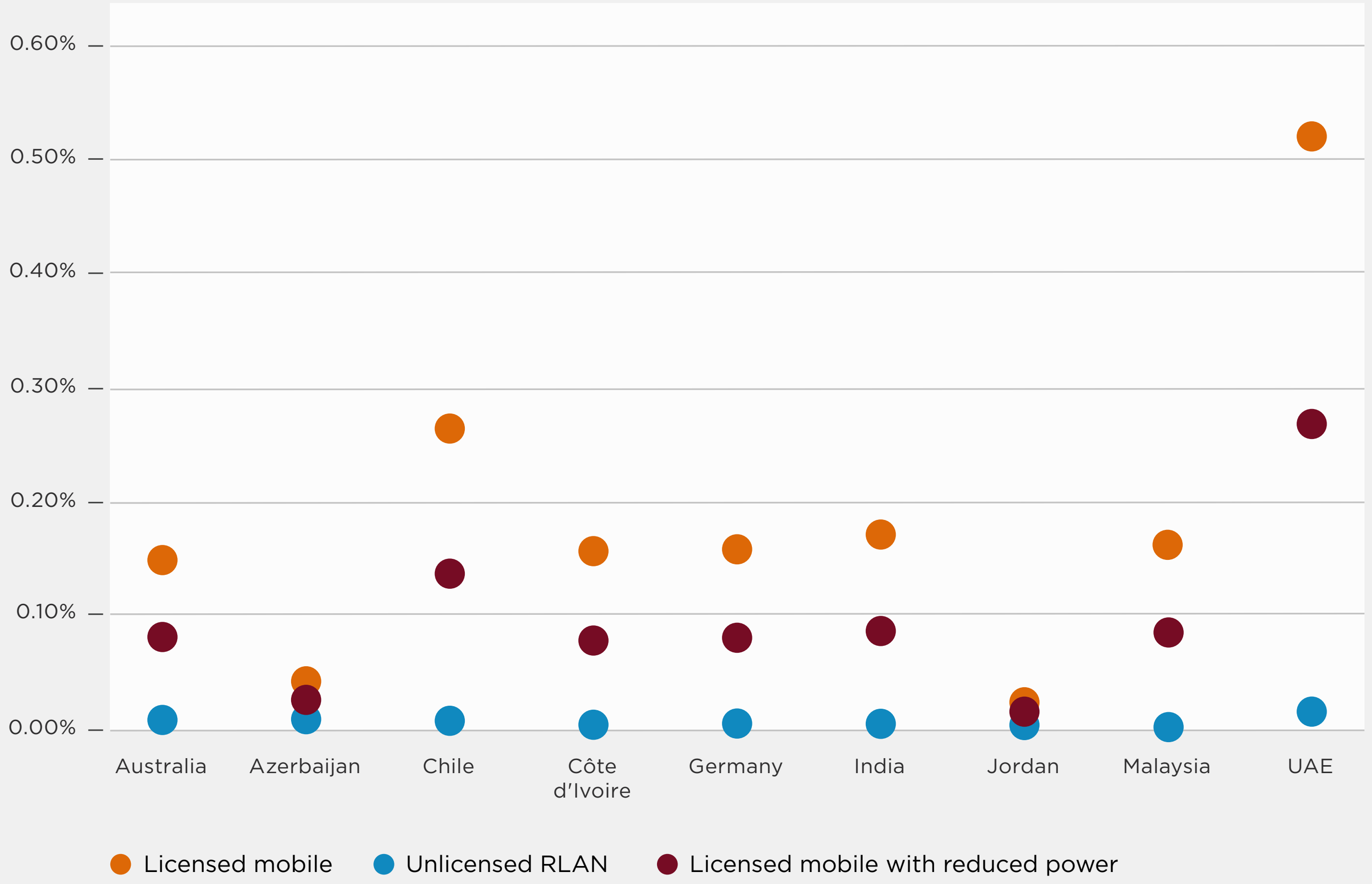
[49] Put another way, if we expect one of the scenarios to increase urban 5G or FTTH/B and cable adoption by 5%, we then estimate the uplift at a national level based on the proportion of populations living in urban areas and the proportion of 5G or FTTH/B and cable users that are in urban areas. This means the national adoption increase will be less than 5%, which we then apply the economic impact analysis to.

A1.6 Results using the data traffic approach

The results of the economic modelling presented in Chapter 4 are based on the speed approach. Figure A5 shows the results based on the data traffic approach, which are consistent in terms of demonstrating that, in all nine countries, Scenario 1: Licensed mobile drives the greatest benefit, followed by Scenario 3: Licensed mobile with reduced power and then Scenario 2: Unlicensed RLAN

Figure A5
The economic benefits of the three scenarios in nine countries (data traffic approach)
Proportion of expected GDP in 2035



Source: GSMA Intelligence

Appendix 2:
List of countries by region

Country	Region	Country	Region
Afghanistan	South Asia	**Costa Rica**	Latin America & Caribbean
Albania	Europe	**Côte d'Ivoire**	Sub-Saharan Africa
Algeria	Middle East & North Africa	**Croatia**	Europe
Andorra	Europe	**Cuba**	Latin America & Caribbean
Angola	Sub-Saharan Africa	**Cyprus**	Europe
Antigua and Barbuda	Latin America & Caribbean	**Czechia**	Europe
Argentina	Latin America & Caribbean	**Denmark**	Europe
Armenia	Eurasia	**Djibouti**	Sub-Saharan Africa
Australia	Developed Asia Pacific	**Dominica**	Latin America & Caribbean
Austria	Europe	**Dominican Republic**	Latin America & Caribbean
Azerbaijan	Eurasia	**Ecuador**	Latin America & Caribbean
Bahamas	Latin America & Caribbean	**Egypt**	Middle East & North Africa
Bahrain	GCC	**El Salvador**	Latin America & Caribbean
Bangladesh	South Asia	**Equatorial Guinea**	Sub-Saharan Africa
Barbados	Latin America & Caribbean	**Eritrea**	Sub-Saharan Africa
Belarus	Eurasia	**Estonia**	Europe
Belgium	Europe	**Eswatini**	Sub-Saharan Africa
Belize	Latin America & Caribbean	**Ethiopia**	Sub-Saharan Africa
Benin	Sub-Saharan Africa	**Fiji**	Other Asia Pacific
Bhutan	South Asia	**Finland**	Europe
Bolivia	Latin America & Caribbean	**France**	Europe
Bosnia and Herzegovina	Europe	**Gabon**	Sub-Saharan Africa
Botswana	Sub-Saharan Africa	**Gambia**	Sub-Saharan Africa
Brazil	Latin America & Caribbean	**Georgia**	Other Asia Pacific
Brunei Darussalam	Developed Asia Pacific	**Germany**	Europe
Bulgaria	Europe	**Ghana**	Sub-Saharan Africa
Burkina Faso	Sub-Saharan Africa	**Greece**	Europe
Burundi	Sub-Saharan Africa	**Grenada**	Latin America & Caribbean
Cabo Verde	Sub-Saharan Africa	**Guatemala**	Latin America & Caribbean
Cambodia	Southeast Asia	**Guinea**	Sub-Saharan Africa
Cameroon	Sub-Saharan Africa	**Guinea-Bissau**	Sub-Saharan Africa
Canada	North America	**Guyana**	Latin America & Caribbean
Central African Republic	Sub-Saharan Africa	**Haiti**	Latin America & Caribbean
Chad	Sub-Saharan Africa	**Honduras**	Latin America & Caribbean
Chile	Latin America & Caribbean	**Hong Kong; SAR China**	Greater China
China	Greater China	**Hungary**	Europe
Colombia	Latin America & Caribbean	**Iceland**	Europe
Comoros	Sub-Saharan Africa	**India**	South Asia
Congo	Sub-Saharan Africa	**Indonesia**	Southeast Asia
Congo; Democratic Republic	Sub-Saharan Africa	**Iran**	Middle East & North Africa

Country	Region	Country	Region
Iraq	Middle East & North Africa	**Morocco**	Middle East & North Africa
Ireland	Europe	**Mozambique**	Sub-Saharan Africa
Israel	Middle East & North Africa	**Myanmar**	Southeast Asia
Italy	Europe	**Namibia**	Sub-Saharan Africa
Jamaica	Latin America & Caribbean	**Nauru**	Other Asia Pacific
Japan	Developed Asia Pacific	**Nepal**	South Asia
Jordan	Middle East & North Africa	**Netherlands**	Europe
Kazakhstan	Eurasia	**New Zealand**	Developed Asia Pacific
Kenya	Sub-Saharan Africa	**Nicaragua**	Latin America & Caribbean
Kiribati	Other Asia Pacific	**Niger**	Sub-Saharan Africa
Korea; North	Other Asia Pacific	**Nigeria**	Sub-Saharan Africa
Korea; South	Developed Asia Pacific	**North Macedonia**	Europe
Kosovo	Europe	**Norway**	Europe
Kuwait	GCC	**Oman**	GCC
Kyrgyzstan	Eurasia	**Pakistan**	South Asia
Laos	Southeast Asia	**Palau**	Other Asia Pacific
Latvia	Europe	**Palestine**	Middle East & North Africa
Lebanon	Middle East & North Africa	**Panama**	Latin America & Caribbean
Lesotho	Sub-Saharan Africa	**Papua New Guinea**	Other Asia Pacific
Liberia	Sub-Saharan Africa	**Paraguay**	Latin America & Caribbean
Libya	Middle East & North Africa	**Peru**	Latin America & Caribbean
Liechtenstein	Europe	**Philippines**	Southeast Asia
Lithuania	Europe	**Poland**	Europe
Luxembourg	Europe	**Portugal**	Europe
Macao; SAR China	Greater China	**Qatar**	GCC
Madagascar	Sub-Saharan Africa	**Romania**	Europe
Malawi	Sub-Saharan Africa	**Russian Federation**	EURASIA
Malaysia	Southeast Asia	**Rwanda**	Sub-Saharan Africa
Maldives	South Asia	**Saint Kitts and Nevis**	Latin America & Caribbean
Mali	Sub-Saharan Africa	**Saint Lucia**	Latin America & Caribbean
Malta	Europe	**Saint Vincent and the Grenadines**	Latin America & Caribbean
Marshall Islands	Other Asia Pacific	**Samoa**	Other Asia Pacific
Mauritania	Sub-Saharan Africa	**Sao Tome and Principe**	Sub-Saharan Africa
Mauritius	Sub-Saharan Africa	**Saudi Arabia**	GCC
Mexico	Latin America & Caribbean	**Senegal**	Sub-Saharan Africa
Micronesia	Other Asia Pacific	**Serbia**	Europe
Moldova	Eurasia	**Seychelles**	Sub-Saharan Africa
Monaco	Europe	**Sierra Leone**	Sub-Saharan Africa
Mongolia	Other Asia Pacific	**Singapore**	Developed Asia Pacific
Montenegro	Europe	**Slovakia**	Europe

Country	Region
Slovenia	Europe
Solomon Islands	Other Asia Pacific
Somalia	Sub-Saharan Africa
South Africa	Sub-Saharan Africa
South Sudan	Sub-Saharan Africa
Spain	Europe
Sri Lanka	South Asia
Sudan	Middle East & North Africa
Suriname	Latin America & Caribbean
Sweden	Europe
Switzerland	Europe
Syria	Middle East & North Africa
Taiwan; Province of China	Greater China
Tajikistan	EURASIA
Tanzania	Sub-Saharan Africa
Thailand	Southeast Asia
Timor-Leste	Southeast Asia
Togo	Sub-Saharan Africa
Tonga	Other Asia Pacific
Trinidad and Tobago	Latin America & Caribbean
Tunisia	Middle East & North Africa
Türkiye	Middle East & North Africa
Turkmenistan	EURASIA
Tuvalu	Other Asia Pacific
Uganda	Sub-Saharan Africa
Ukraine	Europe
United Arab Emirates	GCC
United Kingdom	Europe
United States of America	North America
Uruguay	Latin America & Caribbean
Uzbekistan	EURASIA
Vanuatu	Other Asia Pacific
Venezuela	Latin America & Caribbean
Vietnam	Southeast Asia
Yemen	Middle East & North Africa
Zambia	Sub-Saharan Africa
Zimbabwe	Sub-Saharan Africa

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