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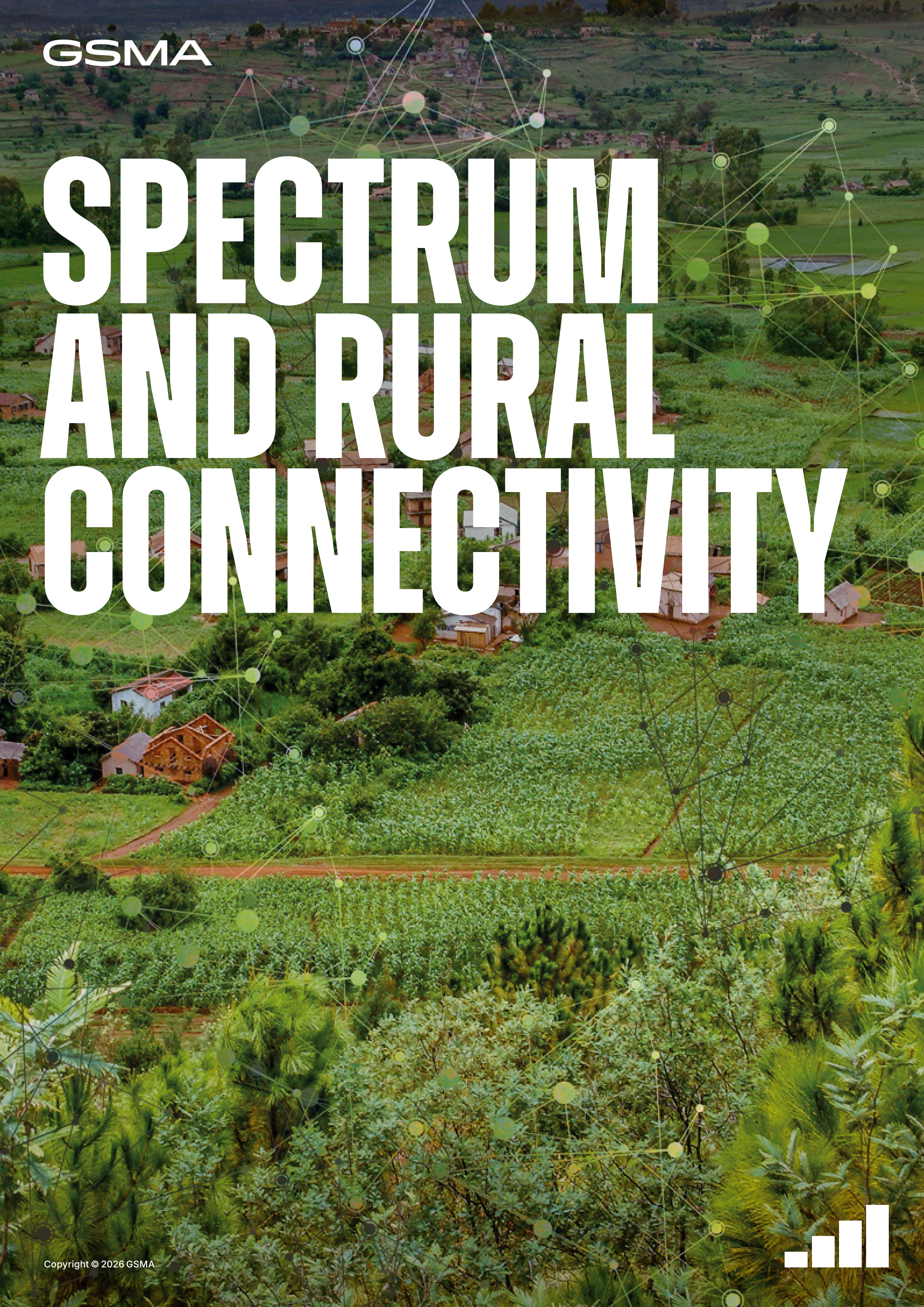

SPECTRUM AND RURAL CONNECTIVITY

The GSMA is a global organisation unifying the mobile ecosystem to discover, develop and deliver innovation foundational to positive business environments and societal change. Our vision is to unlock the full power of connectivity so that people, industry and society thrive. Representing mobile operators and organisations across the mobile ecosystem and adjacent industries, the GSMA delivers for its members across three broad pillars: Connectivity for Good, Industry Services and Solutions, and Outreach. This activity includes advancing policy, tackling today's biggest societal challenges, underpinning the technology and interoperability that make mobile work, and providing the world's largest platform to convene the mobile ecosystem at the MWC and M360 series of events.

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GSMA Intelligence is relied on by leading operators, vendors, regulators, financial institutions and third-party industry players, to support strategic decision-making and long-term investment planning. The data is used as an industry reference point and is frequently cited by the media and by the industry itself.

Our team of analysts and experts produce regular thought-leading research reports across a range of industry topics.

www.gsmaintelligence.com

info@gsmaintelligence.com

Authors:
Hrushikesh Kyathari, Geospatial Data Scientist
Jakub Zagdanski, Principal Economist
Kalvin Bahia, Senior Director of Economics
Pau Castells, Head of Economic Analysis

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EXECUTIVE SUMMARY

THE RURAL CONNECTIVITY GAP: DISPARITIES IN ACCESS AND USAGE

Rural communities are yet to realise the full potential of mobile connectivity. In low- and middle-income countries (LMICs), adults in rural areas are 25% less likely to use mobile internet than their urban counterparts. Even among mobile internet users, rural populations record a lower intensity of use; they are 30% less likely to regularly engage in key activities such as instant messaging, online calls and accessing services such as banking or education. In high-income countries, the gap is narrower but still significant, with rural users up to 20% less likely to regularly use services such as online maps, video calls and other digital tools.

Despite progress with rural coverage over the past decade, these disparities represent missed opportunities for broader societal benefits, including economic growth, improved access to healthcare and education, and enhanced network effects that amplify value for all users.

In low- and middle-income countries, adults in rural areas are

25% less likely

to use mobile internet than their urban counterparts

Rural populations are up to

30% less likely

to engage in online activities: messaging, calls, banking, education

Low-band spectrum is essential for rural networks:

Rural users spend

2× as much time

connected to low bands as urban users

An additional 50 MHz of sub-1 GHz spectrum is linked to

7 PERCENTAGE-POINT

increase in **4G coverage**

11 PERCENTAGE-POINT

increase in **5G coverage**

Lower spectrum cost boosts network deployment

A reduction of spectrum cost-to-revenue ratio by

10 PERCENTAGE-POINTS...

4G increases 4G coverage by **4 PERCENTAGE POINTS**

5G increases 5G coverage by **6 PERCENTAGE POINTS**

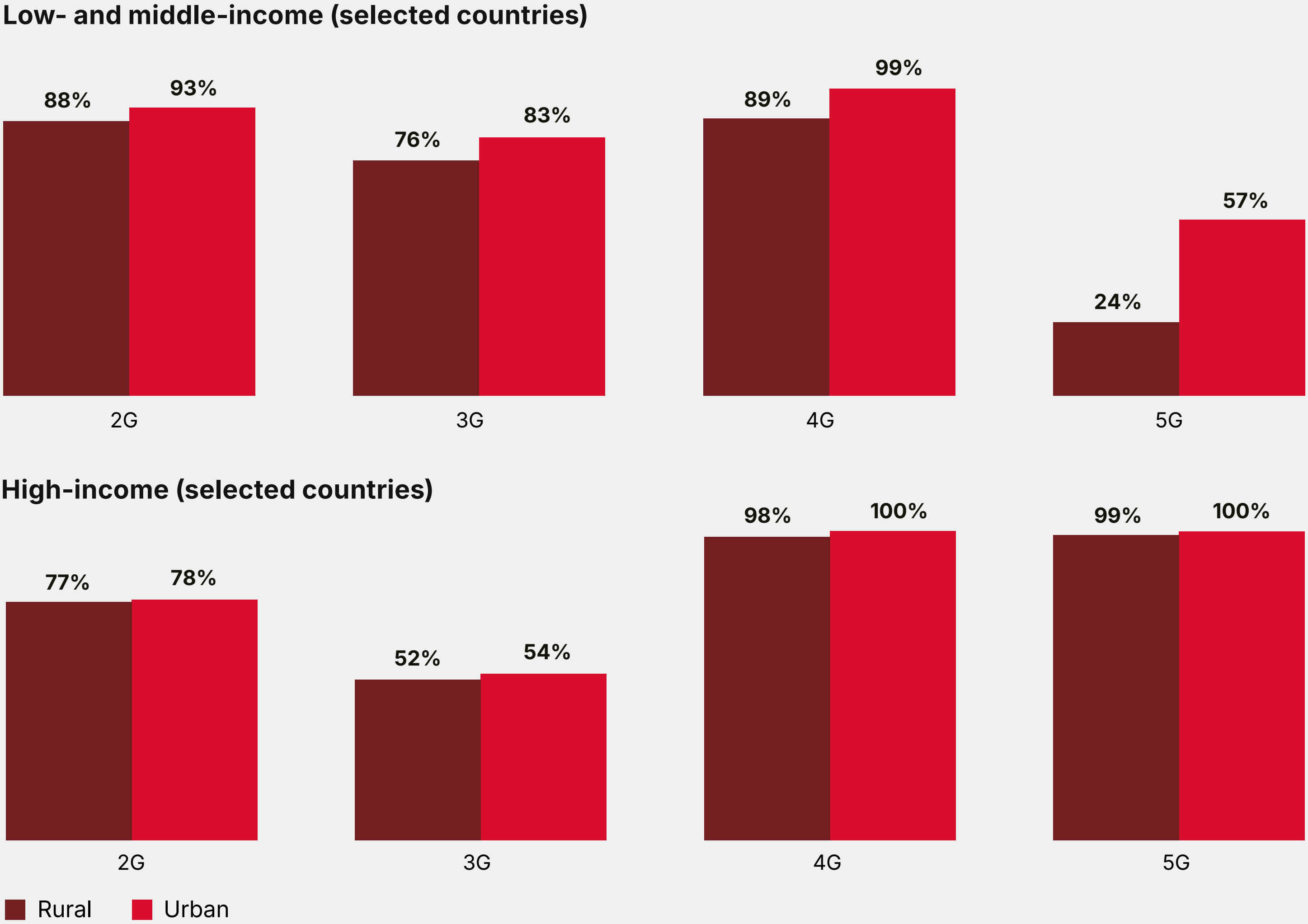
increases speeds by up to **8%**

The rural connectivity gap can be reduced by improving affordability and network quality in rural areas. Spectrum policy can play an important part in advancing both.

Governments can support rural development by lowering network rollout costs for operators

- **Lowering the regulatory costs (including site access)**
- **Ensuring long-term regulatory certainty of access to spectrum**
- **Lowering the barriers to voluntary network sharing**

Figure 1
Urban-rural difference in mobile network population coverage



Note: Based on countries where recent data was available. Further detail can be found in the Methodology.
Source: GSMA Intelligence

The rural connectivity gap stems from multiple barriers. While literacy and affordability are primary hurdles to initial adoption across urban and rural areas, network quality is a critical obstacle for greater engagement among existing users. In LMICs, 18% of rural mobile internet users cite inconsistent coverage and slow speeds as the main barrier to more intensive use. This is 50% higher than the share among urban users. Rural consumers also more frequently report affordability as a barrier.

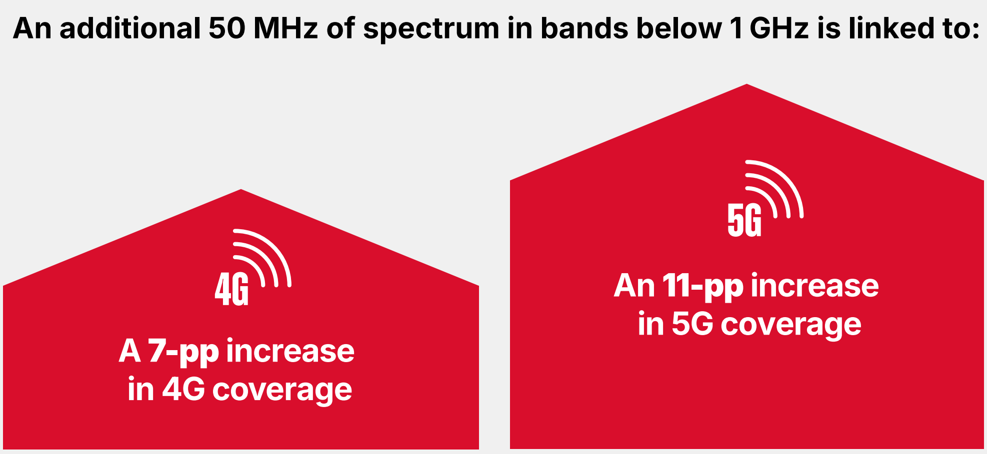
GSMA Intelligence analysis shows that appropriate spectrum policy choices can alleviate these barriers by reducing the cost of deploying networks in rural areas and boosting capacity.

SPECTRUM USE IN RURAL AREAS: LOW BANDS FOR COVERAGE AND CAPACITY

Spectrum plays a pivotal role in rural connectivity, with usage patterns different to urban environments due to the need for wide-area coverage over sparse populations. Rural users spend significantly more time connected to sub-1 GHz (low-band) spectrum – over twice as much as urban users on 4G and 5G networks. In countries such as Australia and the UK, rural users rely on low bands for more than half their connection time. This reliance stems from the superior propagation characteristics of low bands, which enable signals to travel further. For instance, a base station can cover up to 10× the area using 700 MHz compared to the area it could reach using only 2.6 GHz. Sufficient low-band spectrum reduces deployment costs and improves the quality of connection for users.

Additionally, low-band spectrum directly enhances rural networks. Each 50 MHz of sub-1 GHz spectrum is associated with a 7 percentage-point (pp) increase in 4G coverage and an 11-pp increase in 5G coverage, with a more pronounced impact than higher bands. Where viable, rural areas also benefit from the deployment of mid-bands (e.g. 3.5–3.8 GHz), boosting capacity near base stations and freeing low-band resources for cell-edge users.

Figure 2
The impact of low-band spectrum availability on mobile coverage



Source: GSMA Intelligence analysis

Despite lower population density, rural networks face capacity constraints, particularly at cell edges where only low bands penetrate effectively. This translates into user experience. Countries assigning over 130 MHz of sub-1 GHz spectrum achieve average rural download speeds above 50 Mbps, while those with less than 100 MHz often fall below this threshold. Due to larger distances, signal strength declines in rural areas, but additional low-band spectrum improves speeds and mitigates congestion.

VOLUNTARY SHARING CAN REDUCE COST OF RURAL DEPLOYMENT

Network sharing allows operators to use infrastructure and spectrum in different ways to avoid duplication, pool resources and improve the viability of rural deployments. The different modes of sharing spectrum include spectrum leasing, channel aggregation, national roaming and shared access frameworks. However, long-term access to spectrum is still required to ensure the viability of network assets in rural areas. Sharing options do not replace the need for exclusive, nationally licensed spectrum.

The limits to efficient spectrum sharing and leasing are set by technological and commercial factors, which impact how effectively spectrum can be shared under different models. For example, imposed sharing between technologies has limited rural applicability due to power limits that reduce coverage and the long-term investment certainty needed for infrastructure such as towers. On the other hand, voluntary sharing can provide the flexibility to allow sharing when optimal.

POLICY ACTION REQUIRED TO BRIDGE THE RURAL-URBAN GAP

Effective spectrum management is essential to closing the rural connectivity gap, focusing on timely assignment, affordable pricing and incentives for investment.

Make low-band spectrum available to boost rural coverage and speeds

Policymakers should prioritise assigning to mobile operators all low-band spectrum allocated to mobile and identified for IMT. This reduces deployment costs and accelerates coverage for the remaining unconnected populations. For instance, making 20 MHz of spectrum available per operator in the 600 MHz band can enable 21% fewer sites for equivalent coverage, while 40 MHz supports sufficient cell-edge speeds with 33% fewer sites.[1]

Allow spectrum prices to follow economic fundamentals

Spectrum pricing must align with economic realities. Global recurring revenue per MHz has fallen 67% over the past decade, due to declining consumer prices and rising spectrum needs.[2] Prices of low bands have declined faster than those of other bands, and further adjustments are needed. Reserve prices in auctions should not be anchored to historical or benchmark values.

Renewal fees should prioritise administrative cost recovery over revenue maximisation to prevent returned spectrum, which harms consumer outcomes. Lower aggregate spectrum costs (as a share of operator revenue) correlate with better rural networks. A 10-pp reduction in spectrum cost increases 4G coverage by 4 pp, 5G by 6 pp and speeds by up to 8%.

1 Vision 2030: Low-Band Spectrum for 5G, GSMA and Coleago Consulting, 2022
2 Global Spectrum Pricing, GSMA, 2025

Use of quality and investment obligations requires careful cost-benefit analysis

Some regulators rely on quality and investment commitments to promote expansion and quality of rural networks. Bundled approaches attach obligations directly to licences, while unbundled approaches allow operators to opt in for fee reductions, introducing additional flexibility.

Regardless of the approach, obligations can become overly stringent. The cost of meeting obligations substantially increases for more remote and less populated rural areas. This means the costs of meeting an obligation can outweigh social benefits, contrary to the objective of maximising the social benefits of spectrum. Another important factor to consider in cost-benefit analyses is that costs can be severely underappreciated due to the optimism bias at the planning and design stage.

Bring down the cost of rural deployments

The density and quality of rural deployment are driven by commercial considerations. Sufficient revenue needs to be generated to cover the capital and operating cost of a site. Policymakers can seek to reduce these costs through the following:

- Lowering the regulatory costs of setting up and operating base stations – for example, by simplifying planning regulations and site access, and promoting the proximity of grid electricity.

- Ensuring long-term regulatory certainty of access to spectrum, to reduce investment risk in rural infrastructure. Rural deployments require heavy upfront spend on long-term assets such as towers, backhaul, access roads and grid connections, with lifespans stretching decades. Certainty of access to spectrum needs to match these lifespans.

- Lowering the barriers to network sharing, allowing operators to use various cost-saving strategies and reduce the duplication of infrastructure and associated costs.

Facilitate voluntary spectrum and network sharing

The opportunity offered by rural network and spectrum sharing can be best maximised with permissive licences within the exclusive licencing framework. Regulator-imposed sharing generally reduces the value of spectrum for operators, as it constrains the viable network deployment strategies. Similarly, other types of regulation-imposed network sharing, such as single wholesale networks (SWNs), lack the flexibility and incentives grounded in competitive mobile markets.

Address affordability as a key barrier for rural consumers in LMICs

Lack of demand – due to limited affordability and other barriers to adoption – is the fundamental reason why expanding coverage to further areas remains challenging in LMICs. Insufficient demand means rural locations are unable to generate sufficient revenues to justify deployment.

In many countries, consumers face additional sector-specific taxes, which inflate the price of devices and telecoms services and distort incentives for mobile internet use. In particular, in rural areas where affordability is lower, removing these could boost rural demand and make network deployment viable. Limited digital skills and literacy, and lack of reliable grid electricity in the most remote areas, stand as additional policy barriers to spectrum issues.

Looking ahead, the right approach to maximise the value of spectrum in rural areas can unlock low-band 5G’s projected $130 billion in global economic value by 2030, with half of these benefits arising from massive IoT applications in agriculture and transport. By prioritising affordability, flexibility and evidence-based incentives, policymakers can bridge the rural-urban divide, fostering inclusive growth and meaningful connectivity for all.

1. RURAL CONNECTIVITY IN CONTEXT

Improvements in rural coverage are needed to reach universal and meaningful connectivity, bridge the digital divide, foster economic growth and ensure all communities are equipped to access online services such as education, healthcare and finance. Consumers in rural areas are 25% less likely to use mobile internet than urban populations.[3] Many of those who use it find network quality is the main barrier to greater use. This disparity not only impacts rural users, it also represents a missed opportunity to maximise broader societal benefits. As network effects amplify the value of connectivity, each new user enhances the ecosystem for all.

However, rural areas face specific challenges. Due to distances, mobile deployments involve significant cost, while demand is distributed more sparsely and among consumers with lower levels of disposable income. This typically means rural areas have lower coverage and/or lower network quality.

Effective spectrum management is pivotal to improving rural mobile networks. It determines the network coverage, capacity and quality experienced by users. This research examines how spectrum policy can enhance rural mobile connectivity. It uses data-driven analysis, establishing the current status and analysing how rural connectivity depends on spectrum choices.

NETWORK EFFECTS: CONNECTING THE UNCONNECTED BENEFITS EVERYONE

Network effects play an important role in maximising the benefits of connectivity. When examining the benefits and costs of investment in improved rural infrastructure, the benefit calculation should consider not only the benefits accruing to the rural population in question, but also those accruing to the rest of the network. Growth in the adoption of mobile broadband creates a virtuous circle. For each new user, additional benefits of connectivity accrue not only to the new user but also the existing user base, who can now reach a wider network for business and social purposes.

The wider population benefits from other network and spillover effects. For example, traffic congestion may reduce due to wider use of live information, while AI may become more intelligent as a wider pool of users train the models.

3 The State of Mobile Internet Connectivity, GSMA, 2025

2. STATE OF RURAL MOBILE

Rural users experience connectivity differently to those in urban areas, and face unique challenges that limit their ability to access and benefit from digital services on the same terms as urban users. Their mobile experience is shaped by distinct barriers, in terms of both obstacles to starting to use the mobile internet and adopting additional use cases. Similarly, operators face different challenges to rural network deployment, which can often be traced back to policy.

Rural populations in this research are defined as those living in areas of a density below 300 inhabitants per km^2, and some areas with higher density which are not a part of a cluster with a population greater than 5,000 inhabitants.

GEOSPATIAL ANALYSIS INSIGHTS

The analysis for this research linked high-resolution geographical data on service availability and quality with data on population distribution and urban-rural classification from the Global Human Settlement Layer (GHSL) data.[4]

To estimate population coverage, we rely on coverage maps provided by network operators in 50 high-income and 58 low-income countries, which offer a high-resolution picture of coverage typically at a resolution of 250m. We combine this data with global population maps to estimate the total population covered by networks. We classify the populations using GHSL data on the degree of urbanisation, aligning our definitions with the recommendations of the UN Statistical Commission.

To measure network speeds and the use of different networks and spectrum bands, we rely on crowdsourced Ookla Speedtest Intelligence data measuring real-world experience of mobile users. We rely on a global spatial dataset presenting key metrics on average download and upload speeds and latencies, estimated using performance tests initiated by users. In addition, for an illustrative sample of selected regions in four countries (Australia, Brazil, Indonesia and UK), we draw on detailed micro-level datasets based on performance tests and background scans performed by the device. These provide granular information on local network conditions in rural and urban areas (for example, connectivity status, mobile network generation, band, signal strength and performance). Further details are provided in the Methodology.

4 Global Human Settlement Layer, Copernicus, 2025

2.1. THE RURAL CONNECTIVITY GAP

Rural populations record a lower adoption level for mobile connectivity and lower intensity of use

Universal and meaningful connectivity defined by the ITU means allowing everyone to derive productive and enriching value from their online experience.[5] To measure whether rural populations are able to derive similar value to those in urban areas, we compared how widespread and diverse their use of mobile connectivity is.

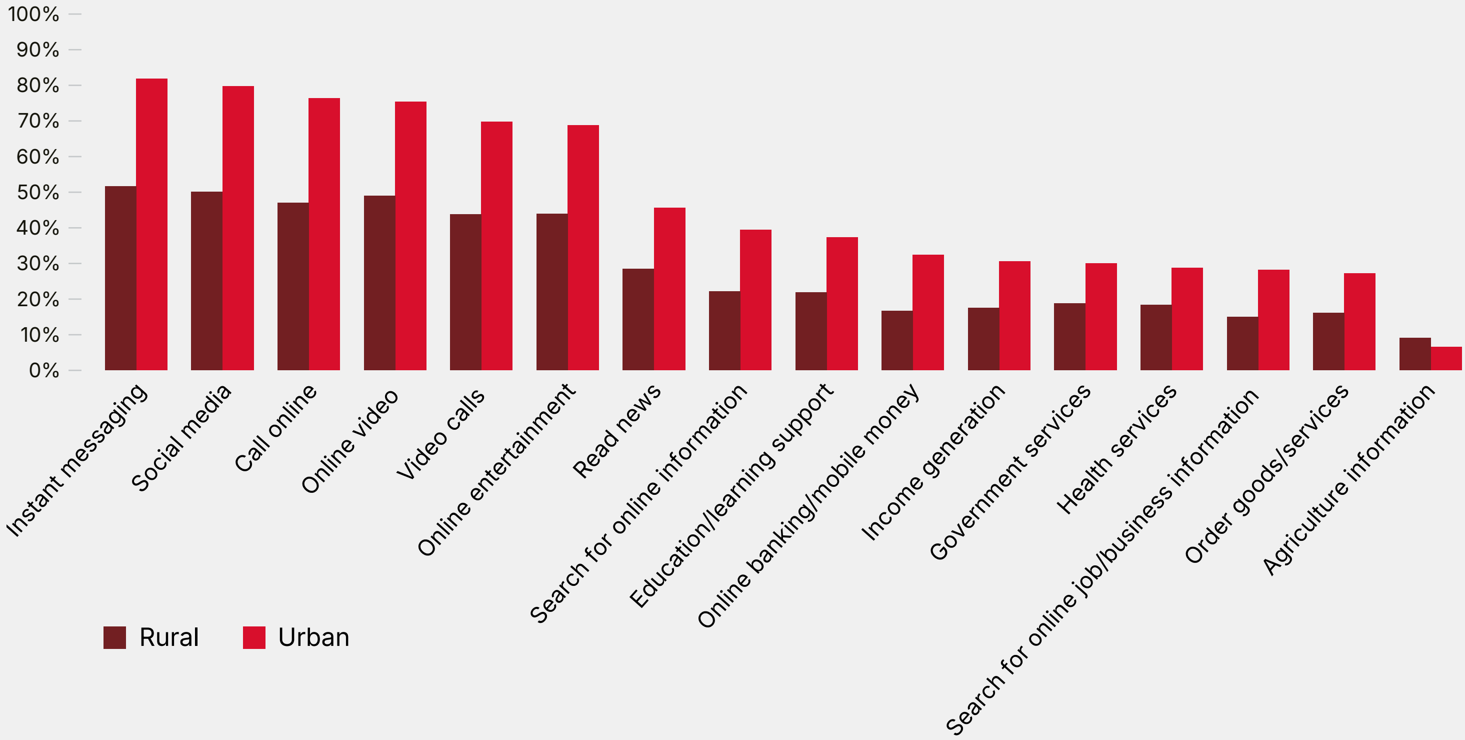
In LMICs, adults in rural areas are 25% less likely than those living in urban areas to use mobile internet.[6] Among those who use mobile internet, intensity of use is also lower among rural populations, as shown in Figure 3. The rural connectivity gap is more pronounced in LMICs, where rural consumers are 30% less likely to rely on key mobile use cases such as instant messaging, online calls and accessing online services, from banking to education.

The rural connectivity gap is lower in high-income countries, but rural mobile internet users are still up to 20% less likely to regularly use services such as online maps, video calls and online services.

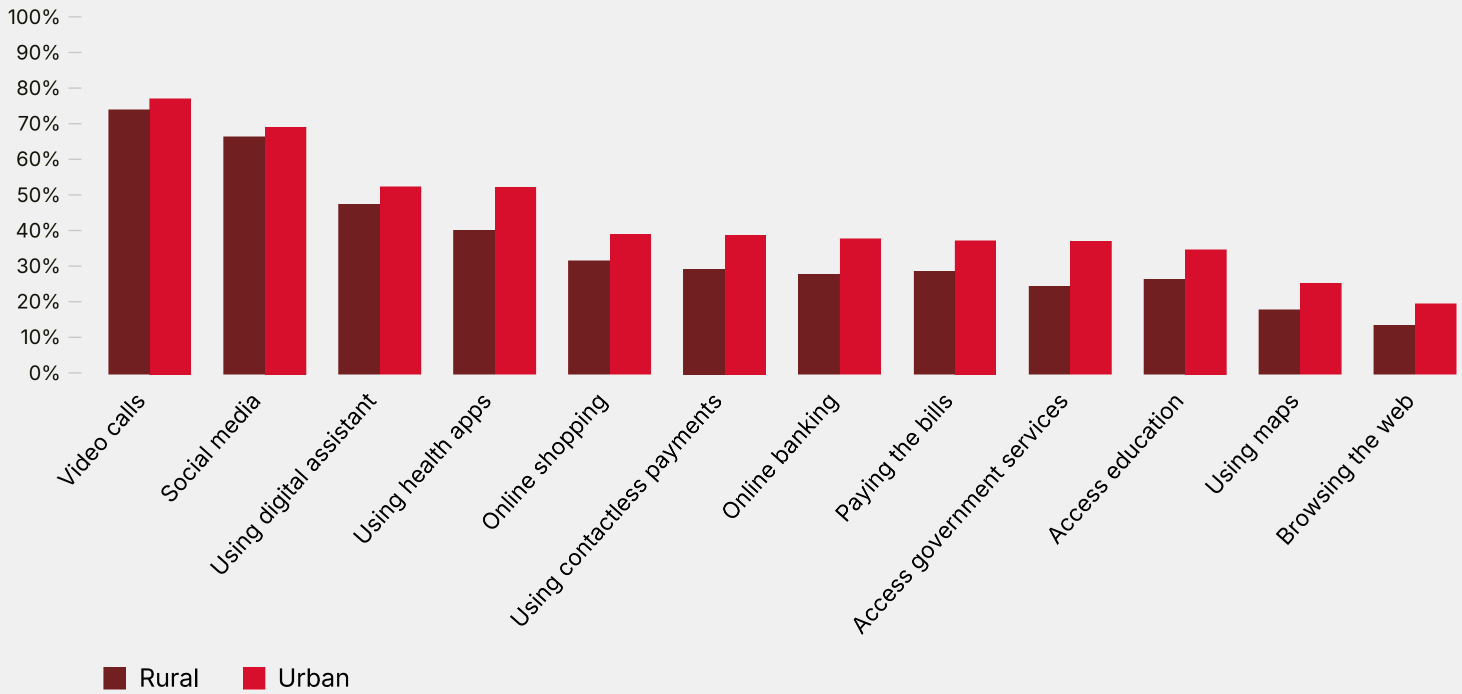
5 Universal and Meaningful Connectivity, ITU, 2025
6 The State of Mobile Internet Connectivity, GSMA, 2025

Figure 3
Mobile use-case adoption by urban and rural populations
Share of mobile internet users engaging in use case at least weekly (2024)

Low- and middle-income countries



High-income countries



Note: Aggregates based on a population-weighted sample of countries in each income group. Due to different survey methods, comparisons between the high-income and low- and middle-income results cannot be directly made.
Source: GSMA Intelligence

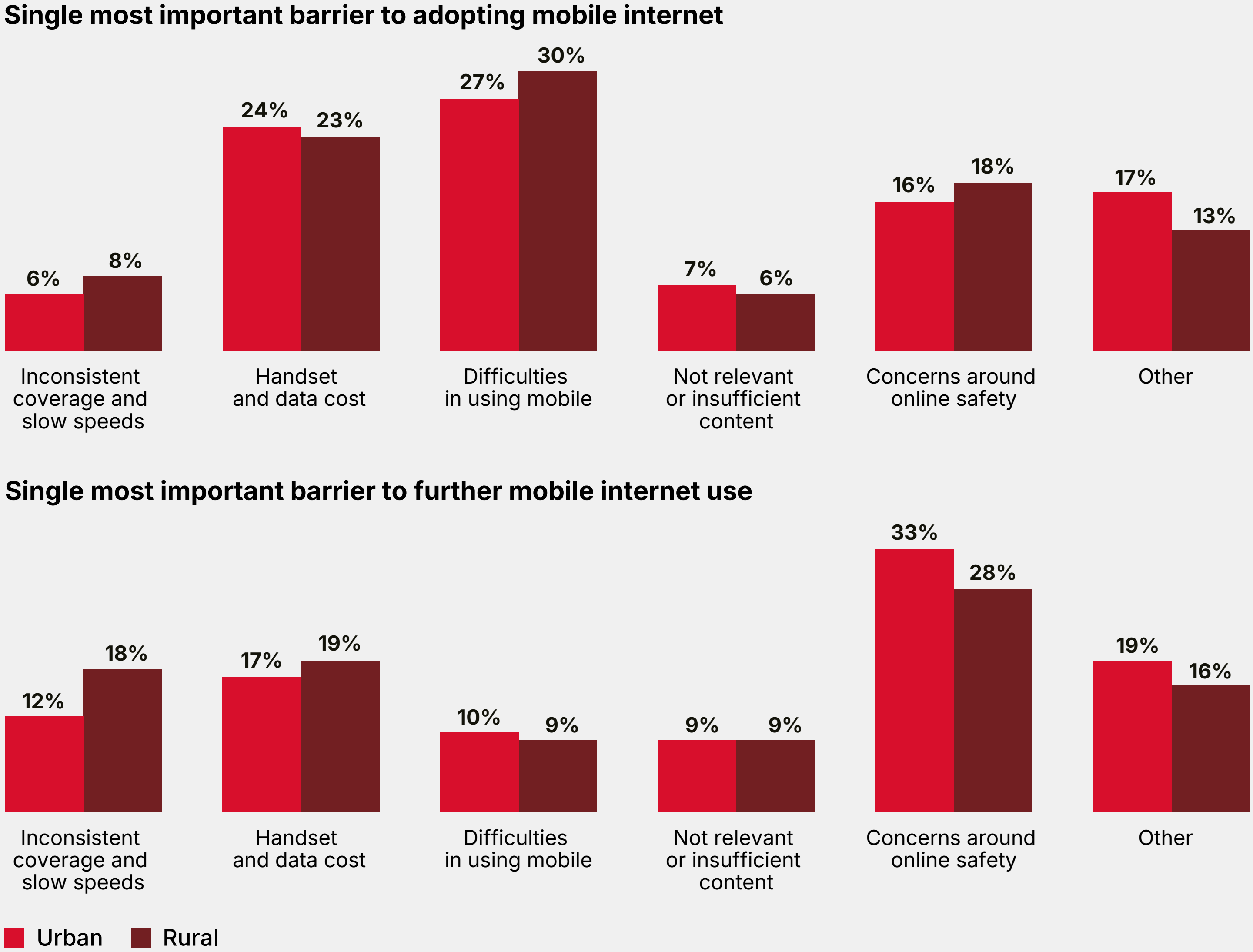
Coverage gaps and slower speeds limit rural adoption in LMICs

The rural connectivity gap can be explained by multiple factors. Figure 4 presents the barriers reported by rural and urban populations in LMICs. Difficulties using devices, primarily due to insufficient digital literacy and a lack of skills, are the most frequently-reported barrier to initial adoption of mobile internet. Another important barrier is handset and data affordability. Inconsistent coverage and slow speeds were less frequently cited as a barrier to initially adopting mobile internet.

For consumers who already use mobile internet, concerns over online safety were the most frequently cited barrier to using it more often, with users primarily reporting scams and fraud as a factor. However, inconsistent coverage and slow speeds are also a relatively important barrier to wider adoption. This is even more evident among rural populations, with 18% of rural users citing coverage and speeds as the single most important barrier to wider adoption, compared to 12% of urban users.

Policies aimed at reducing the rural connectivity gap should focus on improving both affordability and network quality in rural areas. Spectrum policy can play an important part in advancing both.

Figure 4
Barriers to adoption: urban versus rural (LMICs only)
Mobile internet users who reported the following as the most important barrier



Note: Aggregates based on a population-weighted sample of surveyed countries. Data for high-income countries was not available
Source: GSMA Intelligence

CASE STUDY

EXPANDING COVERAGE IN NIGERIA AND TANZANIA

The rollout of mobile broadband networks in Tanzania and Nigeria provides an illustration of the positive impact of improved connectivity for rural populations. In both countries, mobiles are the primary internet access point. Rural and poorer areas benefited progressively as rollout extended.

In both countries, empirical analysis has shown overwhelmingly positive effects. Mobile connectivity facilitates more work opportunities and increased productivity, leading to improved living standards.

Tanzania:[7]

- Households covered by 3G networks experienced a 7–11% increase in total per-capita consumption, with effects felt just one year after rollout.
- The proportion of households below the national poverty line decreased by 5–7 pp. Importantly, poorer households benefitted more, as shown through increased food and non-food consumption.
- Working-age individuals in covered areas saw a 4–6-pp increase in labour force participation, a rise in wage/salaried employment (by 2–4 pp) and an increase in non-farm self-employment (by 3–5 pp), increasing local economic diversification and resilience.

Nigeria:[8]

- Connectivity brought improved work opportunities and increased disposable incomes. After just one year of being able to access mobile internet, households recorded a 5.8% increase in total consumption, rising to 7–9% after two or three years. Food consumption increased up to 9%, with similar increases in non-food consumption.
- The extreme poverty rate fell by up to 8 pp, while moderate poverty fell by up to 5 pp after one year, with stronger effects over time.
- Covered areas experienced a 3.3-pp increase in labour force participation. Farm self-employment declined slightly, indicating a shift to non-farm opportunities.

Targeted strategies are essential to expand mobile broadband in low-income countries, focusing on closing both the coverage gap, which remains higher in low-income countries, and the usage gap (affordability, skills).

7 Mobile Broadband Internet, Poverty and Labor Outcomes in Tanzania, Bahia et al, 2021
8 The welfare effects of mobile broadband internet: Evidence from Nigeria, Bahia et al, 2024

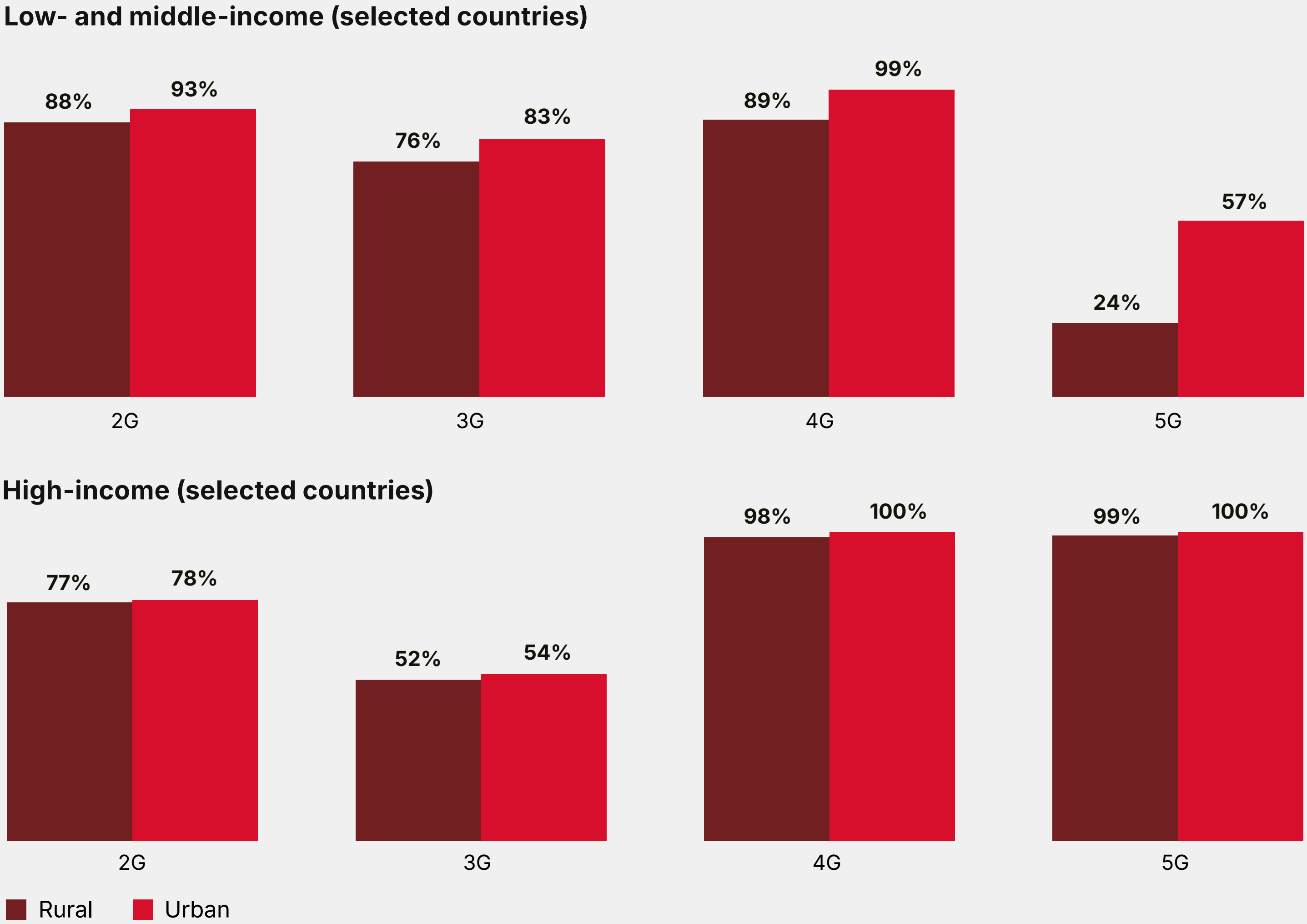
2.2. RURAL NETWORK COVERAGE AND AVAILABILITY

On average, mobile network coverage in rural areas is lower than in urban areas (see Figure 5). There is consistently an urban-rural gap in coverage across all network generations, which is more pronounced in LMICs. This reflects that the viability of deployment is generally lower due to supply factors (the high cost of deployment due to the distance from backhaul infrastructure and a lack of grid electricity) but also demand factors (low disposable income and a sparsely distributed population).

The urban-rural coverage gap is generally lower in the sampled high-income countries. While these figures may differ across high-income countries, it shows that affordability and sufficient demand are key factors driving viability of deployment in less densely populated areas. However, for the most remote populations and the remaining one or two percent, connectivity remains unavailable. Particularly in high-income countries, overall coverage of 2G and especially 3G is lower than 4G and 5G due to several countries shutting down legacy networks.

The figures presented refer to coverage based on the location of resident populations. User-experienced coverage also depends on time spent across residential and commercial areas and transport links, as well as the devices used. Analysis of Ookla data shows that around a quarter of mobile users globally spent the majority of their time on 5G in 2024 (more detailed analysis on this is presented below for a selection of countries). Hence, despite near-universal coverage of inhabited places in the high-income countries included in the analysis, there are additional areas where demand for reliable connectivity exists. These include places such as roads and railways where travellers rely on mobile to remain connected, and agricultural and industrial land where mobile can play a transformative role through IoT. Given the benefits mobile connectivity can generate in these places, ensuring reliable connectivity outside residential areas is also important and is becoming the next target for governments and regulators, especially in high-income countries.

Figure 5
Urban-rural difference in mobile network coverage (Percentage of population)



Note: Based on data for countries where recent data was available. Further details are available in the Methodology.
Source: Analysis of GSMA Intelligence Mobile Coverage Explorer data

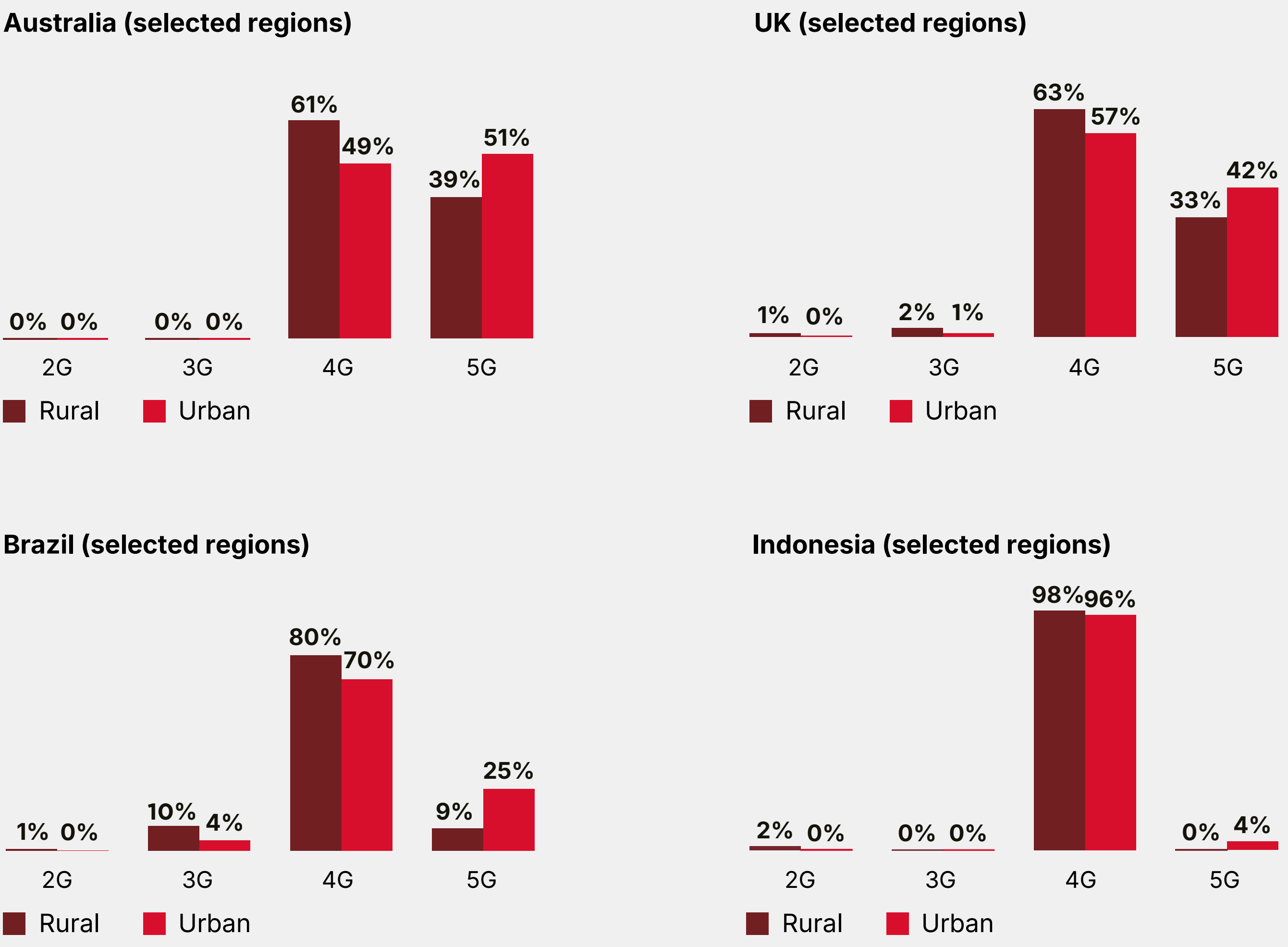
In the regions of four countries where we were able to gather more granular performance data, we compared the relative reliance on different network generations between urban and rural areas. As shown in Figure 6, nearly all consumers in both rural and urban areas rely on 4G and 5G, demonstrating their widespread use. In high-income countries, 5G network availability has rapidly increased, and rollout in rural areas has closely followed that in urban areas. However, in the rural areas of LMICs, use of 5G is still much lower than in urban areas.

There are several reasons why in some instances, despite the availability of 5G, consumers may still spend time connected to 4G networks:

- consumers may not have 5G-capable devices or 5G subscription plans
- operators prioritise 4G for reliability in certain areas given mixed 5G device readiness.

Legacy networks (2G and 3G) play only a minor role. Some analysed countries have completed the shutdown of networks. Australia shut down 2G and 3G in 2024, while Indonesia completed the switch-off of 3G in 2023, with the full shutdown of 3G network in the UK planned for 2026. This presents opportunities to re-farm spectrum, allowing operators to use it more efficiently for the latest network generations to boost performance.

Figure 6
Share of network scans by different mobile network generation (Mbps)



Note: Presented as the share of background signal scans conducted by the device when connected to different network generations and excluding scans when connected to Wi-Fi or unconnected. Country figures based on selected regions within them where data was available. 5G includes non-standalone and standalone deployments.

Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

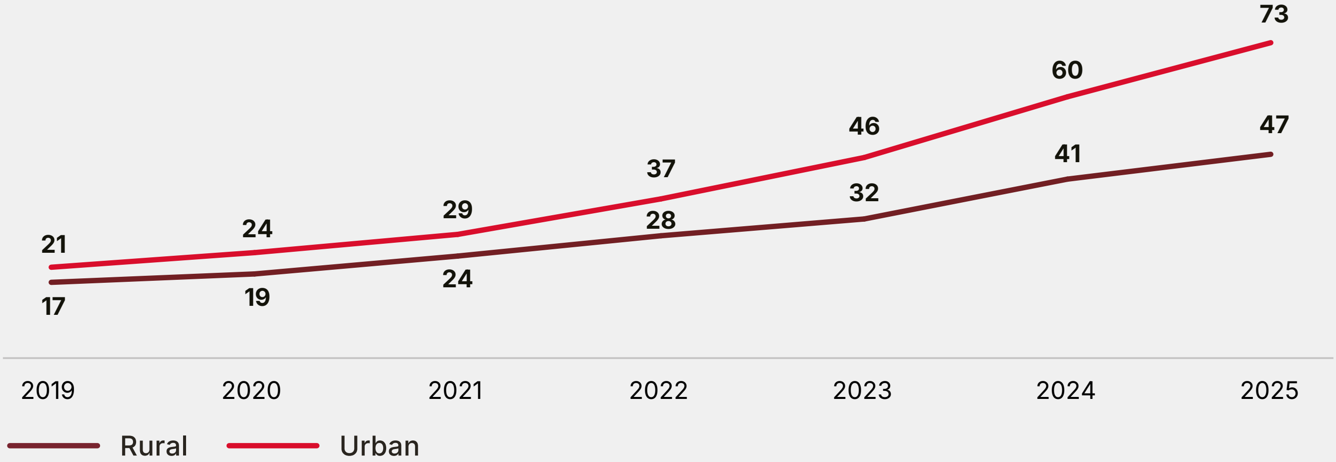
2.3. QUALITY OF EXPERIENCE

The shift to 4G and 5G infrastructure and other network improvements mean rural speeds have markedly increased in low- and high-income markets (Figure 7). However, average speeds experienced on mobile networks in rural areas are lower than in urban areas. Between 2019 and 2025, the gap in download speeds has increased from 24% to 36% in high-income countries, and from 17% to 35% in LMICs.

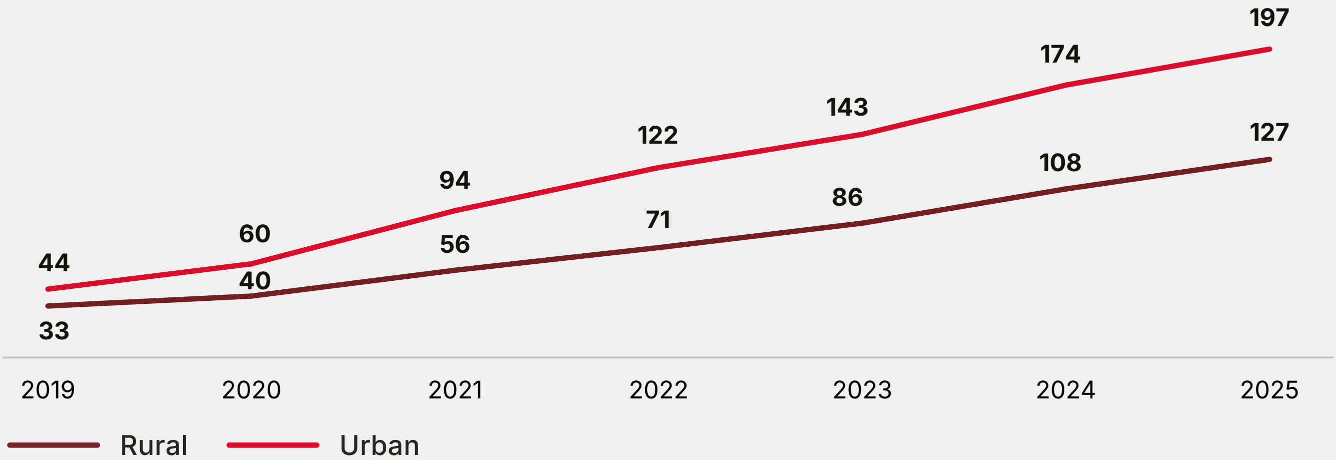
This shows a growing urban-rural gap in the quality of mobile connectivity. It may reflect urban areas benefitting from speeds boosted by high-capacity 5G relying on the 3.5 GHz band. Due to sparse demand and the distances involved, users in rural areas rely more on lower bands, which propagate further but have less capacity to handle large amounts of throughput. However, growth in the urban-rural quality gap is not inevitable and can be addressed by various spectrum policy approaches, as discussed in Chapters 3 and 4.

Figure 7
Average mobile network download speeds in rural and urban areas (Mbps)

Low- and middle-income countries



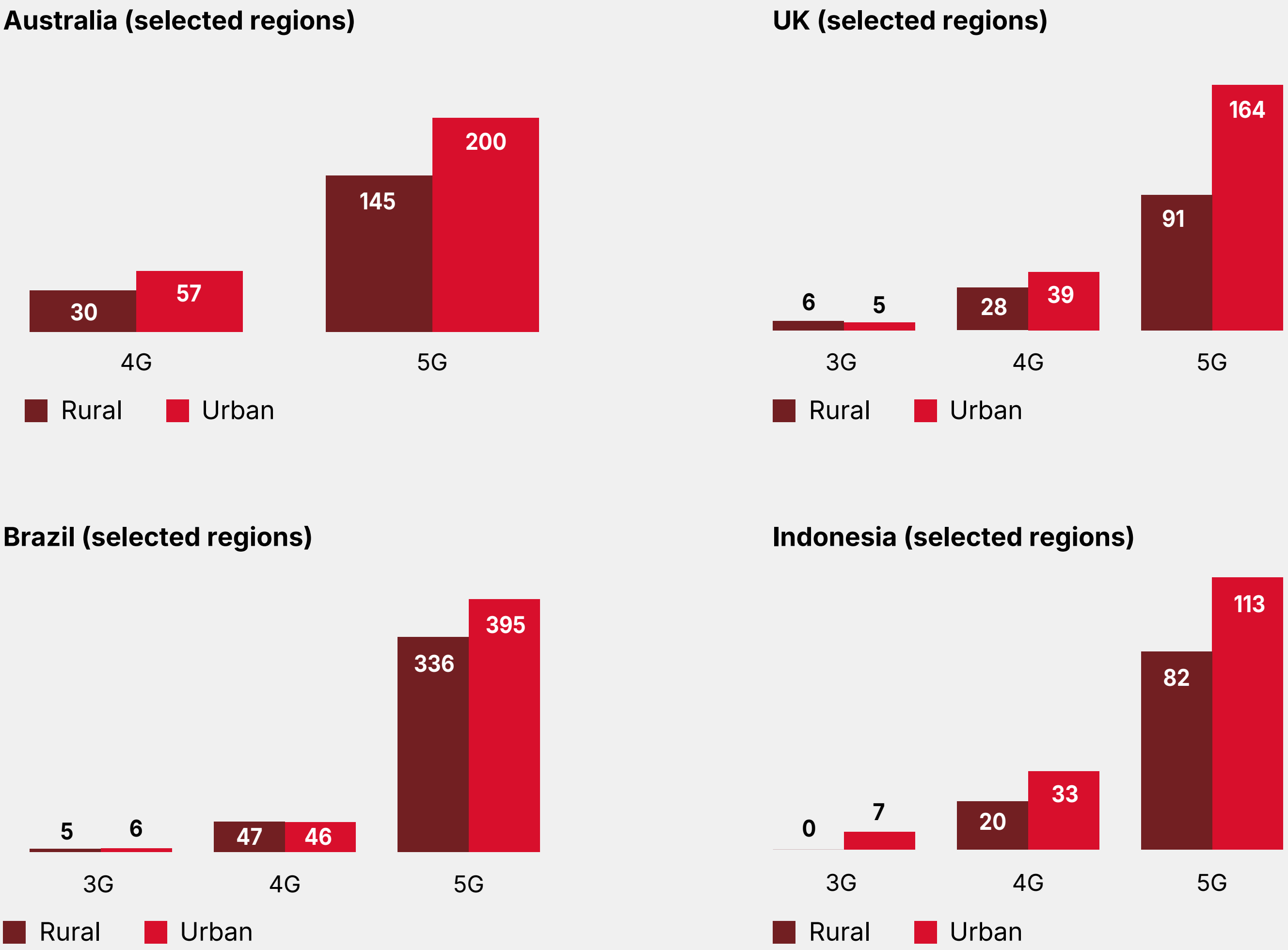
High-income countries



Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

The difference in experienced speeds can be observed in more detail when comparing specific network generations, using examples taken from different countries (Figure 8). The gap in speeds between urban and rural areas generally remains lower when comparing 4G traffic, and widens when comparing 5G network traffic.

Figure 8
Average rural and urban network download speeds by network generation (Mbps)

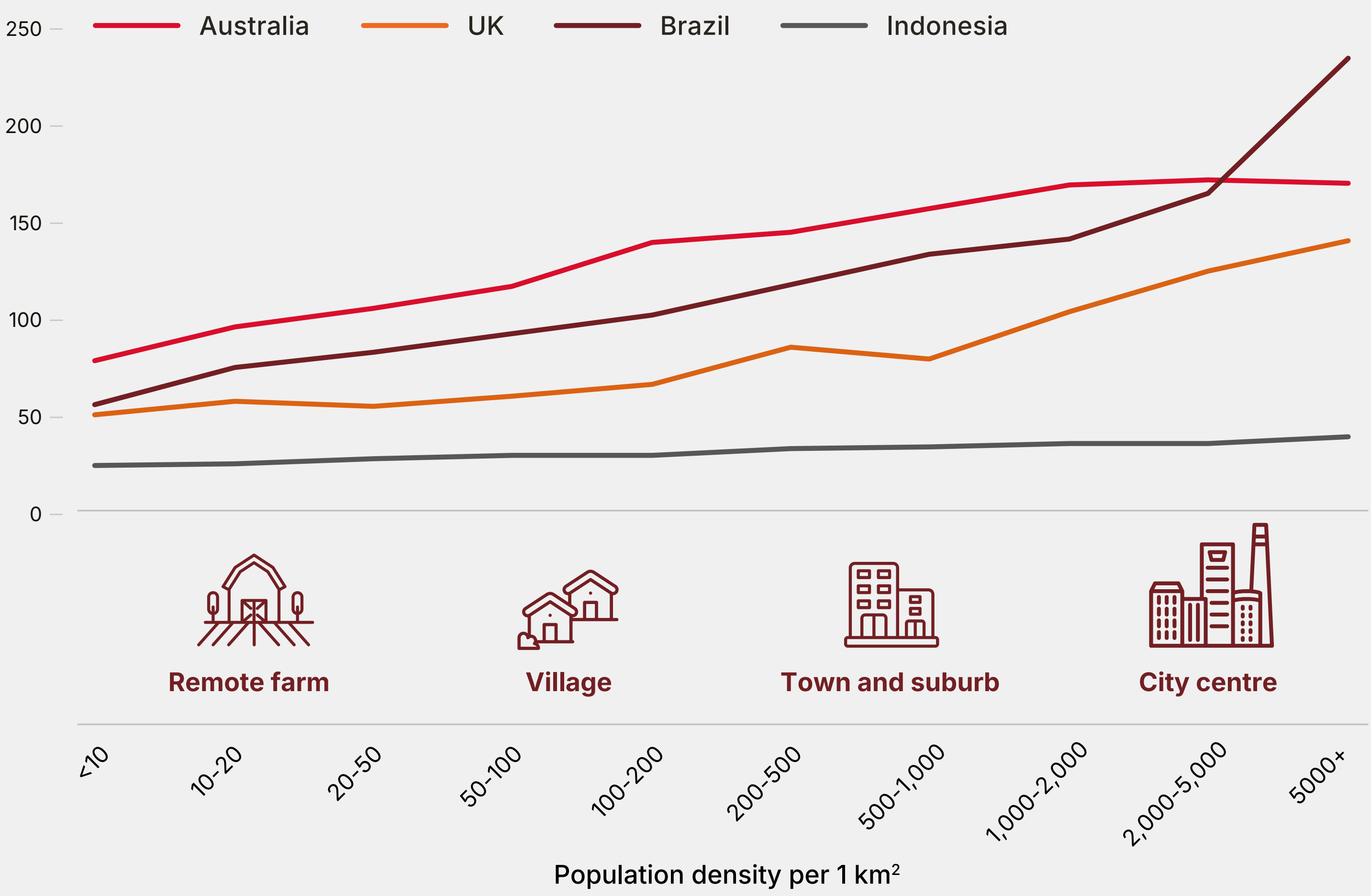


Note: Country figures based on selected regions within them where data was available.
Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

There is no specific population density threshold at which network experience deteriorates (see Figure 9). Typically, the experienced speeds gradually become lower in less densely populated areas. This is expected, given the following:

- Due to inherently larger distances from the base station, networks in rural areas rely more heavily lower spectrum bands with better long-distance signal propagation. These bands provide relatively less data throughput capacity than higher bands, which can be more frequently used in densely populated areas where the distances to base stations are lower.
- As population density decreases, lower local demand means deployment of the latest technologies becomes commercially viable with a delay, when technology becomes cheaper and demand matures.
- In rural and remote areas, incomes are lower, and users rely on older or budget smartphones, which may not be capable of the same speeds as the latest premium devices.[9]

Figure 9
Average network download speeds (Mbps) by population density



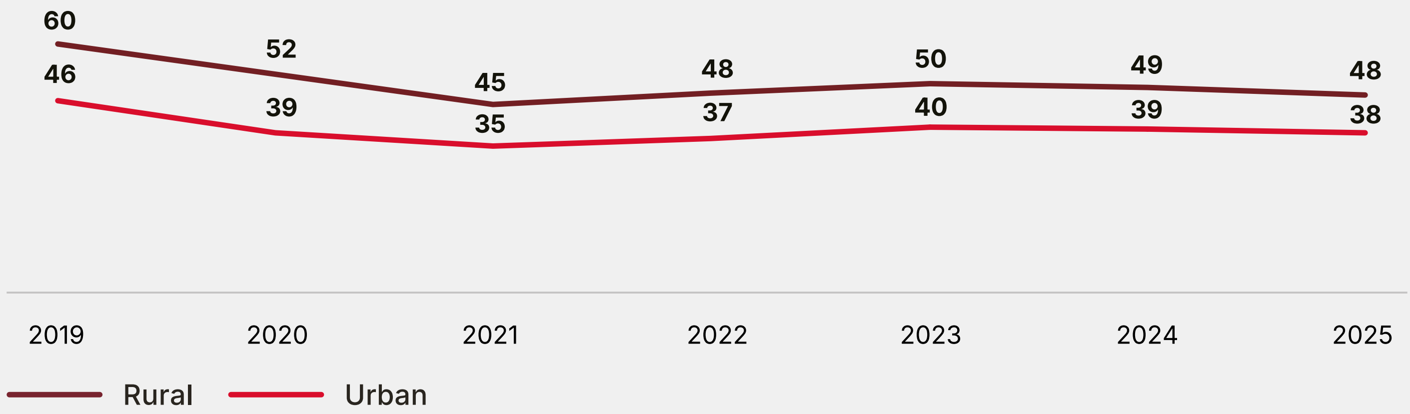
Note: Country figures based on selected regions within them where data was available.
Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

9 Towards better mobile quality of service in Asia Pacific, GSMA, 2025

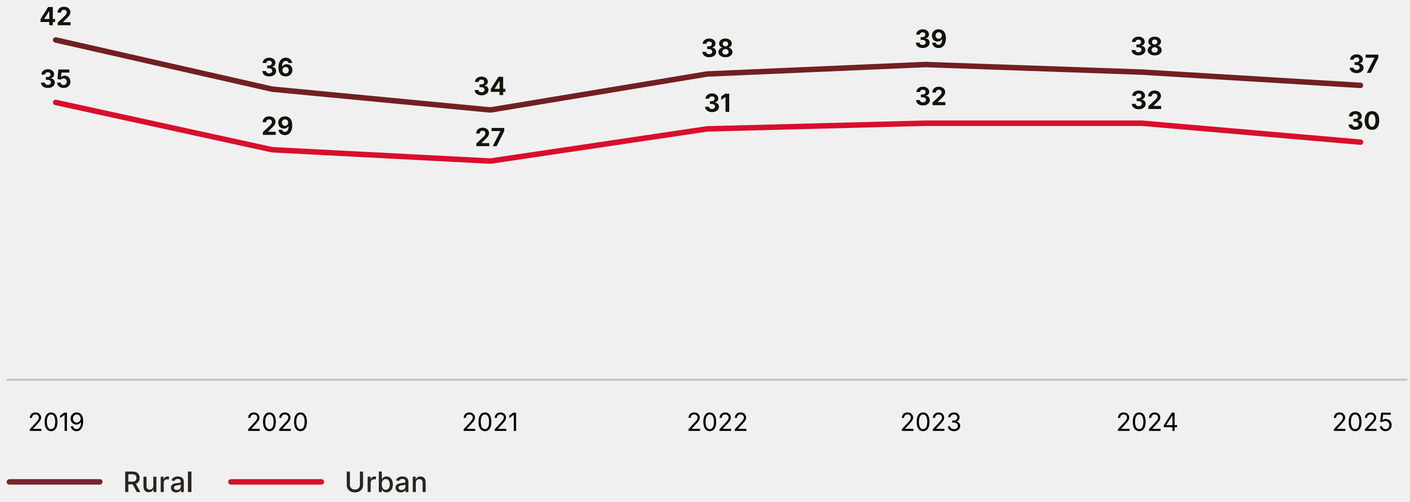
Rural users also tend to experience about 25% higher latencies than urban users (see Figure 10). Higher latencies in rural areas primarily arise due to a greater reliance on older network generations. Latency improvements are primarily brought by generational evolution, from 3G to 4G, and from 4G to 5G (Figure 11). However, in contrast to speeds, they are less dependent on a specific spectrum band. Hence, lower latency stemming from shorter transmission time intervals and faster processing on newer network generations benefits nearly equally consumers in rural and urban areas as they switch network generations.

Figure 10
Latencies in urban and rural networks (ms)

Low- and middle-income countries

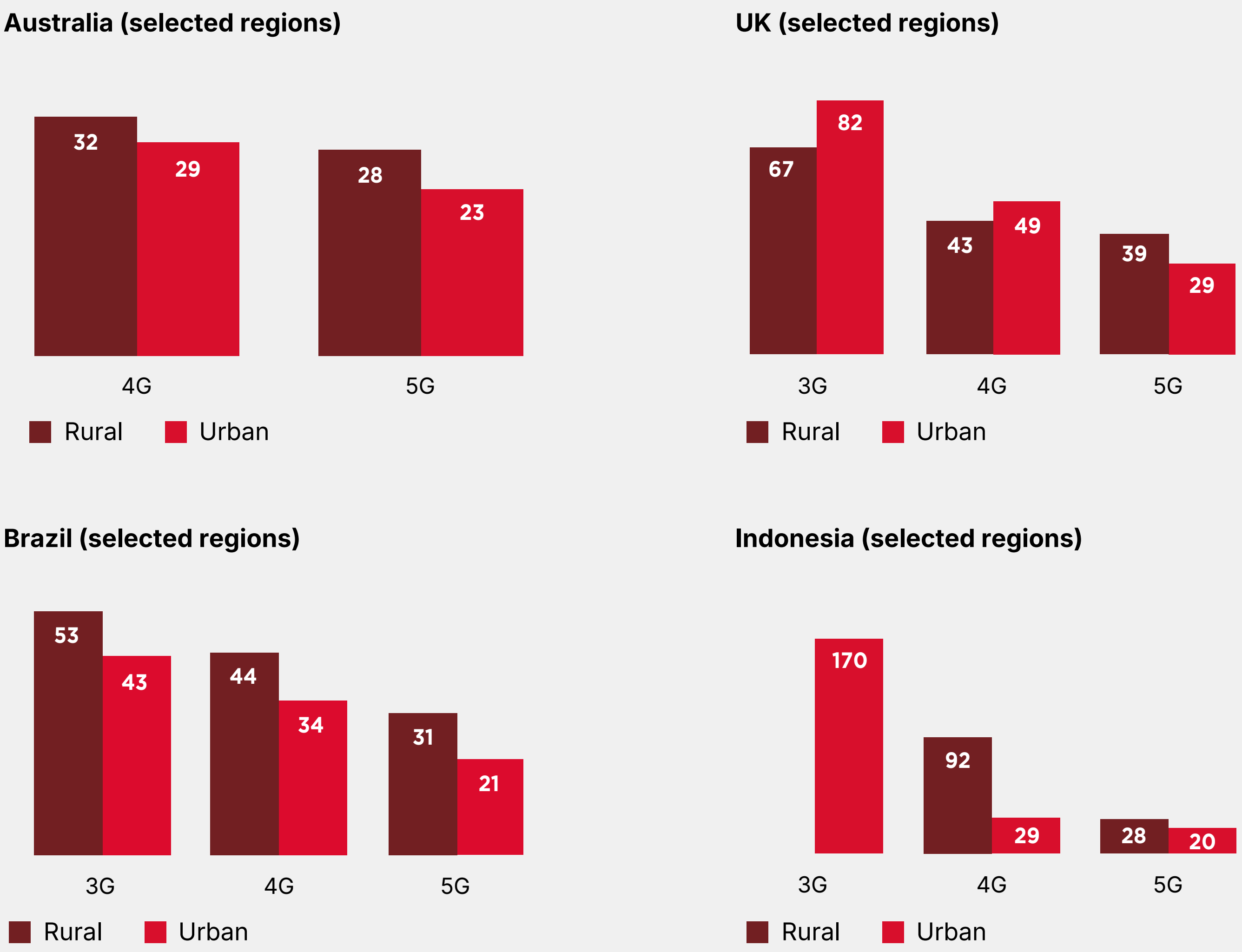


High-income countries



Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

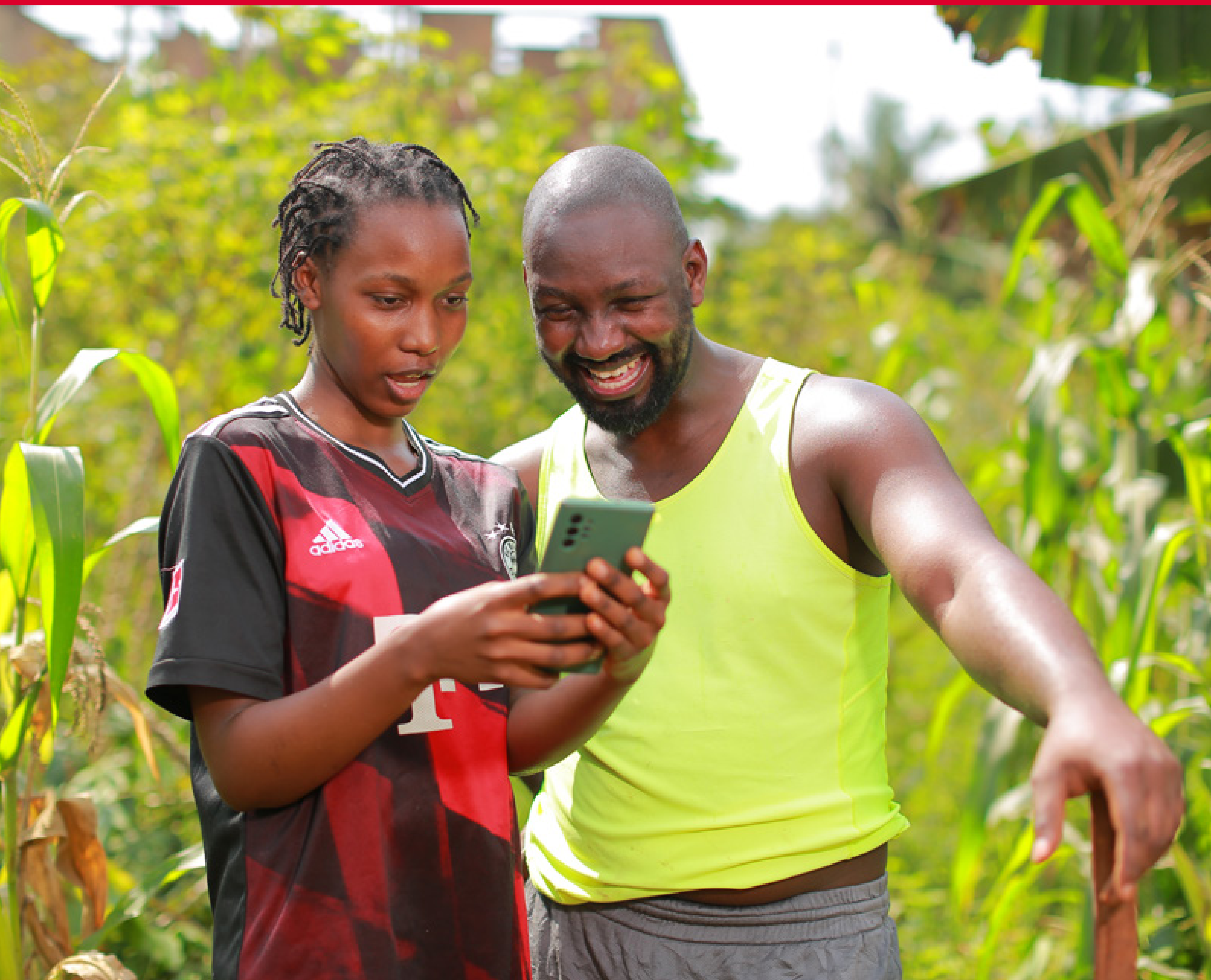
Figure 11
Latencies in urban and rural areas by network generation (ms)



Note: Country figures based on selected regions within them where data was available. Estimates presented for country/network/urban-rural classification combinations with sufficient sample sizes.

Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

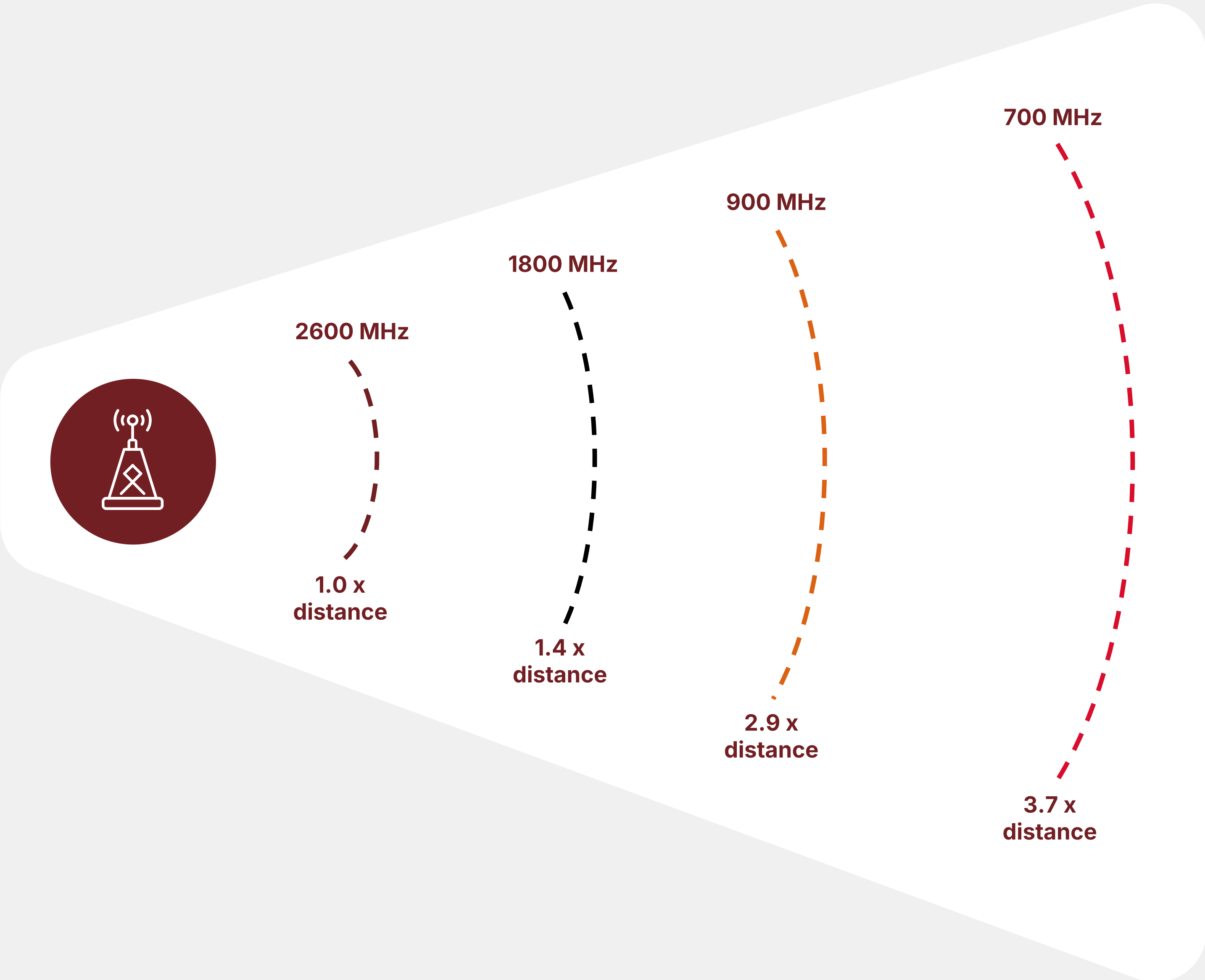
3. SPECTRUM AND RURAL CONNECTIVITY



3.1. WHICH BANDS POWER RURAL CONNECTIVITY?

Making sufficient spectrum available in lower bands allows for reductions in deployment cost in rural areas. The propagation characteristics of lower bands allow signals to reach further from the cell site. Ensuring that all sub-1 GHz spectrum allocated to mobile use and identified for IMT is assigned to operators will improve the viability of deployment in rural areas. For example, a base station using the 700 MHz band can provide a reliable connection at a distance up to 3.7× greater than a cell site relying on the 2.6 GHz band. This means over 10× greater coverage per site achievable using the 700 MHz band.

Figure 12
The use of low-band spectrum allows for efficient deployment



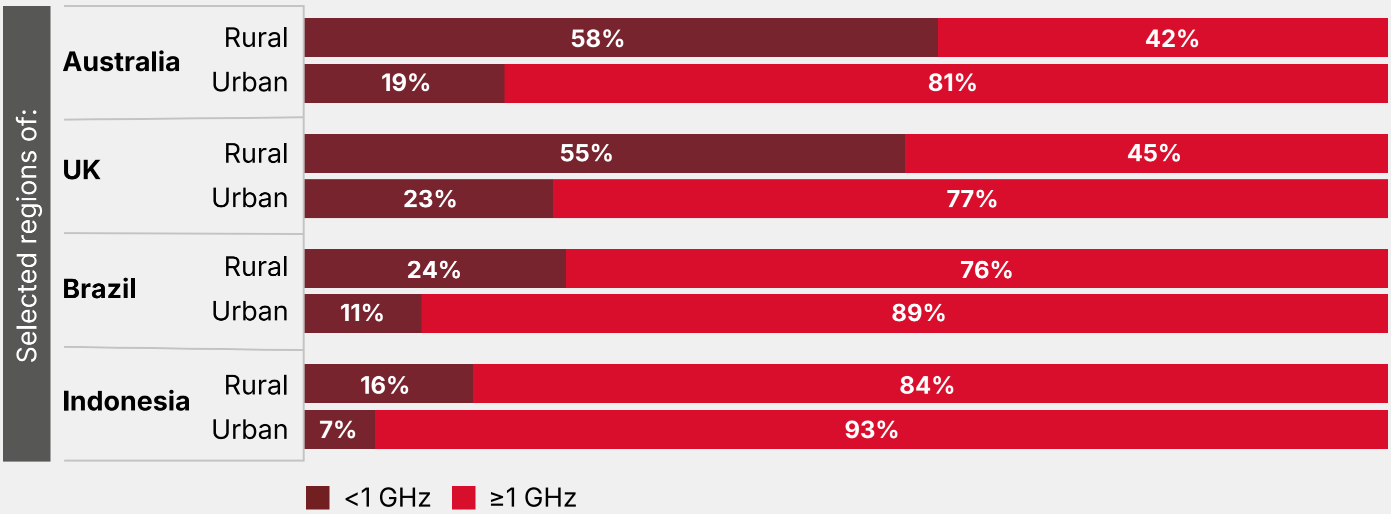
Source: Vision 2030: Low-Band Spectrum for 5G, GSMA and Coleago Consulting, 2022

Because of propagation characteristics, rural consumers spend significantly more time connected to sub-1 GHz bands than urban consumers (see Figure 13). This is true for both 4G and 5G networks, where rural users are much more frequently connected to low bands. In Australia and the UK (4G only), this means for over half the time when network scans were performed, users were relying on sub-1 GHz bands to remain connected. Selection of the optimal band is jointly conducted by the mobile device's modem and network algorithms based on the prevailing conditions, such as signal strength, interference, application needs and even mobility, as low bands provide a more reliable connection when on the move.

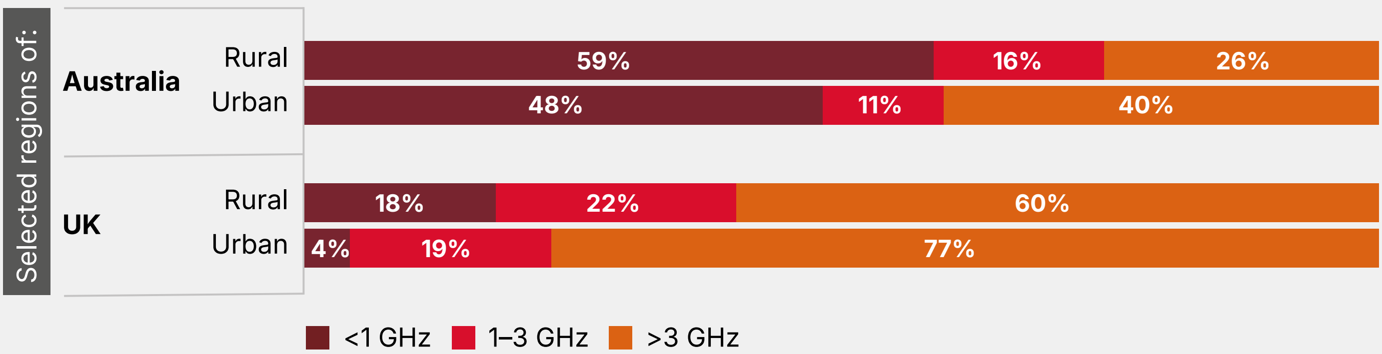
We also find that rural areas see deployment of higher bands, including frequencies in the 3.5–3.8 GHz range. This reflects that, where needed and usable, higher bands are deployed by operators. This not only improves capacity within the propagation area of 3.5–3.8 GHz bands but also frees the capacity of low bands, making them available to users located further from the base station or indoors where higher bands do not penetrate.

Figure 13
Share of network scans connected to different network bands in rural and urban areas

Percentage of network scans connected to different bands: 4G



Percentage of network scans connected to different bands: 5G



Note: Presented as the share of background signal scans conducted by the device when connected to different network generations and excluding scans when connected to Wi-Fi or unconnected. Country figures based on selected regions. Data for share of time spent on different 5G bands was not available in Indonesia due to a low sample size. Due to possible issues in distinguishing between 4G and 5G when working in dynamic spectrum sharing (DSS) mode, estimates for Brazil 5G are not shown.

Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

In line with the theoretical considerations, statistical analysis of data on operators in more than 100 countries reveals that greater availability of low-band spectrum plays an important role in improving the viability of deployment in more remote areas. Each 50 MHz of additional low-band spectrum is linked to 7-pp greater 4G network coverage and 11-pp greater 5G coverage. Making the full capacity available in bands such as 700 MHz (up to 90 MHz) could make an important difference by increasing the viability of rural deployment to the remaining unconnected populations and markedly accelerating rural 5G deployment.

The impact of each additional MHz of sub-1 GHz band spectrum on coverage is therefore much more pronounced than higher bands, though higher bands also have a positive effect on network availability.

Figure 14
Relationship between coverage and amount of low-band spectrum the country has assigned – econometric results

An additional 50 MHz of spectrum in bands below 1 GHz is linked to:

Source: GSMA Intelligence analysis

How the impact of spectrum availability on coverage and speeds was measured

How the statistical analysis was conducted

To provide robust evidence, we empirically identify the relationship between spectrum availability and network coverage and speeds. The methods are discussed in detail in the Appendix.

In brief, they isolate the effect of spectrum availability (total MHz in different bands) from confounding factors, such as:

- the growth in speeds brought by technological improvements that took place independent of changes to spectrum availability
- changes to mobile market structure and changes to rural population share, as an influential driver of network cost
- unobservable confounders (we eliminated the effect of these by estimating the effect on the basis of comparisons between operators in the same country and across time)
- the cost of spectrum.

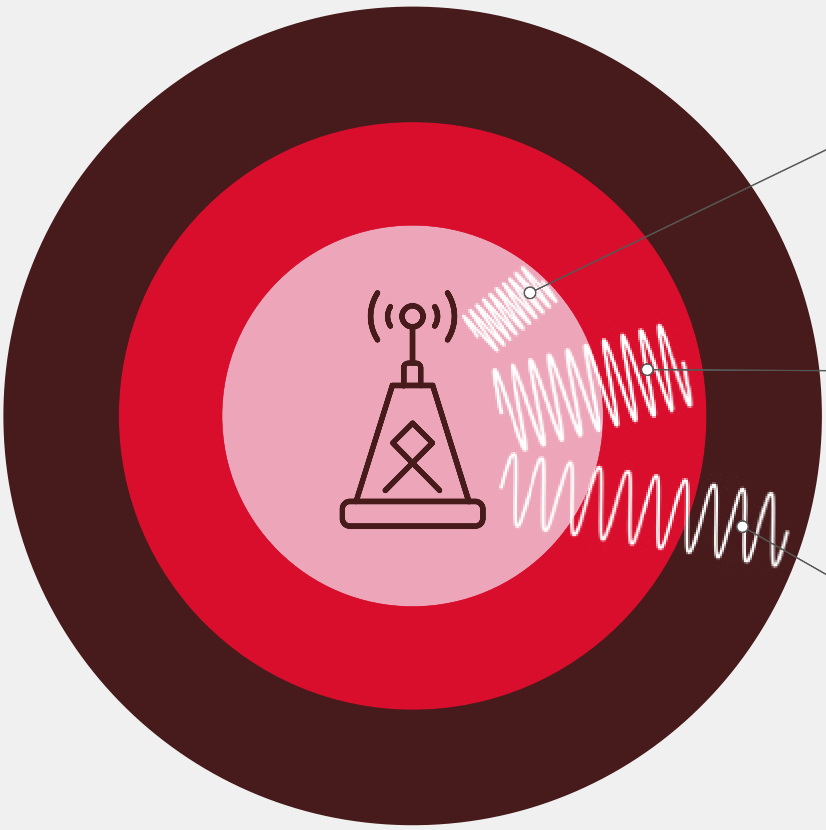
The dataset used covers more than 230 operators in 97 countries between 2014 and 2023. To ensure robustness, we limit the sample of analysis to operators where data is most reliable. We rely on transparent inclusion criteria based on measures of data completeness.

3.2. DOES RURAL CONNECTIVITY BENEFIT FROM MORE SPECTRUM?

Limits to how much data can be transmitted per unit of spectrum apply everywhere – rural and urban areas alike. Despite a much lower population density than urban areas, rural network speeds also benefit from greater availability of spectrum for the following reasons:

- To be commercially viable, base stations are more sparsely distributed in rural areas. Each rural site covers a wide area and serves populations that can be comparable in size to those served by individual urban sites, where infrastructure is denser. Demand for data from rural consumers located in a single cell site can therefore be as high as demand for data in a smaller urban cell area.
- In rural areas in particular, demand for data frequently exceeds the capacity in the cell edge areas, located furthest from the mobile base station, as shown in Figure 15. Frequently, only the capacity in the sub-1 GHz band can be used to serve users in the cell edge area.

Figure 15
In rural areas, the capacity in the cell edge area is driven by the amount of low-band spectrum



Cell centre
Area within the propagation range of all frequently-used bands, including the 3.5 GHz band. Enjoys strong signal quality (>-90 dBm) and full capacity offered by all available bands.

Mid-cell
Area that is still within the propagation range of some mid-bands (1.8 GHz, 2.6 GHz) and enjoys strong (-100 to -90 dBm) sub-1 GHz signal.

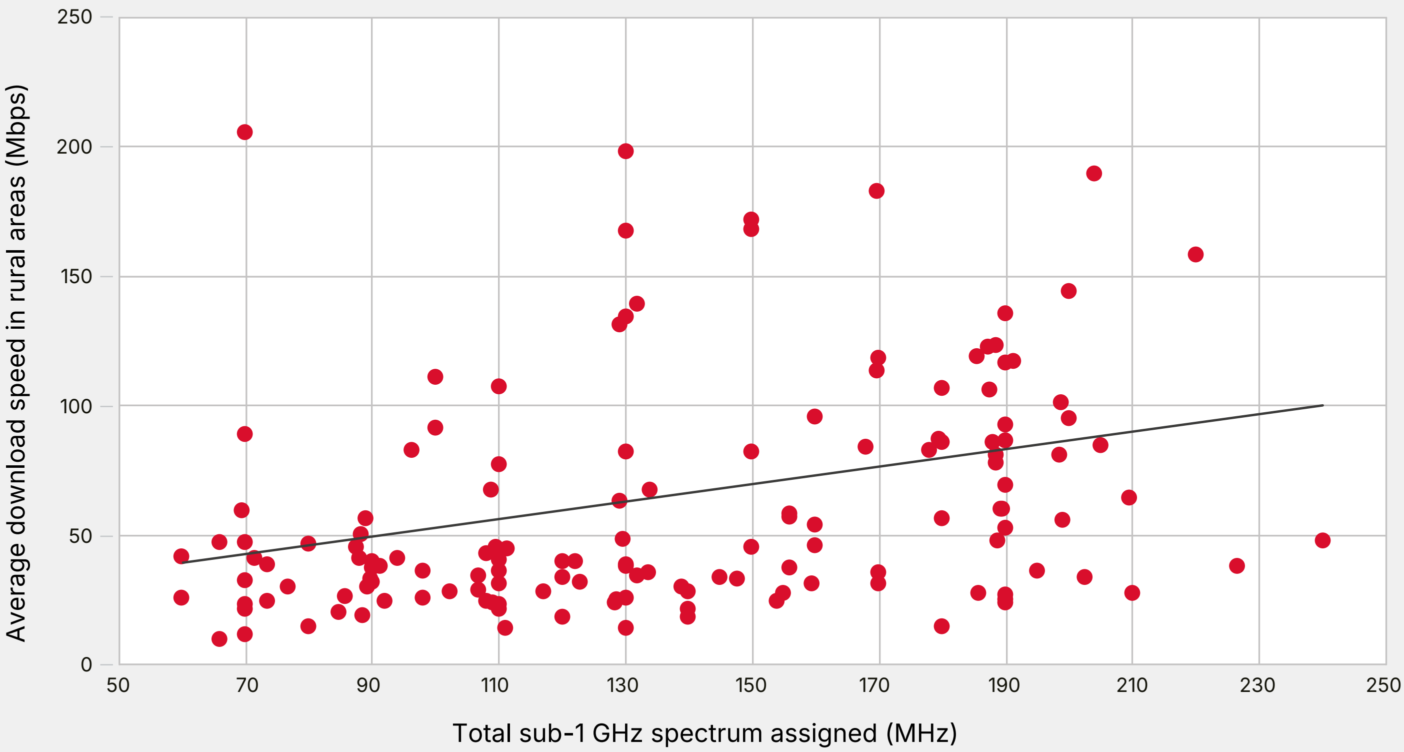
Cell edge
Only reachable using sub-1 GHz frequencies. The capacity of usable frequencies is limited by the amount of spectrum in bands, such as: 600 MHz, 700 MHz, 800 MHz and 900 MHz. Other bands do not propagate strongly enough (<-100 dBm) to be used in this area.

Note: Actual deployment may vary depending on local conditions.
Source: GSMA Intelligence analysis

The importance of low bands to the quality of rural connectivity can be seen by examining how the increasing availability of sub-1 GHz spectrum corresponds to greater average download speeds in rural areas (see Figure 16). Most countries enjoying high rural speeds have assigned to mobile operators more than 130 MHz of sub-1 GHz spectrum. Conversely, nearly all countries that assigned less than 100 MHz of sub-1 GHz spectrum achieve average rural speeds of only 50 Mbps or lower.

Figure 16

Relationship between rural network speeds and amount of sub-1 GHz spectrum



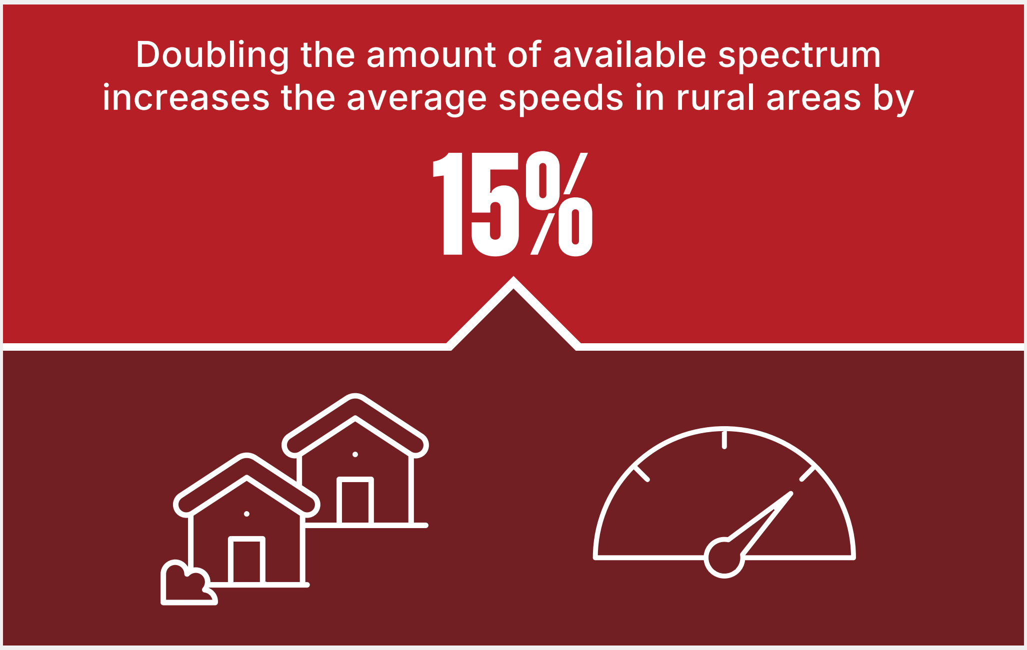
Note: Based on data where a sufficient number of speed samples was collected.

Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence and GSMA Intelligence data

Network quality benefits from increasing availability of spectrum in rural areas. To show this, we estimate the impact of the amount of all spectrum in sub-7 GHz bands on network speeds. We look at all spectrum because different bands are used in complementary ways. Higher band capacity allows for offloading of traffic in areas located nearest to the cell tower (for example, a village centre), freeing-up the capacity in sub-1 GHz bands to reach users in areas at the edge of the cell (surrounding farms).

The econometric estimates in Figure 17, eliminating the influence of confounding effect, show that doubling the amount of available spectrum results in 15% greater download speeds in rural areas. While this effect is lower than urban areas, where doubling of spectrum available results in 34% greater download speeds, each additional MHz of spectrum can make a difference to improve rural connectivity.

Figure 17
The relationship between the availability of sub-1 GHz spectrum and rural mobile network speeds



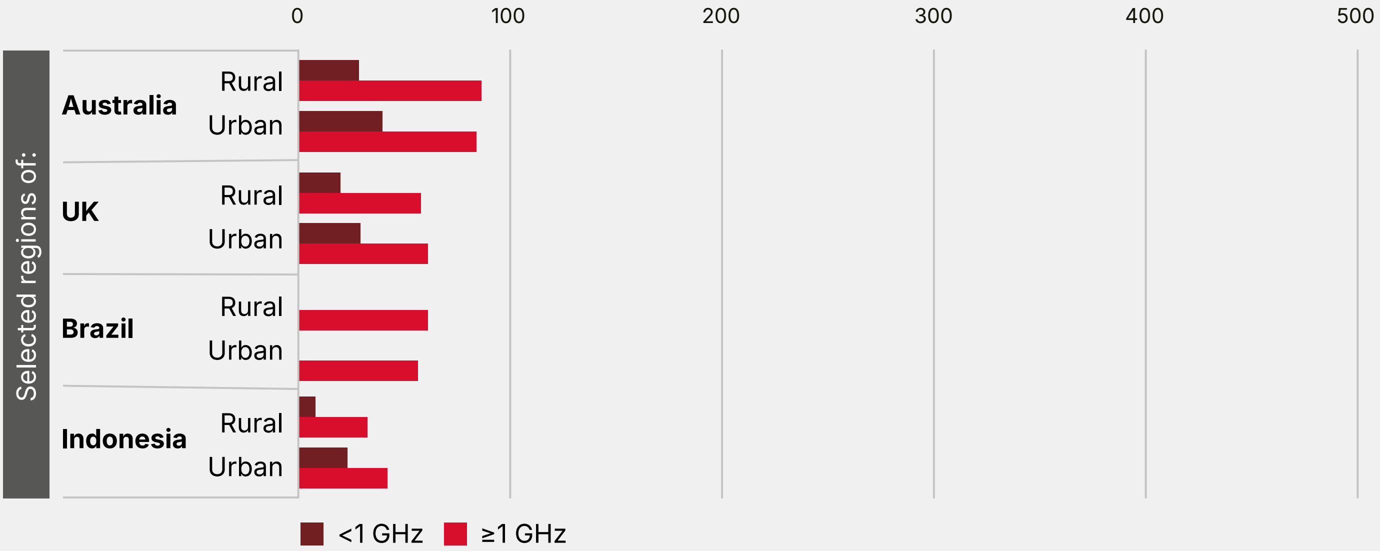
Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

Low-band spectrum is inherently scarce due to the physical limits of how much bandwidth (MHz) is available and how much data can be transmitted per MHz. Spectrum in widely-used sub-1 GHz bands (700, 800 and 900 MHz) is typically arranged in channel widths from 5 to 20 MHz. This limits the throughput achievable when connected to the band. Higher frequency ranges offer hundreds of MHz and allow for much wider channels, up to 100 MHz. This makes for greater capacity to handle traffic and translates into higher speeds.

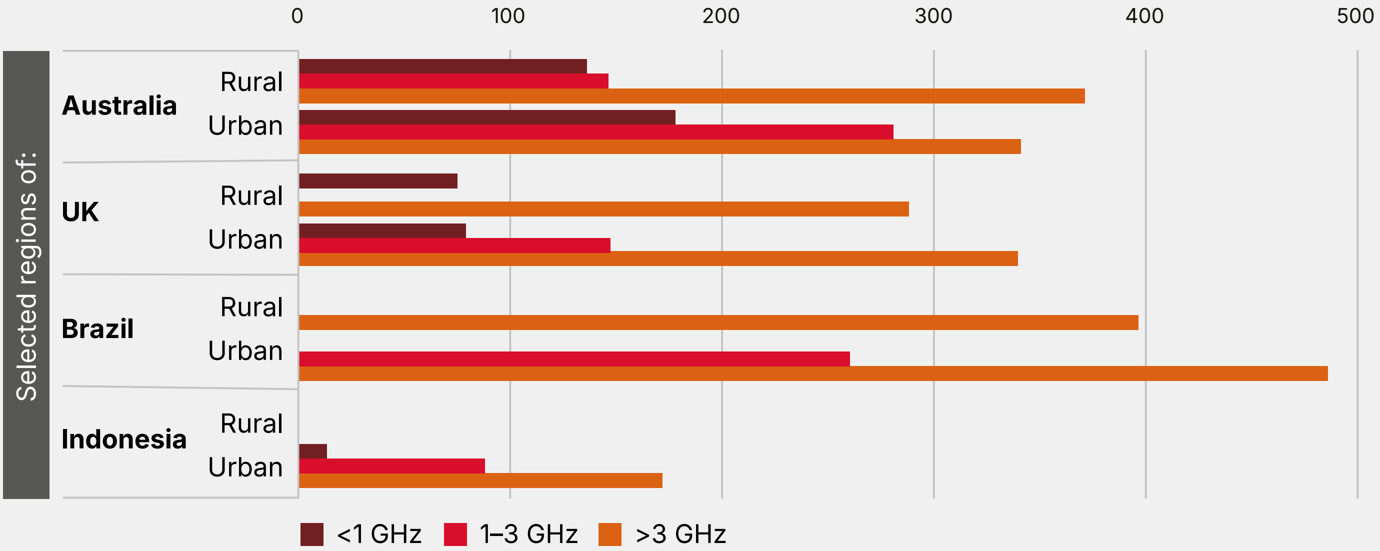
Much of the urban-rural gap in network speeds can be attributed to greater reliance on low bands in rural areas. Due to longer distances from the base station, low bands become the only viable option to remain connected in these areas, stretching the capacity of these bands and leading to lower service quality. Where rural users are able to access bands above 1 GHz, the gap between rural and urban speeds is reduced or even reversed (see Figure 18).

Figure 18
Rural and urban mobile network speeds by connected band

4G average download speed (Mbps)



5G average download speed (Mbps)

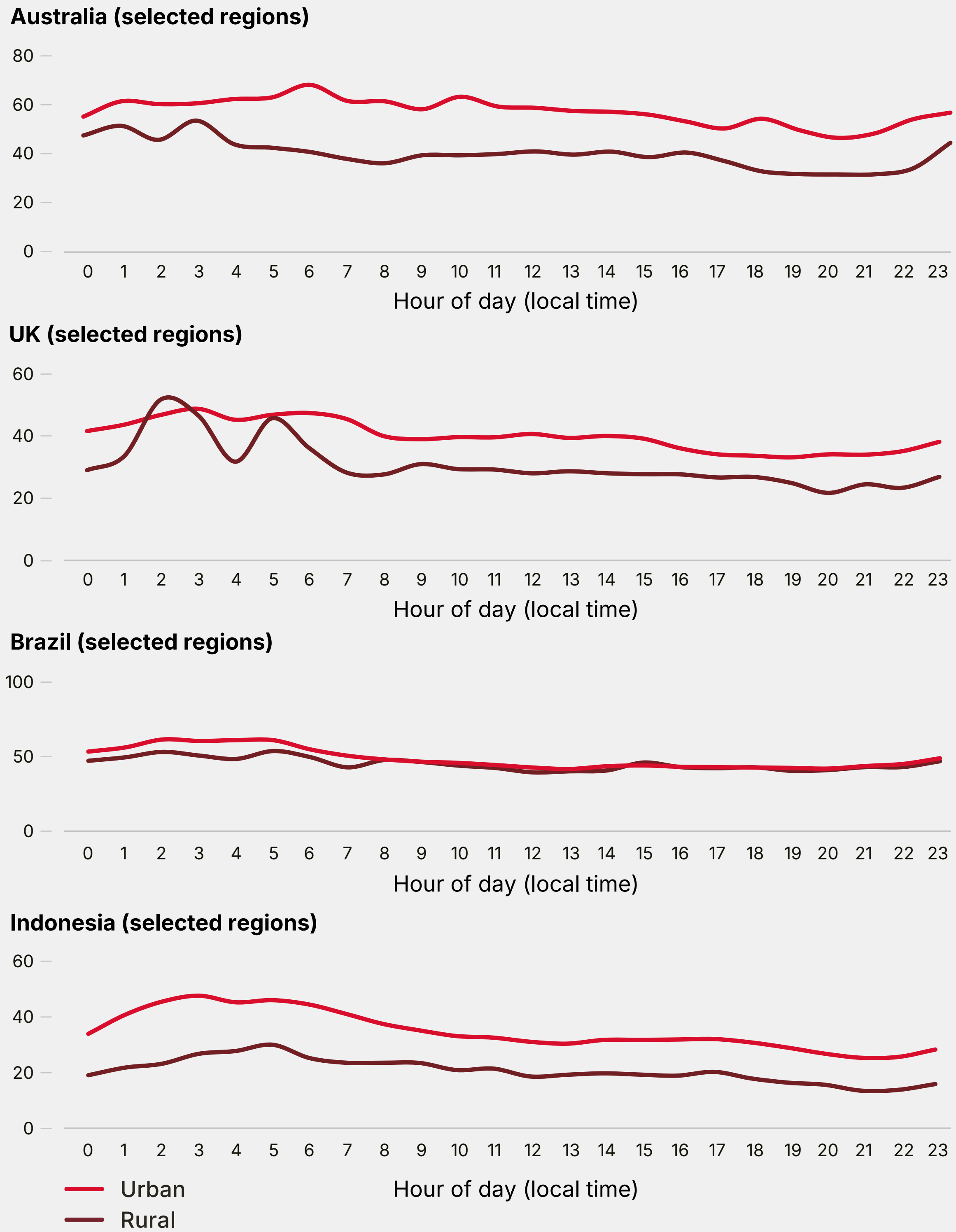


Note: Country figures based on selected regions within them where data was available. Selected cuts are not presented due to insufficient sample size. Due to possible issues in distinguishing between 4G and 5G when working in dynamic spectrum sharing (DSS) mode, estimates for Brazil 5G <1 GHz band are not presented.

Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

Network congestion in rural areas is also evidenced when examining the variation of average speeds between peak and off-peak times (see Figure 19). Network speeds in rural and urban areas follow nearly identical patterns, achieving peak speeds during early morning hours followed by degraded performance during evening peak-usage hours, with download speeds typically reduced by about 30%. This shows additional capacity could improve the rural network experience.

Figure 19
Variation in 4G network download speeds during peak and off-peak hours (Mbps)



Note: Country figures based on selected regions within them where data was available. Figures presented for area/network combinations where sufficient sample sizes could be obtained.

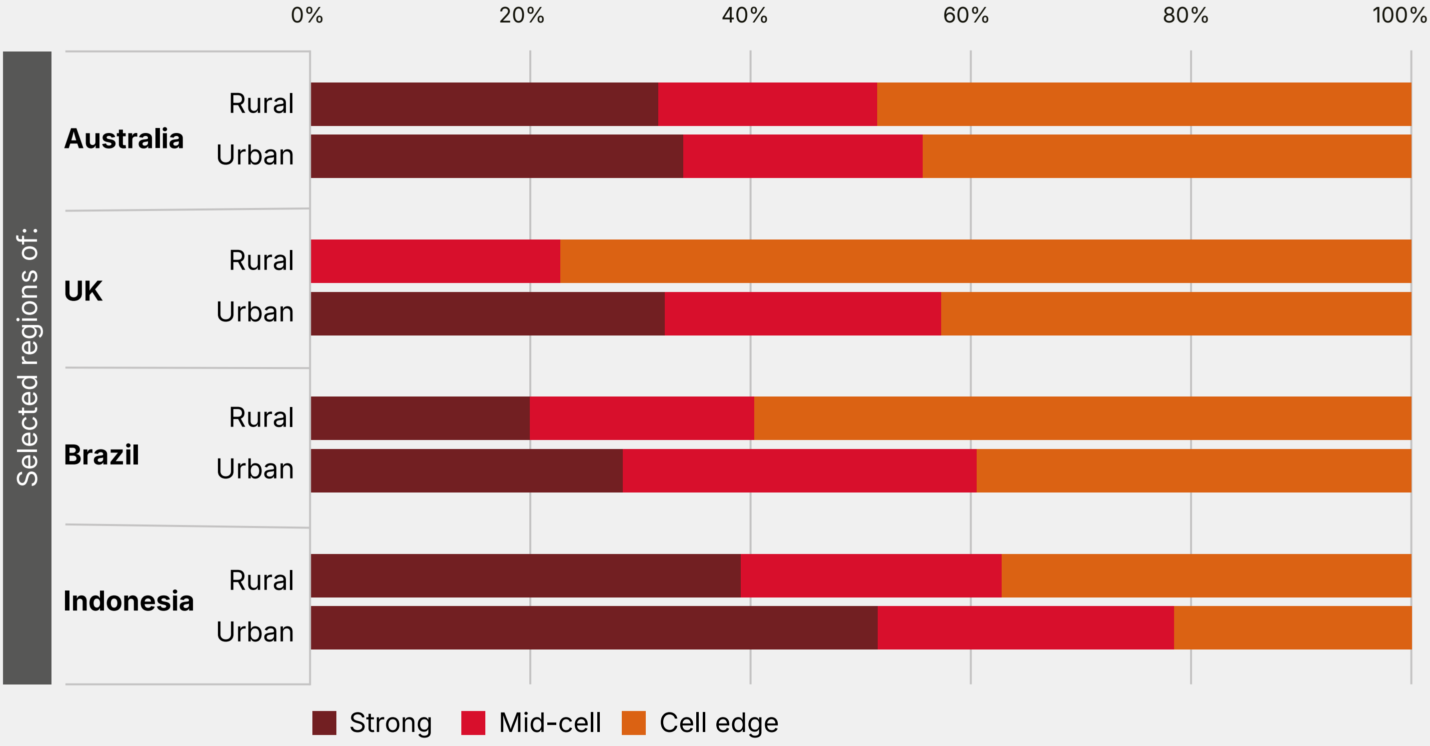
Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

3.3. SIGNAL STRENGTH IN RURAL AREAS AND QUALITY OF EXPERIENCE

Rural users tend to experience lower signal strength (see Figure 20). We rely on the Reference Signal Received Power (RSRP) metric, which captures the average signal strength received from the cell tower when connecting to a cell and transmitting data.

In some regions, users receive a lower signal strength consistent with being located at the edge of cell coverage (<100 dBm). This is despite more frequently being connected to low bands and is an inherent result of being further from the base station. A typical radius of rural networks is approximately 3.5 to 10 km; hence, many users are frequently located kilometres away from the site.

Figure 20
Signal strength in rural and urban areas
Percentage of network scans when connected by RSRP signal strength (4G and 5G networks)

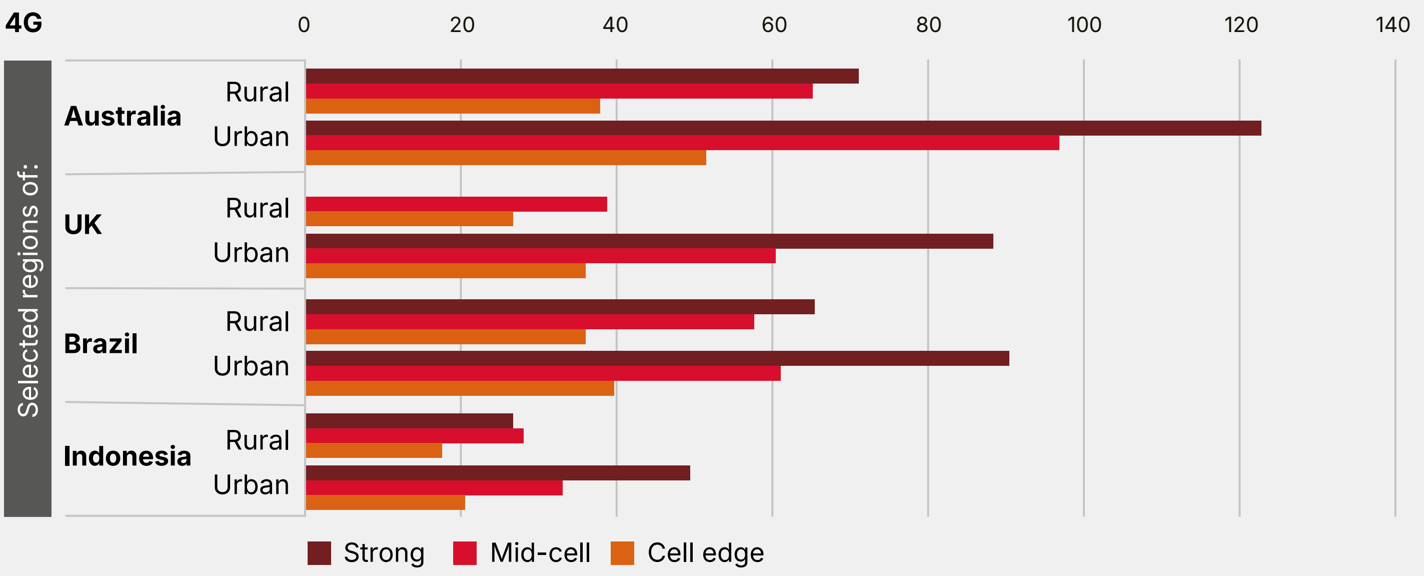


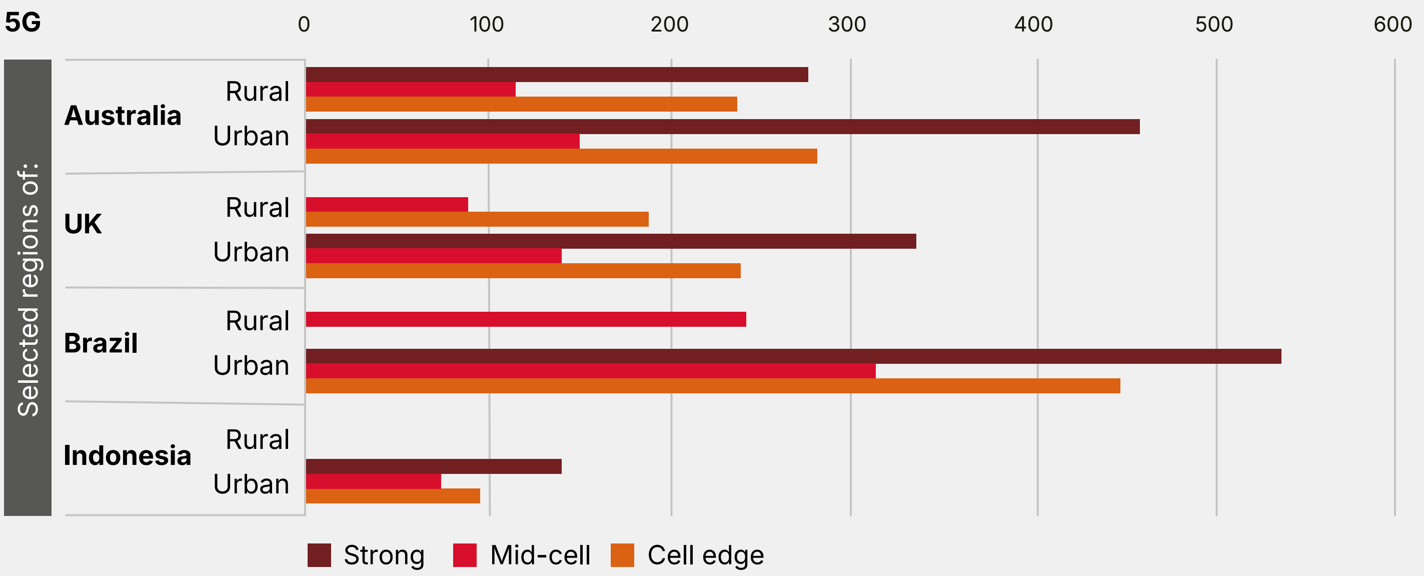
Note: Country figures based on selected regions within them where data was available. RSRP signal strength measures the power level of the reference signals received from a base station (cell tower), for tasks such as cell selection, handover between cells, and overall network performance.

Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

Mobile network speeds degrade as the signal quality weakens (see Figure 21). At lower RSRP levels, typically near the cell edge in rural areas, the quality degradation is more pronounced. This reduces the ability to maintain a consistent connection, lowering throughput due to frequent handovers, packet corruption or loss, and the need to use less efficient modulation and coding.

Figure 21
Relationship between signal strength and mobile network speeds
Average download speed for users connected to 4G and 5G mobile networks (Mbps)





Note: Country figures based on selected regions within them where data was available. Figure presents groups where the number of observations exceeds 500.

Source: GSMA Intelligence analysis of Ookla Speedtest Intelligence data

These findings and the analysis of barriers faced by rural consumers in Chapter 2 highlight three implications for rural connectivity, as shown in Table 1.

Table 1
Implications for rural connectivity

1. **Bringing down the cost of rural deployments will allow operators to densify rural networks and improve network experience**	The density of rural deployment is driven by commercial considerations to ensure sufficient revenue is generated to cover the capital and operating cost of a site. To boost availability and quality in rural areas, policymakers can seek to reduce these costs through the following: – Lowering the regulatory costs of setting up and operating base stations – for example, by simplifying planning regulations and site access, and ensuring the proximity of grid electricity. – Ensuring planning regulations do not unnecessarily constrain tower height. Taller towers allow for better rural coverage and boost network-sharing options. – Lowering the barriers to network sharing, allowing operators to use various cost-saving strategies and reduce duplication of infrastructure and associated costs. – Ensuring long-term regulatory certainty, to reduce investment risk in rural infrastructure. Rural deployments require heavy upfront spend on long-term assets such as towers, backhaul, access roads and grid connections, with lifespans stretching decades.
2. **Aligning EMF exposure limits with international guidelines will ensure reliable signal strength in rural regions**	Use of harmonised EMF exposure limits will optimise the number of base stations needed to deliver the same level of service and ensure optimal signal strength and quality away from a site. Countries should adopt EMF limits based on the ICNIRP guidelines. These are based on up-to-date and acknowledged scientific evidence, and form the basis of policy in most countries. Harmonised EMF limits also increase the flexibility to rely on site sharing where multiple operators can co-locate antennas (passive sharing), allowing for further efficiencies.
3. **Affordability remains a key barrier for rural consumers in LMICs, limiting the business case for expanding networks**	Lack of demand, due to limited affordability and other barriers to adoption, is the fundamental reason why expanding coverage to further areas remains challenging in LMICs.[10, 11] Insufficient demand means rural locations are unable to generate sufficient revenues to justify deployment. In many countries, consumers face additional sector-specific taxes which inflate the price of devices and telecoms services, distorting the incentives to taking up mobile internet use and increasing intensity of use. Limited digital skills and literacy, and lack of reliable grid electricity in the most remote areas, stand as additional barriers that remain in the realm of policy areas other than spectrum.

10 The State of Mobile Internet Connectivity 2025, GSMA, 2025
11 Using Geospatial Analysis to Overhaul Connectivity Policies, The World Bank, 2022

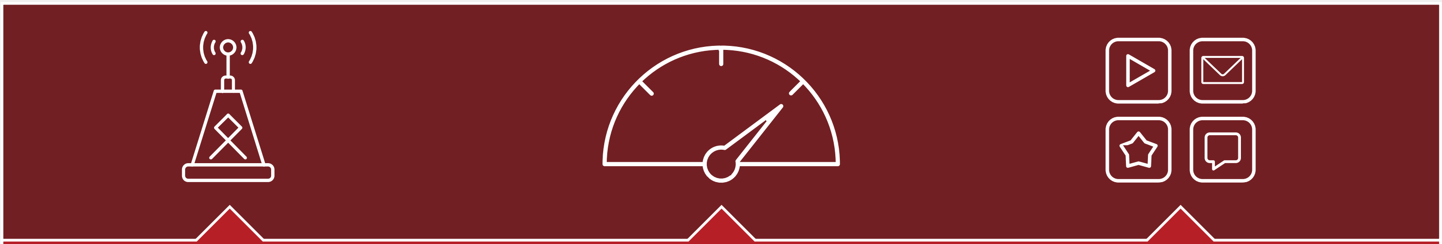
3.4. THE IMPACT OF NETWORK SHARING ON RURAL CONNECTIVITY

Network sharing allows operators to use infrastructure in different ways, from relying on a shared antenna mast, to national roaming, where in certain locations an operator fully relies on infrastructure and spectrum that belongs to another operator.

Network sharing has largely been driven by commercial considerations, such as cost saving, and founded by voluntary agreements. Network sharing can be particularly useful to enhance the viability of deployment in rural areas, where market demand is not sufficient to warrant the simultaneous presence of all operators. This is why regulators took an interest in facilitating sharing as a mechanism to expand connectivity further.

Network sharing has generated significant benefits for both mobile operators and consumers (see Figure 22). Operators that entered into network-sharing agreements were able to increase network coverage and quality. This was achieved through reductions in capital costs, higher returns on investment (providing operators with the ability and incentive to invest) and increased competition. In addition to benefits measured in terms of positive consumer outcomes, positive impacts of savings on physical infrastructure could help achieve climate goals due to reduced emissions from equipment and lower energy use.[12]

Figure 22
Impact of network sharing



Up to **9-pp** increase in coverage due to cost saving, expanded infrastructure and roaming agreements

Up to **15%** higher download speeds with active sharing due to better utilisation of spectrum and equipment

Up to **30%** increase in data consumption due to greater service availability and quality

Source: Koutroumpis, Castells, and Bahia (2023)

Operators can also employ the following strategies to share spectrum, benefiting rural connectivity by pooling resources to extend coverage and/or improve quality:

- spectrum leasing
- channel aggregation
- national roaming
- shared access frameworks.

Spectrum sharing has the potential to benefit rural connectivity, offering options such as channel aggregation to deliver higher speeds. However, regulators seeking to facilitate spectrum sharing and leasing need to consider technological and commercial factors that affect how effectively spectrum can be shared under different models – from leasing of exclusive licences to sharing frameworks based on priority rules.

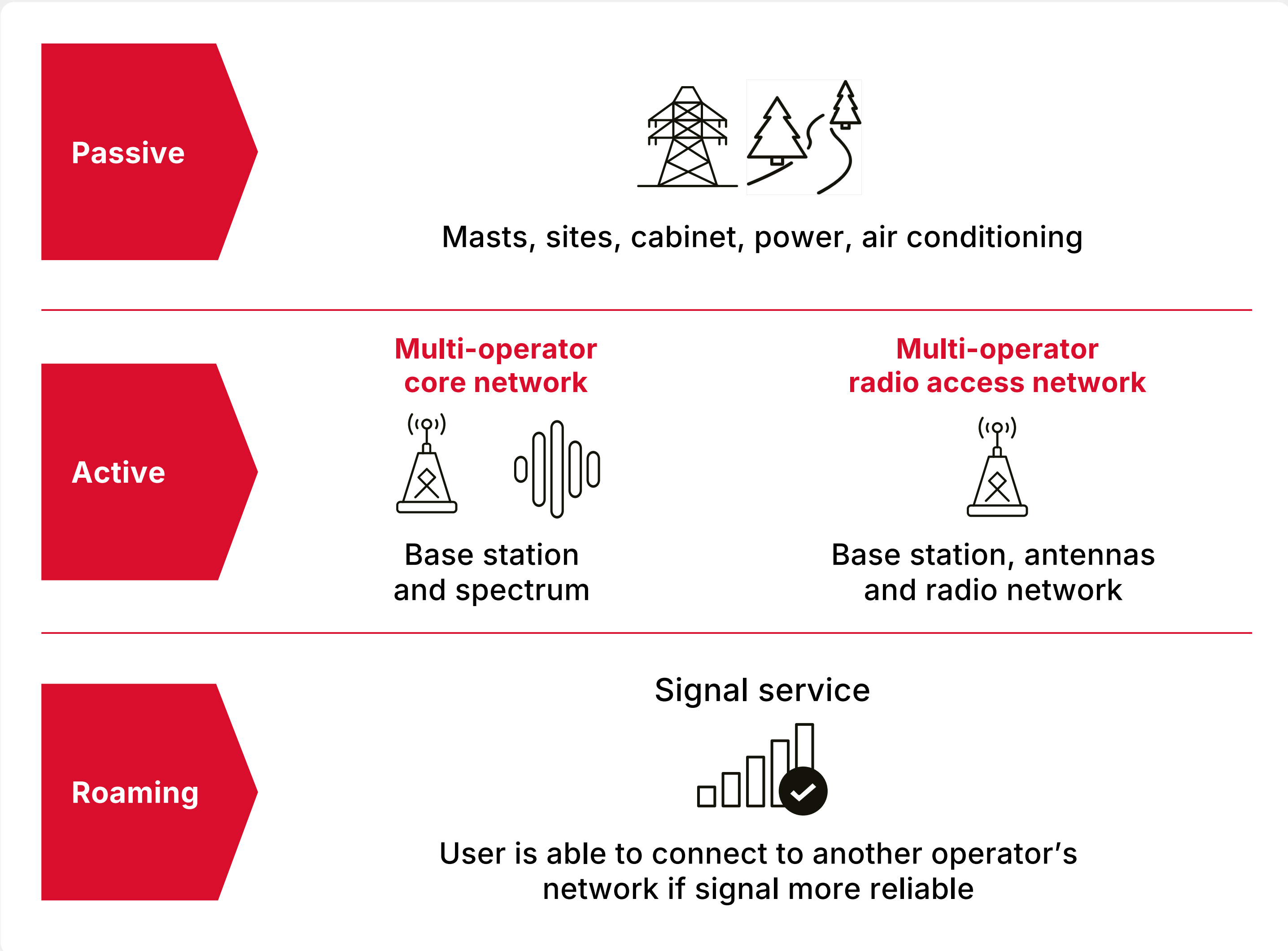
12 Spectrum: The Climate Connection, GSMA, 2023

CASE STUDY

MALAYSIA'S OPERATORS CREATE A MULTI-OPERATOR CORE NETWORK

Malaysia's six-way multi-operator core network (MOCN) is a vehicle to bring 4G to populations without reliable access to mobile internet. The model encompasses both passive and active infrastructure and spectrum sharing through the MOCN technology (see Figure 23). Priority areas include suburban and rural regions, seven designated focus areas, sparsely populated areas, and addressing connectivity complaints.

Figure 23
Mobile network sharing models



Source: Adapted from To share or not to share? The impact of mobile network sharing for consumers and operators, Koutroumpis, Castells and Bahia (2023)

While operators in Malaysia have a long history of bilateral infrastructure sharing, the MOCN is an innovative step to reduce set-up and transaction costs, which remain the main obstacles to network sharing. The MOCN standardises the operational protocols, maintenance activities that often require site access, and quality-of-service monitoring. This sets up a framework for cooperation that can be replicated

The implementation of the six-way MOCN is closely tied to Malaysia's Jendela programme, which aims to achieve 100% population coverage for 4G composite and internet connectivity. 4G coverage increased from 92% of the population in 2020 to 99% by the end of 2024.

Importantly, the six-way MOCN initiative is separate from Malaysia’s earlier single 5G wholesale network, which mandated all operators deliver their 5G services using shared physical 5G infrastructure managed by a state-owned entity. In 2023 the policy was reversed, opening up space for additional privately-owned 5G network infrastructure providers.

4. THE FUTURE OF RURAL CONNECTIVITY

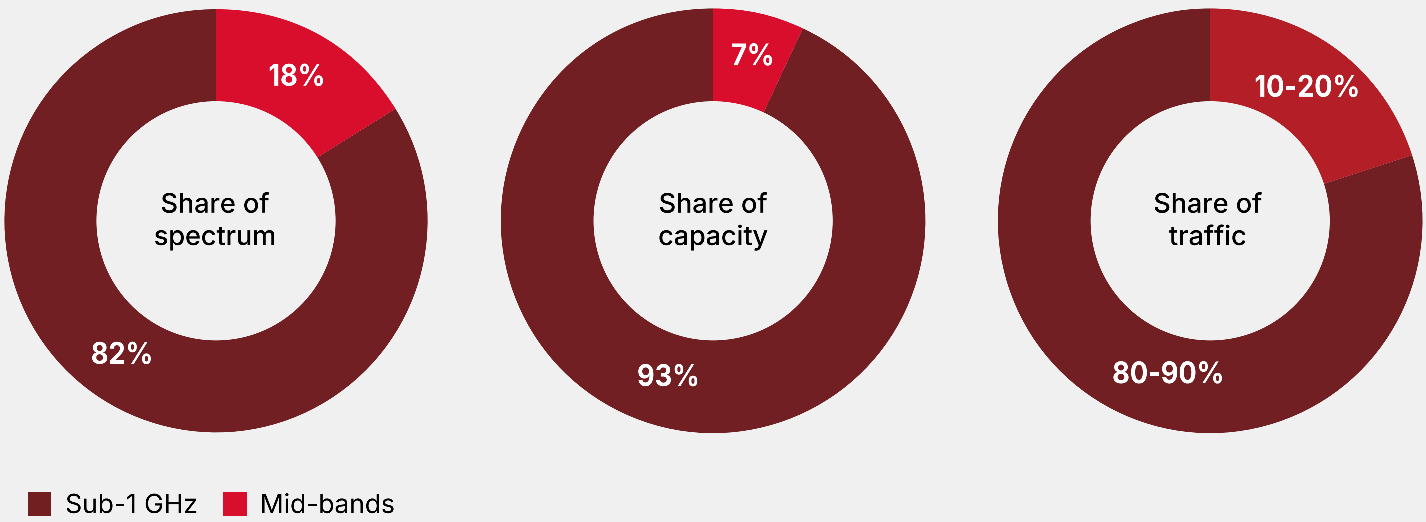
Growth in demand for data in rural communities means new challenges to 5G-Advanced and 6G deployments

5G-Advanced and 6G are designed to support ubiquitous connectivity, helping achieve the UN SDGs and connect the rural and remote areas.[13] Spectrum policy will play a crucial role in ensuring sufficient bandwidth. As rural consumers are more reliant on sub-1 GHz bands, specific challenges apply:

- Low-band spectrum is used with larger antennas, which limits the incremental gains in spectral efficiency from using MIMO and beamforming.[14] The efficiency gains provided by the latest technological advances may therefore yield lower gains in throughput provided by low bands.
- At the same time, the cost of building sites and backhaul infrastructure in rural areas is four to six times greater than urban areas.[15] This makes improving network throughput by further densification a less financially viable option in rural areas than in urban areas.
- Making more low-band spectrum available and improving the utilisation of already available spectrum will remain within the priorities for policymakers seeking to advance rural connectivity and close the digital divide.

The relative scarcity of low-band spectrum is a key limiting factor that will continue to influence the gap between rural and urban areas. According to previous estimates, spectrum needs in low bands exceed the amount of available spectrum. Despite accounting for 7% of total capacity, low bands will remain responsible for carrying up to 20% of total traffic volume.

Figure 24
Sub-1 GHz band capacity and share of traffic estimates



Source: Vision 2030: Low-Band Spectrum for 5G, GSMA and Coleago Consulting, 2022

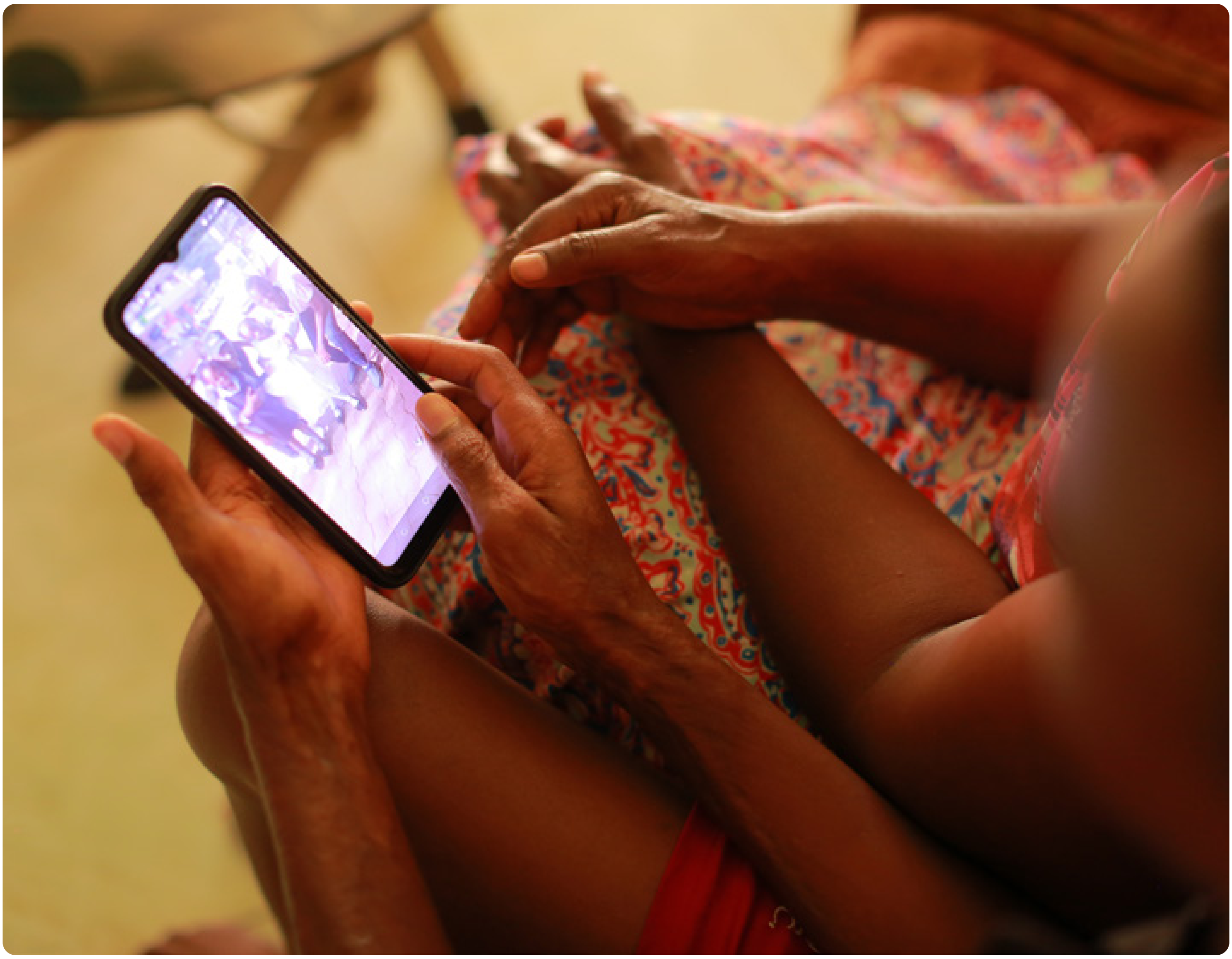
13 Recommendation ITU-R M.2160-0, ITU, 2023
14 Vision 2030: Low-Band Spectrum for 5G, GSMA and Coleago Consulting, 2022
15 Ibid.

However, the future presents new opportunities. The 470–694 MHz band, though currently primarily used for digital TV, is allocated to mobile service in some regions and has been identified for IMT use by several countries with different frequency ranges (see Table 2).[16] As the use of linear broadcast TV rapidly declines, continued use of these frequencies is under debate, given the likely benefits from repurposing spectrum for mobile use and enhanced services.

Table 2
Additional frequencies used or considered for future mobile use

Footnote no.	Frequency range	Region
5.295	470–608 MHz	Some countries in ITU Region 2
5.296A	470–698 MHz	Some countries in ITU Region 3
5.307A	614–694 MHz	Some countries in ITU Region 1
5.308A	614–698 MHz	Some countries in ITU Region 2

Source: ITU



16 Radio Regulations, ITU, 2024

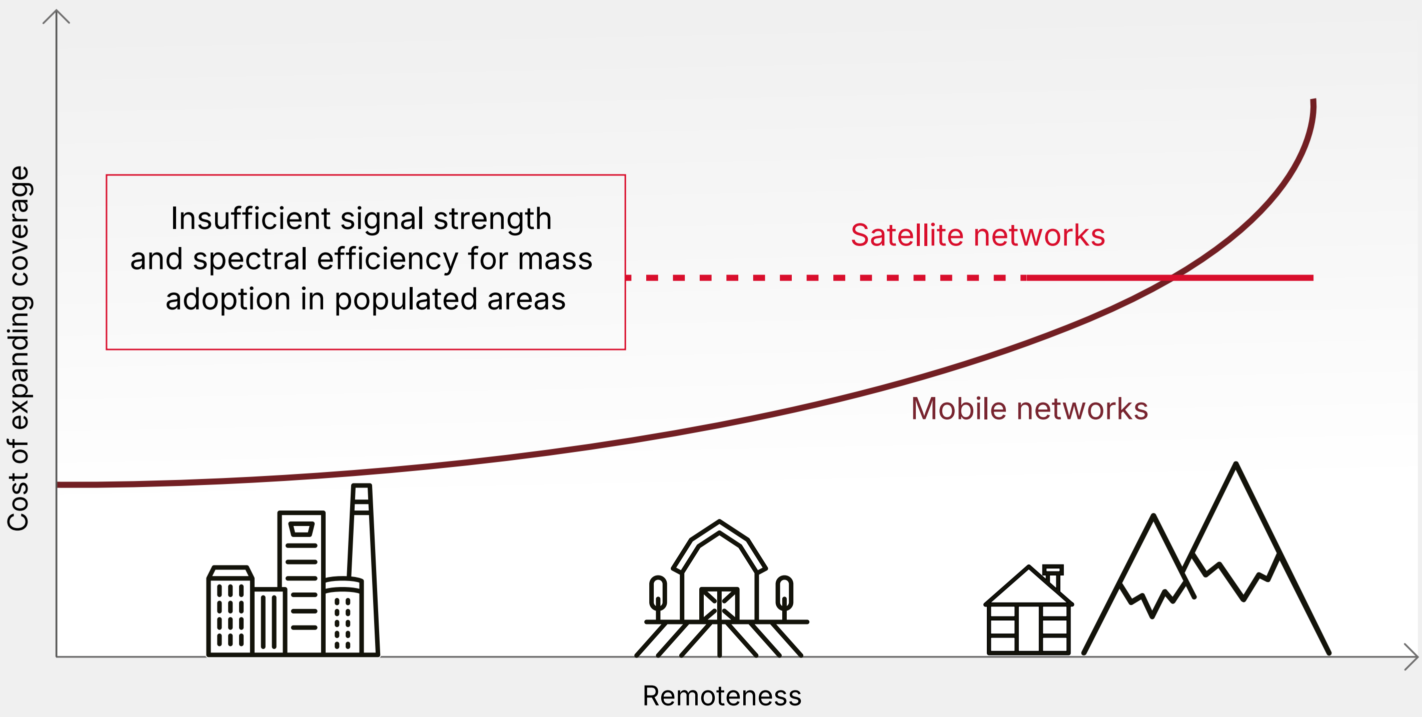
D2D networks offer an opportunity to supplement mobile connectivity

Recent advances in technologies such as beamforming and phased-array antennas allow satellites to focus signals more directly to individual devices, allowing connectivity direct to mobile devices. However, due to the distances and the size of the beam, satellite D2D connectivity can provide sufficient service quality only in the most remote areas.

Given the technological differences between satellite D2D and rural mobile networks, their suitability and cost-effectiveness differ depending on remoteness (see Figure 25). Due to weaker signal and lower spectral efficiency, D2D cannot provide meaningful connectivity in populated areas such as cities and towns. In more remote areas, the viability of satellite networks improves – but mobile networks still enjoy a cost advantage over satellite networks.

However, in very remote or unpopulated areas, satellite connectivity may have a role to play.

Figure 25
Satellite D2D connectivity offers an opportunity to connect the most remote places



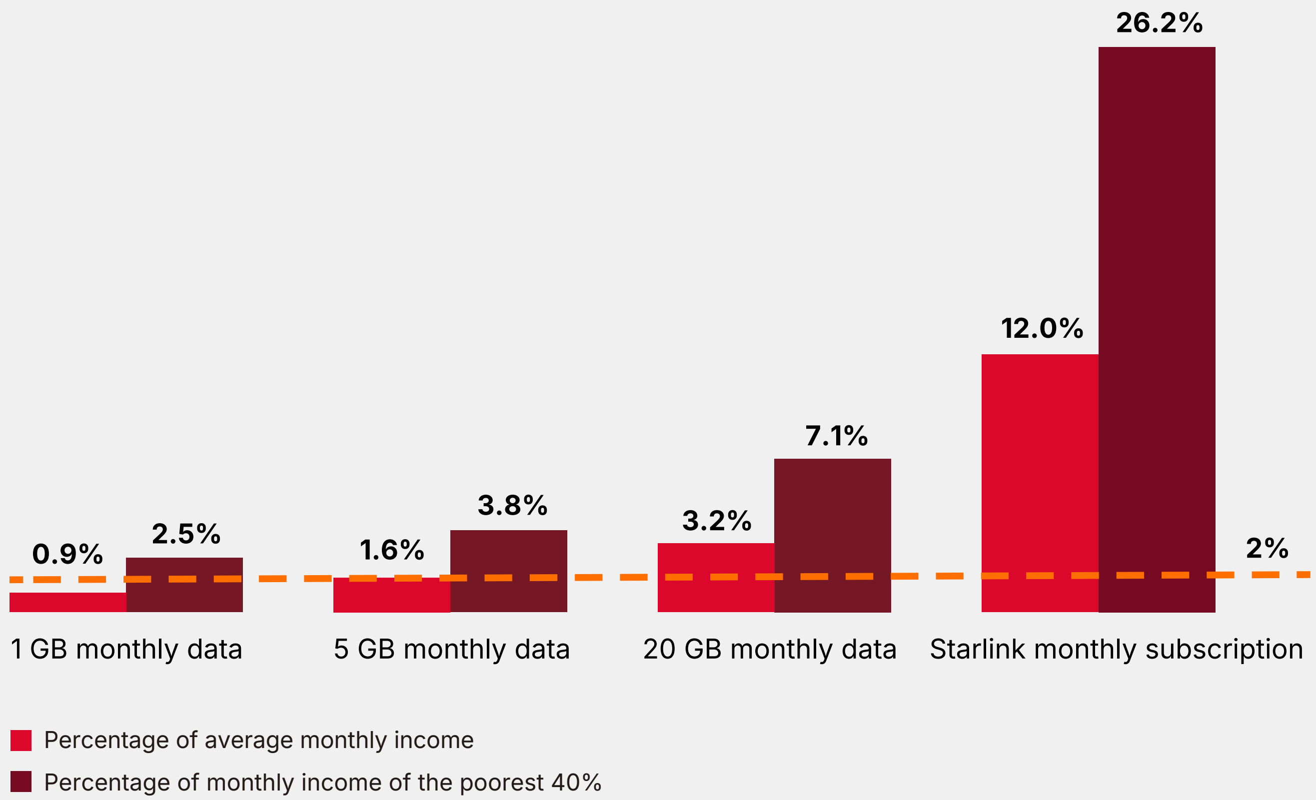
Source: GSMA Intelligence

Fixed satellite broadband provides good performance in rural areas, but affordability is a major barrier to wider adoption

Satellite broadband can also be delivered by a larger antenna. However, satellite broadband services (e.g. Starlink) are primarily targeted at high-income households that live in areas with limited fixed broadband alternatives (particularly a lack of fibre broadband access). This is evident from the cost of access, which ranges from $20 to $220 for the monthly residential subscription price and between $190 and $700 for the hardware.

In 50 LMICs, a subscription is 4–14× less affordable than a mobile data plan when measured against average monthly income. The affordability of fixed satellite service (at 12% of monthly income) is also six times higher than the ITU affordability target for entry-level broadband, which is 2% of monthly income.[17] When considering the poorest 40% of the population in these LMICs, the affordability of Starlink, at 26% of monthly income, is 13× the ITU target.

Figure 26
Comparison of affordability of three mobile data baskets and a monthly Starlink subscription



Notes: 50 countries were included in the analysis based on the availability of data for both mobile and Starlink prices.
Source: GSMA Intelligence analysis of data sourced from Tarifica and Starlink tariff information.

17 Aspirational targets for 2030, ITU

Satellite backhaul is still too expensive to be viable, but could offer opportunities in the future

The cost of mobile backhaul (network infrastructure that connects the RAN to the core network) in rural sites can be more than double the cost in urban areas, accounting for around a sixth of total deployment cost (compared to a 10th of the deployment cost in urban areas).[18] Most backhaul in rural areas uses microwave links due to the lack of fibre deployments. However, in many locations, there is no viable microwave backhaul link – for example, due to there being no line of sight to a nearby site or network node. In such cases, the only viable backhaul solution is via satellite. To date, the cost of satellite backhaul has been prohibitive at up to 10× higher than microwave, which is why it only accounts for around 2% of all macro and small cell backhaul links.[19]

The importance of satellite backhaul is highlighted in two of Africa's largest markets, Nigeria and DRC. The two countries account for almost half the coverage gap in Sub-Saharan Africa. In DRC, 68% of the population are covered by mobile broadband networks but only 24% of the rural population have mobile broadband coverage. Analysis by GSMA Intelligence shows that when looking at new sites that must be deployed to close the coverage gap, satellite backhaul would be needed for almost 20% of the uncovered population.[20] This is because the sites do not have a viable microwave backhaul link. In Nigeria, which has a coverage gap of 11% overall (and 36% in rural areas), satellite backhaul would be needed for 9% of the uncovered population. Going forward, if new LEO constellations can reduce the cost of satellite backhaul, it would go some way to helping to close the coverage gap. However, there remain other site costs (currently prohibitive in remote areas) that need to be addressed, particularly base station and energy costs. This is particularly important in remote sites with few users, as the potential revenues are more limited. Furthermore, while more affordable satellite backhaul can help close the coverage gap, it does not address the usage gap.

18 Rural renewal: telcos and sustainable energy in Africa, GSMA Intelligence, 2024

19 Wireless Backhaul Evolution: Delivering next-generation connectivity, GSMA and ABI Research, 2021, and Using Geospatial Analysis to Overhaul Connectivity Policies: How to Expand Mobile Internet Coverage and Adoption in Sub-Saharan Africa, World Bank, 2022

20 DRC Digital Economy Report, GSMA, 2025

5. SPECTRUM POLICIES FOR RURAL MOBILE

5.1. SPECTRUM POLICIES TO BOOST RURAL MOBILE

Investment costs in rural areas can be lowered by maximising low-band capacity

Closing the coverage gap means bringing mobile connectivity to the remaining few percent of the rural population without access to mobile internet. To achieve this, policymakers need to ensure that all low-band spectrum allocated to mobile service is assigned to operators as soon as possible. Estimates show that with the additional coverage and capacity provided in the cell edge area offered by 20 MHz of spectrum in the 600 MHz band, operators could cover the same area with 21% fewer sites.[21]

The availability of low-band spectrum will also ensure improved speeds. In rural areas, doubling the amount of 600 MHz bandwidth to 40 MHz would allow operators to provide sufficient speeds at the very edge of a cell, enabling them to achieve the necessary throughput at the edge of the cell with 33% fewer sites.[22] This illustrates a marked improvement to the viability of rural deployment offered by the full capacity of low bands.

Thanks to its wide-area propagation, low-band 5G is expected to drive around $130 billion in economic value in 2030.[23] Half of the impact will come from its ability to support massive IoT. IoT applications are set to play an important role in digital transformation across a range of economic sectors, including manufacturing, transport, smart cities and agriculture. The rest of the economic impact will be driven by enhanced mobile broadband and fixed wireless access, with low bands playing a critical role in delivering high-speed broadband connectivity in areas underserved by fixed networks.

21 Vision 2030: Low-Band Spectrum for 5G, GSMA and Coleago Consulting, 2022
22 Ibid.
23 Socio-Economic Benefits of 5G: The importance of low-band spectrum, GSMA, 2023

5.2. LOW-BAND SPECTRUM PRICING

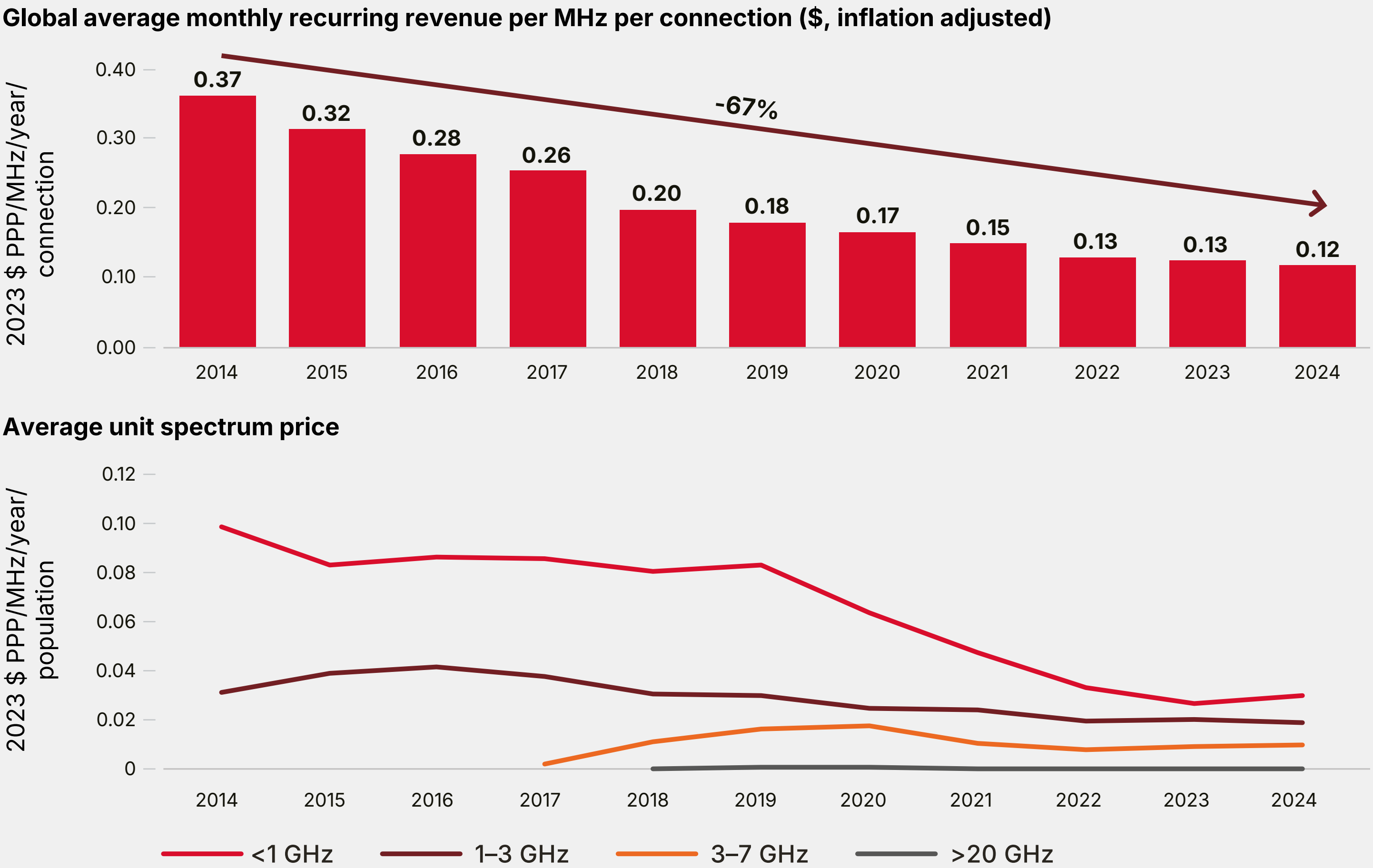
Spectrum needs have increased over the last decade, while consumer prices have gone down. This means that each MHz of spectrum supports less revenue than a decade ago.[24]

Spectrum prices need to reflect this new reality, which is already translating into lower prices paid by operators (see Figure 27). Price reductions particularly affected spectrum in low bands, which have declined more rapidly than other bands, and further declines may occur. To ensure low-band spectrum is used effectively, policymakers should pay attention to the following:

- Auction reserve prices should not be anchored to historical prices observed in the past or in other markets. Reserve prices should be set to discourage frivolous and tactical bidding, but not to increase revenues from the sale of spectrum. In practical terms, reserve prices should be set at a level that reduces the risk of unsold spectrum to negligible levels. Returned spectrum comes with a significant opportunity cost, in that less spectrum for mobile networks leads to worse consumer outcomes.
- Administrative renewal prices should not be linked to historical prices paid for a given assignment, or outdated benchmarks. Renewal pricing could seek to recover administrative costs, especially when the most beneficial use is not contested. In these cases, administrative pricing during renewals need not provide an incentive; the incentive to give up spectrum for more efficient use can be preserved by tradeable or leasable licences.
- Using renewal fees to maximise government revenue will result in an excess burden on operators and scaled down or delayed improvements to mobile networks. Conversely, easing the burden of spectrum cost can improve the viability of further investment, resulting in upscaled and accelerated deployment and enhanced consumer welfare.

24 Global Spectrum Pricing, GSMA, 2025

Figure 27
Global trends in revenue per MHz and unit spectrum prices



Note: Unit spectrum prices presented as three-year moving averages.
Source: Global Spectrum Pricing, GSMA, 2025

The same GSMA research shows that easing the aggregate spectrum cost could also benefit rural networks, as lower spectrum cost is linked to better network coverage and improved speeds.

When the burden of spectrum cost is high, the viability of investment is reduced, leading to downscaled or delayed deployments.

Figure 28
Spectrum cost influences operators' network deployment strategies

A 10-pp lower spectrum cost to recurring revenue ratio increased **4G coverage by 4 pp and 5G coverage by 6 pp**

a 10-pp lower spectrum cost **increased download speeds by 8% and upload speeds by 7%**

Source: Global Spectrum Pricing, GSMA, 2025

5.3. QUALITY AND INVESTMENT COMMITMENTS

Quality and investment commitments are also used as a complement or alternative to paying for spectrum. Such commitments can require operators to expand networks to rural areas that would otherwise not have been commercially viable due to insufficient demand.

This approach is motivated by the wider societal benefits of improved connectivity as a result of meeting the commitment. For example, the commitment is set at a level that requires expansion of networks to areas where it would not have been commercially viable. This means that fulfilment of obligations is costly to operators. Beyond a certain quality-of-service level, the cost of meeting such an obligation can outweigh the benefits, resulting in an increased cost burden on network operators and the diversion of invested capital from more productive uses generating greater benefits. Achieving the right balance requires quantification of potential social benefits and costs.

Approaches to assigning quality-of-service commitments differ:

- **Bundled with licences:** commitments are attached directly to spectrum licences. Operators weigh the licence's positive value – its revenue potential and role in reducing network costs – against the additional expense of meeting the obligations.
- **Unbundled commitments:** operators can opt in to specific commitments in exchange for reduced fees or spectrum auction credits. This approach often includes a list of municipalities, allowing operators to choose the areas where they will expand coverage or improve service quality.

Unbundled commitments provide greater flexibility, which can lead to improved efficiency. This is because it is possible that an operator that derives the greatest value from spectrum is not necessarily the same as the operator that can most efficiently fulfil the obligations.

OBLIGATIONS IN AUSTRIA'S MULTIBAND AUCTION

In 2020, the Austrian regulator (RTR) held an auction for the 700, 1500 and 2100 MHz bands. It combined multiple approaches to ensure widespread coverage in the country.[25]

Figure 29
Austria's multiband award relied on various approaches to setting coverage obligations

Bundled with spectrum lots	**Band-specific deployment obligations:** The winning bidders in certain bands were required to deploy the spectrum on a specified number of base stations by a certain date. For example, winners of spectrum in the 700 MHz band had to deploy at least 500 base stations by the end of 2022 and 1,500 base stations by the end of 2023.
	Band-specific coverage obligations: The winning bidders in certain bands were required to achieve pre-defined levels of coverage. For example, winners of spectrum in the 2100 MHz band had to use the spectrum to cover 75% of the population by the end of 2023 with a 5G service that provided 30 Mbps download and 3 Mbps upload speeds. The obligation increased to 80% by the end of 2025. Obligations were also set for coverage in large cities, and on roads, motorways and railways.
Reverse auction	**Extended coverage of communities:** The two levels of obligations described above were bundled with spectrum lots. In addition, RTR identified 2,100 communities underserved with existing mobile networks. Each lot in the 700 MHz band was associated with a list of 350 municipalities, and the winner of each lot was required to select 150 from the list (900 in total). Separate lists were maintained to avoid deployment duplication. The areas not selected in this stage were then offered in a reverse auction in return for a discount on spectrum fees. The bidders nominated municipalities and the price discount, and communities were assigned to maximise the number served. After the auction, bidders could trade obligations during a two-month period.

25 Band specific coverage obligations, Austrian Regulatory Authority for Broadcasting and Telecommunications, 2020

The final result of the auction was the award of all available spectrum for around €200 million. Coverage was procured for 1,702 of the underserved communities (81% of the 2,100 defined). Almost half of these (802) were assigned in the reverse auction.[26]

A key lesson from the auction was recognition that coverage obligations for the most difficult-to-reach areas represent a significant additional cost associated with acquiring the spectrum licence. If obligations are bundled with a spectrum award but are too onerous, the spectrum award may fail, meaning spectrum is not put to efficient use and obligations are not met. This can be the result of trying to apply a tool for one specific objective (auctioning spectrum to the most efficient users in a given country or geographic area) to address a separate problem (market failure in specific locations where the high costs of deployment and limited revenue mean certain populations are underserved).

The Austrian auction addressed this by using a market mechanism (reverse auction) to decouple spectrum awards from specific coverage obligations in high-cost communities. The importance of this is demonstrated by the fact that one operator (Telekom Austria) did not acquire any 700 MHz spectrum but acquired obligations to cover 349 communities in the reverse auction stage. This reflects the possibility that one operator can put a band to optimal use across a country, while another is better placed to deploy in hard-to-reach areas at lower cost.

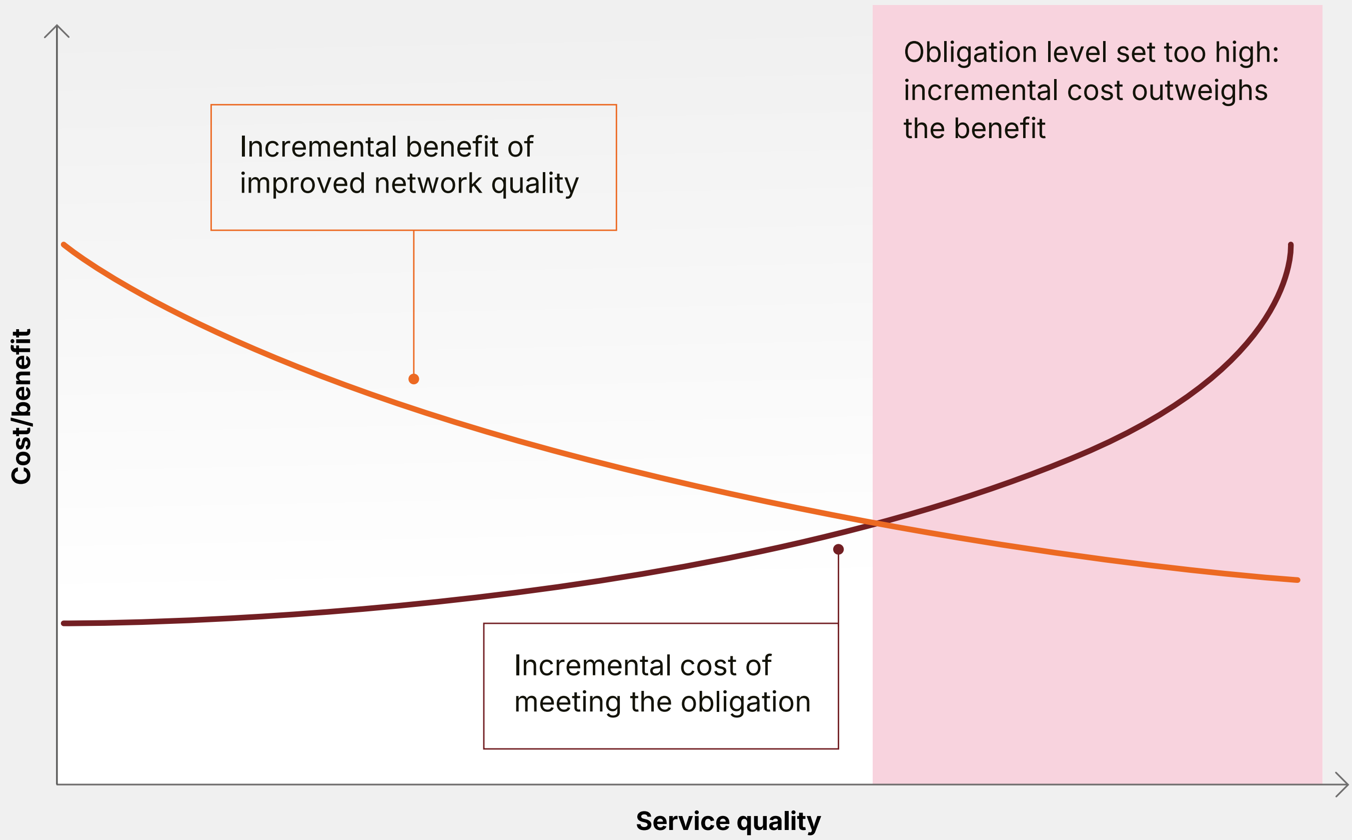
26 Auction results, Austrian Regulatory Authority for Broadcasting and Telecommunications, n.d.

If set too high, the quality-of-service obligations can negatively impact rural deployments

Choosing the level of obligation that maximises the net social benefits requires an understanding of the benefits of improved connectivity and the cost to operators. The incremental cost of reaching more remote populations or increasing speed requirements gradually grows as the obligation level increases (Figure 30). At the same time, the incremental benefits of improved quality of service decline because the largest value-added use cases can be sufficiently supported with lower network speeds.

Because of the inherent optimism bias, ex-ante estimates undervalue the cost of meeting the obligations. In reality, projects frequently encounter delays that offset the timeline of potential benefits, while the complexity and the estimated cost variables tend to be underappreciated.

Figure 30
At high levels of quality obligation, costs could outweigh the benefits



Source: GSMA Intelligence

Rural areas typically involve challenging terrain and sparse populations, making it expensive to expand infrastructure. Operators may need to over-invest in duplicative or underutilised equipment to comply, leading to financial losses since customer bases are too small to recoup costs quickly.

Strict and inflexible obligations can also create reluctance among operators to participate in spectrum auctions or sign up, fearing penalties in case of unforeseen circumstances. International examples show this in practice. In Germany, strict speed and latency requirements for transport corridors led to nearly two-year delays in meeting targets due to local opposition and land acquisition hurdles, disproportionately affecting rural expansion. In the US, rigid construction milestones in licences for 700 MHz and mid-band spectrum have risked cancellations, discouraging smaller operators from serving rural communities with low rates of subscription, widening the digital divide.

CASE STUDIES

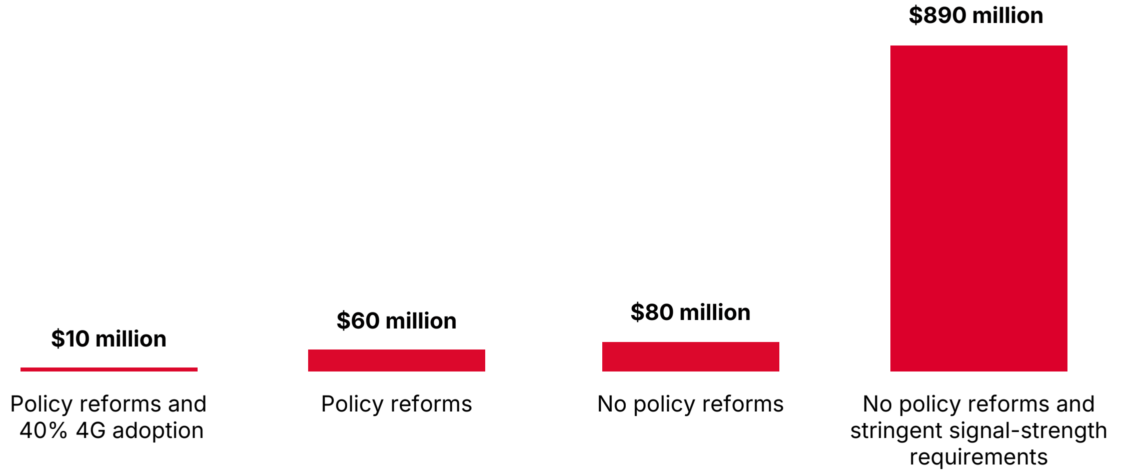
COVERAGE OBLIGATIONS THAT OUTWEIGH THE BENEFITS

1. BENIN

The QoS regulations in Benin require operators to provide 4G network speeds of >5Mbps for the downlink, >3Mbps for the uplink and a failure rate of <3%. These requirements are significantly higher than in other countries – even those with higher incomes. Furthermore, the signal-strength thresholds used by the regulator to determine whether an area has 4G coverage are much stronger than in other countries, at –90 dBm.[27] Meeting the high levels of QoS required by the regulator in Benin would result in much higher capital and operational expenditure.

The signal-strength requirements have a major impact on the area defined as being "covered" by a site. It is estimated that, under Arcep's current QoS rules and signal-strength thresholds, it would cost one of the larger operators almost $900 million to reach 99% population coverage. If all three operators are required to independently meet the regulatory requirements, the total cost would approach $3 billion. In contrast, if standard QoS regulations and signal-strength thresholds were applied, the incremental cost for one operator to meet 99% population coverage would be approximately $80 million.

Figure 31
Additional investment needed to achieve 99% 4G coverage in Benin



Source: GSMA Intelligence

The case of Benin clearly shows that above a certain level, meeting the stringent availability and quality obligations becomes too costly and is unlikely to generate sufficient benefits. In such cases, the policy may have the opposite effect to what it aimed to achieve. The cost of meeting too stringent obligations will be shifted onto consumers, or potentially result in crowding out of investment into improvements to networks which could generate more benefits.

27 See Driving digital transformation of the economy in Benin, GSMA, 2024

2. SAUDI ARABIA

During the recent 2024 auction, Saudi Arabia linked spectrum licences to the following obligations.

For the 600 and 700 MHz band licences by the end of 2027:

- Download speeds of 20 Mbps for 80% of the samples in an area of 4 km2 in every locality that exceeds 5,000 inhabitants.
- Covering all localities with more than 300 inhabitants, so that voice services are provided to more than 99% of users' devices in the service provider's network using 5G technology.

For the 3.8 to 4 GHz licences by the end of 2025:

- Achieving a minimum average download speed of 500 Mbps for mobile broadband services across the country.
- Achieving a minimum average download speed of 100 Mbps for mobile broadband services in every locality that exceeds 5,000 inhabitants.

Given Saudi Arabia's geography and sparsely distributed populations in the interior of the country, the cost of meeting these obligations in some localities will require significant investment in uninhabited areas but provide limited returns on investment. Objections have also been raised to the way performance targets are defined and measured (focusing on the share of area covered rather than the share of population in a given locality).

CASE STUDY

COLOMBIA RELIES ON AN AUCTION COMBINING CASH AND SERVICE QUALITY BIDS TO BOOST RURAL CONNECTIVITY

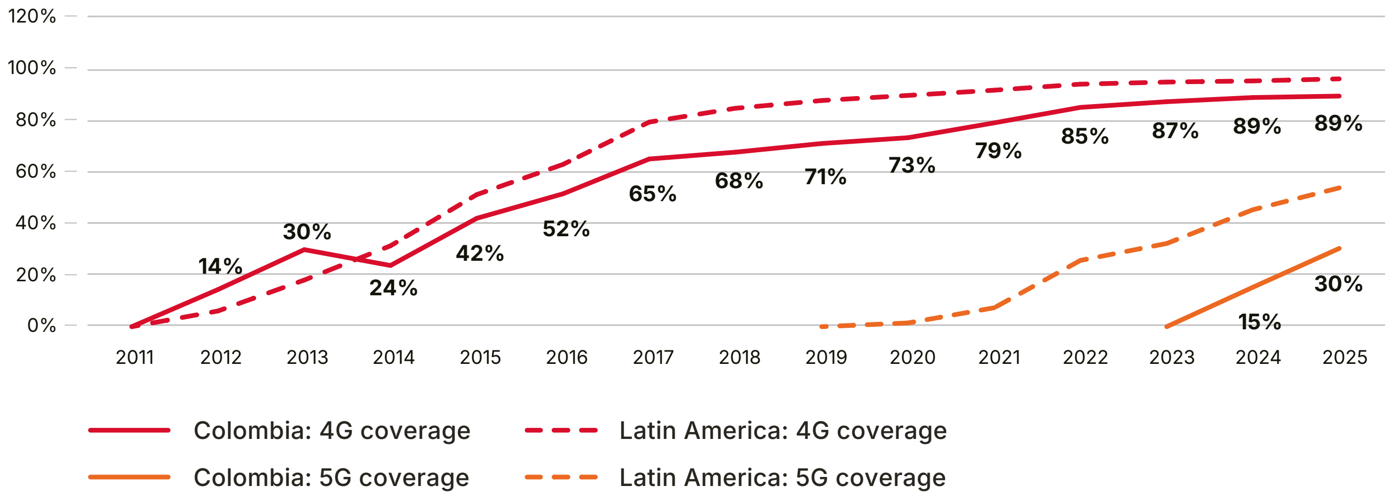
In the past, assignment of spectrum in Colombia tended to lag behind global leaders and regional peers. For years, the strategy focused on maximisation of government revenue from spectrum fees – a strategy enshrined into regulations.[28] At the same time, the lack of a unified approach to spectrum awards contributed to uncertainty and a weak investment climate. This has meant that the necessary spectrum to deploy the latest network generations was available with a delay, leading to slower deployments.

However, the law was updated. The strategy is now focused on maximising social benefit and investment certainty. In the 2019 auction of spectrum in the 700 MHz and 2.6 GHz bands, Colombia has relied on a market-based approach incentivising network deployment to underserved areas. In the 700 MHz band, the submitted bids were expressed via a "bid index" formula composed of the following:

- **Cash commitment:** operators specified a total bid price and committed to a cash payment equivalent to 40–100% of that bid price.
- **Coverage commitment:** for bids with a cash commitment below 100%, operators picked from a list of communities they would cover and a timeline for covering them.

The resulting commitments included bringing 4G coverage to 3,658 rural locations, within five years (2020–2025). Claro was tasked with covering 1,348 localities, Tigo 1,636 and Partners 674, with the government estimating $680 million investment was required to fulfil the obligations.

Figure 32
Network coverage in Colombia and the Latin America region

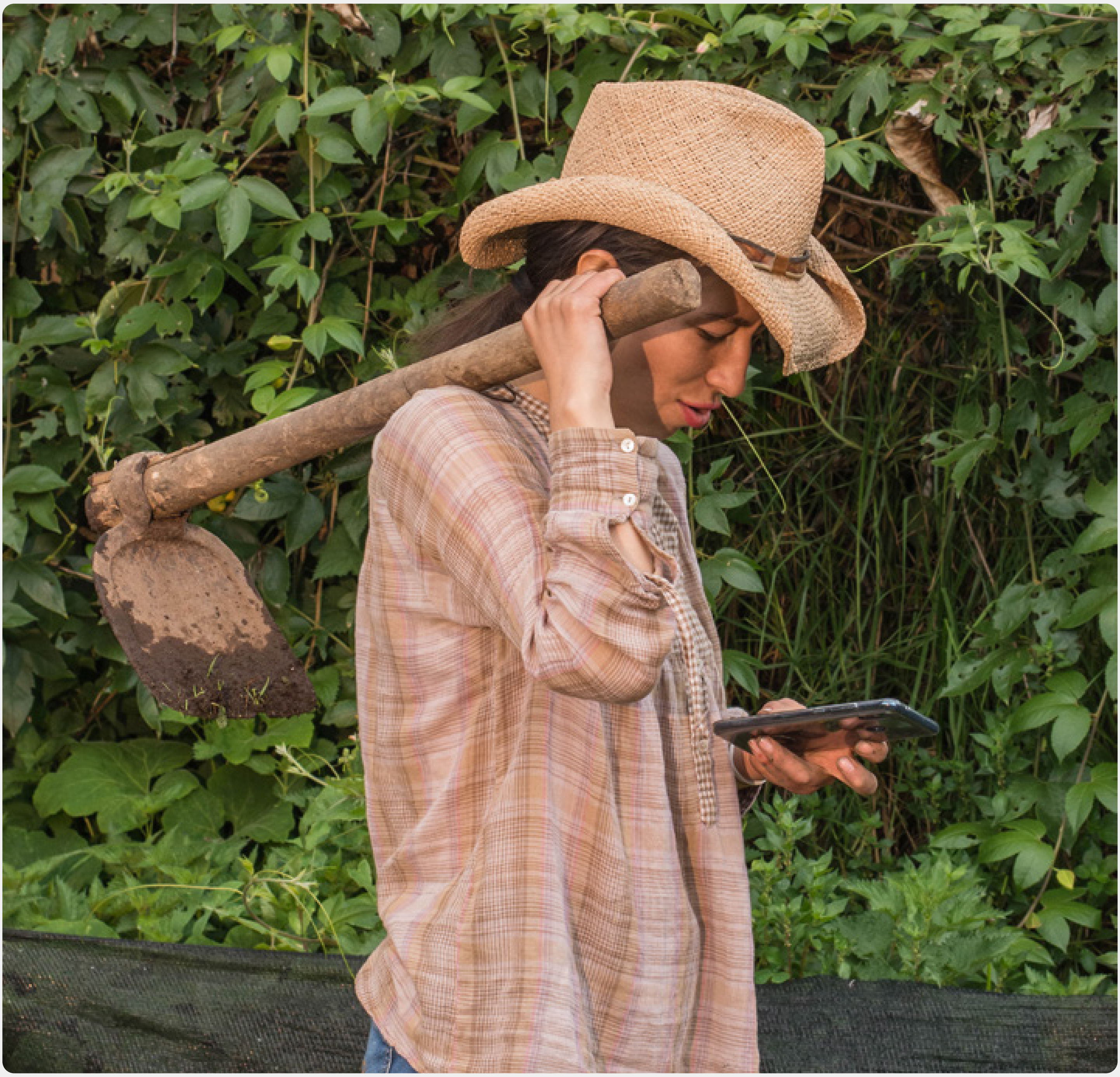


Source: GSMA Intelligence

28 OECD Review of Telecommunication Policy and Regulation in Colombia, OECD, 2014

In the 2023 auction, focused on 5G technology, 83% of the available spectrum was awarded, and revenue exceeded the base price by 30%. However, the frequencies in the 700 MHz, 1.9 GHz and AWS band between 1.7 GHz and 2.2 GHz remained unassigned.

The three national operators (Claro, Tigo and Movistar) and WOM (a new entrant) acquired spectrum in the auction. In the 700 MHz band, Claro acquired 2×10 MHz and committed to covering 1,348 areas, WOM acquired 2×10 MHz and committed to 674 areas, and Tigo acquired 2×20 MHz and 1,636 areas. Movistar did not acquire 700 MHz, while 2×5 MHz remained unsold. In total, MinTic was successful in allocating 3,658 of the available 6,000 target areas during the auction. As of September 2025, out of 3,658 rural locations, 3,059 are operational, while 599 are in the process of being connected.[29] Between 2022 and 2024, the number of mobile connections increased from 45 million to 50 million, while the percentage of rural households with internet access increased from 39% to 46%.[30]



29 Colombia MinTIC, 2025
30 Ibid.

As an alternative to obligations, regulators can also expand networks to rural areas by relying on public funding. This can be used to support the following:

- **The demand side** (for example, providing financial support to rural communities by offering subsidised tariffs). This boosts local demand, resulting in operator entry. Removal of burdensome sector-specific taxes can also effectively boost demand, ensuring their distorting effect does not inhibit existing demand for mobile connectivity.

- **The supply side,** where funding and voluntary public-private partnerships are used to expand networks to additional areas. Targeted funding can be used to bring networks to areas that are just below the threshold of commercial viability for private enterprises, potentially achieving large incremental improvements at relatively low public cost.

Both approaches work by boosting commercial viability of deployment to additional areas. However, unlike obligations, they do not impose additional cost on operators. Similarly to service quality obligations, regulators need to establish whether the social benefits of improved connectivity justify the cost of subsidies, to ensure public funding generates value for money versus its opportunity cost.

CASE STUDY

SPAIN RELIES ON GRANTS AND PUBLIC-PRIVATE FUNDING TO BOOST RURAL 5G DEPLOYMENT

Spanish authorities launched the UNICO 5G programme in 2023, aiming to boost high-performance 5G availability in areas under the commercial viability threshold. This was motivated by the observed connectivity gap, showing that up to 1.4 million people, primarily located in rural areas, have insufficient mobile broadband coverage of 30 Mbps.[31]

The programme supports public–private partnerships. One of the main components, UNICO Redes Activas 5G programme, focuses on rural and small-town deployment (populations below 10,000). The funding includes the following:

- Up to €508 million to accelerate 5G standalone (5G SA) rollout in rural areas of the country, allocated in 2024, supporting high-quality 5G SA deployments in more than 7,000 rural towers and providing coverage to more than 1.8 million people and 30,0000 km of roads.
- An additional €161 million awarded in 2025, enabling operators to deploy 2,000 new 5G SA sites in rural areas.[32] This is estimated to extend 5G coverage to 326,000 people and 6,800 km of the road network.

The early stages of implementation of these projects show measurable progress. Between 2023 and 2024, overall 5G network coverage increased by 3.5 pp.[33] Importantly, the primary driver of this was improved 5G rural coverage. This increased by 11 pp, reaching more than 80% of the rural population.

The deployment will continue over the following months and is expected to finalise in 2026.

31 "Unico 5G", Espana Digital
32 "Spain's big-three take home extra rural 5G SA cash — report", TelcoTitans, December 2024
33 Cobertura De Banda Ancha en España en el Año 2024, State Secretariat for Telecommunications and Digital Infrastructures, 2025

5.4. TECHNICAL AND COMMERCIAL FACTORS AFFECTING RURAL SPECTRUM SHARING

Market-driven network-sharing agreements have proven to be instrumental in addressing the rural connectivity deficit.

It is important to consider two frameworks that are broadly labelled as sharing:

- spectrum sharing frameworks between technologies based on technical and regulatory conditions
- voluntary spectrum leasing of exclusive licences.

These should be treated as distinct approaches to enhance efficient spectrum use and address the rural connectivity challenges.

Spectrum sharing frameworks do not provide particularly clear advantages that could boost rural mobile connectivity. On the one hand, sharing provides additional capacity in bands already occupied by incumbent users but unused in certain localities. This capacity could in some instances serve to boost rural connectivity. However, restrictive power limits decrease the suitability of spectrum sharing to enhance rural connectivity. Because rural deployments require wide-area coverage to reach commercial viability, use of shared spectrum within the necessary power limits to avoid interference can simply lack the necessary scale per site, limiting its real-world usability.

In addition, the cost of deploying physical infrastructure in rural areas is particularly high and skewed towards assets with long lives of tens of years, such as high antenna towers and backhaul connectivity. To invest in these, operators need certain and equally long-term access to spectrum to bring this infrastructure to life.

Therefore, sharing options do not replace the need for exclusive, nationally licensed spectrum. To support rural deployment and provide the necessary capacity, exclusive licencing should seek to provide at least 80 MHz per operator in low bands for current 4G and 5G needs.

Because of these factors, frameworks imposing sharing generally reduce the value of spectrum from the perspective of operators, as they constrain the viable network deployment strategies to only those compatible with the framework's sharing rules. Similarly, other types of regulation-imposed network sharing, such as single wholesale networks, have lacked the flexibility and incentives grounded in competitive mobile markets.

Voluntary spectrum leasing within exclusive licencing frameworks can, however, provide the necessary flexibility to maximise utilisation of spectrum across technologies. This includes allowing "club licensing" where operators pool spectrum for wider low-band channels to deliver greater rural speeds, or sub-leasing of unused rural capacity in higher bands to enterprises and specialised FWA service providers.

Adoption of these strategies is incentivised financially. Operators seeking to maximise the commercial value of exclusive rights they initially acquired will rely on various sharing and leasing modes that also maximise the benefits of spectrum to society as a whole.

Assignment of spectrum to shared rather than exclusive use should be grounded in economic and technological considerations

- The expansion of mobile networks into rural areas has been supported by long-term exclusive licencing that guarantees certainty of access to ensure a return on long-term investments in physical infrastructure.
- Spectrum sharing comes with various technical limitations that need to be understood. For example, shared systems require coordination protocols, which reduce usable bandwidth,

while power limits in shared regimes restrict coverage radius compared to exclusive licences, making the deployment of mobile in sharing frameworks less viable.

Within the existing framework of exclusive licencing for mobile, voluntary spectrum sharing and leasing should be permitted

- Licenced shared access (LSA) refers to permissive licence conditions that allow flexible adoption of various sharing strategies – from passive to active sharing.
- This provides more options to access spectrum and maxmimise its value, while maintaining equal footing in access, in both primary and secondary markets. Markets continue to provide financial incentives to transfer spectrum to the user, who can generate greater value.

Licence sharing and leasing will allow for testing and deployment of different rural business models

- Spectrum sharing and leasing can benefit rural connectivity in different ways, allowing operators to rely on various strategies from aggregating their spectrum in low bands to create wider channels for high-speed connectivity in rural areas, to leasing underutilised spectrum in some areas to specialised FWA providers, and private and community networks.
- Because of aligned incentives, operators seeking to maximise the commercial value of spectrum using various sharing modes will also maximise the benefits of spectrum to society as a whole.

6. METHODOLOGY

6.1. CONSUMER SURVEY ANALYSIS

This analysis utilised survey data collected as part of the GSMA Consumer Survey.[34] We relied on two different surveys, depending on the income classification:

- **Low- and middle-income countries** – In 2024, a nationally representative survey was carried out face to face of around 1,000 adults aged 18 and above. The countries were Egypt, Ethiopia, Kenya, Nigeria, Rwanda, Senegal, Tanzania, Uganda, Bangladesh, India, Indonesia, Pakistan, Philippines, Guatemala and Mexico. More details on the surveyed countries and methods can be found in the GSMA State of Mobile Internet Connectivity Report.[35]

- **High-income countries** – An online survey of consumers was conducted in August 2024. With sample sizes of approximately 1,000, respondents were from Germany, US, France, UK, Italy, Japan, South Korea, Australia, Spain, UAE and Poland.

Aggregates for each the two income groups were calculated by weighting the national results by the countries' shares in the total urban and rural population of all surveyed countries.

34 GSMA Consumer Survey
35 The State of Mobile Connectivity 2024, GSMA, 2024

6.2. GEOSPATIAL DATA ANALYSIS

Data sources

1. **GSMA Intelligence data**
   In this study, we utilise GSMA Intelligence data for several critical purposes:

- documenting network sunset timelines for 2G and 3G technologies across markets
- determining operator market share in countries to ensure representative coverage analysis
- obtaining geographic coverage area information
- categorising countries by income classification (high-income versus low and middle-income economies).

2. **The GSMA Intelligence Mobile Coverage Explorer**
   This dataset contains coverage network data globally, with submissions made voluntarily by operators. The coverage maps represent cumulative data, with each year's dataset incorporating previous years' submissions along with newly added operator coverage information.

3. **Global Human Settlement Layer (GHSL) data**
   The Global Human Settlement Layer, developed by the Joint Research Centre of the European Commission, provides authoritative global spatial information on human settlements. We utilise the GHSL Settlement Model (GHS-SMOD) dataset for 2025, which implements the Degree of Urbanization (DEGURBA) methodology endorsed by the UN Statistical Commission for classifying settlements along the urban-rural continuum. GHS-SMOD delivers global, multi-temporal classification at 1 km spatial resolution based on population density and built-up surface characteristics. This methodology overcomes biases inherent in heterogeneous national definitions of urban and rural areas, providing the standardised classification essential for cross-country comparative analysis.

4. **Ookla Unified Signal Scan Dataset**[36]
   The Ookla Unified Signal Scan Dataset is a specialised commercial dataset secured for four strategically selected countries (UK, Indonesia, Brazil and Australia) to ensure diverse geographic and economic representation. This dataset captures comprehensive information from background network scans performed by mobile devices, including cellular technology in use (2G, 3G, 4G, 5G), frequency band utilised, geolocation (latitude and longitude), and radio signal quality metrics including Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ). Unlike user-initiated speed tests, these background scans provide continuous monitoring of network conditions, offering insights into actual network utilisation patterns and signal quality across different technologies and spectrum bands. The dataset enables analysis of technology and spectrum band usage differentiated by urban and rural contexts.

5. **Ookla Mobile Network Performance Dataset**[37]
   The Ookla Mobile Network Performance Dataset, also secured for the same four countries (UK, Indonesia, Brazil and Australia) contains detailed measurements from user-initiated performance tests conducted via the Speedtest application. Each test record includes technology generation employed, frequency band used, geographic coordinates and measured performance metrics encompassing download speed, upload speed and latency. This dataset captures real-world user experience under actual usage conditions across diverse locations and times. The geographic precision and temporal granularity of the data enables analysis of speed variations across population density gradients, urbanisation categories, signal-strength conditions, and temporal patterns throughout the day. The performance dataset complements the signal scan data by providing actual throughput measurements rather than theoretical capacity or signal quality proxies.

36 See https://www.ookla.com/speedtest-intelligence
37 Ibid.

6. **Speedtest by Ookla Global Fixed and Mobile Network Performance Maps**[38]
   This open-source dataset provides aggregated network performance metrics at a global scale. Data is organised into spatial tiles at zoom level 16 in Web Mercator projection (approximately 610.8 meters by 610.8 meters at the equator). For each tile, the dataset reports average download speed, upload speed and latency for both fixed and mobile network connections, derived from millions of Speedtest measurements with GPS quality location accuracy. The global coverage and standardised spatial aggregation of this dataset enable large-scale comparative analysis of mobile network performance across countries and regions. We use this dataset to examine performance trends across income classifications, geographic regions and time periods, as well as explore relationships between observed speeds and spectrum availability by country.

Analytical methods

Coverage analysis (Figures 1 and 5)

For coverage analysis, we implement a rigorous filtering methodology to ensure data quality and representativeness. Using the GSMA Intelligence Mobile Coverage Explorer dataset, which contains operator-submitted coverage maps, we first identify which operators have submitted data for each network generation (2G, 3G, 4G, 5G) in each country. We then use GSMA Intelligence market share data to retain only those countries where operators with submitted coverage maps collectively represent more than 50% market share for the specific technology generation. This threshold ensures available coverage maps provide meaningful representation of national coverage.

To ensure temporal relevance, we implement an additional filter examining the validity of coverage maps. Using GSMA Intelligence data on operator coverage as reported in their annual reports and other sources, we verify that the operator's reported change in coverage since the map was produced does not exceed 5%. This conservative approach ensures the available coverage maps remain accurate representations of current network extent and prevents analysis of outdated data in countries where operators did not submit recent maps. Countries failing to meet either the market share or recency criteria are excluded from coverage analysis for the specific technology generation. The resulting set of countries included in the analysis is shown in Table 3.

The coverage maps, provided in raster format typically at 250 m resolution, are spatially integrated with the GHSL SMOD dataset, also in raster format, which categorises each grid of 1 km square area by degree of urbanisation. Through spatial overlay analysis, we calculate the percentage of the population covered by each network generation within rural and urban categories for each country. Countries are then grouped by income classification (high-income and low- and middle-income) using the World Bank categorisation. Aggregate coverage statistics are computed for each income group and for each technology generation.

For countries that have completed network sunsets of 2G or 3G technologies, coverage for the sunset technology is treated as zero. Network sunset completion is determined from GSMA Intelligence data (Network Sunsets Database), deeming 2G and 3G networks effectively shut down if the operator(s) completing the sunset accounts for more than 50% of market share. This approach provides a realistic representation of technology availability across markets at different stages of network evolution, ensuring the recent sunsets of legacy networks are correctly reflected in calculated urban and rural population coverage.

38 See https://www.ookla.com/ookla-for-good/open-data

Table 3
Countries included in the coverage analysis

Country	2G	3G	4G	5G
Afghanistan	✔			
Albania	✔	✔	✔	
Algeria	✔			
Andorra	✔	✔		
Angola	✔			
Antigua And Barbuda	✔	✔	✔	
Armenia	✔	✔		
Australia	✔	✔	✔	
Austria	✔	✔	✔	✔
Azerbaijan	✔	✔		
Bahamas	✔	✔	✔	
Bahrain	✔		✔	
Bangladesh	✔	✔		
Barbados		✔	✔	
Belarus	✔	✔	✔	
Belgium	✔	✔	✔	
Belize	✔	✔	✔	
Benin	✔	✔	✔	
Bhutan	✔	✔	✔	
Bolivia	✔			
Bosnia And Herzegovina	✔	✔	✔	
Botswana	✔			
Brazil	✔	✔	✔	✔
Brunei	✔			
Bulgaria	✔	✔	✔	
Cabo Verde	✔			
Cambodia	✔	✔	✔	
Cameroon	✔			
Canada	✔	✔	✔	✔
Central African Republic	✔			
Chad	✔			
Chile	✔	✔	✔	
China	✔		✔	
Colombia	✔	✔		
Congo; Democratic Republic			✔	✔
Costa Rica	✔	✔	✔	
Croatia	✔	✔	✔	
Cyprus	✔			
Czechia	✔	✔	✔	
Denmark	✔	✔	✔	
Dominica		✔	✔	
Dominican Republic	✔	✔	✔	
Egypt	✔			
El Salvador	✔	✔	✔	
Estonia	✔	✔	✔	
Finland	✔	✔	✔	
France		✔	✔	
Gambia	✔			
Georgia	✔	✔	✔	
Germany	✔	✔	✔	✔
Ghana	✔			
Greece	✔	✔	✔	
Grenada		✔	✔	
Guatemala	✔	✔	✔	
Guyana		✔		
Haiti		✔	✔	
Honduras	✔			
Hong Kong; SAR China	✔	✔	✔	
Hungary	✔	✔	✔	
Iceland	✔	✔	✔	✔
India	✔	✔	✔	✔
Indonesia	✔	✔		
Iran	✔			
Iraq		✔	✔	
Ireland	✔		✔	✔
Israel	✔		✔	
Italy	✔	✔	✔	✔
Jamaica	✔	✔	✔	
Japan	✔		✔	
Jordan	✔			
Kazakhstan	✔	✔	✔	✔
Kuwait	✔		✔	✔
Kyrgyzstan	✔			
Laos	✔	✔		

Country	2G	3G	4G	5G
Latvia	✔	✔	✔	
Lebanon	✔	✔	✔	
Lesotho	✔			
Liberia	✔			
Libya		✔		
Liechtenstein	✔		✔	
Lithuania	✔	✔	✔	
Luxembourg	✔		✔	
Macao; SAR China	✔	✔	✔	
Malawi	✔		✔	
Malaysia	✔	✔		
Maldives	✔	✔	✔	
Malta	✔	✔	✔	
Mauritius	✔	✔	✔	
Mexico		✔	✔	✔
Moldova	✔	✔	✔	
Mongolia		✔	✔	
Montenegro	✔	✔	✔	
Morocco	✔			
Mozambique	✔			
Myanmar	✔	✔	✔	
Namibia	✔			
Nepal		✔	✔	
Netherlands	✔	✔	✔	✔
New Zealand	✔	✔	✔	
Nigeria	✔	✔	✔	✔
North Macedonia	✔		✔	
Norway		✔		
Oman	✔	✔	✔	✔
Palestine	✔	✔		
Panama	✔	✔	✔	
Paraguay	✔			
Philippines	✔		✔	
Poland	✔	✔	✔	
Portugal	✔	✔	✔	
Qatar	✔	✔	✔	✔
Romania	✔	✔	✔	
Russian Federation	✔	✔	✔	
Rwanda	✔			
Saint Kitts and Nevis		✔	✔	

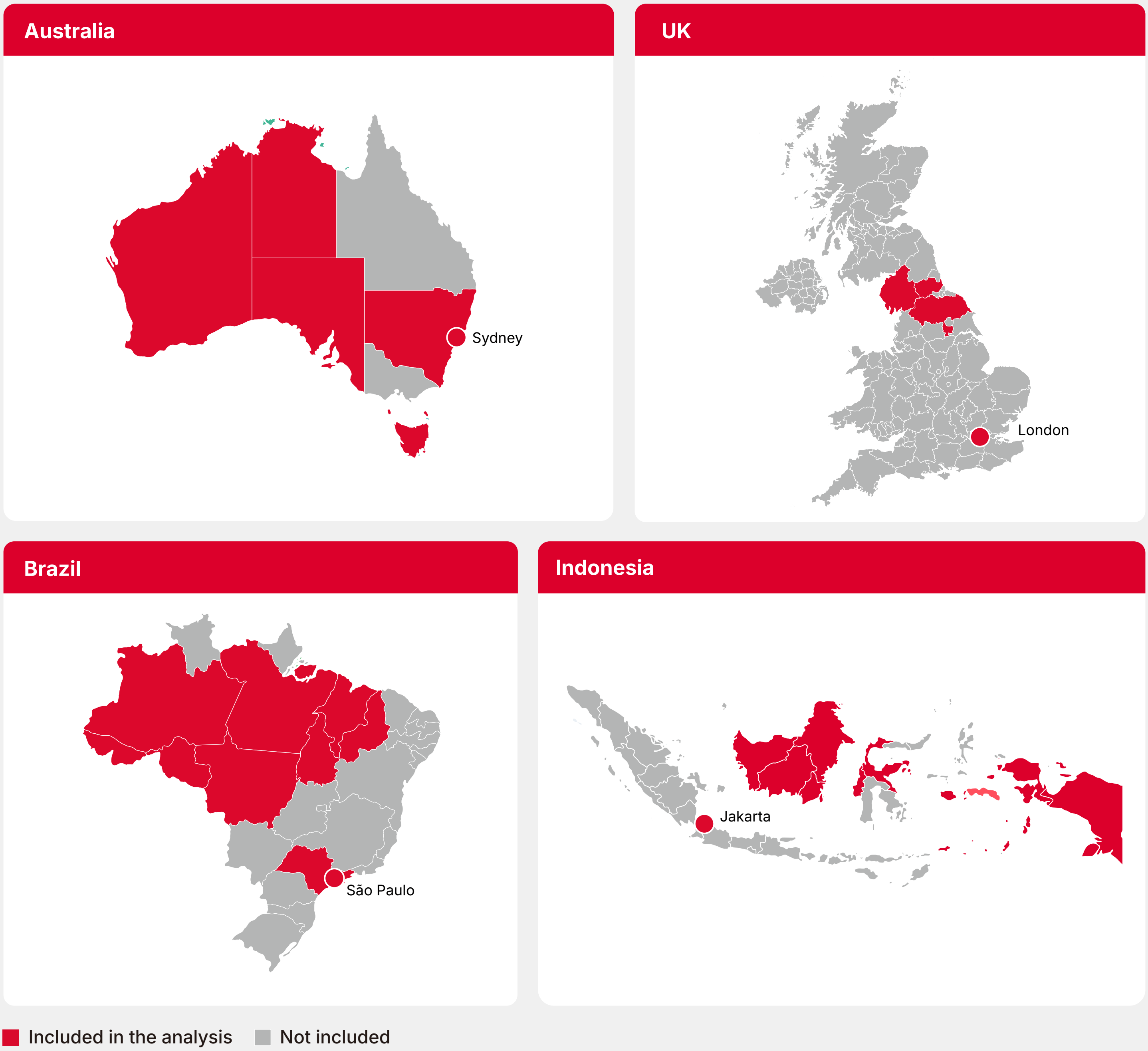
Country	2G	3G	4G	5G
Saint Lucia		✔	✔	
Saint Vincent And the Grenadines	✔	✔	✔	
Sao Tome And Principe	✔			
Saudi Arabia	✔	✔	✔	
Serbia	✔	✔	✔	
Seychelles	✔	✔	✔	
Singapore	✔		✔	
Slovakia	✔	✔	✔	
Slovenia	✔	✔	✔	
Somalia	✔			
South Africa	✔	✔	✔	
Spain	✔	✔	✔	
Sri Lanka	✔	✔	✔	
Sudan	✔			
Suriname	✔	✔		
Sweden	✔	✔	✔	
Switzerland	✔	✔	✔	✔
Syria	✔			
Taiwan	✔	✔	✔	
Tajikistan		✔	✔	
Tanzania	✔			
Thailand	✔	✔	✔	
Trinidad and Tobago		✔	✔	
Tunisia	✔	✔	✔	
Türkiye	✔	✔	✔	
Turkmenistan	✔			
Uganda	✔			
Ukraine	✔			
United Arab Emirates	✔	✔	✔	
United Kingdom	✔		✔	✔
United States of America	✔	✔	✔	
Uruguay	✔	✔		
Uzbekistan	✔	✔	✔	
Venezuela	✔	✔		
Vietnam	✔	✔	✔	
Zambia	✔	✔	✔	✔
Zimbabwe	✔	✔		

Technology and spectrum usage analysis (Figure 6)

The analysis of technology usage patterns employs the Ookla Unified Signal Scan Dataset for the specific areas of four study countries, as shown in Figure 33. Each signal scan record, which captures the technology in use at a specific time and location, is classified as urban or rural through a spatial join with the GHSL SMOD dataset.

The spatial join is performed using the geographic coordinates (latitude and longitude) of each signal scan, matching them to the corresponding SMOD grid cell to assign the appropriate urban/rural classification. Scans are then aggregated by technology generation separately for urban and rural areas, to reveal differential patterns of network utilisation across the urbanisation gradient.

Figure 33
Areas for in-depth analysis of spectrum use



Source: GSMA Intelligence

Speed and performance analysis (Figures 7 to 11)

Trends in global mobile network speeds over time (Figure 7) are derived from the open-source Speedtest by Ookla Global Fixed and Mobile Network Performance Maps. Each country in the dataset is categorised by income level using the World Bank classification. Download speed measurements from mobile networks are spatially joined with GHSL SMOD data to determine the urbanisation category, then aggregated by income level, urbanisation category and year. This technology-agnostic analysis captures overall mobile network performance evolution across different economic and geographic contexts. A similar methodology is applied to generate Figure 10, examining latency trends rather than download speeds.

Detailed speed analysis across rural and urban regions for different technologies (Figures 8 and 9) uses the Ookla Mobile Network Performance Dataset for the four study countries. Each performance test record is classified as urban or rural through a spatial join with the GHSL SMOD raster dataset. Speed measurements (download and upload) are then aggregated by technology generation and urbanisation category to reveal technology-specific performance differentials between urban and rural areas.

Figure 9 extends this analysis by incorporating GHSL population density data in addition to the urbanisation classification. Performance measurements are binned by population density ranges and analysed to examine the relationship between population density and observed network speeds within each technology generation. This gradient analysis reveals how performance varies along the continuum from sparse rural areas through dense urban cores, beyond simple binary urban-rural classification.

Figure 11 applies a similar methodology to examine latency performance patterns, using the same spatial classification and aggregation procedures applied to latency measurements rather than speed metrics.

Usage and speed variance across spectrum (Figures 13 and 18)

Figure 13 examines the distribution of technology and spectrum band usage across urban and rural contexts, derived from the Ookla Unified Signal Scan Dataset. The dataset captures background network scans performed by mobile devices, recording the cellular technology in use (2G, 3G, 4G, 5G) and the specific frequency band being used at each measurement point, along with precise geolocation data. The frequency bands are binned according to commonly used spectrum ranges in the telecoms sector. Figure 18 used the Ookla Mobile Performance Dataset and aggregates the speed across the frequency bins.

Spectrum availability and speed correlation (Figure 16)

Analysis of the relationship between spectrum availability and rural network performance (Figure 16) combines data from multiple sources. Rural speed measurements are extracted from the Speedtest by Ookla Global Fixed and Mobile Network Performance Maps dataset by spatially filtering measurements to rural classifications based on GHSL SMOD data. Country-level spectrum availability data is obtained from GSMA Intelligence's own collection of total spectrum assigned by regulators in each country, documenting the total amount and band distribution of spectrum assigned to mobile services as of 2024. Statistical correlation analysis examines the relationship between spectrum availability in each country and the observed average rural download speeds, testing whether countries with more abundant spectrum resources deliver superior rural performance.

Temporal analysis (Figure 19)

Temporal performance variation analysis (Figure 19) employs the Ookla Mobile Network Performance Dataset with additional temporal processing. Each performance test record contains a timestamp, which is converted to the local timezone for the country of measurement to enable consistent temporal aggregation across countries. Tests are classified as urban or rural via GHSL SMOD data, then aggregated by hour of day and urbanisation category to reveal diurnal patterns in network performance.

Signal quality analysis (Figures 20 and 21)

Signal quality analysis (Figures 20 and 21) uses the Ookla Unified Signal Scan Dataset, incorporating RSRP measurements indicating received signal strength. RSRP values are categorised into three classes representing different serving conditions.

Table 4:
RSRP signal-strength thresholds

Category	Signal strength (dBm)
Strong signal	> –90
Mid-cell	–100 to –90
Cell edge	< –100

Source: GSMA Intelligence

Figure 20 presents the distribution of measurements across these signal quality categories, while Figure 21 correlates signal quality category with observed performance by analysing speed test results from the Mobile Network Performance Dataset classified by their concurrent signal strength conditions. This signal-quality-stratified performance analysis reveals the impact of radio conditions on user-experienced throughput.

GSMA Head Office
1 Angel Lane
London
EC4R 3AB
United Kingdom
gsma.com