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Using Geospatial Analysis to Overhaul Connectivity Policies

How to Expand Mobile Internet Coverage and Adoption in Sub-Saharan Africa

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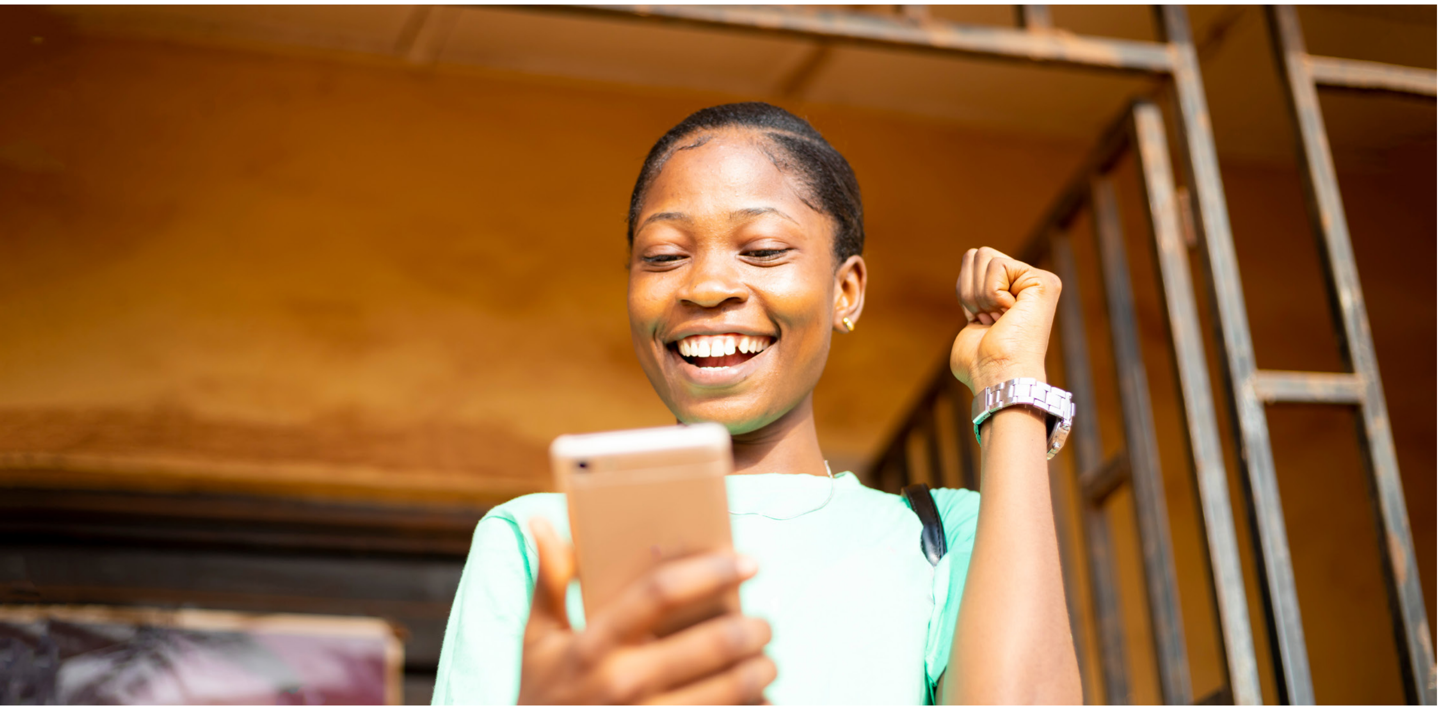
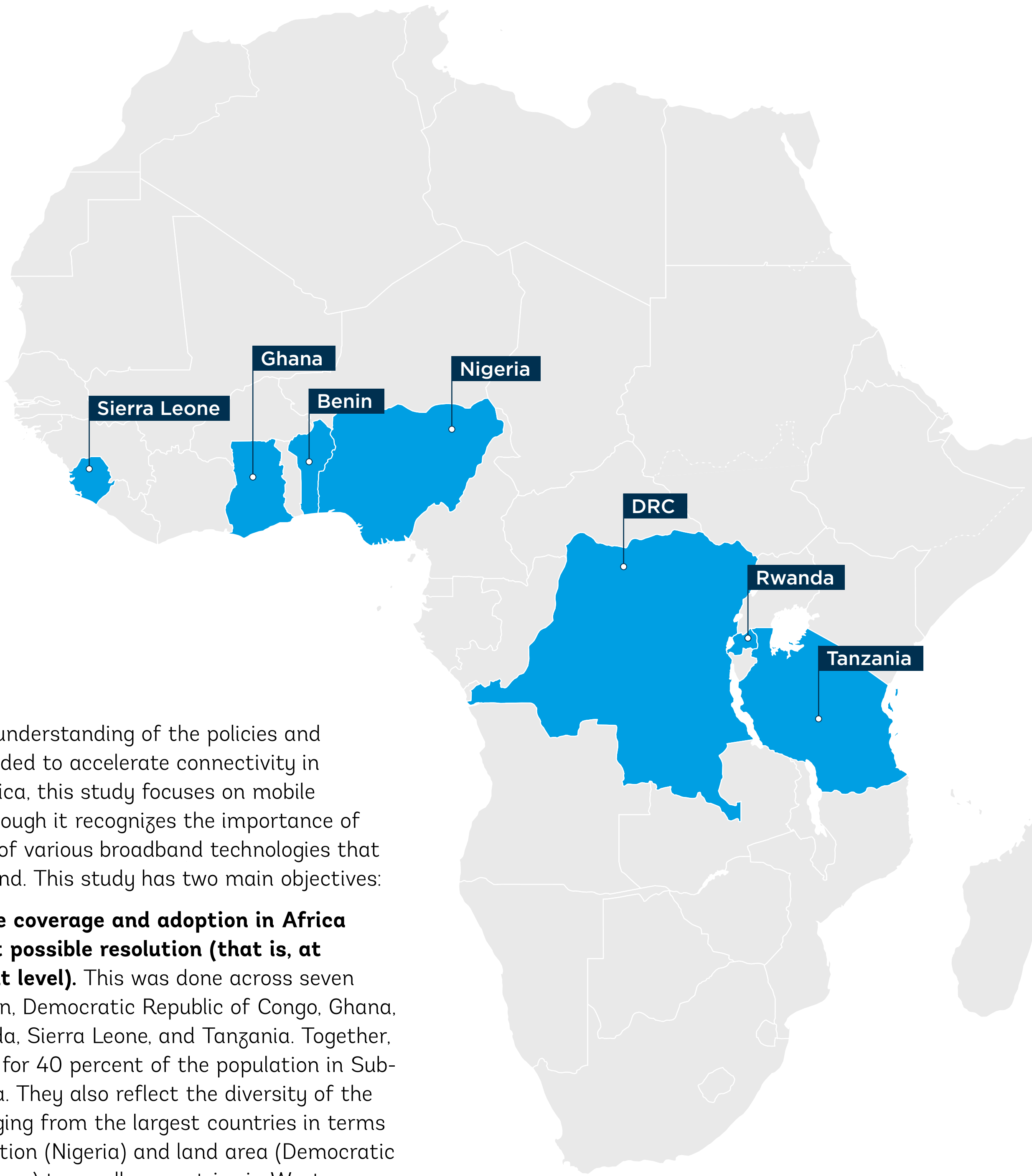


Executive Summary

Increasing access to the internet is one of the great challenges of our time and has grown in importance since the outbreak of the COVID-19 pandemic. Around half the world's population remains online, while in Sub-Saharan Africa just over a quarter of the population uses the internet. The region also accounts for almost half of the 450 million people around the world who do not live in areas covered by 3G or 4G mobile networks.

Connectivity gaps are a consequence of fundamental economic challenges around supply and demand. In a market-led environment, mobile operators will provide coverage where there is existing or expected demand for connectivity. Expanding mobile broadband coverage will partly depend on lowering costs and investments risks, but the main driver will be enhanced demand for connectivity services. Mobile technology is particularly important to drive connectivity forward in Africa, as it accounts for more than 98 percent of broadband connections.[1]

1 Source: International Telecommunication Union (ITU).



To gain a better understanding of the policies and interventions needed to accelerate connectivity in Sub-Saharan Africa, this study focuses on mobile connectivity, although it recognizes the importance of enabling the use of various broadband technologies that respond to demand. This study has two main objectives:

- **To map mobile coverage and adoption in Africa at the highest possible resolution (that is, at the settlement level).** This was done across seven countries: Benin, Democratic Republic of Congo, Ghana, Nigeria, Rwanda, Sierra Leone, and Tanzania. Together, these account for 40 percent of the population in Sub-Saharan Africa. They also reflect the diversity of the continent, ranging from the largest countries in terms of both population (Nigeria) and land area (Democratic Republic of Congo) to smaller countries in Western Africa (Benin, Ghana, and Sierra Leone) and Eastern Africa (Rwanda and Tanzania).
- **To simulate the effects of different policies using granular data on both the location of infrastructure and demand for mobile and internet services.** This enables more precise calculations and therefore a deeper understanding of the impacts policy reforms can have on coverage and adoption, as well as the additional investment needed to achieve universal connectivity by 2030.

Key Findings

- **Mobile operators are very close to the 'market frontier' for 2G coverage,** with at least 87 percent of the population covered across the seven countries. There is a limited amount of additional 2G coverage that can be provided by the private sector that is financially viable and sustainable in current market conditions. Almost all the uncovered areas are in rural, often remote, locations.
- **Extending mobile broadband to areas with no coverage presents a substantial economic challenge.** It will require efforts to reduce deployment costs and, more importantly, increase demand. Both are contingent on continued, collaborative action by all stakeholders, building on private sector innovation, which in recent years has driven significant cost reductions in rural network deployments, as well as in handset and data prices.
- **While 3G and 4G coverage are lagging at 74 percent and 48 percent of the population, respectively, they could catch up with 2G coverage in the coming years if spectrum management is updated,** for example, to ensure operators have access to sufficient and affordable spectrum in sub-1 GHz bands, including the refarming of the existing spectrum so that it is technology neutral. Across four countries where not all operators have access to sub-1 GHz spectrum for 4G (in Ghana, Nigeria, Sierra Leone, and Tanzania), an operator could increase rural 4G coverage by more than 5 percentage points (or 7.5 million people) if it could use 700 or 800 MHz spectrum for 4G (assuming existing spectrum fees are applied).
- **Infrastructure sharing at the site level would enable coverage to expand while maintaining service-level competition.** Active sharing would allow 2–10 percent of the rural population (depending on the country) to have mobile broadband coverage from more than one operator. Policy makers that are considering single wholesale networks (SWNs) should also consider that active sharing can deliver similar levels of coverage to SWNs while maintaining a greater degree of service competition (so long as competition safeguards are in place).

- **Aligning tax policy with best-practice principles and removing distortive sector-specific taxes solely applied to the mobile sector** would improve investment incentives for operators as well as affordability for consumers. This includes the removal of excise duties on handsets and mobile services that are not applied to other goods and services, as well as the reduction of taxes levied on mobile operators but not on other firms in the economy. This reform, even considering partial pass-through on prices, could expand mobile broadband coverage by up to 4 percentage points (depending on the country) and could bring more than 30 million people online by 2030 (increasing mobile internet adoption by 6 percentage points). Since taxation in the sector is part of broad national taxation policy, expected benefits for the sector and digital transformation of the economy have to be considered when assessing tradeoffs. An encompassing analysis of effects in the whole economy is beyond the scope of this report.
- While these policy reforms would drive important gains in connectivity, by 2030 it would still leave 9 percent of the population without mobile broadband coverage and 17 percent of the population ages 10 and above offline. **Additional interventions on the supply and demand sides are therefore still needed to make mobile broadband coverage and adoption universal by 2030.** In the seven countries studied, with the policy reforms in place, around US$1.7 billion of additional investment would cover the vast majority of populations with 4G networks, of which almost 40 percent could be funded by the private sector, leaving an investment gap of US$1.1 billion. Without the policy reforms highlighted above, the investment gap would be US$1.3 billion; **policy reforms can therefore save around 15 percent of the additional investment needed to achieve near-universal coverage.**
- An alternative, or at least complementary, approach to expanding 4G coverage would be to **focus on additional policy reforms and investment that stimulate demand.** Over the next five years, current forecasts indicate that 4G penetration will not exceed 15 percent in any of the seven countries and in rural areas, it is expected that 4G penetration will be less than 5 percent in every country by 2025. **Lack of demand, given affordability and other barriers to adoption, is the fundamental reason why universal 4G coverage will be challenging without further policy reforms and public investment, and why 'leapfrogging' to 4G is unlikely to occur in rural areas.** However, this could change if further reform and/or investment can stimulate large increases in demand. If expected 4G penetration was 20 percent in uncovered (mostly rural) areas, operators would extend 4G coverage to more than 89 percent of the population in all seven markets without the need of supply subsidies. If 4G penetration increased to 40 percent, 4G coverage would almost reach the same levels as would be achieved with a pure infrastructure subsidy. Further research to better identify and evaluate interventions that can influence mobile internet demand will therefore be important going forward to enable widespread 4G coverage in Sub-Saharan Africa. These could include policies to enhance digital skills and literacy and the availability of relevant content and mobile applications, interventions to expand access to electricity, or interventions to improve access to mobile devices.

The findings from this study can be used to directly inform policy making in the seven study countries, while the analysis can be leveraged to understand the impact of policies and investments in different geographic locations. Many of the policy findings are likely to apply in other countries with similar characteristics. However, given the extent to which mobile connectivity varies by location, it is important to carry out granular analysis in other countries to ensure interventions are targeted at where they are needed and ensure their effectiveness. This report uses a model developed by GSMA based on detailed mobile network data collected from operators; but as coverage and usage expand, simulations need to be updated. Finally, it is also worth noting that addressing connectivity challenges in Africa require the use of various technologies that respond to demand needs in a policy environment that allows for innovation on a level playing field.

Definitions of terms used

- **Coverage.** Population coverage refers to the share of a country's population that lives in an area where the signal provided by a mobile network is strong enough to use telecommunication services (voice, short messaging service [SMS], and data). The signal strength is calculated with standard signal propagation algorithms that use the location of every tower in the country for all operators combined (see Appendix A for further detail). The countrywide coverage footprint for each technology (2G, 3G, and 4G) is obtained by combining the coverage provided by each individual site for every operator in the country. The coverage status for each individual settlement in the country is estimated by overlaying these countrywide coverage footprints with population distribution data.

  It is possible that the estimates of coverage presented in this report may differ from other sources due to differences in population data, the propagation model used, or because the analysis looks at the combined coverage for all mobile operators. Furthermore, the network infrastructure data were collected in Q3 2018 (for Ghana), Q4 2018 (for Rwanda), Q3 2019 (for Nigeria), Q1 2020 (for Benin, Democratic Republic of Congo, Sierra Leone), and Q4 2020 (for Tanzania). It is therefore possible that population coverage in each country has since increased. This report does not analyze coverage by geographic area.
- **Mobile broadband.** 3G, 4G, or 5G technologies that enable high-speed access to the internet.
- **Coverage gap.** Populations that live outside the footprint of a mobile broadband network.
- **Mobile owner/subscriber.** A person who subscribes to a mobile service. They do not necessarily use mobile internet.
- **Mobile internet user.** A person who uses internet services on a mobile device. Mobile internet services are defined as activities that use mobile data. The data presented in this report on the number of unique mobile internet users are sourced from GSMA[2] Intelligence and national regulatory authorities. Granular estimates of demand are calculated at a settlement level based on an estimation model that uses population settlement data, household survey, and night light data (see Appendix A for further detail). The model is calibrated such that the total number of unique mobile subscribers and mobile internet subscribers are consistent with estimates by GSMA Intelligence as of Q3 2020. This ensures that the aggregate level of demand is accurate and that it is distributed across the country based on the relevant demand drivers and where coverage exists.

  As the report refers to unique subscribers, rather than connections or SIM cards, the number of users may be lower than data published by mobile operators and national regulators. This is because individuals can own and use multiple SIM cards. It is also possible that the number of mobile internet users may have increased since Q3 2020.
- **Connected.** 'The connected' or 'connected population' refers to people who use mobile internet.
- **Usage gap.** Populations that live within the footprint of a mobile broadband network but do not use mobile internet.
- **Mobile internet penetration (or adoption).** This refers to the percentage of a country's population that uses mobile internet services. This report refers to the total population as the base (that is, mobile internet penetration is calculated as the number of unique mobile internet subscribers divided by the total population).

2 GSMA = Global System for Mobile Communications.

- **Universal adoption.** As it is not realistic to expect every person to use mobile internet, 'universal adoption' is defined as when a country achieves 90 percent penetration of the population ages 10 years or older. This is consistent with the Connecting Africa Through Broadband Initiative (Broadband Commission 2019) and means young children are excluded from the target. It also considers segments of the population that choose not to use information and communication technology (ICT), are prevented from doing so, or those that use shared facilities. In each of the seven countries considered in the study, achieving this definition of universal adoption would mean they would need to reach 65–70 percent penetration based on the total population.
- **Feature phone.** A mobile handset that allows basic access to internet-based services but on a closed platform that does not support a broad range of applications. The handset supports additional features such as a camera and the ability to play multimedia files such as music and video. A 'smart feature phone' is a feature phone that has an operating system that supports a range of applications created by third-party developers and that are formatted to work on a smaller screen and accessed through a nine-key layout and not a touch screen.
- **Smart feature phone.** A feature phone that has an operating system that supports a range of applications created by third-party developers and that are formatted to work on a smaller screen and accessed via a 9 key layout not a touch screen.
- **Smartphone.** A mobile handset enabling advanced access to internet-based services and other digital functions. Smartphone platforms, such as Android and iOS, support a range of applications created by third-party developers.
- **Settlement.** The population geographic distribution data used for this report is sourced from the High Resolution Settlement Layer database,[3] which provides estimates of human population distribution based on census data and high-resolution satellite imagery. Settlements are defined as clusters of houses and buildings located within a close distance to each other. The clustering process used may result in settlements that differ from local administrative or cultural denominations of towns and villages.
- **Rural/urban.** For each country, we classify a settlement as rural if the population is less than 5,000. We also applied an approach set out in the recommendation to delineate cities and urban and rural areas by several international organizations.[4] For the majority of countries, the results were very similar (that is, rural/urban settlements were mostly classified consistently regardless of the approach used). Where there were differences, the approach used in this report produced rural population estimates that were more consistent with those published by national statistical authorities and the United Nations (UN).[5] We therefore applied a consistent approach across all seven countries.
- **Market frontier.** The level of coverage and adoption that will be provided by the private sector over the next five years based on current market conditions. It represents the coverage that operators can achieve with sites that are profitable. The market frontier can change with policy reforms that have an impact on network deployment costs and/or adoption.

3 Facebook Connectivity Lab and Center for International Earth Science Information Network - CIESIN - Columbia University. 2016. High Resolution Settlement Layer (HRSL). Source imagery for HRSL © 2016 DigitalGlobe.

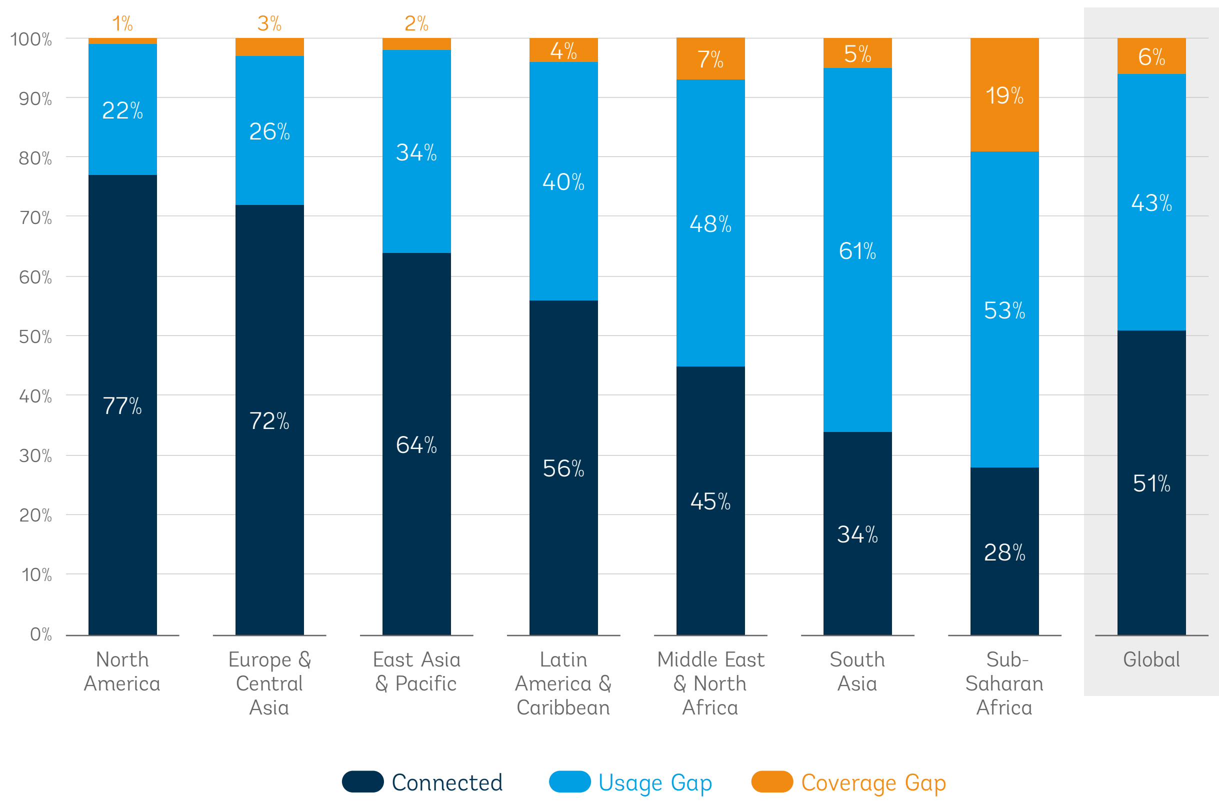
4 'A Recommendation on the Method to Delineate Cities, Urban and Rural Areas for International Statistical Comparisons – prepared by the European Commission – Eurostat and DG for Regional and Urban Policy – ILO, FAO, Organisation for Economic Co-operation and Development (OECD), UN-Habitat, World Bank, 2020.

5 See, for example, https://population.un.org/wpp/.

01 Introduction

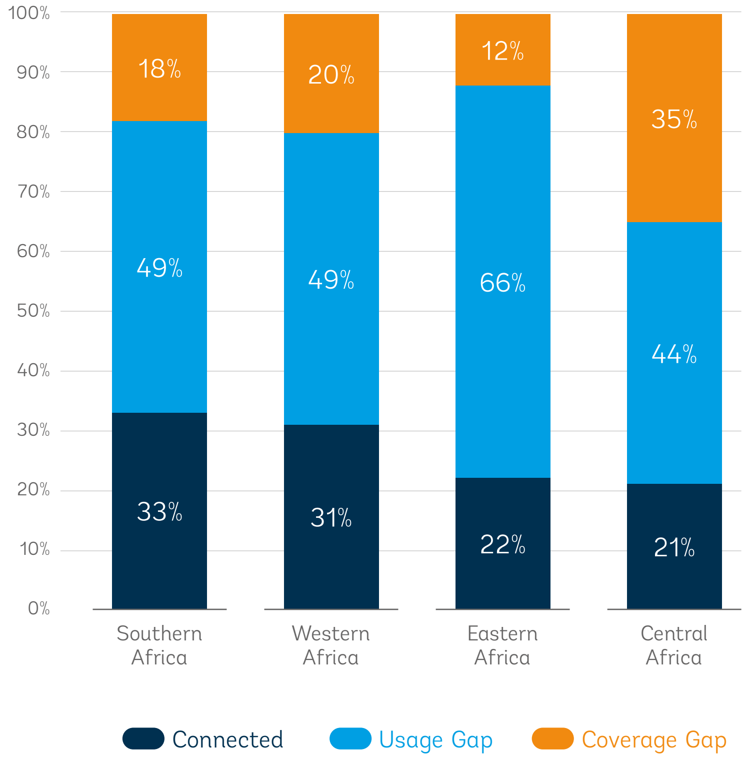
Increasing access to the internet is one of the great challenges of our time and has grown in importance since the outbreak of the COVID-19 pandemic. Around half the world's population do not have access to the internet (GSMA 2020; ITU 2020), meaning they are unable to access the jobs, education, health care, financial services, and information needed to fully participate in social, political, and economic life. This digital divide is most pronounced in Sub-Saharan Africa, where just over a quarter of the population uses the internet (Figure 1). The region also accounts for almost half of the 450 million people around the world who do not live in areas covered by 3G or 4G mobile networks. Within the continent, the coverage gap is notably larger in Central Africa, while the usage gap is highest in Eastern Africa (Figure 2).

Figure 1.
State of mobile internet connectivity, by region (2020)



Source: State of Mobile Internet Connectivity Report 2020, GSMA

Figure 2.
State of mobile internet connectivity in Sub-Saharan Africa, by sub-region (2020)



Source: GSMA Intelligence.
Note: Countries are initially classified based on whether they are in the Southern African Development Community, the West African Economic and Monetary Union, the East African Community, or the Economic Community of Central African States. Countries not in one of these economic unions are classified based on UN geographic classifications.

Connectivity gaps are a consequence of fundamental economic challenges around supply and demand (Figure 3). In a market-led environment, mobile operators will provide coverage where there is existing or expected demand for connectivity. Indeed, two-thirds of the unconnected population in Sub-Saharan Africa already have 3G/4G coverage but are not able to use the internet due to other barriers, including awareness, affordability, access to electricity, digital skills, and literacy and the availability of relevant online content and applications. Expanding mobile broadband coverage will partly depend on lowering costs and investments risks, but the main driver will be enhanced demand for mobile services.

Figure 3.
Supply and demand of mobile connectivity

* Parameters for which we modelled the impact of different policies
** Parameters that are indirectly captured by the model using demand elasticities
Source: GSMA.
Note: ARPU = Average Revenue Per User; Capex = Capital Expenditure; MNO = Mobile Network Operator; Opex = Operating Expenditure.

To address the digital gap in the region, mobile operators, governments, and international organizations have committed to a number of international targets to achieve universal coverage and connectivity.[6] These recognize the transformative impact that internet access can have. Studies have shown that expanding mobile broadband coverage and connectivity in Africa reduces poverty (GSMA and World Bank 2020, Bahia et al. 2020 and 2021) and increases sustainable development (Rotondi et al. 2020) and economic growth (GSMA 2020a; ITU 2019, Calderon and Cantu 2021).

However, while there are common elements to the barriers that stop people from using the internet, each country is unique and presents different challenges in terms of geography, socioeconomic development, and the regulatory and policy framework. To better understand the state of connectivity and identify appropriate policy reforms to expand digital access, the study uses a supply-and-demand model for seven countries in Sub-Saharan Africa: Benin, Democratic Republic of Congo (Democratic Republic of Congo), Ghana, Nigeria, Rwanda, Sierra Leone, and Tanzania. Together, these account for 40 percent of the population in Sub-Saharan Africa. They also reflect the diversity of the continent, ranging from the largest countries in terms of both population (Nigeria) and land area (Democratic Republic of Congo) to smaller countries in Western Africa (Benin and Sierra Leone) and Eastern Africa (Rwanda and Tanzania). The countries are also at different stages in their development of digital connectivity (Table 1), which allows the analysis to consider the broad range of challenges that governments and the private sector face in the region.

Table 1.
Key metrics on seven study countries

Country	Population (million)	Area (km²)	GDP per Capita (US$)	UN Human Development Index (0–1)	Mobile Connectivity Index Score (0–100)*	Mobile Internet Adoption (%)	Mobile Broadband Coverage
Benin	12.12	114,760	1,219	0.545	39.1	27	89
Democratic Republic of Congo	89.56	2,344,860	581	0.480	26.2	18	54
Ghana	31.07	238,540	2,202	0.611	52.0	37	88
Nigeria	206.14	923,770	2,230	0.539	49.1	33	76
Rwanda	12.95	26,340	820	0.543	42.8	24	88
Sierra Leone	7.98	72,300	528	0.447	38.6	28	77
Tanzania	59.73	947,300	1,122	0.524	40.1	21	83

Source: GSMA analysis of data sourced from UN, World Bank, and GSMA Intelligence.
Note: GDP = Gross Domestic Product.
* Reflects the latest score in the GSMA Mobile Connectivity Index, which measures the performance of countries against the key enablers of mobile internet adoption.

6 Examples of such targets include the UN Sustainable Development Goals (SDG 9 includes Target 9c to "Significantly increase access to information and communications technology and strive to provide universal and affordable access to the internet in least developed countries by 2020"); the Broadband Commission for Sustainable Development 2025 targets for "Connecting the Other Half"; the World Bank's Digital Economy for Africa, which aims to ensure that all Africans have universal and affordable access to information and communication technology (ICT) by no later than 2030 and the African Union's Digital Transformation Strategy for Africa (2020–2030).

In each of the seven countries, we carried out hyper-granular supply and demand analysis, leveraging data from the GSMA Mobile Coverage Maps[7] as well as country survey data, to understand current levels of coverage and adoption in each settlement. The analysis also calculated the expected level of connectivity in current market conditions, that is, the additional amount of coverage and adoption that would be delivered by the market, given expected growth in demand over the next five years (Box 1).[8]

The next step was to assess the impact of different policy levers that can affect either supply (that is, costs) and/or demand (that is, adoption or revenue). The study first considered different aspects of an enabling policy and regulatory framework, ranging from infrastructure sharing and spectrum policy to taxation and SIM registration. If these policy reforms were not sufficient to meet the goal of universal connectivity, we estimated the amount of additional investment needed to achieve it. The results from this study should therefore help support policy makers make informed decisions to accelerate connectivity (especially in rural areas)—not just in the seven study countries but also in the wider region.

The policies covered in this report are not exhaustive. When considering policies that might increase adoption of mobile internet services, focus was primarily given to affordability and access to devices. This is because there were insufficient data to model the impact of policies that might influence other enabling factors, especially those related to digital skills and literacy and the availability of relevant content. These are areas that will benefit from further research and analysis, as they remain important barriers to adoption in many countries. Furthermore, the models developed for this study have the capability to assess the impact of other policies that affect operational costs or prices when the relevant data become available.

The structure of the rest of this analysis is as follows:

- **Chapter 2** provides provides an assessment of the current state of connectivity for 2G, 3G, and 4G networks in the seven countries based on granular estimates with latest available detailed country-level information.
- **Chapter 3** discusses the recent innovations that are already enabling increased coverage in rural and remote areas using mobile technologies and that are essential to unlocking the impacts of further policy reforms.
- **Chapter 4** shows which enabling policies considered in the study can increase coverage and adoption.
- **Chapter 5** highlights the additional interventions needed to make connectivity universal.
- **Chapter 6** draws conclusions from the analysis.

7 https://www.mobilecoveragemaps.com/
8 For simulations of the effects of changes in market structure (as a proxy for stronger competition) on coverage and adoption, see Dutz, Begazo and Blimpo (forthcoming).

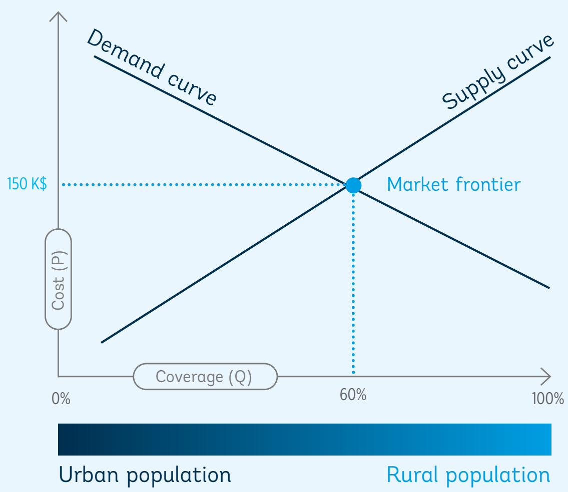
Box 1

Analytical approach

In each of the seven countries, the model used geospatial techniques to carry out hyper-granular supply and demand analysis, leveraging data from the GSMA Mobile Coverage Maps as well as data from household surveys, night-light imagery, and geospatial population distributions. This allowed to calculate, for each population settlement in a country, coverage by technology (2G, 3G, and 4G) and the level of adoption for mobile and mobile internet services. As the mobile infrastructure data are sourced directly from mobile operators, based on a comprehensive list of site locations, the analysis provides the most accurate appraisal of network coverage currently available in the public domain.

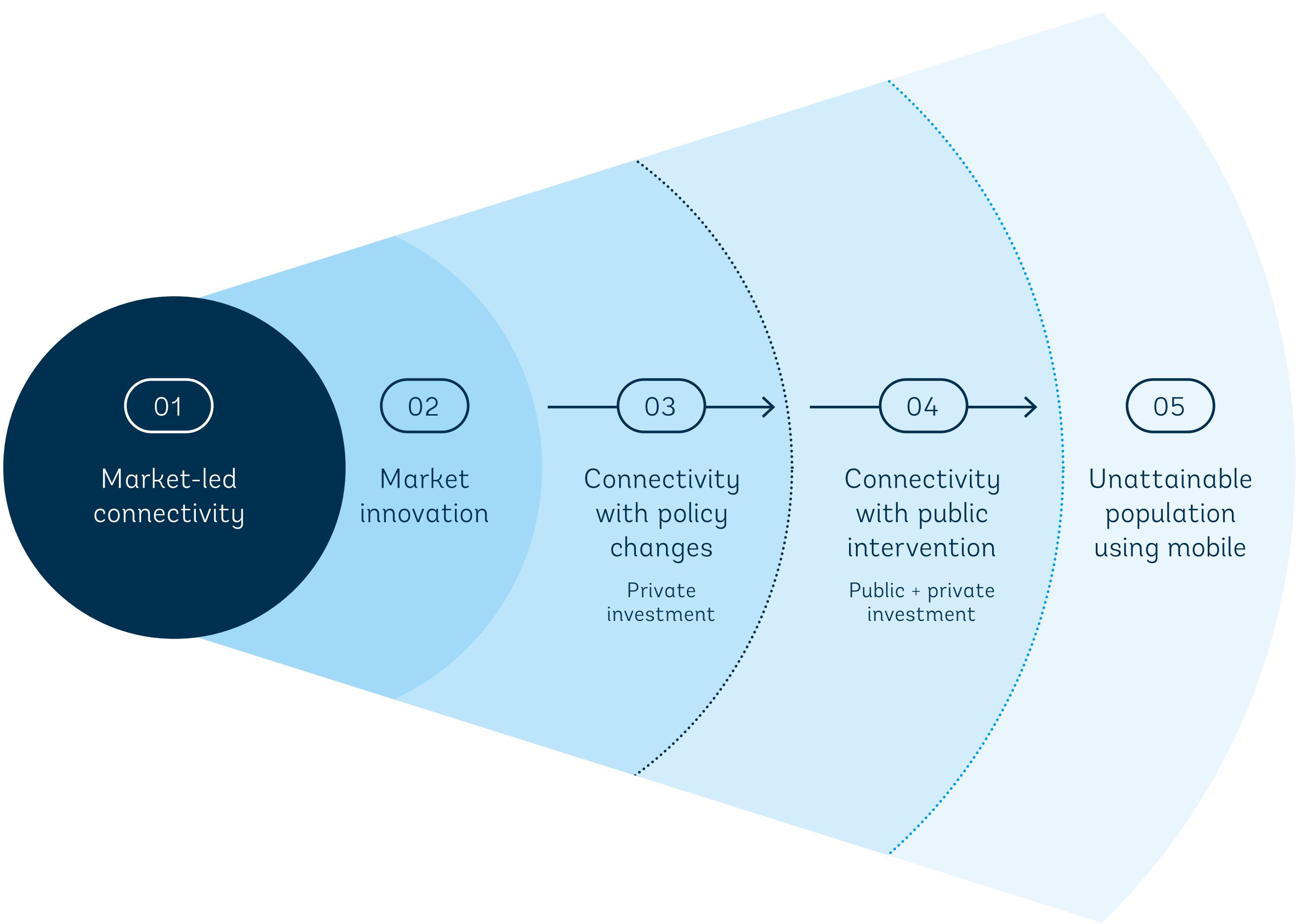
Based on this data, a model was developed to emulate the decision-making process of mobile operators when they consider whether to invest in 2G/3G/4G network expansion. The model is focused on the 'last mile' of infrastructure, that is, the mobile site that connects with the end user as well as the backhaul link that connects sites to the core network. While investments in the 'first mile' (for example, international cables) and 'middle mile' (for example, backbone and internet exchange points [IXPs]) are important in terms of increasing network capacity, especially in urban areas, based on the current and expected levels of data usage in rural areas across the seven countries, we found that operators have sufficient network capacity to meet demand in uncovered areas. The most significant barriers to expanding coverage are in the last mile, so they are the focus of this study.

The analysis was based on a net present value (NPV) approach at the level of individual sites, where operators decide whether to invest based on the expected revenues and the associated capital and operating costs from either upgrading an existing site (for example, from 2G to 3G/4G) or deploying a new site (where no coverage exists). For each site, we assess profitability considering the relevant country weighted average cost of capital (WACC) over five years. The 'market frontier' represents the aggregate number of sites that are profitable (with non-negative NPV), that is, where supply (costs) is equal to demand (revenues). This gives the expected level of coverage that will be provided by the private sector over the next five years, which we define as the current market frontier.



The next step was to assess the impact of different policy levers that can affect costs and/or adoption. This in turn can affect the profitability of new sites, which can then increase (or decrease) expected coverage and therefore change the market frontier. Lastly, for sites that remain unprofitable even after policy reform, the model calculates the level of additional investment needed to achieve near-universal access. There were then some remaining population segments where, given the high cost, alternative technology solutions are likely to be needed. An illustration of the outcomes at each stage in the analysis is provided in figure 4, while further detail on the modelling is provided in Appendix A.

Figure 4
Illustration of mobile connectivity analysis



Market-led connectivity. The level of coverage and adoption expected in prevailing market conditions with no policy reform or innovation. This is discussed in Chapter 2.

Market innovation. The additional coverage and adoption expected due to the deployment of recent technology innovations for mobile connectivity, particularly lower-cost mobile sites. This is discussed in Chapter 3.

Connectivity with policy changes. The additional coverage and adoption that could be achieved by implementing the analyzed policy reform. This is discussed in Chapter 4.

Connectivity with public intervention. The additional coverage and adoption that could be achieved with a subsidy (subsidizing infrastructure and/or handsets and mobile usage). This is discussed in Chapter 5.

Population unattainable using mobile. The proportion of the population unlikely to obtain mobile coverage even with a public subsidy, as the costs are too high; other technologies might be more suitable. This is discussed in Chapter 5.

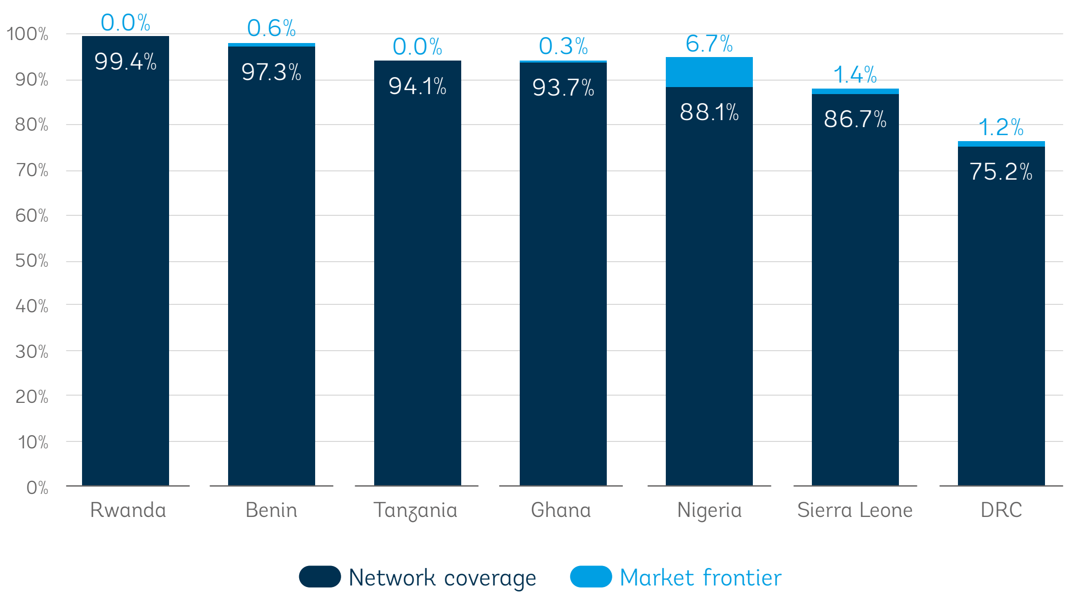
02 Connectivity has Been Delivered by Market Forces

2G coverage has almost reached the current market frontier

Across all the countries studied, mobile operators are very close to the level of population coverage for 2G that is commercially viable (Figure 5). For example, 2G population coverage stands at 75 percent in Democratic Republic of Congo and this analysis suggests that when looking at new potential macro-site deployments, those that are profitable would provide coverage to an additional 1.2 percent of the country's population. Deploying networks in the vast majority of areas that are not covered by a mobile network is therefore not financially sustainable. The notable exception is Nigeria, though it is worth noting that almost half the potential coverage gains are in conflict areas and so are unlikely to materialize until these are resolved.[9]

The extent of 2G population coverage varies across the countries, ranging from almost universal in Rwanda and Benin to 75 percent in Democratic Republic of Congo. In all seven countries, coverage in urban areas is either currently or expected to be more than 99 percent by 2025. The remaining populations that will not have coverage by 2025 are almost entirely in rural areas, many of them being sparsely populated (Figure 6).

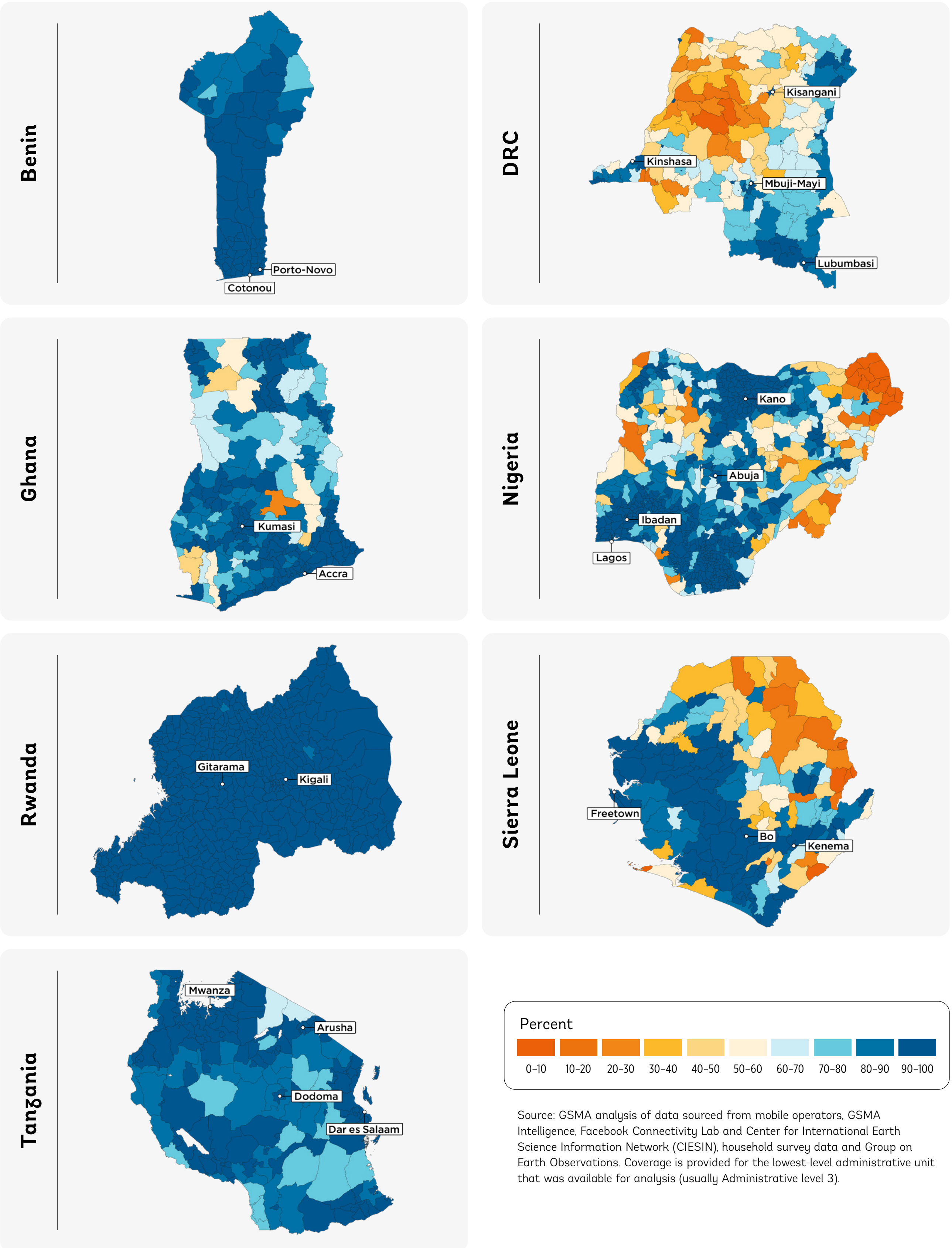
Figure 5.
2G coverage in seven countries



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and Center for International Earth Science Information Network (CIESIN), household survey data, and Group on Earth Observations.

9 In Nigeria, three states—Adamawa, Borno, and Yobe—are identified as high-security risk areas by the regulator. It is therefore likely that no additional coverage will be deployed in these areas until there is a resolution to military and political conflicts.

Figure 6.
2G population coverage maps



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and Center for International Earth Science Information Network (CIESIN), household survey data and Group on Earth Observations. Coverage is provided for the lowest-level administrative unit that was available for analysis (usually Administrative level 3).

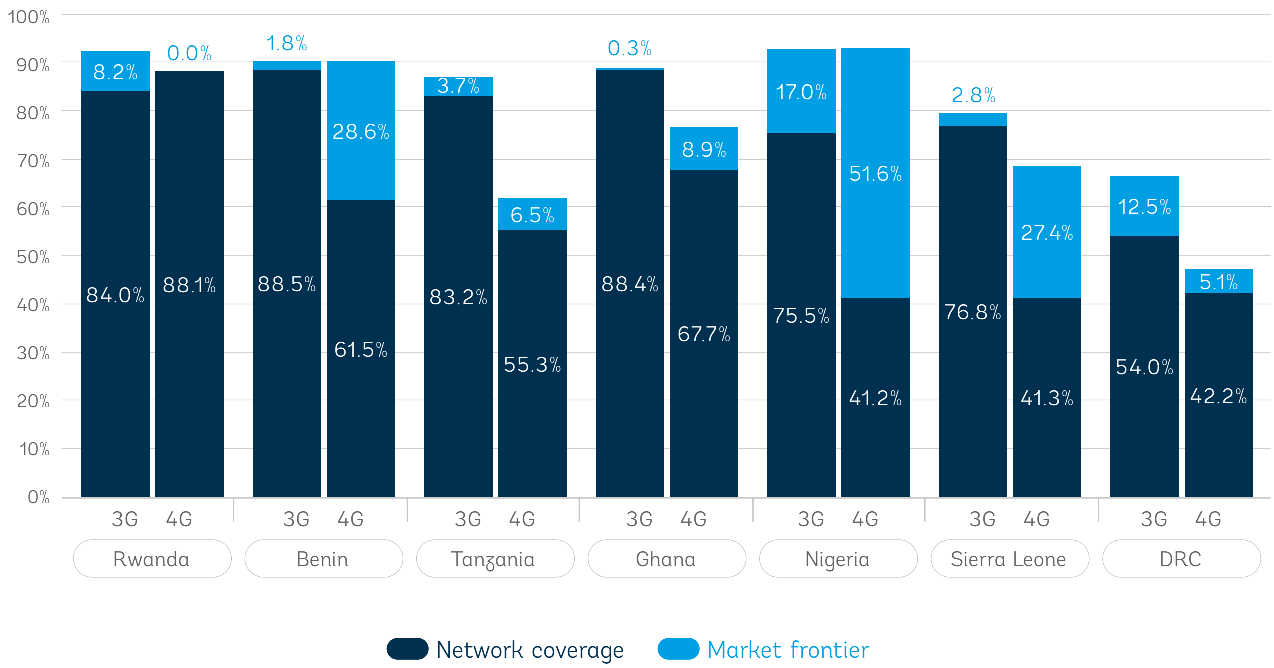
3G and 4G coverage are expected to approach 2G coverage

In the case of 3G and 4G, the market frontier analysis shows that coverage is expected to increase over the next five years, most notably in Nigeria (and Benin in the case of 4G) due to the higher expected demand. Almost all the expected gains in mobile broadband coverage will come from upgrading existing 2G-only sites (given that additional coverage from new 'greenfield' sites[10] is likely to be limited, as highlighted by the market frontier for 2G). This is consistent with the broader trend seen in Sub-Saharan Africa over the last few years, as 3G population coverage in the region increased from 63 percent in 2017 to 75 percent in 2019, while 4G population increased from 25 percent to 49 percent over the same period (GSMA 2020).

These improvements have been enabled by supply and demand factors. In terms of the former, many regulators have allowed operators to refarm the 900 MHz spectrum for 3G use and have assigned sub-1 GHz spectrum for 4G, which has enabled more cost-efficient deployment in more sparsely populated areas (GSMA 2019a).

Similar to 2G coverage, the majority of urban areas have or are expected to have 3G/4G coverage by 2025, meaning most of the uncovered populations will be sparsely populated areas with lower levels of socioeconomic development—for example, in the north of Ghana and outside of the western regions of Sierra Leone (Figure 8).

Figure 7.
3G and 4G coverage by technology in seven countries

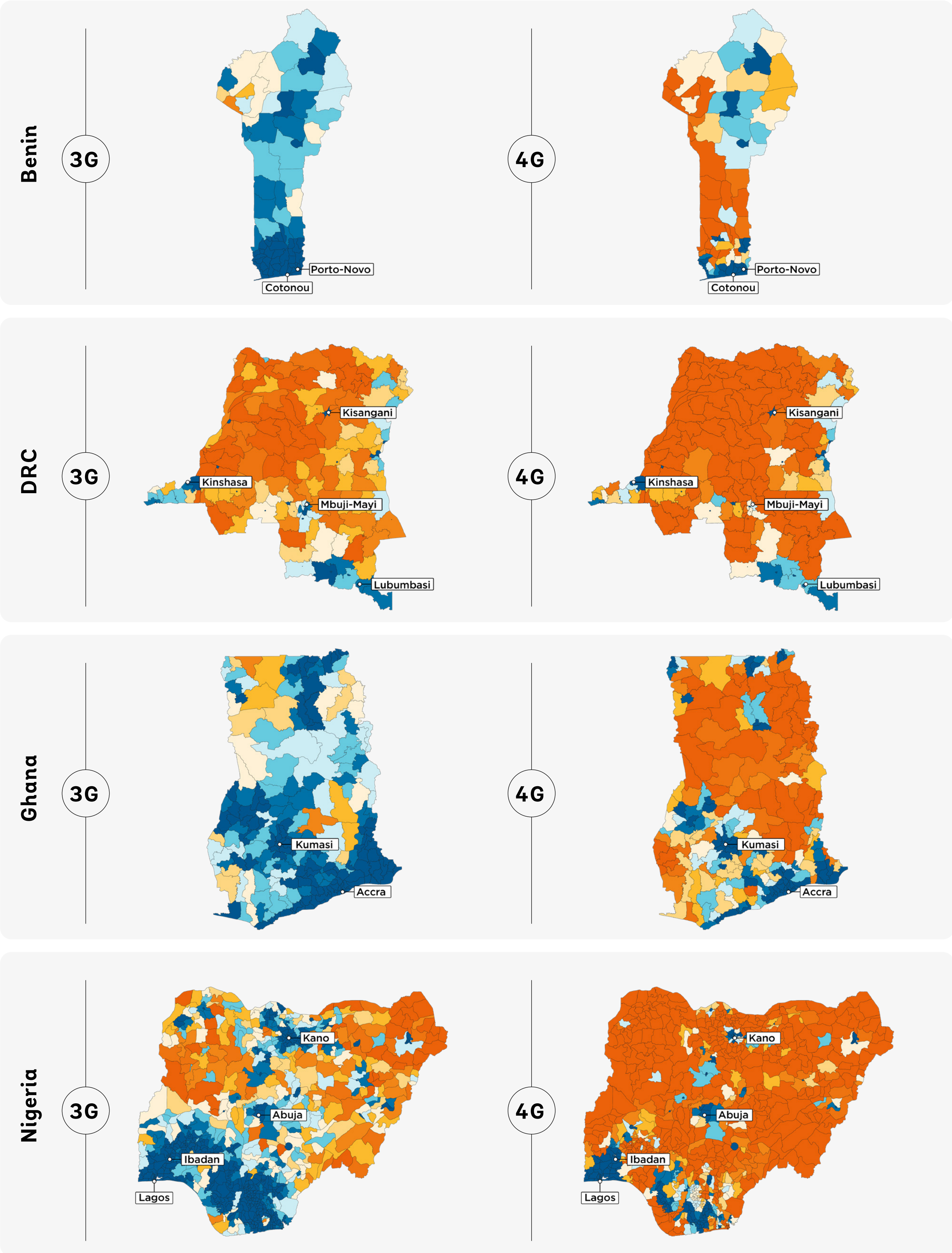


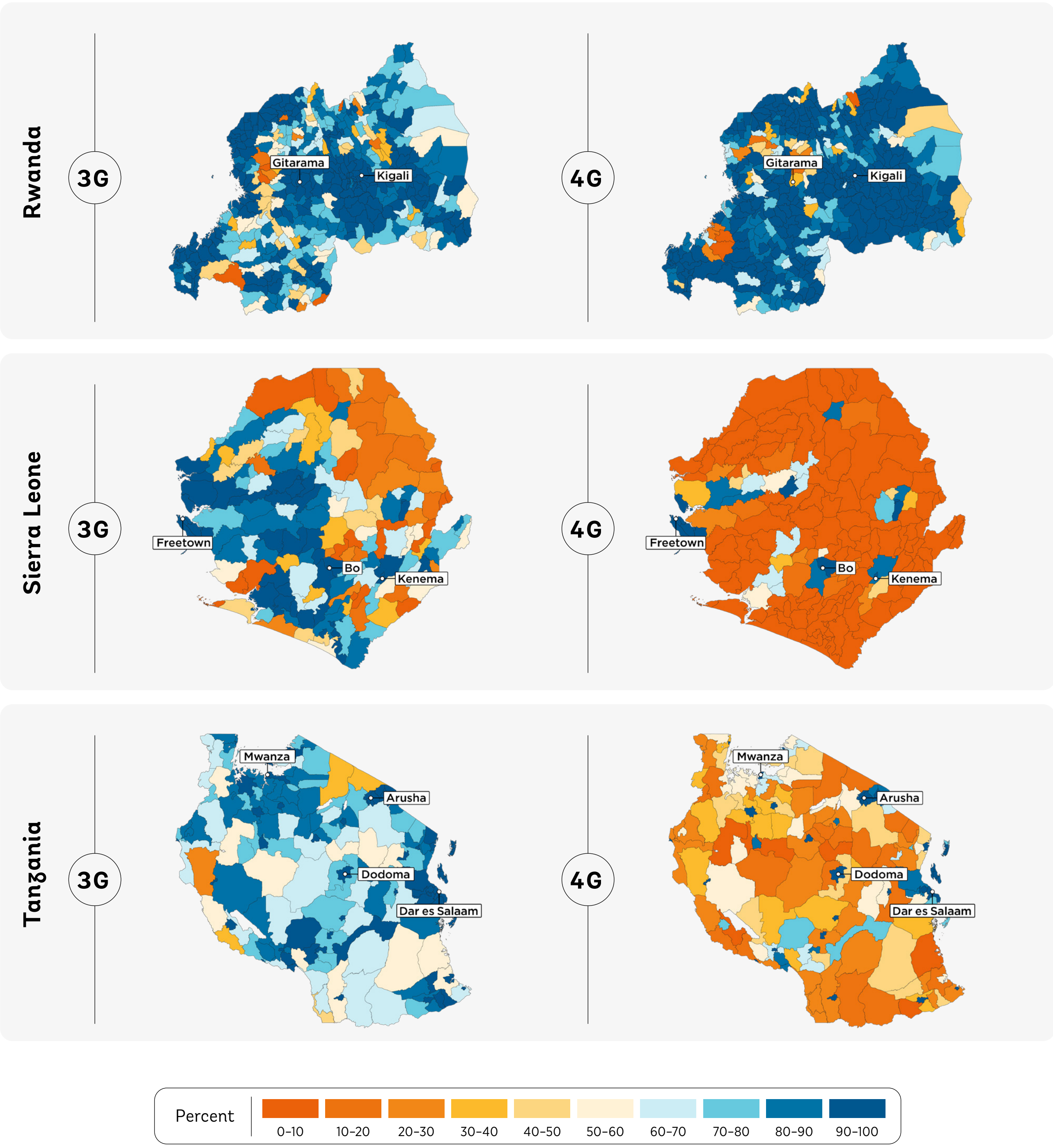
Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations.
Note: For Rwanda, an SWN operator provides 4G services, so no market analysis was carried out to determine the additional coverage that might be provided by mobile operators. This is because the model is built to emulate the decision-making process of mobile operators when they consider whether to invest in network expansion. Given that operators are unable to deploy 4G in Rwanda, and that the objective of an SWN is to meet a public policy goal of wide coverage (as opposed to a profit maximization objective), we are not able to use the model to determine 4G coverage by operators. Recent announcements also indicate that the SWN provider in Rwanda (KT Rwanda Networks) has achieved 4G population coverage above 98 percent.[11]

10 'Greenfield' sites refer to the deployment of new mobile sites in their entirety, including passive (for example, tower and mast) and active (for example, base station or radio network controller) elements. They provide coverage to populations that previously had no network coverage for any technology. 'Brownfield' sites refer to the upgrading of existing sites to provide 3G and/or 4G connectivity. Upgrades can either involve the installation of new hardware and equipment or, if single radio access networks are deployed, they can be upgraded simply by activating the 3G and/or 4G radio bearers.

11 See 'Network upgrade and new product launch', Korea Telecom Rwanda Networks.

Figure 8.
3G and 4G population coverage maps



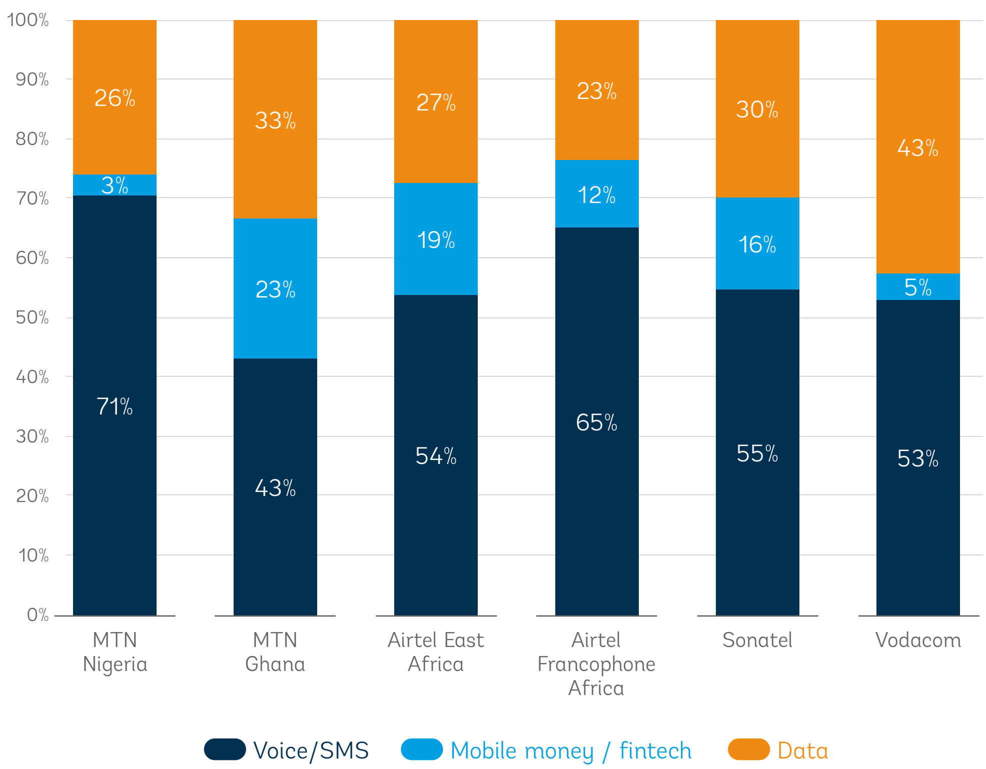


Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and Center for International Earth Science Information Network (CIESIN), household survey data and Group on Earth Observations.

'Leapfrogging' to 4G is unlikely to happen in rural areas

The analysis above shows that in none of the seven countries is 4G (or 3G) coverage expected to surpass 2G coverage over the next five years. While such 'leapfrogging' has been suggested as a way of bypassing legacy technologies, barriers such as the affordability of 4G devices or lack of digital skills limit the demand for 4G services and result in revenues that are insufficient to cover the costs of the infrastructure without the revenues coming from 2G services such as voice and SMS (Figure 9). This proportion is even greater in rural areas. Furthermore, in four of the countries studied—Benin, Rwanda, Democratic Republic of Congo, and Sierra Leone—the majority (55–70 percent) of mobile internet users still do not connect with 3G or 4G technology, even though mobile broadband coverage is widespread in three of these countries (and even in Democratic Republic of Congo, 3G networks cover more than half of the population).

Figure 9.
Service revenue breakdown by operator



Source: GSMA analysis of operator annual reports for MTN (2020), Airtel (2020), Sonatel (2020), and Vodacom (2019). Service revenues include voice, SMS, mobile data, mobile money, and fintech. It excludes revenues from devices and wholesale services.
Note: Airtel East Africa includes operations in Kenya, Malawi, Rwanda, Tanzania, Uganda, and Zambia.
Airtel Francophone Africa includes operations in Niger, Chad, Gabon, Congo, Democratic Republic of Congo, Madagascar, and Seychelles.
Sonatel includes operations in Senegal, Mali, Guinea, Guinea-Bissau, and Sierra Leone.
Vodacom includes operations in South Africa, Tanzania, Democratic Republic of Congo, Mozambique, Lesotho, and Kenya.

There are several reasons why users are unable or unwilling to use mobile broadband services, including access to 3G/4G handsets and barriers around awareness, digital skills, and literacy.

For example, estimated smartphone adoption in the study countries ranges from around 15 percent in Tanzania to almost 40 percent in Ghana.[12] However, there is a significant rural-urban gap in smartphone ownership. In Nigeria and Tanzania, adults living in rural areas are around 35 percent less likely to own a smartphone than those living in urban areas.[13]

The key implication is that there is not a strong commercial case to expand 3G or 4G coverage alone. Some operators therefore deploy only 2G in new areas, delaying the decision to roll out 3G or 4G until there is a sufficient return, while others have made a strategic decision to deploy 3G alongside 2G, especially where single radio access network technology (SRAN[14]) is used and operators can reallocate spectrum in the 900 MHz band. However, even in these cases, the majority of revenues still comes from voice and SMS. It is important to note that beyond the costs of the base station, when operators decide to deploy 3G alongside 2G or upgrade sites to 3G, operators may incur an extra cost to add the required backhaul capacity to provide 3G upload and download speeds. The amount of this extra cost depends on the existing backhaul technology and capacity and may vary from zero, when fiber or high-capacity microwave links are in place, to the full cost of deploying a fiber or a new microwave link to connect the site. In some cases, when several microwave hops are needed to reach a point of presence, a further cost is incurred to upgrade those upstream backhaul links. These costs are part of the return on investment calculation made by operators when deciding the technology mix to deploy or upgrade in any given area.

Voice and SMS services, which are powered by 2G devices, are therefore effectively paying for the bulk of the passive infrastructure costs and covering an important part of the cost of deploying 3G and 4G networks. This also explains the limited examples of commercially scalable solutions relying on Wi-Fi technology in rural areas to offer only data services, such as those used in some community network projects. Data-first technology rollouts will become sustainable when there is sufficient demand in rural areas to cover the full costs of the underlying infrastructure (active, passive, and backhaul).

12 Source: GSMA Intelligence (2020). Smartphone adoption estimates are calculated based on the number of SIM cards used in smartphones divided by the average number of SIM cards per unique subscriber. As there can be differences in the number of SIM cards used by smartphone owners and non-smartphone owners, these estimates may not be precise.

13 Source: GSMA Intelligence Consumer Survey. Estimates are based on surveys carried out in 2020 for Nigeria and 2018 for Tanzania.

14 Single RAN technology allows a single mobile base station to support multiple technologies (2G, 3G, and 4G) concurrently. It often relies on software-defined radios which can be activated and configured remotely.

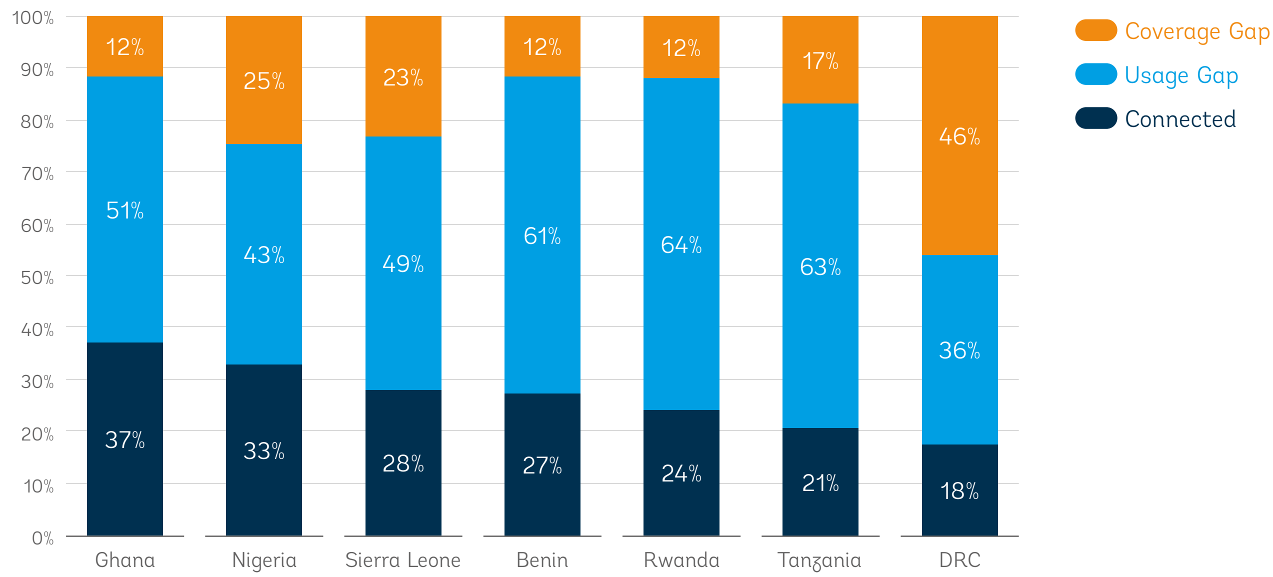
Affordability will remain a key barrier to adoption without policy reform

On the demand side, more affordable handsets and data plans have driven an increase in mobile internet adoption, which has enhanced the business case to deploy 3G and 4G. This is particularly the case in Ghana and Nigeria; both countries now meet the affordability target set by the UN Broadband Commission to make 1 GB of monthly data cost less than 2 percent of the average monthly income per capita (although this is not the case for all segments of the population—see discussion in Chapter 3). As a result, the two countries have adoption levels that are higher than the average for Sub-Saharan Africa. On the other hand, Democratic Republic of Congo has lower levels of mobile internet adoption and mobile broadband coverage, with more than 40 percent of the country's population not living in an area with a 3G or 4G network.

The key barriers to adoption are well known. Mobile users that are aware of mobile internet but do not use it are most likely to cite digital skills and literacy, affordability (including for handsets and data plans), and relevance as the main barriers to adoption (GSMA 2019). Across the seven countries included in this study, adult literacy ranges from 43 percent in Sierra Leone to 79 percent in Ghana.[15] In terms of affordability, Nigeria is the only country in the study where a 1 GB data plan is affordable for more than half the population (based on the 2 percent of monthly income threshold).[16] Access to electricity is a further barrier, for network deployment and for consumers (for example, the ability to charge devices). More than half the population in five of the countries studied (Democratic Republic of Congo, Sierra Leone, Rwanda, Tanzania, and Benin) do not have access to electricity.[17]

As a result of these barriers, the majority of the population in all seven countries is unable or unwilling to use mobile internet services.[18] Furthermore, there are notable digital inclusion gaps within each country; for example, those living in rural areas are on average 75 percent less likely to use mobile internet than those in urban areas (Figure 11).

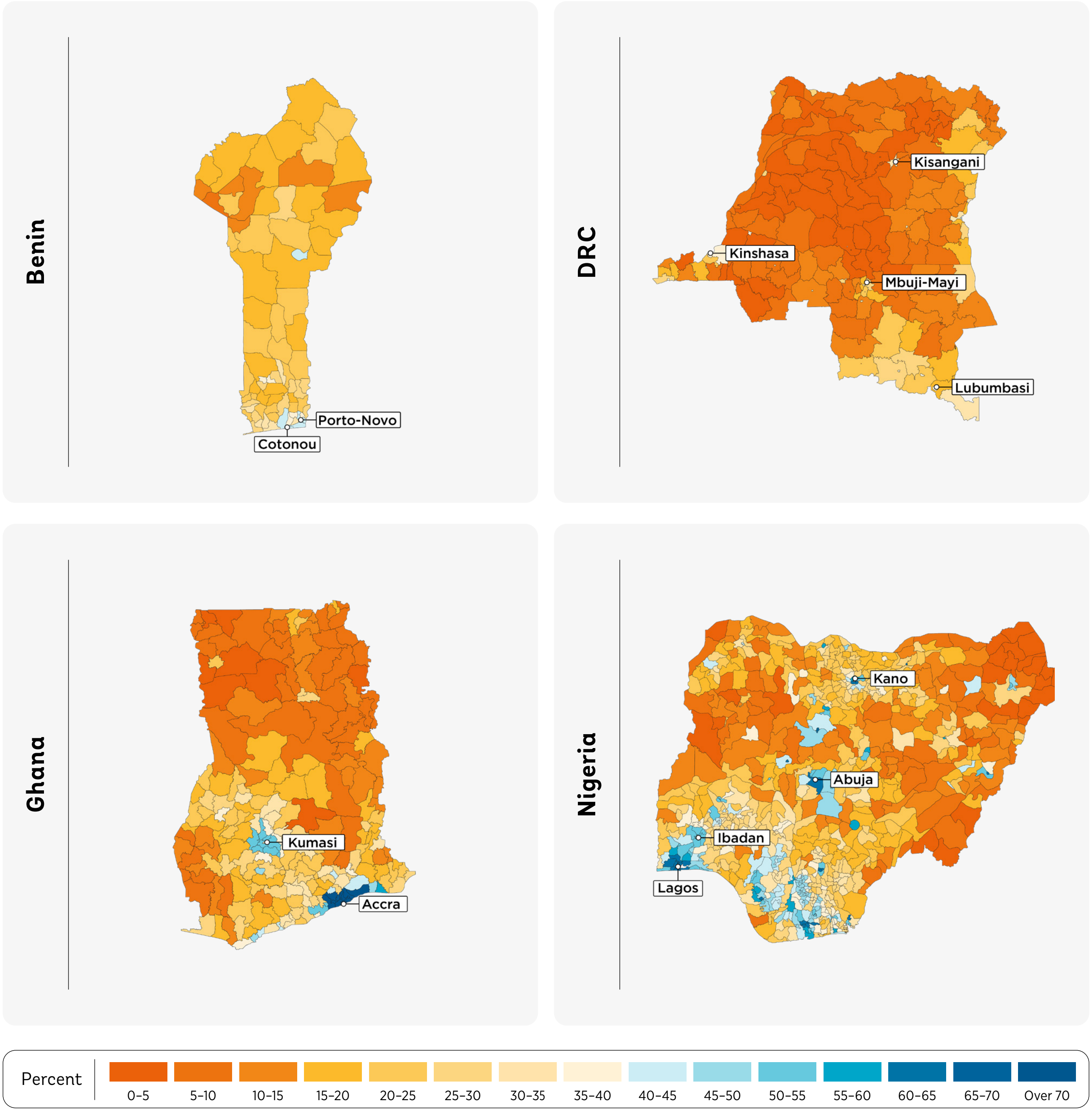
Figure 10.
Connectivity, usage and coverage gaps

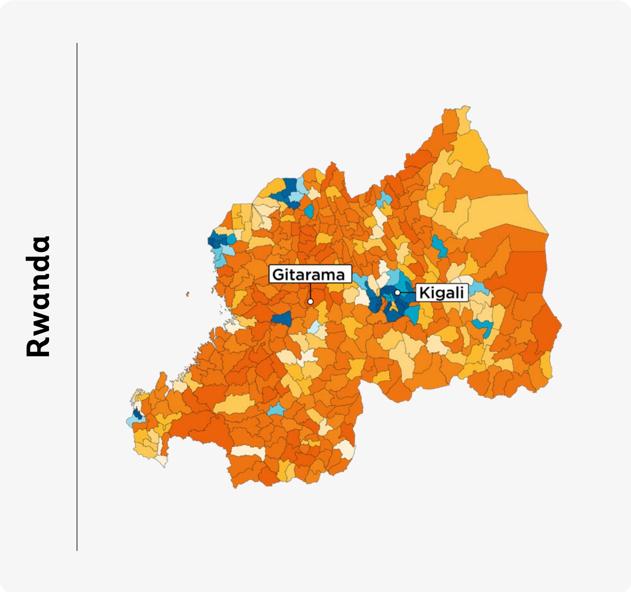


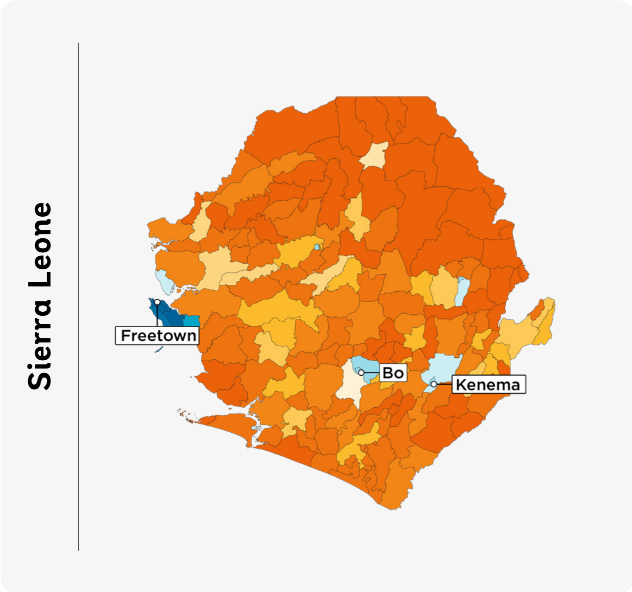
Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations.

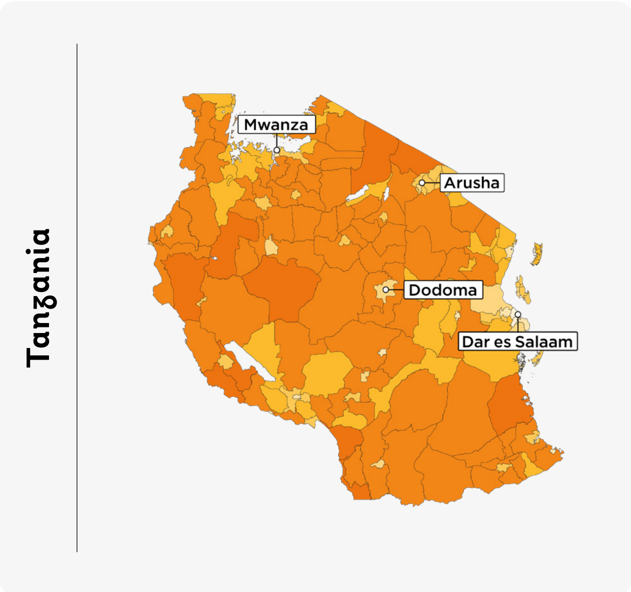
15 Source: UNESCO Institute for Statistics.
16 Source: GSMA Mobile Connectivity Index.
17 Source: Sustainable Energy for All and World Bank.
18 Even if we consider populations ages 10 or above, mobile internet adoption ranges from 11 percent in Rwanda to 50 percent in Ghana, although this is likely to overstate adoption within the age group as mobile internet users can be under the age of 10.

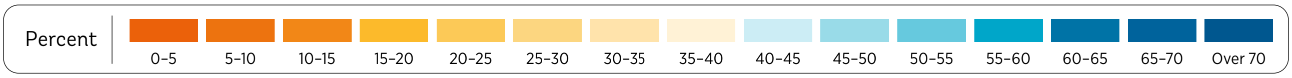
Figure 11.
Mobile internet adoption maps











Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and Center for International Earth Science Information Network (CIESIN), household survey data and Group on Earth Observations.

03
Innovation is Key to Unlocking Rural Markets and Boosting the Impact of Policy Change

The market alone will not deliver universal connectivity

Based on the current trends of coverage and adoption, the goal of universal connectivity by 2030 will not be met in any of the seven countries considered in the study. This analysis suggests adoption of mobile internet and will range from 37 percent in Democratic Republic of Congo to 54 percent in Nigeria by 2030, with significant rural-urban gaps persisting. Policy reform and public intervention will therefore be necessary to narrow that gap and bring connectivity to everyone. However, the impact of these will be enhanced by—and in some cases contingent on—the innovations being led by the private sector and supported by governments and international organizations.

Innovative technologies improve the business case in the last mile

On the supply side, to address the high costs associated with expanding network deployment in rural areas, the mobile ecosystem is innovating to more nimble technical solutions. These target coverage to isolated and dispersed population settlements more cost-efficiently than traditional macro-sites. The innovations also reduce the total cost of ownership of a cell site as they are designed specifically to work in rural settings and are cheaper to deploy, maintain, and power. Most importantly, they are able to target investment where needed, reducing the average investment per person covered.

The three main areas where infrastructure costs can be prohibitive in rural areas are the mobile base station, the backhaul technology that connects mobile sites to the core network, and energy supply. In recent years, there have been a number of commercially developed innovations for base station solutions that provide lower-cost 'light towers', for example Huawei's RuralStar and Nokia's Kuha (GSMA 2019b) or solutions from new vendors such as Vanu, Inc. and NuRAN Wireless Inc. While these do not have the same geographic reach in terms of coverage, they are better suited to covering remote locations with small populations (Figure 12). The typical cost of ownership over five years can range from US$50,000 to US$120,000 for a smaller site (depending on the configuration), compared to US$200,000–500,000 for a macro-site.[19] One of the reasons for lower costs is because they are powered by renewable energy solutions, particularly solar, rather than more expensive diesel generators. Further innovation such as open radio access network (RAN) standards will continue to drive down the costs of last-mile technology. Additional experience and analysis would be needed to ascertain whether this cost reduction will be large enough to disrupt the fundamental economics observed in this study, but this seems unlikely. This

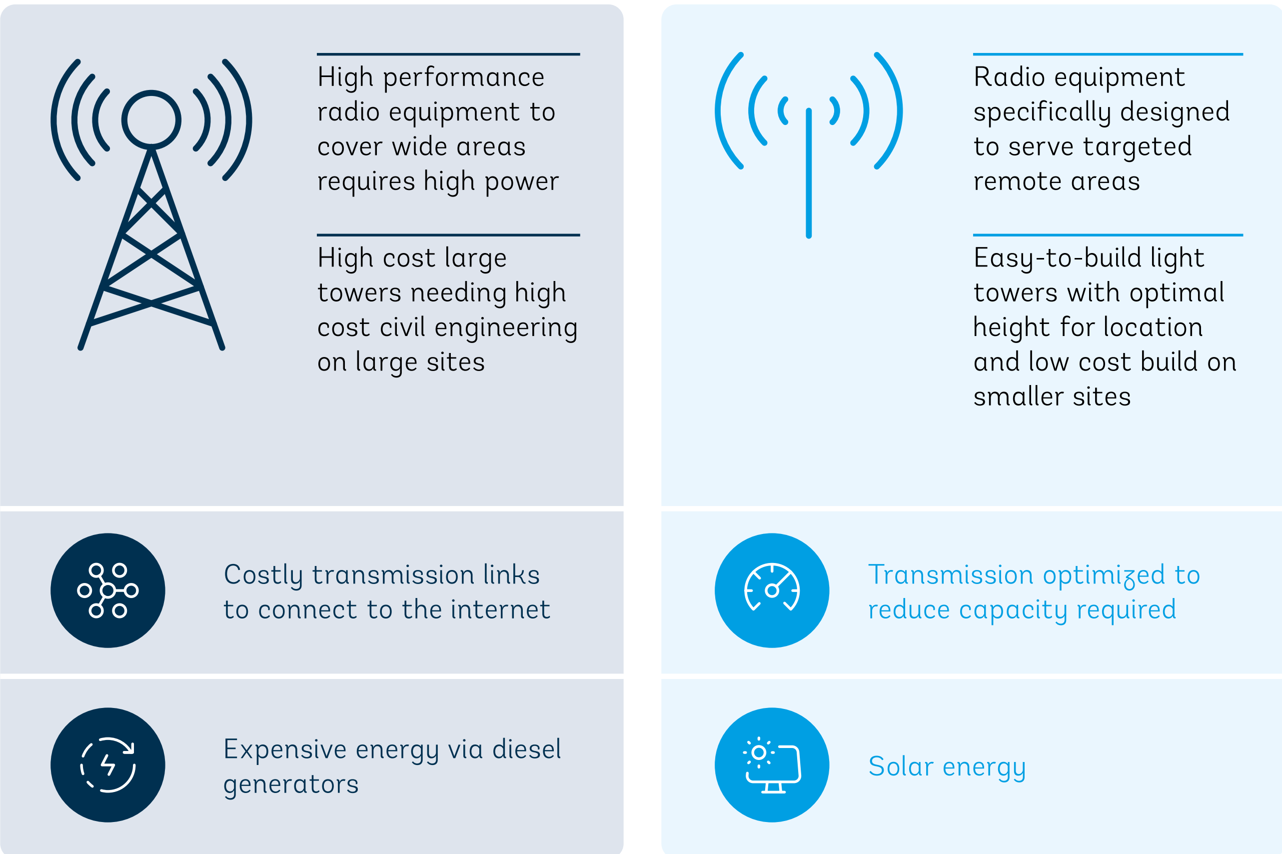
19 Cost data sourced from mobile operators and equipment vendors. The cost of macro-sites varies by country and depends on the commercial model used (for example, whether a tower company operates the passive elements of a site), the technology solution and vendor, power source, the spectrum available, and installation and maintenance costs.

is mainly because the active equipment, such as base stations or backhaul modems, account for only a small part of the total cost of ownership of a site (around 20 percent for a five-year total cost of ownership) so even innovations that can drastically cut the costs of this active equipment will likely only affect that share of the costs and will probably not result in coverage benefits much larger to those in the 'market innovation' scenarios modelled for this report.

Furthermore, while traditional network rollout models have seen mobile operators providing the necessary capex and opex to build and maintain every site, these new smaller sites are often delivered using innovative business models. For example, some vendors or network integrators offer revenue-sharing or 'network-as-a-service' models where they finance and operate the infrastructure and lease the added coverage or capacity to mobile operators. Such models encourage infrastructure sharing and enable third-party investment in rural connectivity. These vendors or integrators, such as Africa Mobile Networks and iSAT, have streamlined their solutions to rural areas, driving efficiencies that result in lower network costs.

Figure 12.

Comparison of traditional macro-sites with smaller, lower cost sites

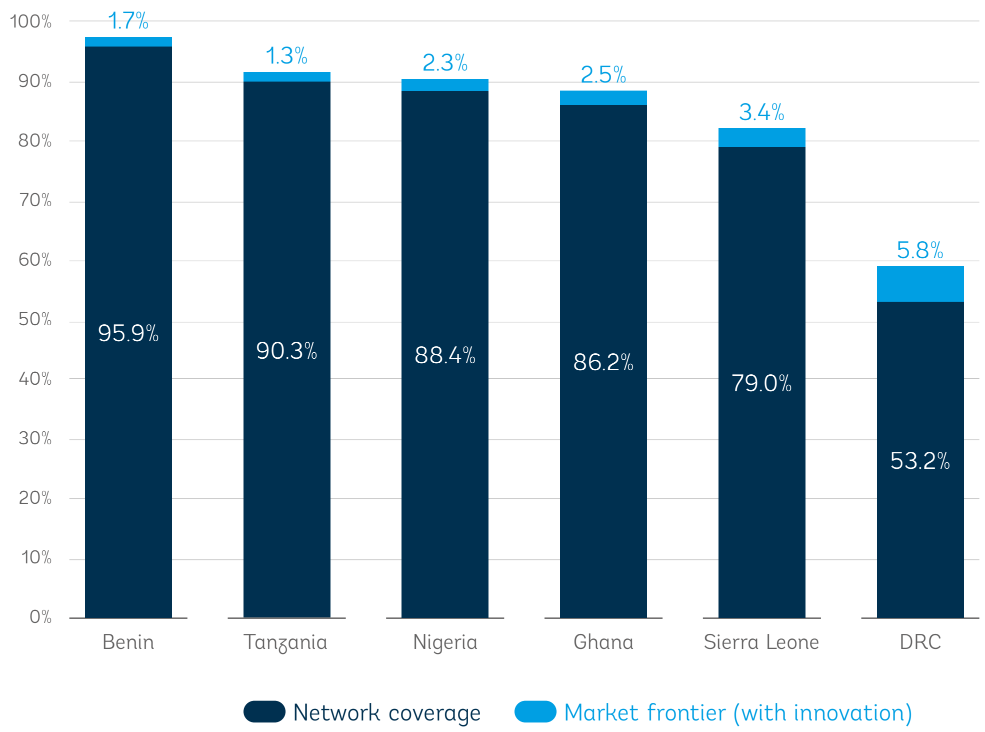


Source: GSMA

For this study, new site innovations were modelled as part of the expansion of coverage in 'greenfield' areas (that is, settlements not covered by any mobile technology).[20] Figure 13 shows that they are expected to expand rural coverage across all markets, notably in Democratic Republic of Congo, which has a larger coverage gap[21] (Rwanda is not included as 2G coverage is almost universal).

Figure 13.

Additional mobile coverage (any technology) in rural areas expected from recent site innovations for greenfield investments



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations.

Innovation reduces the cost of universal coverage

Lower-cost networks will be critical in unlocking further investments in coverage. To illustrate this, one can compare the cost of expanding coverage in Democratic Republic of Congo (which has the lowest level of coverage across the seven countries) with and without new lower-cost sites. When these are included in the list of potential deployment options for operators, it is expected that they would account for more than 97 percent of new greenfield sites and the total cost of achieving near-universal 4G population coverage of 99 percent over a 10-year period would be US$2.6 billion (based on current market costs). By contrast, if only traditional macro-sites are used, the equivalent cost would be US$4.4 billion. This means new lower cost sites will reduce the cost of near-universal 4G coverage by around 40 percent.

20 In 'brownfield' areas, upgrading an existing 2G macro-site to 3G or 4G will be more cost effective than deploying a new smaller site.

21 Operators in DRC have already started to partner with network service providers to expand coverage using new and lower-cost sites (for example, Nuran Wireless).

Microwave backhaul will remain the dominant technology for rural connectivity, though more innovation is needed to reduce costs

In addition to the site configuration and energy source, innovation is needed in terms of backhaul. In Sub-Saharan Africa, around 85 percent of cell backhaul uses microwave, compared to 4 percent for fiber and 5 percent for satellite (with the remainder using copper).[22] In rural areas, the proportion of sites using microwave backhaul is even higher. For example, in rural areas of Ghana and Nigeria, between 98 percent and 99 percent of mobile sites use microwave backhaul, with most of the remainder using fiber. This is not expected to significantly change in the future considering the high cost of fiber deployment. However, in many areas, microwave will not be a viable backhaul solution if there is no line of sight—especially in areas that are mountainous or have rugged terrain. While there are some innovations in backhaul technology (for example, the use of long-term evolution or even laser beams), these have similar physical constraints to microwave and are not sufficient to extend the reach of links to connect the most remote locations.

The next generation of satellite backhaul will therefore play an important role. For this study, we assumed that sites would use satellite backhaul where microwave is not viable. While satellite backhaul can provide a solution for some rural and remote sites (Table 2), they are not currently expected to deploy 3G or 4G at large scale due to the high cost (the annual opex of providing satellite backhaul for a 3G site is currently around four times higher than for 2G, while for 4G it is eight times higher). The most appropriate technology to use depends on the specific requirements for each individual site, such as the terrain in that precise location, the distance to the closest fiber backbone, or the capacity required for the site. Every technology has its trade-offs in terms of deployment costs, licensing costs, capacity, and range.[23]

As data traffic in rural areas increase to the observed levels in urban areas, quality of service might become an inhibitor of adoption if the backbone network does not provide sufficient capacity.[24] Upgrading the backbone capacity will require investing in fiber and high-capacity microwave links. And while the level of coverage is not directly affected by these investments (and as such not included in this study), they will be necessary for maintaining a good quality of service and keeping data bundles affordable in the medium term.

Table 2.
Proportion of new greenfield deployments that use smaller sites and satellite backhaul

	Percentage of new profitable greenfield sites that		
	Use smaller, lower cost configurations	Use satellite backhaul*	Use satellite backhaul for 3G or 4G
Ghana	84	20	0
Benin	75	35	0
Sierra Leone	80	28	0
Democratic Republic of Congo	92	38	15
Nigeria	28	23	9
Tanzania	100	36	0

GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations.
Note: *Satellite backhaul is needed where sites cannot link to the core network with a microwave link, either directly or through multiple 'hops' (that is, connecting to the core network through other cell sites).

22 See, for example, GSMA and ABI. 2018. Mobile Backhaul Options: Spectrum Analysis and Recommendations. These proportions are similar to the backhaul used in other low- and middle-income countries. By contrast, in North America and North East Asia, 70–80 percent of backhaul uses fiber.
23 For a detailed comparison of the trade-offs of backhaul technologies see page 3 the report cited above.
24 For a capacity-based analysis of universal broadband connectivity in Africa, see Oughton, Edward (2022, forthcoming)

Continued price reductions in data plans and devices are fueling adoption

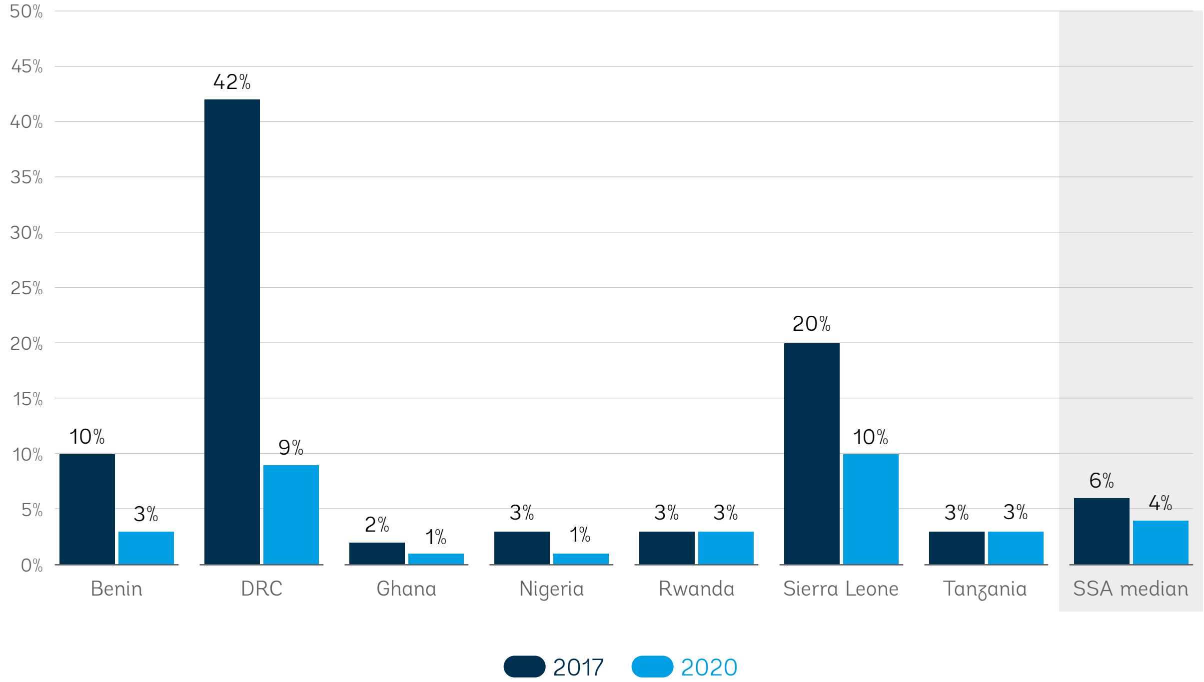
While innovation is critical to improving the provision of mobile infrastructure, it is equally important to increase adoption of mobile and mobile internet services on the demand side. An important area is the development of cheaper devices and mobile data. Figures 14 and 15 show that over the past five years, the cost of accessing 1 GB per month and an internet-enabled device as a proportion of monthly gross national income (GNI) per capita has fallen across almost all the seven markets included in the study, in line with the broader trend in Sub-Saharan Africa. Ghana and Nigeria have achieved affordability levels for data that are below the 2 percent of monthly income threshold set by the UN Broadband Commission, while device affordability in the two countries is also below the global average (around 20 percent) seen in low- and middle-income countries worldwide.

The emergence of cheaper smartphones and 'smart feature phones' has been particularly important in reducing device costs in many countries, in some cases at or close to US$20. Operators have partnered with a range of private sector organizations, including KaiOS technologies, UNISOC, and Google, to bring these devices to several markets in Africa—for example, the MTN Smart Feature Phone in Nigeria (MTN 2018) and the Orange Sanza in Democratic Republic of Congo (Orange 2019). Furthermore, the partnerships often include the leveraging of mobile agents and salespeople to help new users learn and develop the basic skills needed to use their phones (GSMA 2021).

Similar to the innovations in infrastructure, achieving universal connectivity in Sub-Saharan Africa will only be possible if these innovations are built on. Despite these improvements, even a US$20 phone represents a significant one-off cost for many of the poorest populations in Sub-Saharan Africa (for example, the median cost of the cheapest internet-enabled handset represents more than 120 percent of monthly income for the poorest 20 percent of the population) (GSMA 2020c). Other solutions will therefore need to be developed, such as device financing schemes—these are already in place in some markets.[25]

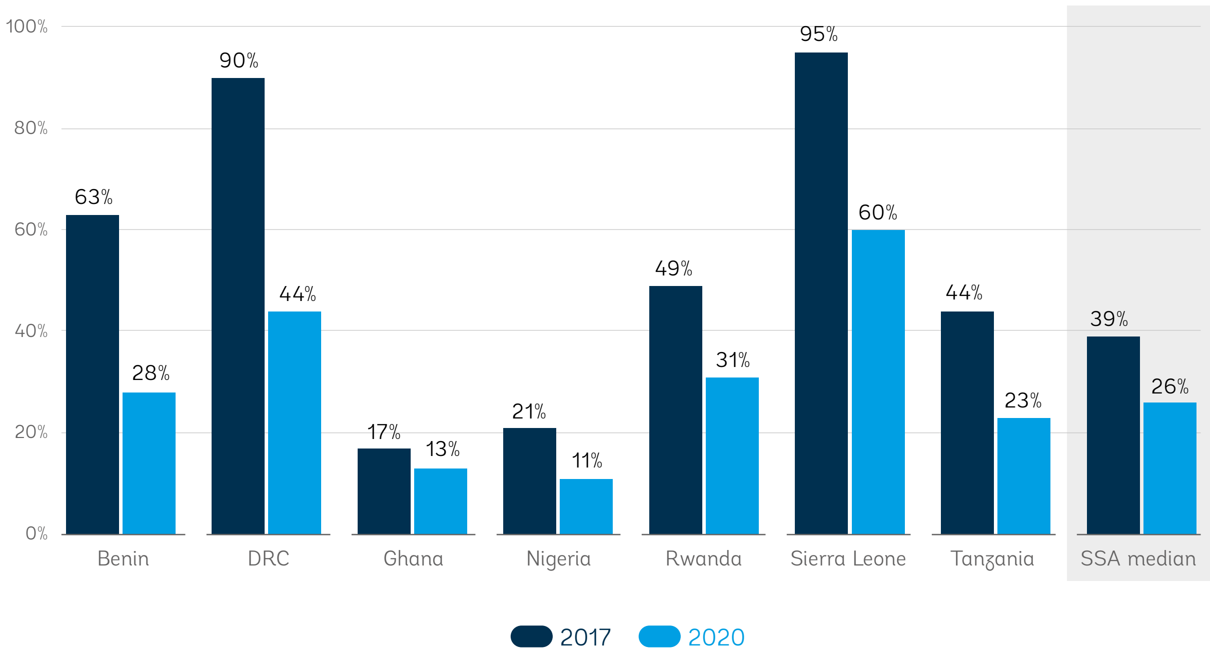
25 See, for example, Safaricom's partnership with Google to help consumers access new 4G smartphones at https://www.safaricom.co.ke/about/media-center/publications/press-releases/release/979.

Figure 14.
Cost of cheapest monthly 1 GB data plan as a percentage of monthly GNI per capita (2016 and 2020)



Source: GSMA analysis of Tarifica data.

Figure 15.
Cost of cheapest internet-enabled smartphone or feature phone as a percentage of monthly GNI per capita (2016 and 2020)



Source: GSMA analysis of Tarifica data.

04
Enabling Policies Can Increase Network Coverage and Adoption

As part of this study, a number of strategies that could increase coverage and adoption in the seven countries were assessed. In this section, we discuss those that could drive the most significant impact based on the model simulations. These include the following:

- **Infrastructure sharing.** The sharing of infrastructure assets can reduce costs and investment risks for operators seeking to expand coverage in new areas, as well as increase service-based competition.
- **Spectrum policy.** Network coverage can be increased, especially in rural areas, if governments and regulators release sufficient spectrum at affordable prices and allow licenses that are technology neutral.
- **Taxation.** A tax framework that ensures taxes are broad and simple, comparable to other sectors of the economy, can increase coverage and adoption by improving investment incentives for operators and affordability for consumers.

The analysis in this section shows the potential impact of these policy changes on the market frontier in some of the seven study countries. In particular, where they affect the profitability of new site deployments (or upgrades) by changing demand and/or costs on the supply side, it is possible that operators will be able to expand coverage beyond the current market frontier.

Infrastructure sharing can enable multiple operators to expand coverage

Infrastructure or network sharing at the site level can be broadly classified into three categories:[26]

- **Passive sharing** – the sharing of the physical mast and energy supply
- **Active sharing** – the sharing of RAN, including site, mast, base transceiver station, backhaul, and base station controllers[27]
- **Roaming** – when a mobile customer uses a network not provided by their operator

In most of the markets included in the study, mobile operators have partnerships with independent tower companies that sometimes own and manage the passive elements of their sites. However, more extensive active sharing that could further reduce deployment costs is generally yet to occur.

The primary benefit of infrastructure sharing is that it can enable increased competition and consumer choice in areas where multiple networks are not commercially sustainable due to a lack of demand. This is shown in Figures 16 and 17, which respectively show the level of 3G and 4G coverage that is financially viable in rural areas in Benin and Tanzania. Infrastructure sharing also reduces the capital intensity for mobile operators looking to expand their coverage, freeing capital to roll out infrastructure in less attractive (but still profitable) locations instead of duplicating infrastructure in places where there is already another provider.

Figure 16 shows that in Benin, where minimal network sharing is in place, around 79 percent of the country's rural population could have 3G/4G coverage from three networks. However, with active sharing this could increase to 85 percent for 3G and almost 88 percent for 4G. Similarly, Figure 17 shows that in Tanzania, which has passive sharing through tower companies, three networks could be sustainable for 78 percent of the country's rural population for 3G and 41 percent for 4G. With active sharing, this increases to 83 percent and 63 percent, respectively and, in the case of 3G especially, is similar to coverage for a single network. While the expected coverage provided by network sharing is slightly inferior to the expected coverage of a single network,[28] network sharing has obvious advantages by promoting competition at the service and retail levels, benefitting consumers in terms of prices and quality. Network sharing allows multiple service providers to operate in areas where there would otherwise only be one. Moreover, in all seven countries studied, it was found that promoting active sharing in new greenfield areas would achieve the same level of additional coverage as a single network expansion. This again highlights the potential role of infrastructure sharing as a means of increasing service-level competition in areas currently uncovered, as well as those with only one active operator.

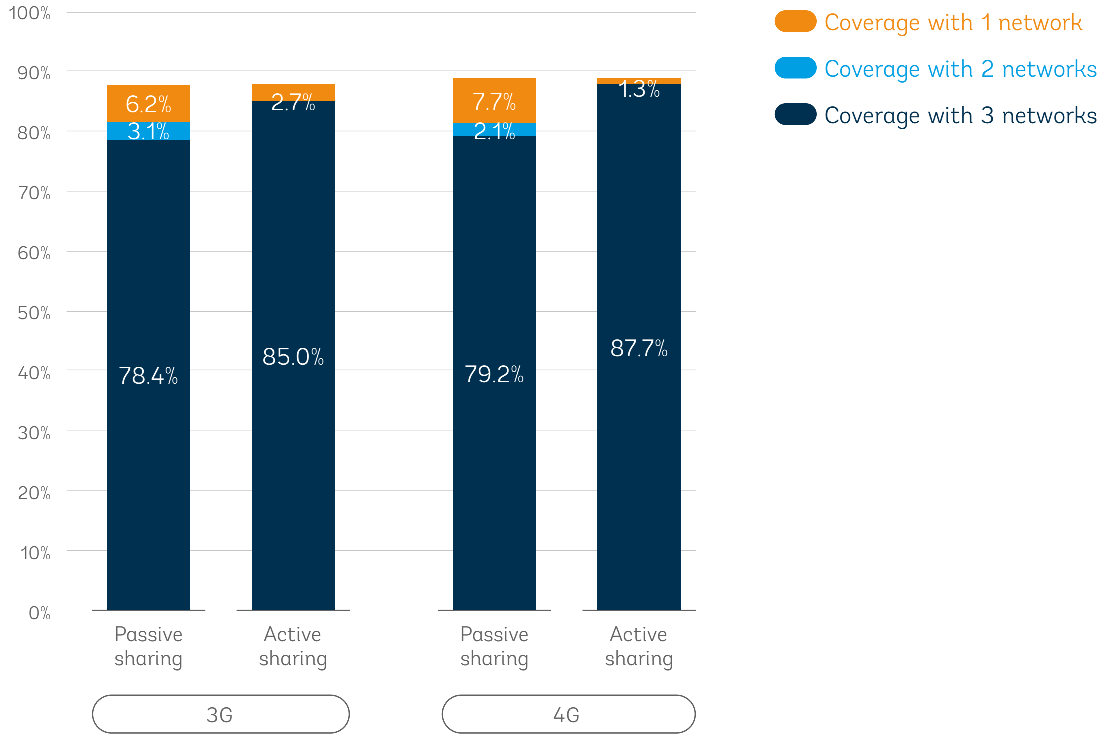
These results show that network sharing is a viable option to extend coverage and competition simultaneously. And because shared networks are co-owned by service-level providers, it avoids the drawbacks of SWNs, which impose a monopoly at the infrastructure level. This can result in a lack of innovation and abuse of monopolistic power on wholesale prices, harming consumers in the long term.

26 For further details on the different types of infrastructure sharing see, for example, Mobile Infrastructure Sharing, GSMA.

27 A deeper level of infrastructure sharing could also involve sharing of spectrum held by each operator (known as Multi-Operator Core Network or MOCN). We focus on Multi-Operator Radio Access Network (MORAN), where radio access networks are shared but each operator uses its own dedicated spectrum.

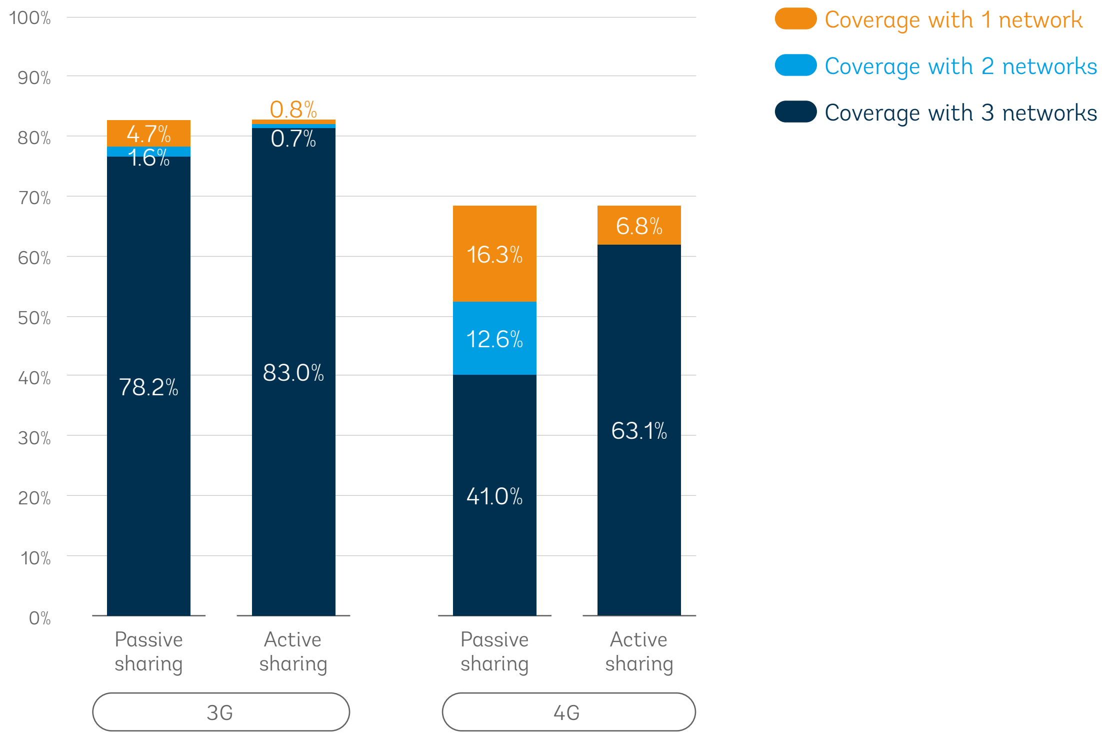
28 The amount of expected coverage is not the same between a single network (with one operator) and a shared network (with multiple operators) because the sharing of assets between two or more operators imposes some additional costs (for example, in terms of power supply)—though they are much less than having multiple operators deploy separate networks.

Figure 16.
Maximum level of commercially viable 3G/4G rural coverage by 2025 in Benin by number of networks and infrastructure sharing type



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations.

Figure 17.
Maximum level of commercially viable 3G/4G rural coverage by 2025 in Tanzania by number of networks and infrastructure sharing type



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations.

While active sharing has benefits for operators in terms of sharing costs and lowering investment risk, as well as offering growth opportunities in new areas, operational challenges have thus far meant it has not developed at scale in Sub-Saharan Africa (both in terms of RAN sharing and roaming). These challenges emerge from the need for coordination between mobile operators. Technical coordination is required to ensure the shared network is compatible with each operator's respective legacy networks and maintenance tools. In addition, coordinated decision-making is required on issues such as the location of new sites, network maintenance responsibilities, and the ownership of the assets. This increased level of coordination involves costs that mobile operators are only willing to incur if the gain of co-investing outweighs those costs, which mostly happens in very dense or remote areas. More sharing is expected to occur naturally as mobile operators push coverage to more remote areas[29] and traffic increases in urban areas drive greater network densification. However, it is important that infrastructure sharing remains voluntary; otherwise, it could negatively affect investment incentives as mobile operators wait for others to invest first.

Network sharing agreements can have different impacts on the degree of competition in the market. For example, the loss of infrastructure-based competition can bring a greater risk of exchange of sensitive information at the service level. On the other hand, network sharing deals can improve competition by allowing smaller mobile players to grow faster and cover a broader range of areas in the country. Considering the high costs of deploying in rural and remote areas, it is unlikely that these areas would benefit from infrastructure-based competition—the examples of Benin and Tanzania show that without active sharing, a significant proportion of rural populations would only have a single network (assuming an operator was willing to deploy at all). In terms of risks to competition, regulators and competition authorities often mitigate such concerns by establishing safeguards and/or monitoring the agreements using ex post competition laws and frameworks.[30]

29 One telling example is the 2×2 RAN sharing agreements in Brazil, where two separate sharing agreements between four operators (Claro-Vivo and Oi-TIM) decided to join forces to co-invest as a way to minimize the investment needed to comply with the ambitious 4G coverage obligations included with their licences.

30 For further discussion, see for example GSMA 2018.

3G and 4G coverage can be increased by assigning the sub-1 GHz spectrum and allowing licenses to be technology neutral

The spectrum used for 2G, 3G, and 4G mobile services can be grouped into two broad categories: coverage bands for frequencies below 1 GHz and capacity bands for frequencies above 1 GHz. This is based on the bands' physical properties—lower frequencies suffer less attenuation, while frequencies above 1 GHz allow operators to carry more capacity.

To expand coverage, having sufficient spectrum in coverage bands is particularly important, especially in rural areas as operators can cover wider areas using fewer sites. In other words, a fixed amount of capex will generate higher returns on investment, which means operators can cover more of a country's population. The low frequencies of digital dividend spectrum (in the 600, 700, and 800 MHz bands) are particularly well-suited for covering rural areas; these have typically been assigned for the use of 4G. Almost all the countries included in this study have assigned some digital dividend spectrum to deploy 4G (Table 3), though not all operators have access to it. While this can be for commercial reasons, it can also be due to governments not licensing all available spectrum or setting prices that are not market driven. For example, in Ghana, only one operator participated in the 2015 auction to acquire 800 MHz spectrum, due to a high reserve price.[31] Vodafone subsequently purchased spectrum in this band in 2019 to launch its 4G network, while other operators are yet to do so.

Table 3.
Spectrum bands assigned and used (by technology), 2020

	700MHz	800MHz	900MHz	1.8GHz	2.1GHz	2.6GHz
Benin		4G	2G/3G	2G/4G	3G	4G
Democratic Republic of Congo	4G	4G	2G/3G	2G/4G	3G	4G
Ghana		4G	2G	2G	3G	4G
Nigeria	4G	4G	2G/3G	2G/4G	3G	4G
Rwanda	4G*	4G*	2G/3G	2G	3G	4G*
Sierra Leone		4G	2G/3G	2G/4G	3G	
Tanzania	4G	4G	2G/3G	2G/4G	3G	

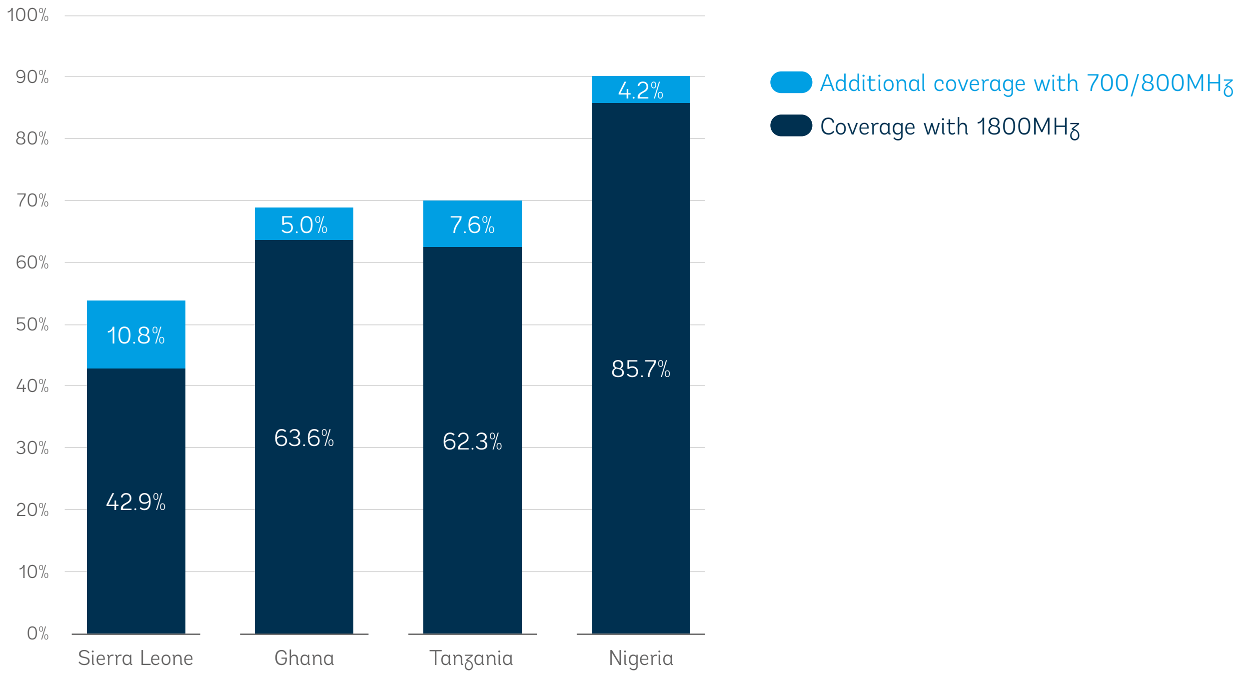
Source: GSMA Intelligence.
Note: *In Rwanda, 4G spectrum bands are assigned and used only by the SWN provider.

31 See GSMA and NERA (2017) and GSMA (2020c).

To illustrate the impact, Figure 18 compares the expected level of 4G coverage in rural areas that an operator could commercially achieve in Sierra Leone, Ghana, Tanzania, and Nigeria if they deployed in the 1,800 MHz and 700 or 800 MHz bands.[32] In Sierra Leone, an operator could make a positive financial case to cover 43 percent of the rural population by using 1,800 MHz spectrum[33], but if they also had access to 700 or 800 MHz, they could cover another 11 percent. In Ghana, Tanzania, and Nigeria, operators using 1,800 MHz could cover 5 percent, 8 percent, and 4 percent more of their respective rural populations if they had access to 700 or 800 MHz spectrum.

Figure 18.

Level of 4G coverage in rural areas that is viable for an operator by 2025 when deploying in 700/800 MHz versus 1,800 MHz spectrum bands



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations. The analysis assumes that annual spectrum fees do not change.

In addition to the assignment of new bands, a further enabling spectrum policy is to make licenses technology neutral and offer operators the flexibility to introduce and use technologies that best suit their customers' needs. In many Sub-Saharan African countries, notably Nigeria, operators have been able to expand 3G coverage significantly in recent years by using refarmed 900 MHz spectrum. However, this has not occurred in all countries. In Ghana, for example, the decision to make all spectrum bands technology neutral has yet to be implemented.[34] The impact of refarming would be significant: in current market conditions, an operator in Ghana would be able to cover around 78 percent of the rural population with 3G networks using 2,100 MHz spectrum, but if they used 900 MHz as well this would increase to more than 81 percent (an increase of almost 450,000 people covered).

32 These are countries where not all operators have sub-1 GHz spectrum to deploy 4G services.
33 Note that in Ghana, the deployment of 1800 MHz spectrum for 4G is hypothetical as operators are not yet able to use the band to deploy 4G networks.
34 As of January 2021.

Aligning tax policy with best-practice principles can drive significant gains in network coverage and adoption

Another important policy reform is the removal of sector-specific (excise) taxes, particularly in Sub-Saharan Africa, where the mobile sector is subject to some of the highest overall tax burdens.[35] Sector-specific taxes are levied on consumers and/or providers of mobile services in addition to other economywide general taxes, such as corporation tax and value added tax (VAT). This can make mobile services more costly in terms of production and consumption, relative to other goods and services, and distort use and investment decisions.

In many countries, the application of these taxes is not aligned with the best-practice principles of taxation recommended by international organizations such as the International Monetary Fund (IMF), World Bank, and OECD. These include the following:

- Taxes should be as broad as possible, to avoid distorting markets.
- Taxes should be simple and certain.
- Taxes should not undermine affordability and access to services.
- Taxes should not distort investment.

It is worth noting that sectoral taxation is part of the broad national taxation policy. A country tax strategy considers other aspects such as the potential for fiscal revenue mobilization in the short term and medium term through tax policy as well as tax administration measures. Given fiscal constraints, countries assess difficult tradeoffs to determine sectoral taxation. This report offers simulations to understand better the effects of taxes on coverage and take up of mobile broadband, and therefore on the digitalization potential of a country.

Taxes on the consumption of mobile services can be particularly impactful as one of the primary barriers to adoption is the affordability of handsets and mobile data. Of the seven countries included in this study, four apply a tax on consumption, in addition to VAT, based on a percentage of the value of services sold (in Ghana, Rwanda, Tanzania, and Democratic Republic of Congo). On the supply side, sector-specific taxes on operators can reduce investment incentives. In Benin, operators pay almost 25 percent of annual recurring revenues in mobile-specific taxation, including annual license and spectrum fees (this compares to around 3 percent in Ghana).

In addition to these, governments can reduce the cost of network deployment (for operators) and handsets (for consumers) by reducing or removing import duties on imported equipment —this has been done in Tanzania, for example.

The study models the removal of sector-specific taxes and import duties in all seven countries to assess the impact on mobile broadband coverage and the adoption of mobile and mobile internet services. Below we show the results for two countries with some of the highest tax burdens in the region: Democratic Republic of Congo, where there is currently a 10 percent excise duty on the consumption of telecoms services, and Benin, where we model the impact of bringing operator taxes and fees in line with other countries in the region. In both countries, we also assume the removal of customs duties on handsets and network equipment.

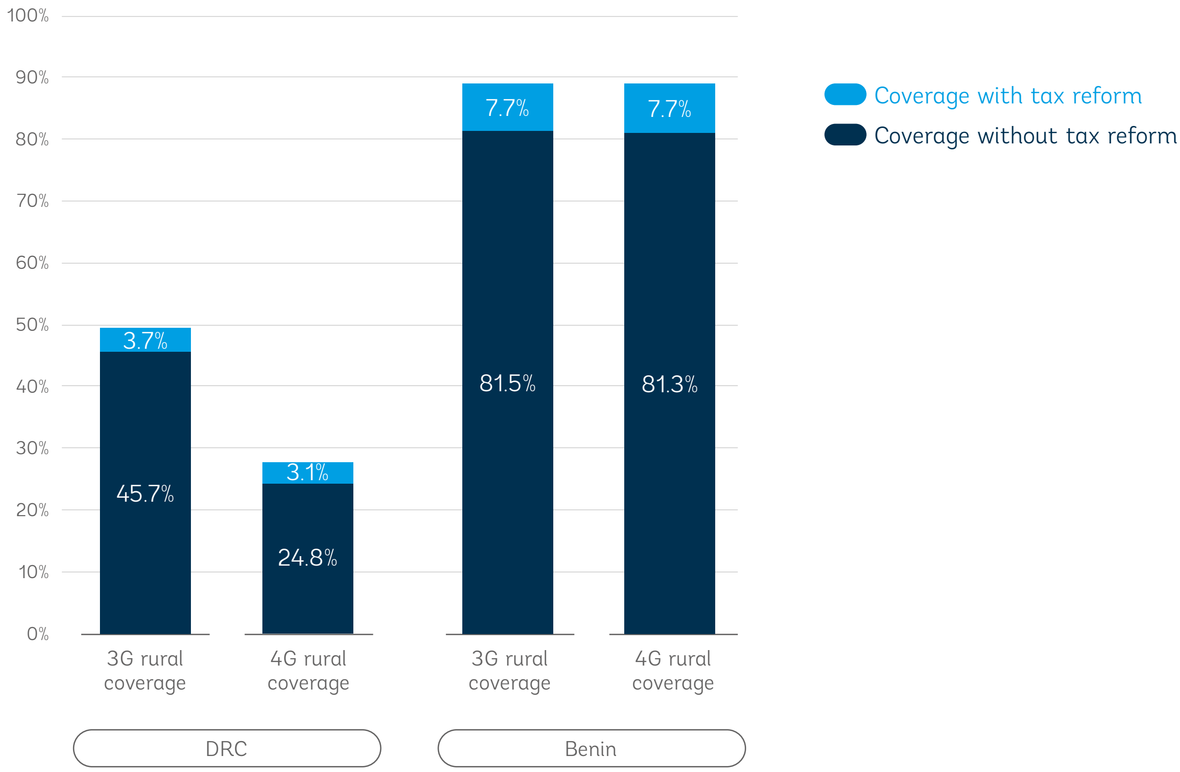
In Democratic Republic of Congo, these combined reforms in tax policy could increase both 3G and 4G rural coverage by more than three percentage points (equivalent to almost 1.5 million people), as improved affordability stimulates demand and therefore the returns on investment. In Benin, the reduction in operator taxes increases the returns on investment and would drive an increase in 3G/4G rural coverage of almost 8 percentage points (equivalent to almost 500,000 people).

The investment and affordability effects of reducing sector-specific taxes also increase demand in areas that are already covered, leading to a broader increase in adoption. Figure 19 shows that based on forecast adoption in 2030, tax policies could increase mobile adoption and mobile internet adoption by 7.4 and 6.4 percentage points, respectively, in Democratic Republic of Congo (equivalent to bringing more than 7.5 million people online). In Benin, it would increase adoption by 7.1 and 5.5 percentage points, respectively (bringing almost 1 million people online).

35 See, for example, Rethinking Mobile Taxation to Improve Connectivity, GSMA, 2019.

Figure 19.

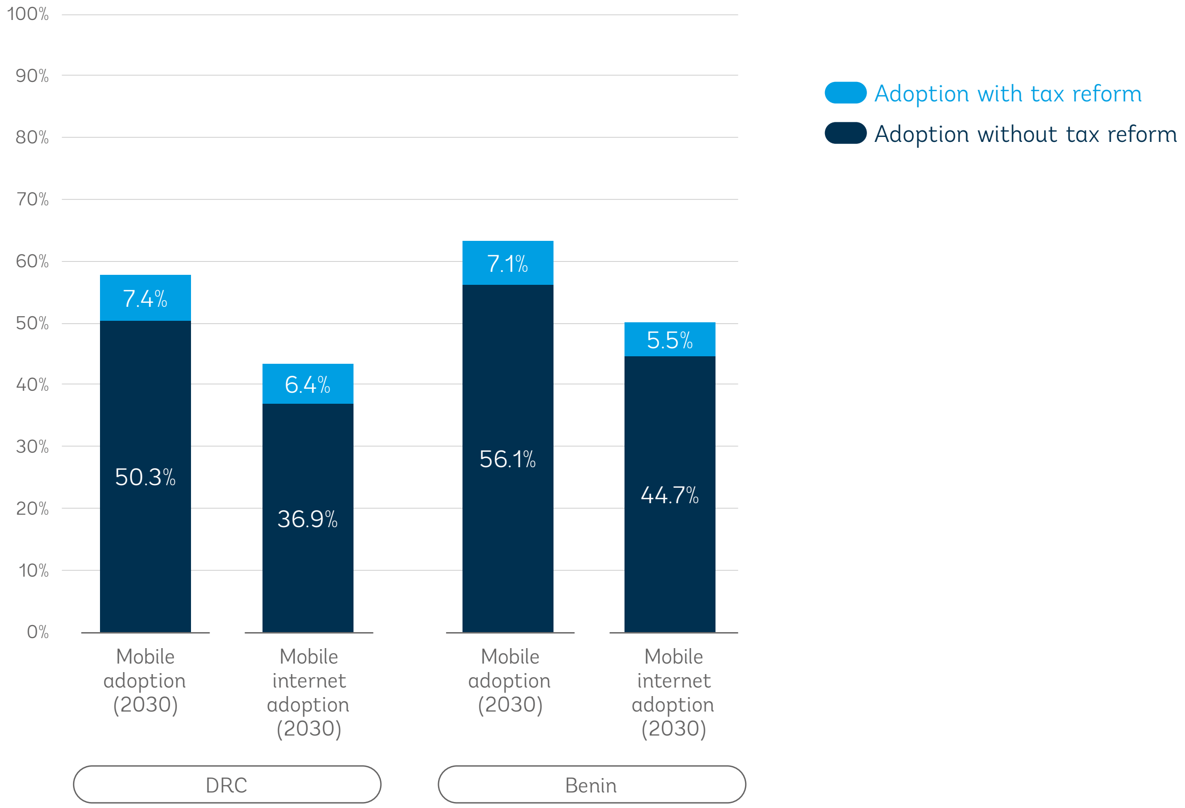
Impact of reduction in sector-specific taxes on rural 3G/4G coverage in Democratic Republic of Congo and Benin by 2025



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook CIESIN, household survey data, and Group on Earth Observations.

Figure 20.

Impact of reduction in sector-specific taxes on mobile and mobile internet adoption in Democratic Republic of Congo and Benin by 2030



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations.

While the removal of sector-specific taxes would improve coverage and adoption, the imposition of new or additional taxes would have the opposite effect. At the end of 2020, a new tax was imposed on mobile consumers in Democratic Republic of Congo, comprising an annual payment of US$1 for 2G handsets and US$7 for 3G/4G handsets, which will make mobiles less affordable and therefore reduce future adoption. The proposed charge for 3G/4G handsets is the equivalent of a price increase of almost 10 percent on the current cost of 1 GB of data. In the absence of reforming other sector-specific taxes, it is estimated that there will be 700,000 fewer mobile users and 2.5 million fewer 3G/4G mobile internet users by 2030 (reducing overall mobile broadband adoption by 2 percentage points compared to a scenario where taxes stay as they were before the handset tax). Furthermore, the reduction in demand is likely to affect the decision to expand 3G and 4G network coverage, resulting in 4.5 million fewer people being covered by 4G (or 5 percent of the population—again, this is compared to a scenario where taxes stay as they were before the handset tax).

Policy reforms will drive significant gains in coverage and adoption

Table 4 provides a list of operator-led initiatives and policy reforms that were modelled in each country. Putting these in place would result in significant gains in 3G and 4G coverage, as well as enable the adoption of mobile and mobile internet services in the seven countries. Figure 21 shows how mobile internet adoption and the usage and coverage gaps would evolve by 2030 under two scenarios: a baseline scenario where adoption and coverage increase based on prevailing market and regulatory conditions and a policy reform scenario where the reforms set out in Table 4 are applied.

In almost all countries, policy reforms would drive significant gains in adoption and mobile broadband coverage. Specifically, over the seven countries, the reforms would result in 23 million more people covered with mobile broadband networks (more than 4 percent of the total projected population considered) and bring 37 million people online (almost 7 percent of the total projected population considered). The gains in coverage would also benefit rural areas that have lower levels of socioeconomic development (Figure 22).

However, even with policy reforms in place, none of the countries is expected to achieve universal coverage and mobile internet adoption by 2030. In Democratic Republic of Congo, Tanzania, and Rwanda, more than half the population is still expected to be offline in 10 years.

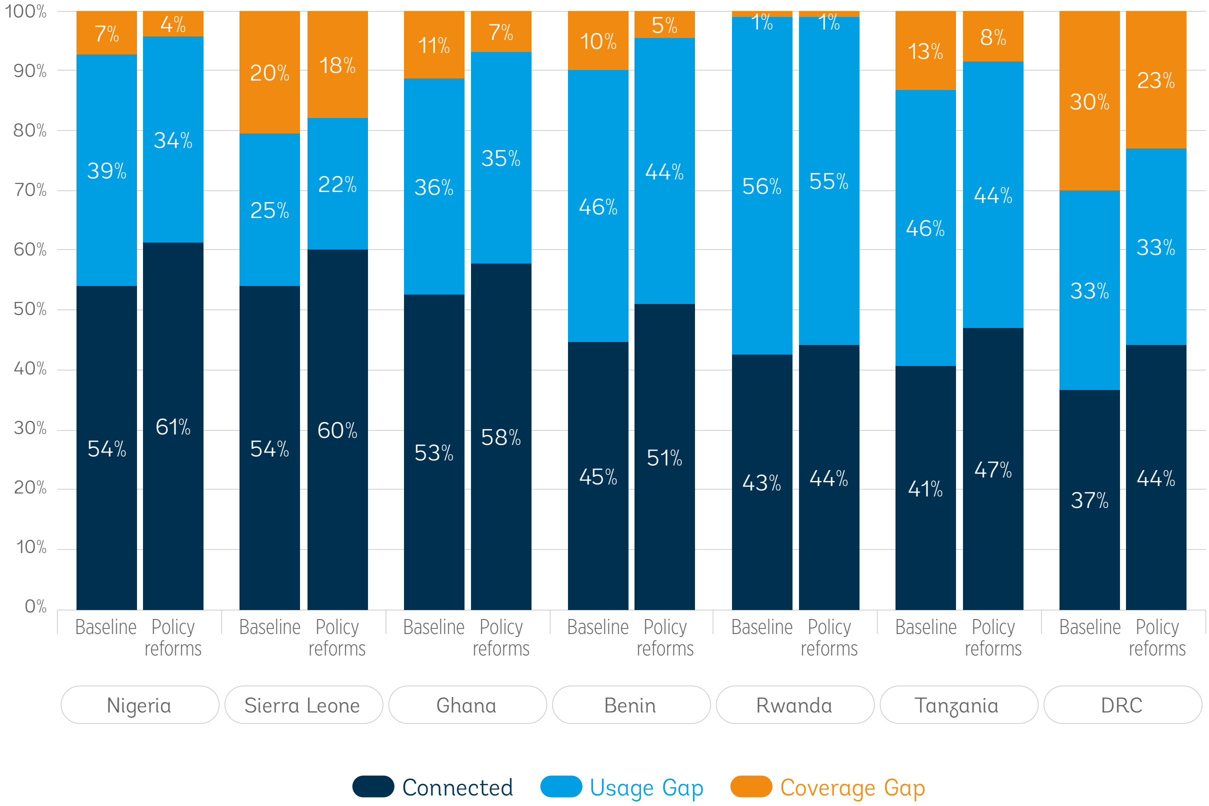
Table 4.

Innovation and policy reforms modelled in each country

	Innovation	Infrastructure sharing	Spectrum	Taxation	Import duties
Benin	Smaller, lower-cost sites	Active site sharing	Reduce annual spectrum fees	Reduce sector-specific operator taxes	Remove equipment and handset duties
Democratic Republic of Congo	Smaller, lower-cost sites	Active site sharing	—	Reduce sector-specific consumption taxes	Remove equipment and handset duties
Ghana	Smaller, lower-cost sites	Active site sharing	Technology neutrality	Reduce sector-specific consumption taxes	Remove equipment and handset duties
Nigeria	Smaller, lower-cost sites	Active site sharing	Sub-1 GHz deployment or 4G	Reduce sector-specific operator taxes	Remove equipment and handset duties
Rwanda	Smaller, lower-cost sites	Active site sharing	—	Reduce sector-specific consumption taxes	—
Sierra Leone	Smaller, lower-cost sites	Active site sharing	Sub-1 GHz deployment or 4G	Reduce sector-specific operator taxes	Remove equipment and handset duties
Tanzania	Smaller, lower-cost sites	Active site sharing	Sub-1 GHz deployment or 4G	Reduce sector-specific consumption taxes	—

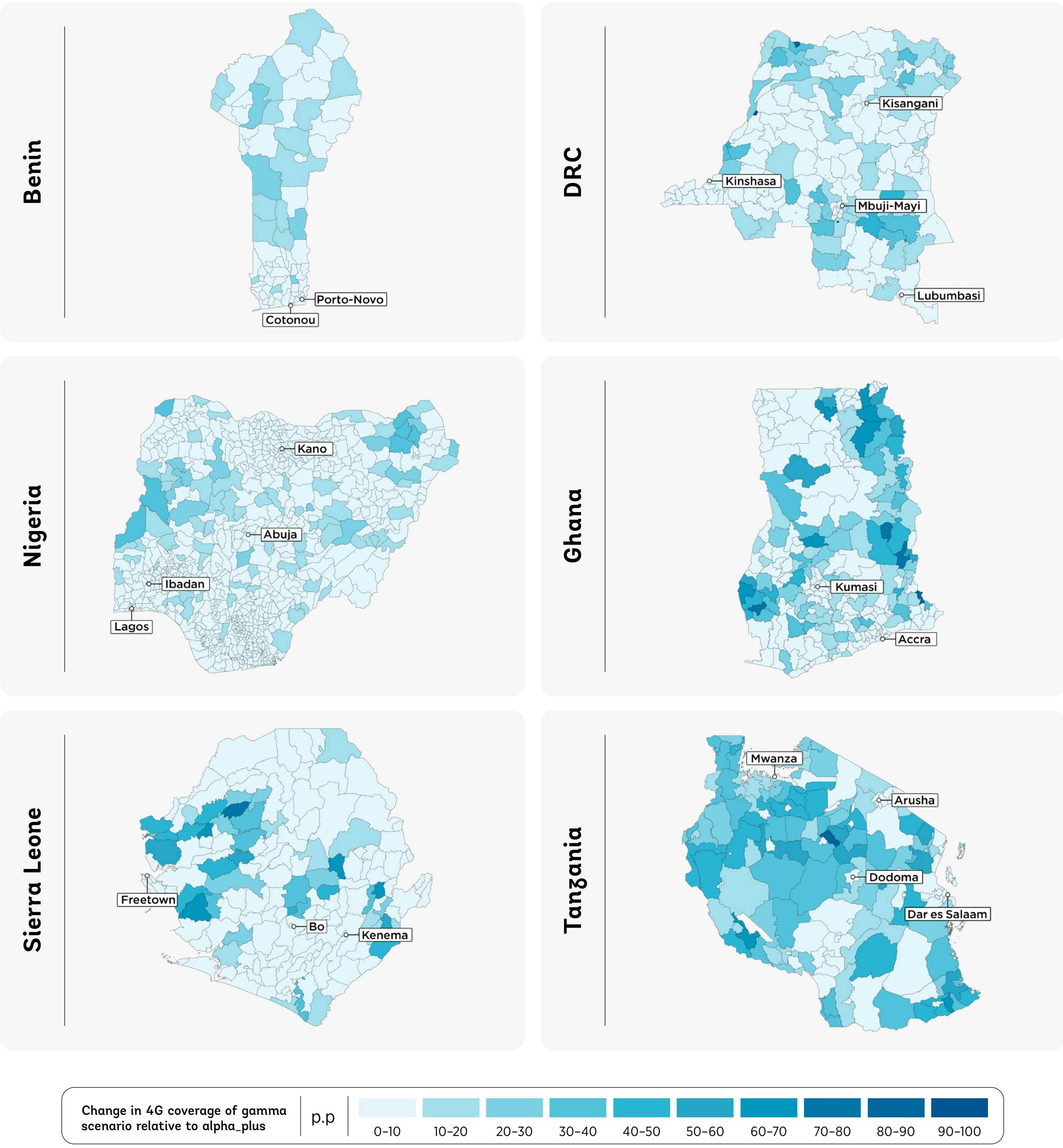
Figure 21.

Connected, usage and coverage gaps by 2030 under baseline and policy reform scenarios



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations. As Rwanda has an SWN for 4G, it is assumed that it will complete deployment for the vast majority of the population by 2030.

Figure 22.
Location of 4G coverage gains by 2025 due to policy reforms



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and Center for International Earth Science Information Network (CIESIN), household survey data and Group on Earth Observations.

05
Public Investment is Needed to Achieve universal Connectivity

Near-universal 4G coverage will require additional investment on the supply and demand sides, though there will remain some areas where alternative technologies are needed.

While the policy reforms considered in this study would have a significant impact, it would still leave around 9 percent of the population in the seven countries (just over 50 million people) without mobile broadband coverage and around 17 percent of the population ages 10 and above (around 65 million people) without internet access by 2030. To expand access and usage, other policies that target the barriers not directly addressed in this study, particularly around awareness and digital skills, will therefore be important. However, even with additional reforms, it is likely that additional investment will be required to fully achieve universal internet access by 2030 in each of the seven countries, especially among the lowest income groups with little purchasing power. Furthermore, for some hard-to-reach areas other broadband technologies need to be considered.

One potential policy option depending on the availability of public funds and the country and sector situation is supply-side subsidies. Table 5 shows the amount of subsidy required to extend 4G coverage to the majority of population. This is calculated based on the amount needed to cover the expected losses on unprofitable sites over a 10-year period. In other words, it is the amount needed to cover the capex and opex costs that cannot be recovered by expected revenues. It therefore minimizes the amount of additional investment needed while maximizing the population that benefits from 4G coverage.[36] The mechanism for allocation of subsidies is not modelled and further analysis would be needed to assess alternatives such as 'pay or play' or reverse auctions for minimum subsidies.[37]

The subsidies are calculated according to two scenarios—one where the policy reforms discussed in Section 4 are applied and one where they are not. The analysis shows that the policy reforms can save 10–20 percent of the cost required to achieve near-universal coverage. The results also show that for most countries, 55–65 percent of the total cost in unprofitable areas requires subsidization, with the rest covered by operators. In Sierra Leone, the proportion is higher due to a lack of 4G demand and the proportion of sites that require high-cost alternative backhaul solutions.

36 Other investment models might cover a certain proportion of capex or opex. However, such an approach may overestimate the amount of additional investment needed. For example, if a public or private entity funded 50 percent of capex for all new sites, this might be more than is necessary if a site only requires 20 percent of capex to be funded to be profitable.

37 For a description of alternative ways of providing supply-side subsidies see ITU and World Bank (2020). Digital Regulation Handbook, Chapter 3.

Table 5.
Amount of investment needed to provide near-universal 4G coverage

	4G coverage without subsidy* (%)	4G coverage with subsidy (%)	Subsidy cost without policy reforms (US$, millions)	Subsidy cost with policy reforms (US$, millions)	Subsidy cost (US$ per capita)	Proportion of total cost that is subsidized (%)
Nigeria**	95.8	99.5	461	407	1.98	65
Benin	95.4	99.7	37	30	2.47	57
Ghana	86.2	99.1	90	76	2.44	61
Tanzania	81.9	98.8	213	185	3.09	62
Sierra Leone	76.7	96.8	100	83	10.46	70
Democratic Republic of Congo	57.6	94.3	380	296	3.31	61

Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations. Subsidies are calculated based on the amount needed to cover expected losses on unprofitable sites over a 10-year period.
Note: *4G coverage without subsidy assumes that the policy reforms discussed in Chapter 4 are applied.
**Analysis for Nigeria assumes that coverage can be deployed in all states. If states with ongoing conflicts are removed from the analysis, it is expected that 4G coverage would reach 92 percent with a subsidy.

An alternative, or at least complementary, approach to expanding coverage is to focus on investment and policy reforms that increase demand for 4G services. This has the benefit of increasing 4G connectivity and making more areas profitable for operators to deploy 4G networks. Table 6 shows that in 2020, penetration of 4G mobile internet services was limited across all markets, ranging from 0.5 percent in Democratic Republic of Congo to 6 percent in Nigeria. Over the next five years, this is expected to increase, but current forecasts indicate 4G penetration will not exceed 15 percent in any country. Furthermore, in rural areas, it is expected that 4G penetration will be less than 5 percent across all six countries by 2025.

This is the fundamental reason why 4G coverage will not be universal without further policy reform and public investment and leapfrogging to 4G is unlikely to occur in rural areas. However, this could change if further reform or investment can stimulate large increases in demand. Table 6 shows that if expected 4G penetration was 20 percent in uncovered areas, operators would extend coverage to more than 89 percent of the population in all markets. If 4G penetration increased to 40 percent, 4G coverage would almost reach the same levels as would be achieved with a pure infrastructure subsidy (as presented in Table 6).

Table 6.
Expected 4G coverage with alternative demand scenarios (%)

	Current and forecast 4G penetration		Expected 4G coverage…		
	2020	**2025**	**With no change in demand**	**With 20% penetration in uncovered areas**	**With 40% penetration in uncovered areas**
Nigeria*	6	14	95.8	98.2	98.6
Benin	3	11	95.4	98.3	98.9
Ghana	5	15	86.2	95.0	96.7
Tanzania	2	8	81.9	95.4	95.9
Sierra Leone	2	9	76.7	90.5	93.5
Democratic Republic of Congo	0.5	2	57.6	89.1	92.0

Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations.
Note: *Analysis for Nigeria assumes that coverage can be deployed in all states.

The analysis therefore highlights the importance of focusing on demand- as well as supply-side interventions. As 4G penetration remains relatively limited, especially in rural areas, any investment that focuses solely on expanding coverage is unlikely to generate a significant increase in mobile internet usage and reduce the internet uptake gap. The example of Rwanda illustrates this—in 2020, 4G internet penetration was around 2 percent (compared to 22 percent for 2.5/3G mobile internet), even though investment in the SWN has extended 4G coverage to more than 98 percent of the country's population.

The modelling carried out in this study suggests that even if 4G infrastructure is subsidized to cover almost all the population in each of the other six countries, mobile internet adoption would only increase by 1–3 percentage points by 2030, as demand would remain limited. Low penetration levels also pose a risk to the viability and sustainability of any public investment in expanding coverage, especially if expected revenues are insufficient to cover opex costs in the long term.

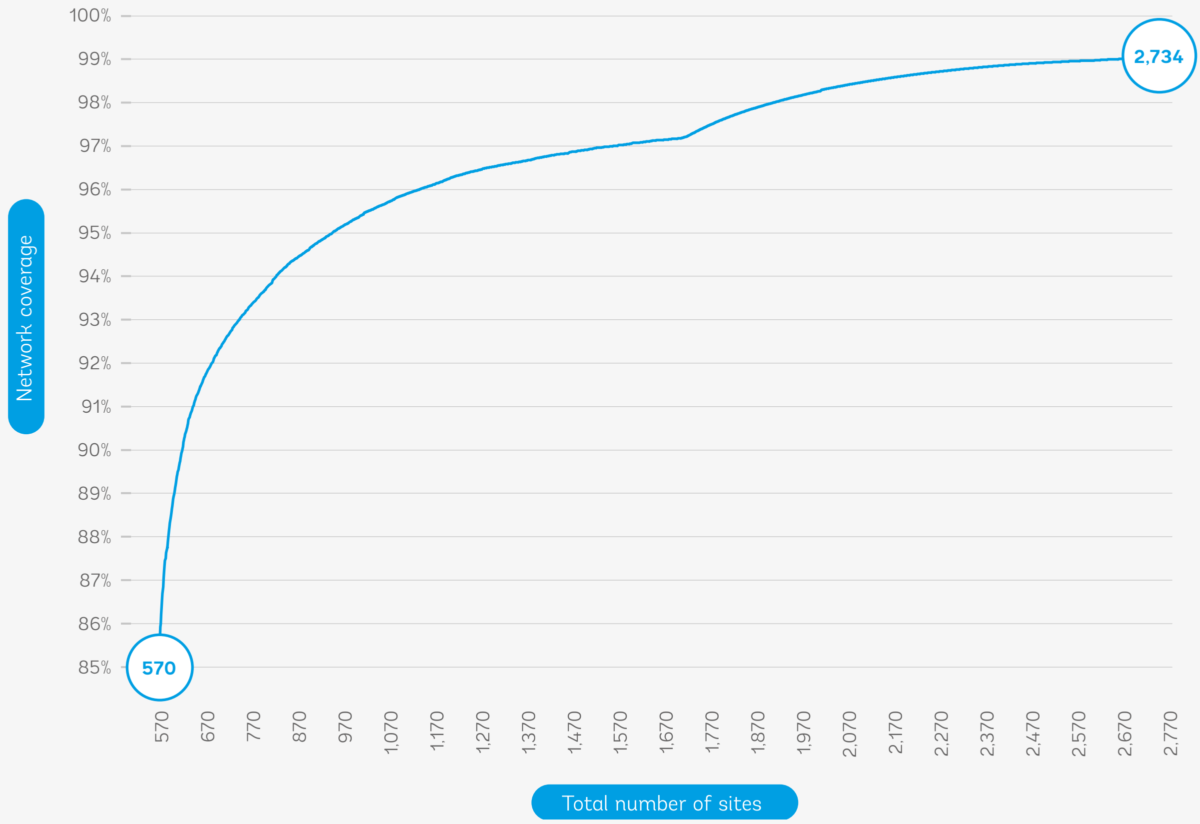
Further research to better identify and evaluate interventions that can affect mobile internet demand will therefore be important going forward, to enable widespread 4G coverage in Sub-Saharan Africa. These might include policies to enhance digital skills and literacy and the availability of relevant content, interventions to expand access to electricity, and/or interventions to improve access to mobile devices. The latter could include replicating and extending successful examples of device financing and/or subsidizing handsets directly—although a subsidy requires careful design to ensure that it is targeted and used only by individuals who cannot otherwise access a device. However, there is a risk of the subsidy crowding out private investment. The operation of energy service companies (ESCOs) could facilitate the provision of electricity to mobile equipment and unconnected communities. With regard to improving the availability of content, governments can take steps to enable and promote online content, for example, mobile education and health services. In partnership with the private sector and education institutions, governments can support programs to increase awareness, digital skills, and literacy.

Why does 4G coverage not reach 100 percent with additional investment?

In all the six countries,[38] there is still a segment of the population that is unlikely to have coverage. To understand the reasons for this, and why these can differ by country, Figure 23 shows the number of additional sites needed for each coverage increment in Sierra Leone. This is the smallest country considered in the study in terms of population, but there are mountainous areas that can make it difficult to expand coverage. To simplify the analysis and interpretation, the analysis focuses on expanding mobile coverage in greenfield areas. At the start of 2020, there were 570 mobile sites in Sierra Leone that covered just over 85 percent of the country's population with at least 2G technology. The next 100 additional sites would expand coverage to around 92 percent, while the subsequent 100 sites would increase coverage to 93.5 percent. At a certain point, the number of sites needed to expand coverage increases exponentially, as settlements become much smaller and sparse. For example, to expand coverage from 98 percent to 99 percent, almost 800 sites would be needed.

This is also reflected in the cost per covered person. Figure 24 shows that when expanding coverage from 85 percent to 86 percent, the cost per covered person is just over US$10. This increases to around US$30 when reaching 90 percent coverage and then increases exponentially once coverage reaches around 96 percent. This is the level of 4G coverage that is assumed would be reached with additional investment in Table 5.

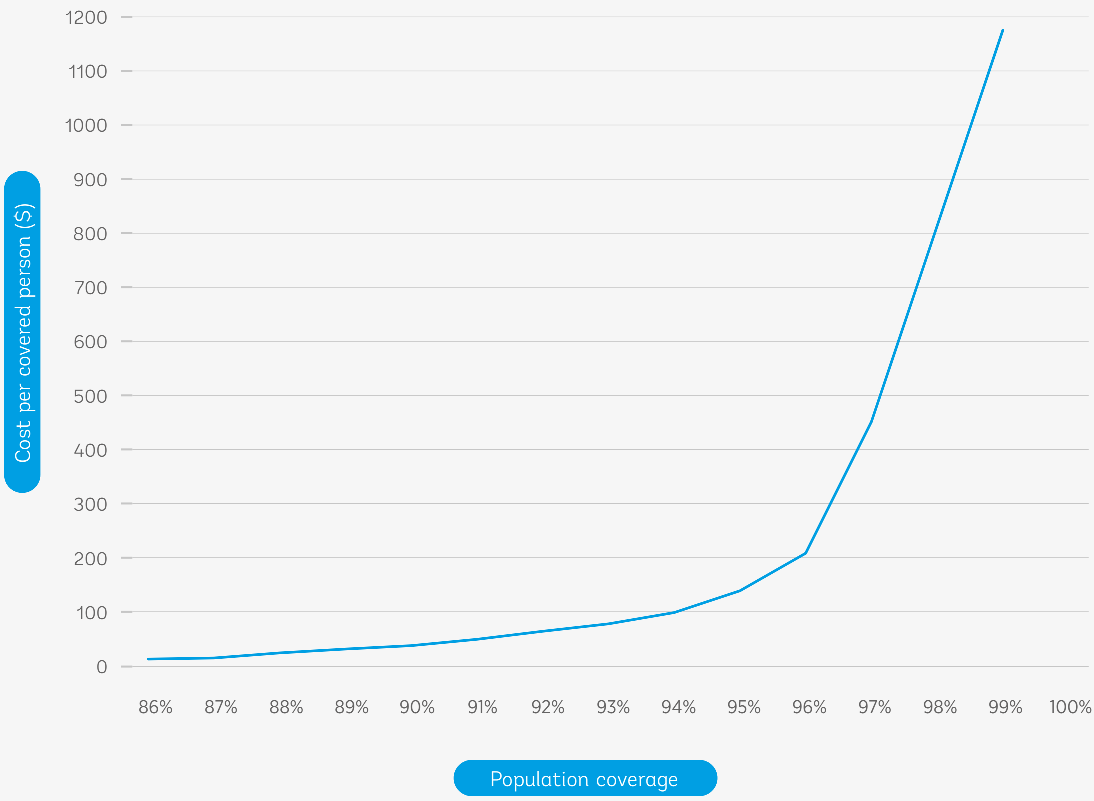
Figure 23.
Number of sites needed to achieve near-universal mobile coverage in Sierra Leone



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data, and Group on Earth Observations.

38 Rwanda is not included as it is assumed that the single wholesale 4G provider will expand 4G coverage to almost all of the country's population by 2030.

Figure 24.
Cost per covered person in greenfield sites in Sierra Leone



Source: GSMA analysis of data sourced from mobile operators, GSMA Intelligence, Facebook Connectivity Lab and CIESIN, household survey data and Group on Earth Observations. Cost is calculated based on the 10-year NPV of deploying greenfield sites.

While it is technically possible to achieve universal coverage with existing technologies, modelling shows that, at a certain point, the amount of additional investment needed becomes an order of magnitude (or sometimes several orders of magnitude) higher. These are areas that are remote and sparsely populated, with some sites covering no more than a few 100 people (sometimes even fewer).

Expanding coverage to these locations will therefore be extremely challenging using existing technologies, due to a combination of low population density and high costs—many of the sites require satellite backhaul, for which the current costs of deploying 3G and 4G can be prohibitive when there is a lack of demand. Providing coverage in these areas in a sustainable manner will therefore likely require new innovations that are, thus far, yet to be developed or are currently unproven on a large-scale, commercial basis. One potential solution could be low-earth orbit satellite constellations which could help significantly reduce the cost of backhaul or even communicate directly from the satellite to normal existing handsets without the need of any terrestrial infrastructure.[39] Other solutions could include wide-area cell sites.[40]

39 For example, Lynk or project Starlink by SpaceX.
40 For example, Altaeros SuperTowers.

06 Conclusions

This study focused on how mobile technologies could support connectivity in Africa. It had two objectives. The first was to map mobile coverage and adoption at a settlement level across seven countries in Sub-Saharan Africa that captured the different socioeconomic and regulatory challenges facing the region. The second was to simulate the effects of different policies using granular data on both the location of mobile infrastructure and demand. This enables more precise calculations and therefore a deeper understanding of the impacts that policy reforms can have on both coverage and adoption, as well as the additional investment needed to achieve universal connectivity by 2030.

The findings from this study can be used to inform policy making in other countries, while the analysis can also be leveraged to understand the impact of policies and investments in different geographic locations. Given the extent to which mobile connectivity varies within countries, it is important to continue mapping and track coverage and adoption at a local level to ensure interventions are targeted where they are needed, to ensure their effectiveness. It is also worth noting that addressing connectivity challenges in Africa require the use of various technologies that respond to demand needs in a policy environment that allows for innovation on a level playing field.

The simulations in seven countries bring out clear and important messages for governments, the private sector, and the international donor community:

- **Mobile operators are very close to the market frontier for 2G coverage,** with at least 87 percent of the population covered across the seven countries. A limited amount of additional 2G coverage can be provided by the private sector that is financially viable and sustainable in current market conditions. Almost all the uncovered areas are in rural, often remote, locations.
- Extending mobile broadband to areas with no coverage presents a substantial economic challenge. It will require efforts to reduce deployment costs and, more importantly, increase demand. Both are contingent on **continued, collaborative action by all stakeholders, building on private sector innovation,** which in recent years has driven significant cost reductions in rural network deployments, as well as in handset and data prices.
- While 3G and 4G coverage are lagging at 74 percent and 48 percent of the population, respectively, they could catch up with 2G coverage in the coming years if spectrum policy is updated so that operators have **access to sufficient and affordable spectrum in sub-1 GHz bands to use the spectrum more efficiently, including the refarming of existing spectrum so that it is technology neutral.** For example, across four countries where not all operators have access to the sub-1 GHz spectrum for 4G (in Ghana, Nigeria, Sierra Leone, and Tanzania), an operator could increase rural 4G coverage by more than 5 percentage points (or 7.5 million people) if they are able to use 700 or 800 MHz spectrum for 4G (assuming existing spectrum fees apply).
- **Infrastructure sharing at the site level would enable coverage to expand while maintaining service-level competition.** Active sharing would allow 2–10 percent of the rural population, depending on the country, to have mobile broadband coverage from more than one operator. Policy makers that are considering SWNs should also consider that active sharing can deliver similar levels of coverage while maintaining a greater degree of service competition (provided competition safeguards are in place) while avoiding the risks of creating a monopoly at the infrastructure level, like is the case with SWNs.

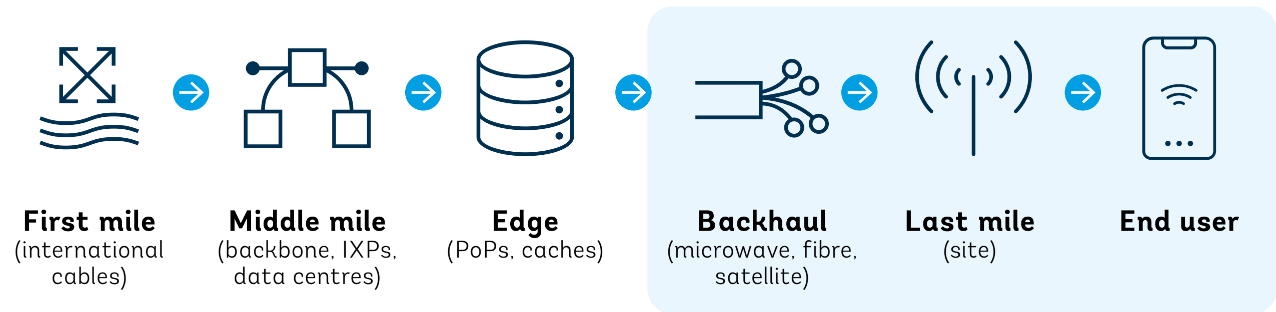
- **Aligning tax policy with best-practice principles and removing distortive sector-specific taxes that are solely applied to the mobile sector** will likely improve investment incentives for operators as well as affordability for consumers. This includes the removal of excise duties on handsets and mobile services that are not applied to other goods and services, as well as the reduction of taxes levied on mobile operators but not on other firms in the economy. This reform would expand mobile broadband coverage by up to 4 percentage points, depending on the country, and would bring more than 30 million people online by 2030 (increasing mobile internet adoption by 6 percentage points).
- While these policy reforms would drive important gains in connectivity, by 2030 it would still leave 9 percent of the population without mobile broadband coverage and 17 percent of the population ages 10 and above without internet access. **Additional interventions on the supply and demand side are still needed to make mobile broadband coverage and adoption universal by 2030.** In the seven countries, with the policy reforms in place, around US$1.7 billion of additional investment would cover the vast majority of populations with 4G networks, of which almost 40 percent could be funded by the private sector, leaving an investment gap of US$1.1 billion. Without the policy reforms highlighted above, the investment gap would be US$1.3 billion, meaning **policy reforms can save around 15 percent of the additional investment needed to achieve near-universal coverage.**
- An alternative, or at least complementary, approach to expanding 4G coverage would be to **focus on additional policy reforms and investment that stimulate demand.** Over the next five years, current forecasts indicate that 4G penetration will not exceed 15 percent in any of the seven countries, while in rural areas it is expected that 4G penetration will be less than 5 percent in every country by 2025. **Lack of demand is the fundamental reason why universal 4G coverage will be challenging without further policy reform and public investment, and why 'leapfrogging' to 4G is unlikely to occur in rural areas.** However, this could change if further reform and/or investment can stimulate large increases in demand. If expected 4G penetration was 20 percent in uncovered (mostly rural) areas, operators would extend 4G coverage to more than 89 percent of the population in all seven markets. If 4G penetration increased to 40 percent, 4G coverage would almost reach the same levels as would be achieved with a pure infrastructure subsidy. Further research to better identify and evaluate interventions that can have an impact on mobile internet demand will therefore be important going forward, to enable widespread 4G coverage in Sub-Saharan Africa. These could include policies to enhance digital skills and literacy and the availability of relevant content, interventions to expand access to electricity and other assets for more productive use of internet, and interventions to improve access to mobile devices.
- Many of the policy findings are likely to apply in other countries with similar characteristics. For example, the impact of active infrastructure sharing and spectrum refarming will be particularly relevant to countries with large coverage gaps and/or large populations that live in dispersed and remote areas. For countries that have achieved high coverage but where a significant usage gap persists, policies that increase demand (for example, by improving affordability and access to devices) will be most impactful.

Appendix A: Methodology

This appendix presents the methodology used to model the effects of public policy options for mobile infrastructure deployment in seven Sub-Saharan Africa countries. The model is focused on the 'last mile' of infrastructure, that is, the mobile site that connects with the end user as well as the backhaul link that connects sites to the core network (see Figure A1). It assesses the incremental profitability of expanding networks, which affects network coverage and adoption. While investments in the 'first mile' (for example, international cables) and 'middle mile' (for example, backbone and IXPs) are important in terms of increasing network capacity, especially in urban areas, based on the current and expected levels of data usage in rural areas across the seven countries, mobile operators normally have sufficient network capacity to meet demand in areas that are not covered. Therefore, we consider that investing in middle-mile capacity is generally not a requirement to increase coverage. However, maintaining a good quality of service and keeping data bundles affordable will require investing in backbone infrastructure to transport larger volumes of data from rural areas as they increase to reach the levels observed in urban areas.

This report focuses on the evolution of coverage and usage, making sure that enough capacity is deployed at the last mile to carry the user traffic. Hence, it does not consider policy reforms or interventions that would increase investment in the core network, first mile, or middle mile, which should be the subject of a separate analysis.

Figure A1.
Last mile



Note: PoP = Point of presence

There are four modules that underpin the analysis:

- A supply module that contains an inventory of existing mobile network infrastructure
- A demand module that incorporates socioeconomic data to estimate demand for mobile voice and data within each country
- An economic and engineering module that combines demand and supply data to estimate the necessary infrastructure and cost of expanding mobile networks in uncovered areas
- A market and public policy module that estimates what level of mobile coverage (for 2G, 3G, and 4G technologies) could be achieved by mobile operators with and without policy reforms and public sector or third-party intervention, based on expected demand and deployment costs.

Supply

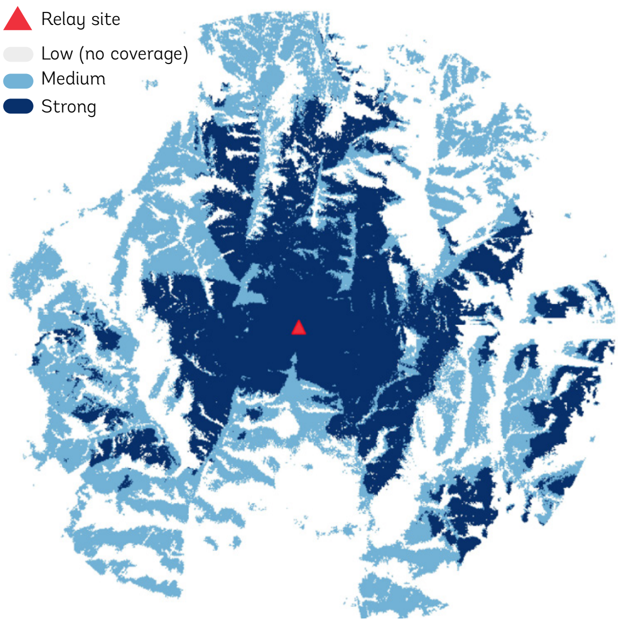
To produce the aggregate coverage data for each country, network infrastructure data were collected from larger MNOs. For each individual relay site, we collected the following parameters:

- Location in geographical coordinates
- Height of the tower hosting the antennas
- Signal emitting power
- Antenna parameters such as the gain, azimuth, and tilt
- Frequency band used
- Type of technology available (2G, 3G, or 4G)
- Date of deployment.

We calculate the coverage of each relay site using a Radio Propagation Model (RPM). RPMs are empirical mathematical models widely used by operators for planning the setup of their networks, allowing them to plan the location and characteristics of each relay site so as to maximize coverage and decrease costs. There are several RPMs available that are optimized for specific settings or technologies. We use an Irregular Terrain Model (ITM), also known as the Longley Rice Model,[41] optimized to deliver accurate results in rural and peri-urban areas.

The ITM uses two sets of input variables. The first are the technical parameters of each individual relay site that we collected from operators. The second are the characteristics of the transmission medium, such as the terrain profile and type of vegetation in the area.[42] The output of the ITM model is a geocoded image showing the area covered with signal strength above a predefined threshold (see Figure A2 as an example). Combining the coverage provided by each individual site for every operator in the country, we obtain the countrywide coverage footprint for each technology (2G, 3G, and 4G). Overlaying these countrywide coverage footprints with the population, we are able to estimate the coverage status for each individual settlement in the country. A settlement is assumed to have coverage if it receives at least the medium signal strength for the relevant technology. The predefined signal strength thresholds that we use are presented in Table A1.

Figure A2.
Area covered with signal strength



Source: GSMA

Table A1.
Signal strength thresholds

Radio technology	Medium signal strength	Strong signal strength
2G	-85 dBm	-73 dBm
3G	-91 dBm	-83 dBm
4G	-105 dBm	-95 dBm

Source: GSMA

41 The ITM model used is based on version 7 of the algorithm released the 26/06/2007 by the National Telecommunications and Information Administration (NTIA) - very similar to version 1.2.2.
42 This is sourced from the Advanced Land Observing Satellite (ALOS) Global Digital Surface Model.

Demand

Demand is estimated based on the probability of mobile and mobile internet adoption, which we calculate at a settlement level based on a function of socioeconomic and demographic characteristics. The following data are used:

- **Settlements.** To overlap network data with population settlements, we use data sourced from the High-Resolution Settlement Layer database,[43] which provide estimates of human population distribution based on census data and high-resolution satellite imagery. The data identify population agglomerates according to an image recognition algorithm. These data give the location and density of the population of a given country.
- **Household survey data.** As part of the study, we carried out most demand analysis using recent survey data from Gallup World Poll. Analysis was also checked using other household survey data, including the Ghana Living Standards Survey, Rwanda Integrated Household Living Conditions Survey, Sierra Leone Integrated Household Survey, Tanzania Household Budget Survey, and Nigeria Living Measurement Study.
- **Demographics.** We used UN-adjusted unconstrained population data sourced from WorldPop[44] to calculate the distribution of settlement populations in terms of age and gender.
- **Night light data.** We used Visible Infrared Imaging Radiometer Suite (VIIRS)[45] data to assign a light radiance value to each settlement. This was used as a proxy indicator for income and electricity access in each settlement.

To estimate demand in each settlement (including potential demand for settlements currently without coverage), an econometric model was used to estimate mobile ownership and mobile internet use. We constructed a model of the probability of adopting mobile phone ownership (sim_i) and mobile internet capability (mi_i) conditional upon a vector of independent variables (x).

We define a latent independent variable (y_i*) as

$$y_i^* \,(\boldsymbol{X};\, \beta_0, \boldsymbol{\beta}) \equiv \beta_0 + \boldsymbol{\beta X} + \varepsilon_i$$

This latent variable determines the outcome variable (y_i) for each individual i in the following way:

$$y_i = \begin{cases} 0 \text{ if } y_i^* < 0 \\ 1 \text{ if } y_i^* \geq 0 \end{cases} \quad \textit{where} \;\; y_i \begin{cases} sim_i \\ mi_i \end{cases}$$

By assuming that the errors follow a logistic distribution (i.i.d.), we used a logit model to estimate the conditional probabilities of the two mobile adoption outcomes. Standard errors were clustered at a country 'region' level. The independent variables used in the model included gender, age, whether the individual lived in a rural or urban location, income quintile, employment, education, and electricity access (where data were available). Using the coefficients of the regressions in each country, we estimated the probability of demand in each settlement.

43 https://data.humdata.org/organization/facebook.
44 https://data.humdata.org/organization/worldpop.
45 https://ngdc.noaa.gov/eog/viirs/download_dnb_composites.html.

As a final step, estimated penetration rates in each settlement were then adjusted so that the total number of mobile and mobile internet subscribers in covered areas matched country-level estimates for unique mobile subscribers and unique mobile internet subscribers. The country-level data were sourced from GSMA Intelligence and verified with data from the national regulator where available. This step ensured that the aggregate level of demand is accurate—and that it is distributed across the country based on the relevant demand drivers and where coverage exists.

To estimate revenues, assumptions on ARPU were required. These were initially sourced from GSMA Intelligence, from data reported by mobile operators (this was verified with data published by national regulators where available). To reflect spatial variation, we adjusted ARPU according to whether the settlement is in a rural or urban area.

The relative differences between urban and rural ARPU were sourced from survey data gathered by GSMA Intelligence and, where available, from operators and national statistical offices. A further input was required in terms of the incremental ARPU gained when a customer upgrades to a 3G and 4G connection (compared to being on 2G). These assumptions (ARPU differentials by rural-urban geography and technology) were based on analysis of mobile spend in the GSMA Intelligence Consumers in Focus Survey and, where possible, verified with mobile operators.

Mobile and mobile internet ARPU were then calibrated so that total estimated revenues in covered areas matched the latest annual market recurring revenues, which were sourced from GSMA Intelligence and mobile operators (or otherwise data from the national regulator).

Economic and engineering module

To estimate the cost of expanding network coverage, we combined the supply and demand modules to produce a list of new sites and site upgrades (for 3G and 4G network expansion). These site locations were optimized according to a profitability algorithm, such that they reflect the sites that operators are most likely to deploy. The algorithm was designed to find the optimal combination of sites that maximizes the NPV of investment. The starting point is a set of greenfield site simulations, where we model hypothetical new sites in sub-settlements that do not have coverage.[46] For each of these new sites, we modelled four different site configurations (as explained in Chapter 3), with an associated capex and opex that was sourced from operators and equipment vendors. To estimate the coverage of each site, we applied the propagation model described in the supply module above.

The profitability algorithm searches for the best combination of sites and site configurations that maximizes the NPV of each site. Site overlaps (sites whose coverage overlaps with other sites) were considered. This provides an optimal network deployment to extend coverage to all populations currently uncovered by any technology.

When modelling the deployment or upgrade to 3G or 4G, a similar algorithm was applied to calculate the best combination of site upgrades that maximized the NPV of investment among existing (brownfield) site upgrades and new greenfield sites. The algorithm was run assuming different spectrum bands for deployment.

46 Due to the large number of settlements in a country, we limit the number of settlements where we simulate the deployment of new sites. This limit changes for each country but is roughly close to settlements where there are more than 50 uncovered people. Note that even sites below this limit can receive coverage from neighbouring settlements. For every country, we ensure that coverage simulations reach at least 99 percent of the population.

Market and policy module

To develop a model that quantifies the impact on coverage and adoption of different public policies, the outputs of the economic and engineering module were used to assess the impact of various policies or changes in the market. The starting point is the list of brownfield and greenfield sites that would enable coverage to reach the uncovered populations in each country for 2G, 3G, and 4G networks.

For brownfield sites, which already have 2G, the analysis considers the costs of upgrading to 3G or 4G (or both) and determines whether the site is financially viable to generate a positive return, given expected demand and ARPU. If it is, the model assumes the site will be upgraded and coverage will expand. The model selects the most profitable of three potential upgrades—3G, 4G, or 3G+4G combined (unless the site only needs to be upgraded to 4G).

In terms of greenfield sites, the model takes the deployment of 2G as the starting point. It determines whether a site is financially viable, given expected demand and returns for 2G voice and data. It then separately assesses the incremental cost and revenue of deploying 3G and/or 4G at the site. The final deployment decision is then based on the following:

- If 2G is profitable and 3G/4G is not profitable, the site is assumed to be 2G only.
- If a 2G site with 3G/4G is more profitable than a 2G-only site, the site is assumed to have 2G as well as 3G/4G technology (the latter will be determined based on the most profitable of the three potential upgrades, similar to the approach for brownfield sites).
- If there is no profitable deployment option (that is, both 2G and 2G+3G/4G have a negative NPV), it is assumed that the site will not be built.

The results of this analysis determine the additional coverage that could be provided by the market without any further policy reforms or interventions (as set out in Chapters 2 and 3). The following policies can then be modelled to determine the impact on both coverage and adoption.

Infrastructure sharing

- **No sharing.** When modelling the expected coverage assuming more than one network, this scenario assumes that additional networks incur the same capex and network opex, meaning, for example, that if two networks are modelled in uncovered areas then the amount of capex and network opex per site doubles compared to a single network. The model also includes variable costs, which are estimated based on revenues, and capacity costs that depend on the number of users and traffic.
- **Passive sharing.** This assumes that the passive elements of a new site (including the cost of land, tower, and power) are only incurred once, even if multiple networks are assumed. However, an uplift is applied based on the number of carriers sharing the infrastructure. The uplift is sourced from information from operators.
- **Active sharing.** This assumes that the active elements of a new site (including radio and backhaul equipment) are only incurred once even if multiple networks are assumed. Again, an uplift is applied based on the number of carriers sharing the infrastructure. The uplift is sourced from information from operators.

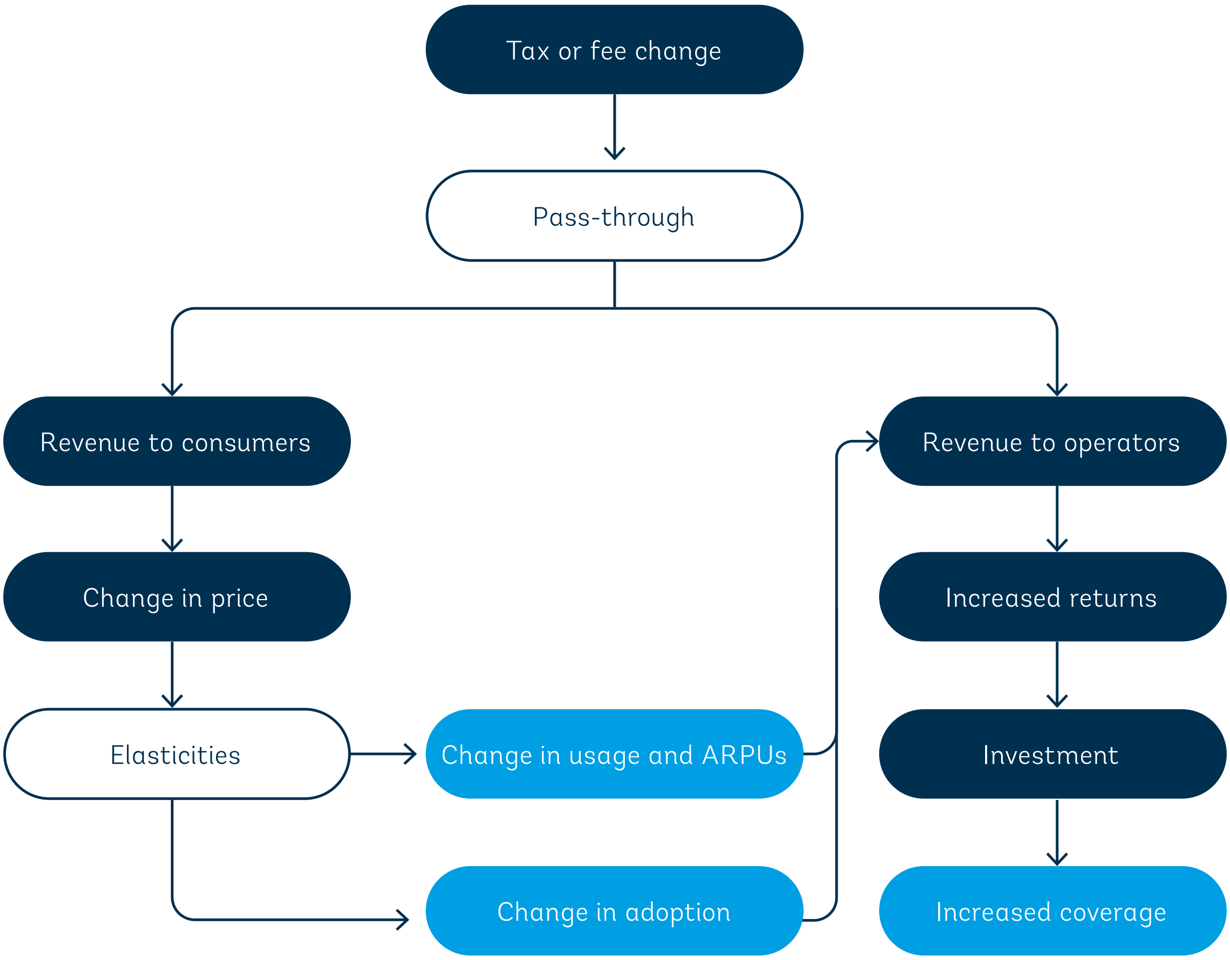
Spectrum

To model the impact of deploying different bands, we run the 3G/4G supply and demand analysis for both brownfield and greenfield sites based on different spectrum scenarios. Where lower bands are used, the population covered for each site will be higher than that when higher frequency bands are used.

Taxation

Figure A3 presents how the analysis models tax policy reforms. Taxes can either apply to consumers or operators and are a function of the tax base (for example, recurring revenues, accounting profits, and import value) and the relevant tax rate. When modelling the impact of a tax change, adjustments to the tax rates—whereby the sector-specific operator and consumer taxes are either reduced or increased—are applied and the difference between total tax payments in the baseline and scenario are combined with pass-through rates to prices and demand elasticities to adjust for impacts on usage and adoption.

Figure A3.
Modelling the impact of tax reforms



Source: GSMA

Pass-through and demand elasticity assumptions are currently based on previous taxation studies carried out by GSMA and Ernst & Young (EY).[47]

Given the change in tax payments in the baseline and scenario, operators will make the decision on how much of this to retain or 'pass-through' to prices. We vary the pass-through for changes in three types of tax: consumer taxes, operator taxes, and taxes on equipment.[48] The pass-through rates are based on results from the previous taxation studies carried out by GSMA and EY, which estimate the impact on prices through tax shocks in computable general equilibrium (CGE) models (based on data from the Global Trade Analysis Project).

47 For further details, see https://www.gsma.com/publicpolicy/regulatory-environment/taxation; GSMA and Ernst & Young. 2020. 'Mobile Taxation Studies: Methodology Documentation.

48 For example, import duties.

We take an average of the pass-through rates for the studies that have been carried out on countries in Sub-Saharan Africa[49] by the above tax types. We assume price changes are passed through equally to the prices of each type of service provided. In line with the previous GSMA/EY studies, pass-through rate assumptions are based on and applied to 'effective prices', which are calculated using recurring revenues. A change in the effective price reflects an overall benefit to consumers and does not necessarily imply a reduction in like-for-like prices. For example, it could instead reflect an increase in the quality of the service received; an increase in the number of included minutes, messages, and/or data provided at the same price; or a combination of these outcomes.

Table A2.
Pass-through assumptions

Tax type	Pass-through rate (%)
Consumer	90
Operator	85
Operator - taxes on equipment[50]	0

Once the pass-through is established, we model the impact of changes in prices on consumer demand, split into usage elasticities based on the price of data and voice, ownership elasticities based on the price of handsets and services, and 2G to mobile broadband migration elasticities based on the prices of data and mobile broadband handsets. These elasticities are based on a 2019 literature review as part of the previous GSMA/EY taxation studies. This literature review was limited to studies in the past 15 years, and we use the average for low-income countries.[51]

Table A3.
Elasticity assumptions

Tax type	Change in price of voice	Change in price of data	Change in price of handsets
Usage	-0.84	-1.11	—
Adoption	-0.90	—	-1.30
Technology migration (2G to mobile broadband)	—	-0.32	-0.47

By estimating the change in the price of services (which we calculate by multiplying the changes in tax revenues by the pass-through rates), and subsequently applying the above elasticity assumptions, we calculate new levels of usage and adoption.

49 Sub-Saharan countries included in these studies are DRC, Guinea, Madagascar, Tanzania, and Zambia.
50 For taxes on equipment we assume these influence the decision to buy equipment or to build a new base station, with limited impacts on the final consumer price.
51 For further details, see GSMA and Ernst & Young. 2020. Mobile Taxation Studies: Methodology Documentation.

Appendix B: Acronyms and Abbreviations

ARPU	Average Revenue Per User
Capex	Capital Expenditure
CIESIN	Center for International Earth Science Information Network
DRC	Democratic Republic of Congo
ESCO	Energy Service Companies
EY	Ernst & Young
GDP	Gross Domestic Product
GSMA	Global System for Mobile Communications
GNI	Gross National Income
HRSL	High Resolution Settlement Layer
ICT	Information and Communications Technology
IMF	International Monetary Fund
ITM	Irregular Terrain Model
ITU	International Telecommunication Union
IXP	Internet eXchange Point
LTE	Long-term Evolution (4G)
MOCN	Multi-Operator Core Network
MORAN	Multi-Operator Radio Access Network
MNO	Mobile Network Operator
NPV	Net Present Value
Opex	Operating expenditure
RAN	Radio Access Network
RPM	Radio Propagation Model
SDG	Sustainable Development Goal
SIDA	Swedish International Development Cooperation Agency
SMS	Short Message Service
SRAN	Single Radio Access Network
SWN	Single Wholesale Network
UN	United Nations
VAT	Value Added Tax
WACC	Weighted Average Cost of Capital

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