GLOBAL CONNECTIVTY REPORT 2022

CHAPTERS 3-4. ACCELERATING PROGRESS TOWARDS UNIVERSAL AND MEANINGFUL CONNECTIVITY & THE CRITICAL ROLE OF MIDDLE-MILE CONNECTIVITY

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ABSTRACT

The Global Connectivity Report 2022 takes stock of the progress in digital connectivity over the past three decades. It provides a detailed assessment of the current state of connectivity and how close the world is to achieving universal and meaningful connectivity, using a unique analytical framework. It goes on to showcase solutions and good practices to accelerate progress. The second part of the report consists of seven thematic deep dives on infrastructure, affordability, financing, the pandemic, regulation, youth, and data. *Chapter 3* explores options to accelerate progress towards universal and meaningful connectivity. Expanding broadband networks is needed to eliminate the remaining blind spots and improve the quality of connectivity. Measures include reducing constraints on foreign direct investment to attract capital for upgrading and expanding digital infrastructure; ensuring sound ICT sector regulation to help build competitive markets and enhance predictability; promoting infrastructure sharing to reduce costs; ensuring the supply of adequate, inexpensive spectrum to help reduce coverage gaps; and ensuring sufficient capacity and a shift to new generations of mobile broadband. Solutions to ensure an adequate energy provision to power ICT infrastructure include policy incentives, reducing duties and taxes on green power equipment and allowing independent power producers. *Chapter 4* explores the importance of middle-mile connectivity as countries develop digital economies – achieving better quality, lower costs and greater redundancy. The "middle mile" consists of infrastructure responsible for storing and exchanging data. It is an overlooked yet critical link in the connectivity chain, between international connectivity – or "first-mile" connectivity – and "last-mile" connectivity, made of the infrastructure that connects the users, which is hence more visible and tangible. The three key components of a domestic data infrastructure ecosystem are Internet exchange points (IXPs), data centres and cloud computing.

KEYWORDS: *ITU, universal and meaningful connectivity, critical role of middle-mile connectivity, digital onnectivity, Internet of Things (IoT).*

INTRODUCTION

This chapter looks at potential solutions to accelerate progress towards universal and meaningful connectivity and mitigate the dangers of online threats to user security and safety. Consistent with the universal and meaningful connectivity framework introduced in Chapter 2, solutions are organized around these enablers: infrastructure, affordability, device, skills, and security and safety. The chapter also examines specific policy options to address the needs of disadvantaged groups and aspects of environmental risk.

Meaningful connectivity implies safety of use. Threats include a breach of data privacy, misinformation and harmful content, and overuse of digital technology. It is important to know how to mitigate risks to preserve trust in the use of the Internet. Countries need to enact better data protection laws to safeguard privacy, social media companies need to moderate content to detect false and inciteful content, and media literacy must be part of any digital skills training [2].

To achieve universal connectivity, disadvantaged groups such as persons with disabilities, older persons, those with low incomes and people living in remote areas, require special attention. Greater collaboration is needed across governments, agencies, advocacy organizations and digital companies to accelerate the acquisition of digital skills. To reduce the gender gap, non-governmental organizations should be supported in providing mentoring and digital skills training for women and girls. Technology companies, too, can play a role, not only by supporting skills initiatives but also by setting their own gender equity targets. Digital products and services should be customized to the needs of women in terms of design, safety and security. Training of older persons is necessary if they are to access online public services. Measures to reduce the digital disability gap include raising awareness, enacting laws that require online public services to be accessible to persons with disabilities, adapting products by adhering to international design guidelines, and supporting entrepreneurs in the development of contextually relevant digital assistive technologies. Since data are often lacking, there is a need to ensure that the scope of ICT surveys addresses disadvantaged groups as well.

Among the challenges posed by increased digital connectivity, e-waste continues to grow, and what happens to over four-fifths of e-waste is unknown. As a minimum, the recycling process should be made easier for consumers. Connectivity will help reduce carbon emissions across the economy, for example video conferencing for work and education will reduce travel while the greater use of sensors will generate energy efficiencies across many sectors. Furthermore, there is considerable untapped renewable potential from solar, wind, hydro and geothermal sources in many low- and middle-income countries. As major energy users, ICT companies can provide the scale of investment to make renewable energy economically feasible. Governments can help enormously by creating climate friendly energy strategies and liberalizing markets, particularly by welcoming independent renewable power producers.

INFRASTRUCTURE

This section outlines areas where government measures can expand high-speed telecommunication network coverage to achieve meaningful connectivity.

• Reducing constraints on foreign direct investment (FDI) can be effective in attracting capital to upgrade and expand digital infrastructure. Of the 43 low- and middle-income economies included in the OECD FDI restrictiveness indicator, only six were fully open to foreign investment in their telecommunication sector (OECD 2022). Such restrictiveness limits investment by large international telecommunication groups and the expertise and technology transfer they represent. Some countries profess to have a liberalized sector but often impose restrictions, particularly when governments retain a stake in telecommunication operators.

• Ensuring sound ICT sector regulation will help build competitive markets and enhance predictability, attracting investment. The ITU ICT Regulatory Tracker measures regulatory performance among countries with a framework that identifies how far countries have travelled on their regulatory journey and which 'generation of regulation' they fit into: G1 indicates regulated public monopolies with a command and control approach; G2 indicates basic reform with partial liberalization and privatization; G3 enables investment for innovation and access, has dual focus on stimulating competition in service and content delivery, and provides for consumer protection; and G4 indicates integrated regulation, led by economic and social policy goals. A fifth stage of regulation (G5) is a collaborative generation of regulation where digital transformation is promoted across all sectors of the economy. Almost 40% of countries are at the G1 or G2 generation of regulation, hampering their ability to expand connectivity (Figure 1).

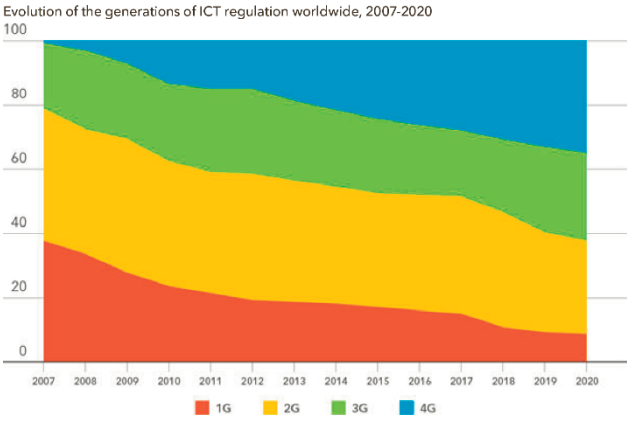

Figure 1. Performance in the ITU ICT Regulatory Tracker
Source: ITU

• Regulation can improve investment but can also introduce additional rules and costs. A light regulatory touch can result in competitive markets with higher adoption and cheaper prices, particularly in low-income countries. Seventy per cent of the population use mobile money services

in Somalia for example, ahead of most countries in Africa. In Cambodia, light touch regulation has stimulated competition and foreign investment. Cambodia also leads LDCs in data usage and mobile-phone ownership, is second for mobile-broadband affordability, and is one of few countries where ownership is higher among women than men.

• Promoting the sharing of infrastructure can reduce costs. Operators could, for example, share mobile towers and underground ducts. Network deployment investment is reduced by laying fibre-optic cable along railway lines, power transmission grids and pipelines. Estimates suggest that sharing antenna sites can save operators up to 40% on both capital expenditure and 5G deployment.

• Ensuring the supply of adequate, inexpensive spectrum can help reduce coverage gaps, ensure sufficient capacity and support the shift to new generations of mobile broadband. Low frequency spectrum is needed for rural areas, as it provides wide coverage, requires fewer sites and reduces investment costs. Challenges are delaying progress in this area. In some countries migration from analogue to digital television has been delayed, reducing availability of low frequency spectrum for mobile broadband use. Some countries also auction frequencies with high reserve prices, thereby raising investment costs, which results in higher prices for users. Some governments charge recurring fees for spectrum, raising the cost of deploying infrastructure in rural areas.

• Ensuring that energy provision is adequate to power ICT infrastructure is essential. This is a challenge in some low- and middle-income countries especially in remote rural locations. Diesel is often used but this is expensive and unkind to the environment (GSMA 2020b). Renewable solutions are not always feasible or price competitive, for instance because of a lack of sunlight, infrequent wind, or the need for expensive battery storage. Solutions to these challenges include reduced duty, tax incentives on green power equipment, and allowing independent power producers.

• Recalibrating universal service funds (USFs) can help deployment of infrastructure in unserved areas. Many funds have been unsuccessful, suffering from challenges such as poor design, mismatches in funds collected and disbursed, political interference, lack of training and education, and maintenance and energy supply.

Niche technologies for expanding telecommunication infrastructure

Although a universal solution has yet to be found, a variety of technological solutions to cheap access for people living in rural and remote regions have been available for many years. Examples of such technological solutions include:

• TV white space (TVWS) utilizes buffer frequencies between TV channels to provide broadband Internet access. In remote parts of Colombia cellular coverage has not been feasible due to frequency bands being congested, high licensing costs and limited communication range. TVWS is being used as an alternative to connect rural schools and coffee plantations in geographically challenging locations such as mountainous rainforests.

• High altitude platform service (HAPS) such as Loon (operated by Alphabet, the parent company of Google) uses a network of hot air balloons to provide connectivity to unserved locations. Loon was used during floods in Peru in 2017 as well as in Kenya to provide Internet access to a region covering 50 000 sq km. Loon stopped operating in January 2021 as it could not be made commercially viable.

• Networked tethered flying platforms (NTFP) are tethered gas balloons. Due to their altitude, an NTFP can replace numerous regular cell towers, lowering costs. NTFPs are being proposed for use in Australia where 70% of the land mass has no cellular coverage.

• Satellites provide backbone transmission services as well as direct to consumer television and broadband access. Low earth orbiting (LEO) satellites blanketing the Earth delivering affordable service to handheld devices have been promoted as a solution for remote areas but remain unaffordable for many low- and middle-income countries. LEOs are providing important backhaul transmission services to the Internet in landlocked or remote islands. They can be a useful backup when terrestrial systems are damaged, for example if an undersea volcano were to damage a submarine cable, as was the case in Tonga, or other disasters disrupt the Internet network.

In addition to the niche technologies above, improvements in wireless cellular technologies are lowering the cost of deploying last-mile access. The OpenRAN project is promoting the use of inter-operable open source software and hardware to reduce the cost of proprietary products.9 Moving to a cloud-based, software-driven environment can lower the cost of cellular networks. In Japan, Rakuten launched the world's first cloud-based mobile network, claiming 40% lower costs than those of traditional cellular networks.

Many people are learning digital skills without formal training, resulting in shortcomings in acquiring further skills. They use social media acquiring basic skills from family and friends People with limited literacy in Africa have used a simple customized version of the Internet with audio and icon-based interfaces. These applications often mean people are 'unconscious Internet users', not knowing what the Internet is or that they are actually using it, and therefore unaware of the variety of uses, benefits and risks it can bring. Informal training often omits important security skills such as protecting privacy, for example, minimizing the digital trail left on social media and elsewhere. Nor does it teach how to distinguish between fact and misinformation. The result is an urgent need to train millions of people formally in using the Internet to ensure they have safe and meaningful connectivity [1].

COVID-19 has seriously hampered the provision of face-to-face digital literacy training. Although programmes have moved online, they are not practical for those who have never used the Internet. If there is no other option, courses should be provided in a webinar format with instructors able to interact with students.

DIGITAL SKILLS

Overcoming digital illiteracy is critical to shrinking the usage gap. Effective and large-scale programmes are needed to address the challenge. Providing digital literacy as part of the school curriculum is a solution for those at school. Recent data on how many countries include digital skills training in the curriculum is not available. Data compiled a decade ago indicate that 55% of countries included basic computer skills training for primary schools and 74% for upper secondary schools [3-4].

Worldwide only 40% of primary, 51% of lower secondary and 66 per cent of upper secondary schools had Internet access in 2020. Giga, a partnership between UNICEF, ITU and the private sector, seeks to connect every school to the Internet. The programme has shown that schools can be "anchor tenants" in a community, extending access and digital skills to those living close by. Funding school connectivity remains a challenge however, with many low- and middle-income countries struggling to build schools with electricity let alone Internet access. Increasingly, the private sector is helping to support digital literacy in schools.

Ensuring school connectivity and digital skills

The private sector plays a key role connecting schools in certain countries (World Benchmarking Alliance 2020). Safaricom's 47-in-1 Initiative is installing a computer lab in one primary school in every county in Kenya. Mobile operator Millicom has committed to the Organization of American States (OAS) goal of connecting every public school in Latin America and the Caribbean to the Internet by 2030, providing Internet access to 2 000 schools throughout the region. Vodafone's Instant Network Schools provides Internet to schools with refugee students. Launched in 2013 in partnership with UNHCR, it has provided school connectivity to 36 schools in five African countries reaching over 86 500 refugees.

Those not in school and without digital skills also need to be reached. The Rwanda Government launched the Digital Ambassador Program (DAP) with the target of training 5 000 youth and sending them all over the country to provide digital skills training to 5 million people. By December 2019, DAP had reached nearly 50 000 people. An evaluation of DAP made specific, practical recommendations to further enhance its impact: i) greater community outreach to increase participation; ii) minimizing technical aspects; and iii) linkages to programmes such as mobile money, device and service charge affordability and national content.

The private sector is providing digital literacy training to adults. The Mobile Internet Skills Training Toolkit (MISTT) was developed by GSMA for mobile operators. Available in Bengali, English, French, Hindi, and Kinyarwanda, MISTT uses a 'train the trainers' approach, whereby staff from the mobile operator train sales agents who then teach customers. MISTT has been used in countries throughout South Asia and Africa. South Africa mobile group MTN offers MISTT in eight African countries and, as of April 2021, has trained over 18 million people, finding that incentives (commissions for trainers and free data for trainees) had a real impact.

AFFORDABILITY

The cost of devices and Internet use represents a major barrier to connectivity. This section sets out recommendations on what can be done to overcome this challenge both in regard to devices and services.

Device affordability

The price of a device is a significant barrier that stops many people developing digital skills. Price reduction has its challenges, however. Very few countries manufacture and therefore control pricing of these products, and importing countries have no say in how the pricing is arrived at. Three approaches set out below offer promise.

Governments do, however, affect device price (and therefore affordability) through imposing import duties and sales taxes. The World Trade Organization (WTO) Information Technology Agreement (ITA) calls for countries to eliminate duties on information technology products. Despite the initiative having 82 signatories, many of the world's poorest countries, particularly in Africa where the impact could be greatest, have not signed. Although sales taxes serve a purpose, taxes on devices should be kept relatively low and certainly not higher than for other products.

A4AI has carried out research on smartphone pricing. They found that the average world price in 2021 was around one-quarter of monthly income, that in South Asia the figure rises to 40%, and in the LDCs it is 53%. Among its recommendations for lowering device prices, A4AI calls for using USF funding to subsidize the cost, highlighting the examples of Malaysia and Costa Rica (A4AI 2020).

Some operators are playing their part to lower the costs of handsets. Mobile group MTN which operates in 21 countries throughout sub-Saharan Africa and the Middle East has launched several initiatives (MTN 2021). Working with Chinese manufacturers, MTN introduced a handset that costs less than USD 40 across its markets. In Zambia it is subsiding handsets and in Uganda it offers customers an installment plan amounting to USD 0.17 per day.

There is a market opportunity for low-cost manufacturers. TECNO, the brand of the Chinese mobile phone manufacturer Transsion, has the highest mobile phone sales in Africa because it sells affordable handsets.

Service affordability

In over half of countries worldwide, ITU analysis suggests broadband services remain unaffordable. Governments can however take action to remedy this in these three areas:

1. Reduce taxes on services to make them more affordable. In 2017, of total payments made by mobile operators to governments, almost a third was specific to the mobile sector (mobile consumption taxes, spectrum and licence

fees, etc.). This was in addition to other, economy-wide, general taxes paid by telecommunication operators and consumers. Reductions in sector-specific taxes enhances affordability and increases demand, with spillover effects on other industries. GSMA studies find that increased demand from lowering taxes and indirect impacts across the economy raise the tax base, off-setting the loss of sector-specific taxes. Uganda for example has a range of taxes that negatively impact affordability (Stork and Esselaar 2018). In addition to value-added tax, the government levies a mobile services excise tax and an Internet data tax that has replaced a social media tax. Almost half of what is spent on mobile airtime in Uganda consists of taxes.

2. Governments should encourage operators to offer plans that reflect different income levels and circumstances and that offer a minimum of 2 GB data a month for the cheapest plans. In almost all low- and middle-income countries, prepaid and data-limited mobile offers dominate Internet access packages. In Zambia, for example, mobile operators offered 17 plans ranging from a one-hour plan featuring 5 MB of usage, to weekly bundles offering unlimited access to popular social media services such as Facebook and WhatsApp. An ITU report found such bundles successfully enabled access to mobile Internet for lower-income users at low cost. This illustrates that while affordability need not be a barrier to Internet use, it limits how much is consumed and when it is consumed, a less than perfect solution when measured against the aspiration of universal and meaningful connectivity.

3. Make mobile data more affordable in a world where 6 GB a month is reasonable. COVID-19 has made users look at data consumption, one hour of Zoom for example consumes between 0.5 GB and 2.5 GB.26 Data consumption patterns vary widely across the world and generally relate to income levels. ITU data for 2020 show that an individual in Finland and Kuwait, for example, consumed 30 GB of mobile data a month in contrast to less than 1 GB for those living in 21 low- and middle-income countries. The volume of monthly data that a person would need to access key online activities was recently estimated at 660 MB per user per month and included access to public services, health information, shopping, learning, and news. When recreational activities were included, the estimated volume of data rose to 6 GB per month (an extra 5.2 GB). Such a monthly data package in the six low- and middle-income countries included in the study costs more than 2% of income for the bottom 40% of the population.

However, there are concrete measures that can make data more affordable in low- and middle-income countries. Governments can:

• Ensure provision of unlimited broadband access to community centres and schools, with access to those in the surrounding community who cannot afford it at home.

• Ensure that the temporary COVID-19 concessions that were put in place by operators in many countries (higher data allowances or providing free Wi-Fi) are maintained for the poorest segment of the population , those needing medical support and for students.

• Subsidize data use for the poorest segment of the population through social tariffs similar to those for food allowances.

• Apply zero ratings for critical services such as e-government, education and health services.

• Create haritable data donation schemes. In Australia for example, users can donate their unused monthly data to those in need.

SECURITY AND SAFETY

To be sustainable, meaningful connectivity must equate to having limited or no risks associated with connecting to the Internet. This section explores the nature of online threats to user security and safety, and considers personal data, misinformation, overuse of digital technology, and vulnerability of children.

According to a global survey carried out in 2019, eight out of ten Internet users are concerned about their online privacy and one in four do not trust the Internet. Over a third of Internet users in the European Union experienced a security incident of some description in 2019. Personal data breaches, online harassment, children accessing inappropriate websites, hacking, viruses, pharming and phishing, and the spread of misinformation are just some of the negative consequences of going online.

Protecting personal data is a critical issue but only 23% of countries around the world have adequate data protection laws on a par with the EU General Data Protection Regulation (GDPR). One source reports that 69% of countries have data protection laws, however, many are not implemented; do not adequately reflect present day user needs; often require no user consent for use of personal information; offer limited control mechanisms for transferring personal data abroad; and lack provisions for a data protection authority [5-9].

Countries that are falling short need to create adequate data protection laws or update their existing laws in line with best practice, and many telecommunication operators and platform companies should exceed minimum duty of care requirements and put in place a single policy that meets international best practice to ensure the security and safety of their customers.

The spread of misinformation is rising steeply, driven by social media platforms. Analysis of social media use in the United States found that 17% of information from among the top 100 news platforms came from unreliable sources, up from 8% in 2019. The World Health Organization noted that the spread of misinformation about COVID-19 is “proving to be as much a threat to global public health as the virus itself”. Top social media platforms have begun to label or take down false information, but ex post facto action is often too late. Hate speech is now a major concern and has led to documented violence against ethnic minorities.

Social media companies should take more action, too, for example by increasing moderators on the ground in all countries to detect false and inciteful content.

In situations of political conflicts they need to come to a balanced judgement on the type of content they restrict. They need to demonstrate greater transparency of how platforms use algorithms to disseminate content, or add features that discourage the sharing of harmful content or that limit the spread of viral content.

The overuse of digital technology is a now a recognized health risk with a range of dangers. Gaming addiction is estimated to affect around 5% of the population. Internet addiction is also recognized in many countries, for example, in Germany the rate has been estimated at 2%, while in Bangladesh over a quarter of young adults are Internet addicted. Efforts to limit online gaming addiction include parental controls, limited access set by some online gaming companies and, in China for example, restricted access for those under 18 (Figure 2).

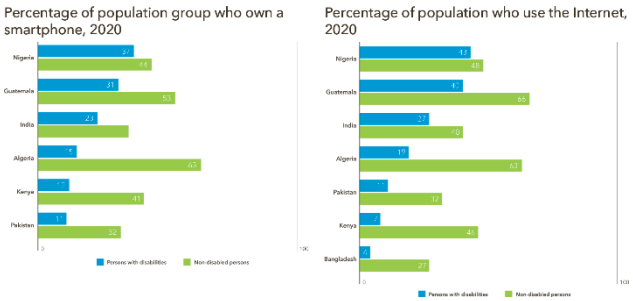

Figure 2. Disability gap for smartphone ownership and mobile Internet use

Note: Based on survey results for adults aged 18 and over. n=49-260 for persons with disabilities and n=900–1 866 for persons without disability.

Source: GSMA Consumer Survey 2020

ACCELERATING CONNECTIVITY AMONG DISADVANTAGED GROUPS

To attain universal connectivity, special attention must be paid to the needs of disadvantaged groups including persons with disabilities, older persons, women and girls in some countries, those with low-incomes, and people living in remote areas. People with one or more disadvantages are at greater risk of digital exclusion (for instance women with low-incomes and older persons with disabilities.) Other groups at risk are country specific, such as migrants, refugees or ethnic minorities [10-14].

Persons with disabilities

It is estimated that 1 billion people have a disability or about 15% of the global population. Global statistics about the connectivity status of persons with disabilities do not exist. GSMA has collected data for some middle-income countries that indicates significant gaps separating persons with disabilities and the rest of the population in smartphone ownership and Internet use.

Many leading hardware manufacturers have adapted products to be more disability friendly through features such as enabling large fonts and screen readers, and many adhere to the W3C global standard for web accessibility. Designed with disability experts, the GSMA Principles for Driving the Digital Inclusion of Persons with Disabilities offers guidelines for the mobile industry to reduce the gaps in access and use.

Innovation is an important means of empowering persons with disabilities, for example, persons with visual impairment are using smartphone technology to scan and read documents, to get accessibility ratings for public places and audio and vibration alerts for approaching obstacles.

Older persons

Available survey data indicate gaps between rates of Internet usage by age group. Young people use it most and older persons use it least. In Norway, for instance, the Internet use gap is much less pronounced at 92% for the 75+ age group compared with 99% for the 15-74 age group. However, for most economies the age gap is wide, at more than 50 percentage points in over half of economies providing data and 80 percentage points in Kazakhstan (Figure 3).

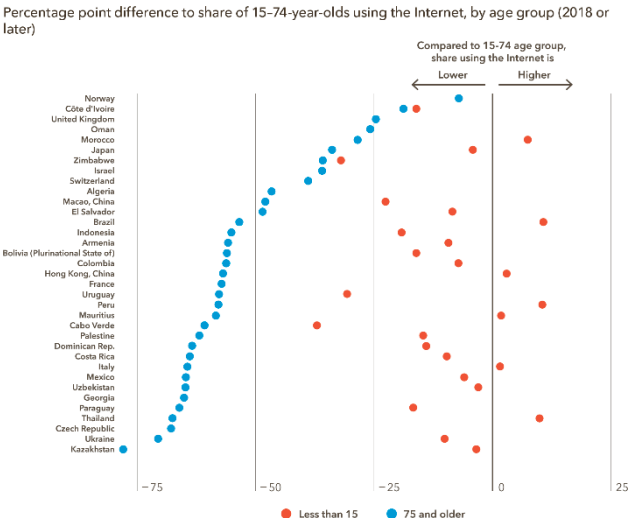

Figure 3. The inter-generational gap in Internet use

Source: ITU

Digital skills training for older persons is an imperative for governments if older persons are to access online public services.

The New Zealand Government has allocated funding to train up to 4 700 older persons in digital skills over three years. Some digital companies are providing training, for example in Singapore, Singtel is upgrading community centres with Internet access and tablets, its staff volunteer for one-on-one digital skills training, and it opens its shops early to provide training workshops.

Training should be designed for and delivered exclusively to older persons. Design should take comfort levels, learning relevance and application focus into account. Course numbers should be small and include modules on security to build trust in using online services. Training should be ongoing to reinforce learning and have a lasting effect.

CHAPTER 4.
THE CRITICAL ROLE OF MIDDLE-MILE CONNECTIVITY

INTERNET EXCHANGE POINTS

As IXPs grow to handle an increasing amount of data, they are relocated to a professionally managed data centre, allowing companies that need to exchange data to be closer to the IXPs and with their servers located in the same data centres. Similarly, as demand increases for cloud computing, service providers also situate data centres to be closer to customers. The IXPs sit at the core of this ecosystem (Figure 4).

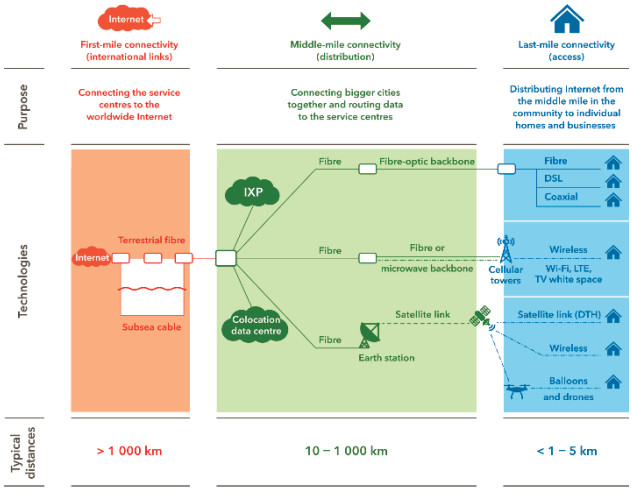

Figure 4. The connectivity chain and the "miles" of connectivity
Note: IXP = Internet exchange point; DSL = digital subscriber line; DTH = direct-to-home; LTE = Long-term Evolution.
Source: Adapted from World Bank (2021)

IXPs are a core component of data infrastructure, enabling Internet service providers (ISPs) and content providers to exchange their data traffic – known as "peering". The IXP method of data exchange offers substantial advantages, some of which are listed below:

• It is less costly than using international bandwidth, since traffic is not sent back and forth over costly overseas links. Latin America could slash by one-third the USD 2 billion a year it spent on international bandwidth through greater use of IXPs, according to one study. Studies for Kenya and Nigeria also find that IXPs reduce overseas payments and improve latency.

• ISPs do not need to make peering agreements with each potential partner.

• Redundancy is enhanced, since countries do not rely on international bandwidth if there is a disruption.

• IXPs also improve quality, since they are situated closer to the user and hence have less latency.

• IXPs reduce the time it takes to retrieve data, enhancing user engagement. In Rwanda, it is 40 times faster to access a local website (<5 milliseconds) compared with those hosted in the United States or Europe (>200 milliseconds).

IXPs grow organically – and attract big content providers

IXPs begin as locations for ISPs to exchange traffic. Initially, this may not amount to much traffic, since in many developing countries locally relevant content is limited or is hosted abroad. IXP participation has grown more diverse over time, now frequently including companies, governments, content providers and cloud operators as members. Diverse and growing participation also stimulates demand for data centres, boosting the economy. Companies also want to be closer to end users to reduce latency and enhance the Internet experience [15-20].

IXPs also reduce the need for international bandwidth due to a reversal of network routing. Instead of countries having to pay international transit fees to access content overseas, large content and cloud providers are increasingly moving to IXPs (Table 1). These companies handle the backhaul to their data centres, on occasion through their own submarine cables. Content providers have now overtaken telecommunication carriers as the largest users of international capacity. Three content providers – Google, Facebook and Netflix – account for two-thirds of all mobile application traffic, highlighting the importance of attracting content providers to IXPs.

Table 1

Top 10 companies by presence on an IXP, December 2021

Company	ASN*	Type	Number of IXPs present on
Hurricane Electric	6 939	Network service provider (NSP)	275
Cloudflare	13 335	Content delivery network (CDN)	263
Packet Clearing House	3 856	Educational/Research	212
Google	15 169	Content	207
Microsoft	8 075	Content	194
Akamai	20 940	CDN	182
Facebook	32 934	Content	168
Amazon	16 509	Enterprise	129
Subspace	32 261	CDN	116
Netflix	2 906	Content	107

**ASN = Autonomous System Number uniquely identifying organizations routing traffic over the Internet.*
Note: There were almost 24 000 organizations with an ASN in December 2021. CDNs deliver other companies' data to the IXP, whereas "Content" refers to companies that deliver their own content to the IXP.
Source: PeeringDB (www.peeringdb .com)

According to Packet Clearing House, there were 726 active IXPs around the world in December 2021. Despite the benefits of an IXP, 65 countries and territories do not have one. These are mainly countries where there is only one ISP or are small island States where the volume of domestic traffic may be insufficient to warrant an IXP. In contrast, a number of countries have multiple IXPs – much needed to reduce latency in large countries with dispersed populations.

Multiple IXPs also deliver redundancy and, through competition, are likely to reduce costs of use. However, introducing multiple IXPs in a country in the early stage of middle-mile connectivity risks reducing the scale of the IXP and its attractiveness to content providers.

The top 10 IXPs by the volume of traffic exchanged speak to well-developed ecosystems with high levels of

participants (Table 2). While most are based in high-income nations, two entries are based in Brazil and one in Ukraine. This top 10 group boasts an average age of 17 years, reflecting the importance of experience in developing an efficient IXP. Most have hundreds of participants and are available in multiple data centres to better reach their customers. Some are expanding operations into other countries. For instance, Deutscher Commercial Internet Exchange (DE-CIX) is available in 16 other countries. Of these, nearly all are high- and upper-middle-income nations – but this model could be more widely applied through partnerships in developing nations.

Table 2

Top 10 IXPs by traffic exchanged, December 2021

IXP	Country	Age* (years)	Number of data centres located on	Number of participants	Peak traffic (terabits)
IX.br São Paulo	Brazil	17	17	2 413	12.5
AMS-IX	Netherlands	24	15	881	10.8
DE-CIX	Germany	26	22	1 066	10.2
London Internet Exchange (LINX)	United Kingdom	27	18	885	6.6
PIT Chile - Santiago	Chile	5	3	109	6.1
Neutral Internet Exchange (NL-IX) - Amsterdam	Netherlands	19	22	448	3.4
Japan Network Access Point (JPNAP) Tokyo	Japan	20	8	130	2.7
EPIX. Warszawa-KIX	Poland	8	3	702	2.7
Giganet Internet Exchange Kiev	Ukraine	9	7	119	2.5
IX.br Rio de Janeiro	Brazil	11	12	470	2.1

Age = From the year it was established.*
Sources: PeeringDB (www .peeringdb .com) and IXP websites

The existence of an IXP does not guarantee its potential benefits. Although the number of IXPs has grown in developing nations, many in low-income nations are stuck in first gear, with few participants and very little traffic. Average membership per IXP in low-income nations is 9, compared with a world average of 57.

Interestingly, upper-middle-income economies – not high-income economies – have higher membership levels and traffic per IXP. This is because large countries such as Brazil, Russian Federation and South Africa have well-developed IXP ecosystems and boast some of the largest IXPs in the world.

Regionally, there are also notable gaps. Europe generates 260 gigabits per second (Gbit/s) of traffic per IXP, the highest of any region. Most long-established IXPs are European, with many years of experience. On the other hand, Africa (excluding South Africa) has on average 14 participants per IXP, compared with a world average of 57, and generates just 9 Gbit/s per IXP, compared with a world average of 173. While South Africa accounts for just over 10 per cent of the continent's IXPs.

Stages of IXP growth

IXPs progress in stages, and each higher stage of development increases its impact. The first IXPs are typically established by universities or as non-profit associations of ISPs. They are located in small server rooms, with technical tasks carried out by volunteers. As traffic increases, and new participants join, a more sustainable technical and operational environment becomes necessary – more formal governance, staff hiring and equipment upgrades. The final stage sees many participants wishing to join without having to deploy a physical connection to the exchange. Multiple IXPs in different locations are created and the IXP is relocated to a colocation data centre (discussed below).

Developing countries are at different stages of maturity in regard to IXPs. At one end of the scale are countries with no IXPs, while at the other are countries that boast a dense fabric of multiple IXPs located in connected data centres, usually operated by the private sector and with many different participants. As countries progress through the stages, prices drop, performance improves and traffic increases (Figure 5).

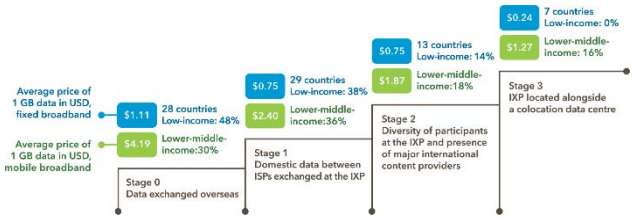

Figure 5. IXPs and stages of growth
Sources: ITU; Srinivasan et al. (2021)

Data centres

Data centres provide space, power and cooling for servers hosting data and network cabling. They play a fundamental role in the digital economy by the storing of data, and the local hosting of domestic content. In addition, data centres offer a significant advantage when processing large volumes of data – and in the development of big data services [21-24]. Their presence is also a measure of the digitalization of the economy, reflecting demand from the information and communication technology (ICT) sector and beyond – finance and insurance, transportation, legal and accounting activities, research and development, advertising and the public sector. IXPs also benefit from data centre hosting, attracting more diverse participants and enjoying more professional facilities [25-28].

Data centres can be classified into four broad categories:

• Enterprise data centres are single-tenant facilities owned by a company to store data. They are either located on a company's site or in a dedicated facility off-site.

• Carrier data centres are provided by telecommunication operators to host their clients' data. This has historically locked clients into exclusive use of the operator's data centre services. However, growing numbers of telecommunication operators are now providing "carrier-neutral" connectivity.

• Multi-tenant data centres (MTDCs) are operated by companies that rent out space for data storage. Leading operators usually have certifications for security and reliability.

• Hyperscale data centres belong to major content and cloud providers such as Facebook, Google, Amazon and Microsoft (who together account for over half). There were close to 600 hyperscale data centres at the end of 2020, more than doubling in five years (Synergy Research Group, 2021).

In the past, data centre connectivity was often via a direct telecommunication link between a company's office and the data centre. Today, however, more flexible communication links from the data centre to the outside world are essential – many companies may be using the centre and employees can also be at disparate sites throughout a country or the world and, working from home.

Three ways to organize data centre connectivity

Data centre connectivity can be accomplished in different ways. In some instances, telecommunication companies may operate MTDCs but require the tenant to use their services – this can result in higher prices and a lack of flexibility. A further option is for an IXP located in the data centre to handle data exchange – an attractive option, since this is often done through free peering arrangements. The benefit is magnified when content and cloud providers are also in the data centre. A third option is carrier-neutral MTDCs operated by companies that do not provide telecommunication services – tenants are free to use any telecommunication provider to handle their data transport needs. Notably, some telecommunication operators now offer open peering MTDCs and own IXPs.

Global overview of data centres shows large disparities

PeeringDB provides a global listing of companies that exchange traffic over the Internet and the data centres they are located in. Globally, there were 4 300 data centres connected to the Internet in November 2021. Large disparities exist in connected data centre penetration: 57 economies do not have a connected data centre. While connected data centre penetration is 2.7 per million inhabitants in high-income nations, it is considerably less in low- and middle-income nations. Similarly, sharp regional disparities exist – with a penetration of more than 1.5 connected data centres per 1 million inhabitants in Europe and North America, compared with less than 0.5 in other regions. While such disparities are related to income and demand for large-scale data storage, they are also caused by a lack of complementary infrastructure (particularly energy) and by policies that have inhibited private investment [29-30].

Another view of data centre dispersion is to examine where the leading carrier-neutral MTDC operators are headquartered. The MTDC big picture is dominated by United States-headquartered operators, including the two largest, Digital Realty Trust (DRT) and Equinix, with some hundreds of data centres between them. Of the 2 113 organizations with a connected data centre, 1 565 (74%) report operating just one. The top 20 MTDCs account for less than 1% of organizations offering connected data centres – but do account for over a quarter (27%) of the total data centres and 74% of the total of those operating more than five data centres.

Mapping data centre locations of the 20 largest MTDCs reveals stark geographical gaps (Figure 6). Dense concentrations occur in developed regions such as North America and Western Europe, the powerhouses of the digital economy, while in much of the rest of the world there are none.

Data centres are costly to build, and in many low- and middle-income countries, the private sector lacks the capital and necessary expertise.

Major MTDC operators such as Equinix, DRT and NTT rarely have data centres in low- and middle-income countries. However, some MTDC companies partner with local investors to build data centres. In India, EdgeConneX (2021), a large MTDC operator, is partnering with local company the Adani Group to help build six data centres. Private companies with a regional focus are also operating MTDCs in developing countries – several companies are building data centres in Africa.

Development partners are providing investment funding in government data centres, but companies often do not want to locate in State-owned facilities. In 2021, China loaned Senegal USD 18 million for a government data centre, with Chinese company Huawei providing equipment and technical support. In Togo, also in 2021, the World Bank provided USD 24 million to the Government for the country's first world class data centre, providing space for non-government tenants. The centre is built by French company APL, and managed by Africa DataCenters, which operates nine facilities throughout the continent.

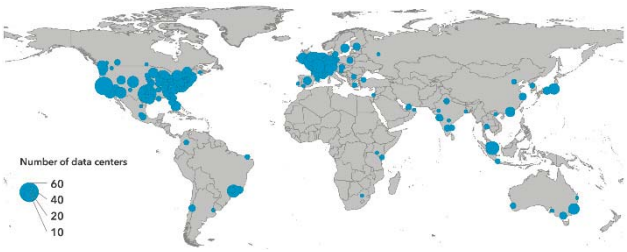

Figure 6. Data centre locations of top 20 MTDC operators
Note: The size and colour of the dots refer to how many data centres there are in that location. For example, there are 63 in London.
Source: Compiled from locations reported by top 20 MTDC operators

Cloud computing

Cloud computing has transformed data storage and analysis by allowing users to access scalable data storage and computing resources as needed. As broadband connectivity has boomed, delays associated with remote storage, processing and analysis of data have dropped significantly – and cloud use by businesses and governments has taken off. Cloud computing is especially attractive, since it helps avoid costs associated with maintaining on-site hardware, software and storage.

Microsoft Azure, Amazon Web Services and Google Cloud – large firms from the United States –dominate the cloud. They have hyperscale cloud data centres, most located in developed countries with stringent data protection and sovereignty regulations.

However, the lack of a cloud data centre in a country is overcome through "on-ramps" to cloud computing services. Customers can meet cloud providers at IXPs located in colocation data centres, avoiding costly international transit to access cloud services – and enjoying greater security and reliability, improved performance and reduced

costs.

Cloud and content providers have emerged as some of the largest investors in backbone infrastructure, including submarine cables to route traffic from MTDCs to their own hyperscale data centres. Countries no longer need to spend money on international bandwidth to access popular content and the cloud, since the providers will come to a country's MTDC if conditions are favourable.

Big data analysis and sharing applications are often available only on the cloud, and while it may seem attractive to store data on the cloud, there are three factors to consider. First, it can be costly to store data on the cloud. Organizations often use a "hybrid cloud approach",12 storing on the cloud only the data needed for cloud analytics. Second, latency is a key issue for applications such as finance and gaming, if stored on the cloud. Third, national security grounds may dictate that sensitive data be stored in the country – the cloud data centre needs to be located in the country and the cloud provider needs to adhere to national data laws.

CONCLUSIONS

There is no single pathway to universal and meaningful connectivity. The scope and nature of intervention depends on where a country stands on the path from basic connectivity for the few to meaningful connectivity for all. Multiple factors are at play, including a country's institutional framework, income level, demographics, geography, and culture that require a range of options, rather than a single solution, and which can differ significantly across countries within a region.

There is a huge divide in core data infrastructure between high-income and other countries. Many low- and middle-income economies have inadequate data infrastructure that cannot support transformation to sustainable digital economies – and which function at higher cost and with poorer quality. While investment has in the past been flat because of a perceived lack of demand, many such countries have seen accelerated use of the Internet, spurred by COVID-19. Investment limitations in core data infrastructure persist, however.

Scale is critical. Private investment in data centres has not been forthcoming in countries with small populations – though possibilities are emerging. Smaller, energy-efficient facilities are increasingly viable, as are schemes involving countries working together on regional data infrastructures featuring Internet exchange points. Most low- and middle-income countries in fact increasingly have the scale to attract investment, especially in view of data infrastructure operators' need to be close to customers, to reduce latency. Often what holds back investment is the absence of an enabling environment and an immature data infrastructure ecosystem – it does take time for IXPs to achieve large scale. In short, countries need to build data ecosystem environments that attract investment.

There are five building blocks to create a more conducive environment for middle-mile connectivity.

• *Liberalization:* Liberalization of the telecommunication market fosters growth in core data infrastructure. Deregulation increases investment opportunities and provides businesses more options in their choice of providers. Introducing unhindered competition in the international transit market would benefit IXPs, making large ISPs less dominant and more likely to join an IXP. For example, South Africa attributes its leading data centre position in Africa to the early liberalization of the telecommunication market. Similarly, Equinix, one of the world's largest multi-tenant data centre (MTDC) operators, entered the Mexican market following the country's 2013 telecommunication reform.

• *Data protection:* Data protection laws are especially important for attracting investment into MTDCs and cloud computing. Such laws stimulate investment if they require certain data to be stored in the country – and offer protection to investors who are looking to limit reputational risk arising from data breaches. Europe has the highest share of countries (96%) with a data protection law, due to the 2018 introduction of the EU General Data Protection Regulation. Since then, a growing number of economies – including China, Japan, Singapore, Thailand, India, Brazil and the United States state of California – have adopted data protection regulations. Globally, two-thirds of countries have data protection laws, but a number of developing countries have yet to adopt one.

• *Energy:* Data centres consume a lot of energy in powering servers and keeping them cool – a challenge that has become more pointed in the context of the climate crisis. Investors have been more focused on a strategic path towards carbon neutrality than on price. Governments could facilitate investment in this regard by liberalizing energy markets, thereby allowing independent renewable power producers and suppliers to enter the market. With set targets for carbon neutrality, most major MTDCs prefer renewable sources to be available in countries where they invest. The largest hyperscale data centre owners are the world's leading buyers of renewable power purchase agreements.

• *Collaboration:* This is essential across the many parties involved in a country's data infrastructure – governments, IXPs, ISPs, data centre operators and investors (such as development partners, content developers and cloud providers). Governments need to grasp the vital role that IXPs play in developing a country's data ecosystem – and put in place enabling policies, strategies, laws and regulations. Developing countries should pursue partnerships with large IXPs, providing capacity-building as well as helping to establish facilities. Those developing countries with enabling data infrastructure policies need to market more robustly their advantages, thereby encouraging private sector investment. While some development agencies have supported IXPs and data centres, more work can be done.

• *Key metrics:* There are no official international sources of key metrics for IXPs and data centres at a country level – in spite of the great importance of data infrastructure. Improving the availability of key statistics on the digital

economy at country level is essential. Timely, comparable and reliable statistics on data infrastructure are essential for countries to measure their performance and better understand the relationship between international and domestic traffic exchange. Several organizations collect relevant administrative statistics related to IXPs and data centres, and many IXPs and MTDC operators also report on their activities. Groups such as the Expert Group on Telecommunication/ICT Indicators (EGTI) could partner with those already collecting relevant statistics – to identify and define key indicators, to review and harmonize existing data sets.

REFERENCES

[1] A. Alhassan, and A.A. Kilishi, "Weak economic institutions in Africa: a destiny or design?". International Journal of Social Economics. 2019. Vol. 46. No. 7, pp. 904-919. doi.org/10.1108/IJSE-12-2018 -0651

[2] Alliance for Affordable Internet. 2020. From luxury to lifeline: Reducing the cost of mobile devices to reach universal Internet access. Web Foundation. https://a4ai.org/research/from-luxury-to-lifeline-reducing-the-cost-of-mobile-devices-to-reach-universal -Internet-access/

[3] World Bank. 2021. World Development Report 2021: Data for Better Lives. Washington, DC: World Bank. Available at https://openknowledge.worldbank.org/handle/10986/35218.

[4] Broadband Commission for Sustainable Development. 2020. The Digital Transformation of Education: Connecting Schools, Empowering Learners. https://www.broadbandcommission.org/Documents/working-groups/SchoolConnectivity _report.pdf.

[5] T. Burt. 2019. "CyberPeace Institute fills a critical need for cyberattack victims". Microsoft Blog. https://blogs.microsoft.com/on-the-issues/ 2019/09/26/cyberpeace-institute-fills-a-critical-need-for-cyberattack-victims.

[6] R. Chen, and M. Minges, 2021. "Minimum Data Consumption: How Much is Needed to Support Online Activities, and Is It Affordable?". World Bank Analytical Insights. https:/www.worldbank .org/en/topic/digitaldevelopment/brief/minimum-data-consumption-how-much-is-needed-to-support-online-activities-and-is-it-affordable.

[7] Global e-Sustainability Initiative (GeSI). 2015. #SMARTer2030: ICT Solutions for 21st Century Challenges. http://smarter2030.gesi.org/downloads/Full_report.pdf.

[8] P. Gilbert, 2020. "Safaricom, Google partner on Kenyan smartphone financing". Connecting Africa. 28 July. http://www.connectingafrica.com/author.asp?section_id = 761 & doc_id = 762720 & print = yes.

[9] Enabling Rural Coverage. https://www.gsma.com/m obileforde velopment wp-content/uploads/2018/02/Enabling_Rural_Coverage_English _February_2018.pdf.

[10] Survey of Universal Funds: Key Findings. https://www .gsma.com/publicpolicy/wp-content/ uploads/2016/ 09/ GSMA2013 _Report _SurveyOfU niversalSe rviceFunds_KeyFindings.pdf.

[11] T. Hassan, M. M. Alam, A. Wahab, et al. 2020. Prevalence and associated factors of Internet addiction among young adults in Bangladesh. *J. Egypt. Public. Health*. Assoc. 95, 3. https:/doi.org/10.1186/s42506-019-0032-7.

[12] IEA. 2021. "Data Centres and Data Transmission Networks". IEA, Paris https://www.iea.org/reports data-centres-and-data-transmission-networks.

[13] ITU. 2021a. Connectivity in the Least Developed Countries. https://www.un.org/ohrlls/sites/www.un.org.ohrlls/files/21-00606_1e_ldc-digital_connectivit -rpt_e.pdf.

[14] C. Lewis, 2017. Universal Access and Service in South Africa: Policy Success, Policy Failure and Policy Impact (SSRN Scholarly Paper ID 2980803). Social Science Research Network. doi.org/10.2139/ssrn.2980803.

[15] K. Müller, H. Glaesmer, E. Brähler, K. Wölfling, and M. Beutel, 2013. "Prevalence of Internet addiction in the general population: Results from a German population-based survey". Behaviour and Information Technology. No. 33, pp. 757-766. 10.1080/0144929X.2013.810778.

[16] Optus. 2020. Sustainability Report 2020. Australia. https://www.optus.com.au/content/dam/optus/documents/about-us/sustainability/reporting/2020/Optus-Sustainability-Report-FY2020.pdf.

[17] L. Silver, A. Smith. 2019. "In Some Countries, Many Use the Internet without Realizing It". Pew Research Center Fact Tank. https://www.pewresearch.org/fact-tank/2019/05/02/in-some-countries-many-use-the-Internet-without-realizing-it.

[18] "Soaring 'SuperTowers' Aim to Bring Mobile Broadband to Rural Areas". *IEEE Spectrum: Technology, Engineering, and Science News*. https:// spectrum.ieee.org/tech-talk/telecom/ wireless/soaring-supertowers-to-bring-mobile-broadband-to-rural-areas. 2018.

[19] D. Strusani, and G.V. Houngbonon, 2020. "Accelerating Digital Connectivity Through Infrastructure Sharing". *EMCompass*. https://doi.org/10.1596/33616.

[20] M. Agudelo, R. Katz, E. Flores-Roux, M.C. Duarte Botero, F. Callorda and T. Berry. 2014. Expansión de infraestructura regional para la interconexión de tráfico de internet en América Latina. Available at http://scioteca.caf.com/handle/123456789/522.

[21] Deutscher Commercial Internet Exchange (DE-CIX). 2021. "White Paper: 10 Reasons Why You Should Peer". Available at www.de-cix .net en/ resources/white-papers/10-reasons -why-you-should-peer.

[22] C. Dietzel. 2020. "Why the Internet Holds Firm: Internet Infrastructure in Times of Covid-19". DE-CIX. June. Available at www.de-cix.net/en/ resources/articles/why-the-internet -holds -firm-internet-infrastructure-in-times-of-covid-19.

[23] DP Facilities (n.d.). "The Critical Role Data Centers Play in Today's Enterprise Networks: Part 3 – Why Cloud On-Ramps Are Key for an Enterprise Migrating to the Cloud". Four-part blog series. Available at www.dpfacilities.com/blog/cloud -onramps-are-key-to-migration.

[24] Feldmann et al. 2020. "The Lockdown Effect: Implications of the COVID-19 Pandemic on Internet Traffic". *Proceedings of the ACM Internet Measurement Conference*. 1-18 October. doi.org/10.1145/3419394.3423658.

[25] T. Katsuyasu. 2020. "The impacts of COVID-19 pandemic on the IXPs in APAC region". IX.br IX Forum. 2-4 December. Available at https://forum.ix.br/files/apresentacao/arquivo/1025/20201204-ixbr-forum-katsuyasu-for-publish.pdf.

[26] K. Olsen. 2021. "Peering in Norway: Traffic growth and shifting patterns". Netnod. 20 September. www.netnod.se/blog/peering-norway-traffic-growth-and-shifting-patterns.

[27] Oxford Business Group. 2021. "Data Centres in Africa Focus Report: How is Africa positioned as a destination for data centres?" Available at https://oxfordbusinessgroup.com/news/focus-report-how-africa-positioned-destination-data-centres.

[28] Sandvine. 2020. "Mobile Internet Phenomena Report 2020". Available at www.sandvine.com/download-report-mobile -internet-phenomena-report-2020-sandvine.

[29] S. Srinivasan, S. Comini and M. Minges. 2021. "The Importance of National Data Infrastructure for Low and Middle-Income Countries". SSRN Scholarly Paper ID 3898094. Rochester, NY: Social Science Research Network. Available at https:// doi.org/10.2139/ssrn.3898094.

[30] The Economist. 2021. "Data Centres Are Taking Root in Africa". 4 December. Available at www.economist.com/middle east-and-africa/2021/12/04/data-centres-are-taking-root-in-africa.