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Executive Briefing

CURTAILING CARBON EMISSIONS – CAN 5G HELP?

Data volumes are growing inexorably. 5G can help to improve networks' energy performance and curtail carbon emissions.

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Preface

The document has been prepared by independent consulting and research firm STL Partners. It is based on extensive research into the impact of 5G on industries and leveraged the output of an interview programme and surveys with telecoms and manufacturing industry representatives, including regulators, in developing and developed countries. The research programme has kindly been supported by Huawei.

This report should be read by telecoms regulators, governments seeking to leverage 5G technology, and telecoms operators, particularly CSOs, strategists, CMOs, enterprise executives and CSR directors. The content is also relevant to industry players who are interested in using technology to enhance operations, particularly those responsible for operations and digitalisation: COOs, CEOs and CSOs.

Mentions of companies in this document are intended as illustrations of market evolution and are not intended as endorsements or product/service recommendations.

If you find this report of interest and would like to discuss any aspects of the content further, please contact any of the following:

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STL Partners is continuously working to understand how 5G can benefit other industries and develop strategies for telecoms operators and other industries to accelerate the delivery of benefits. Should you like to learn more about this research and future projects or find out how we can help regulators, governments and operators to work more effectively together and take advantage of 5G please contact us.

Other reports in this 5G series include:

- $1.4Tn Of Benefits In 2030: 5G's Impact On Industry Verticals
- 5G's Impact On Manufacturing: $740bn Of Benefits In 2030
- 5G's Healthcare Impact: 1 Billion Patients With Improved Access In 2030
- 5G Regulation: Ensuring Successful Industrial Transformation

Executive Summary

Global warming: a shared challenge

The telecoms industry has a clear role in the Coordination Age[1] in tackling global warming by making other industries much more efficient, enabling a greater proportion of renewable electricity generation and reducing travel. Faster 5G roll-out will accelerate this.

Indirectly supporting customers to reduce CO_2 emissions is not enough. The telecoms industry also needs to urgently address its own **direct** greenhouse gas emissions. This is expected (and increasingly demanded) by our customers (consumers, public and private sector organisations). Investors are also factoring in the higher risk profile associated with companies with high carbon emission exposure. Finally, this also matters to employees – particularly younger ones with the digital skill sets that operators are looking to attract. Operators must openly set themselves ambitious targets, plan to meet these, and report on outcomes.

Significant improvements in energy load (the average amount of energy needed for a network to transmit a given amount of data to a device) will be achieved with existing 4G networks through greener electricity supply, continuous improvements in network hardware, software upgrades, and by introducing smarter network power optimisation (e.g. base station shutdown, intersite co-coverage, carrier dormancy).

However, the inexorable growth in data volumes over mobile networks means that relying on "evolutionary" improvements to 4G will not be sufficient to curtail emissions from networks. Telcos need to achieve a step-change in networks and business practices. In essence, public authorities, operators, customers, and investors are asking: ***How should mobile network operators deal with the rapid rate of growth in data, and seek to curtail the associated energy consumption and CO_2 emissions?***

It turns out that part of the answer to this question lies in the question***: What is the net carbon emissions impact of accelerating the roll-out of 5G?*** This study seeks to address both these questions, the second in most detail.

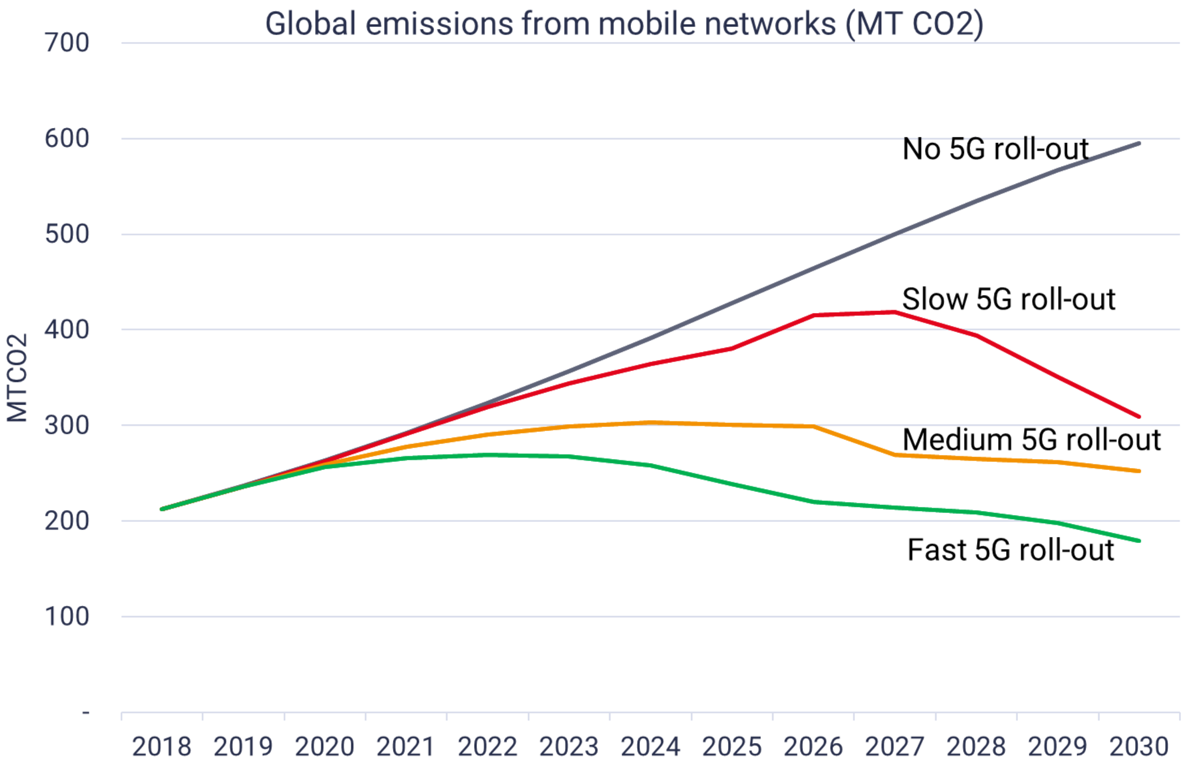
Our findings: Faster 5G roll out could reduce cumulative carbon emissions by 0.5 billion tonnes of CO_2 by 2030

Our analysis shows that rapidly rolling out 5G networks could reduce the cumulative CO_2 footprint of mobile networks globally by over a third, compared with a slower roll-out. The difference between a quick roll-out and medium "base-case" roll-out of 5G networks is also significant – cumulative global savings (2020-2030) would be 0.5 billion tonnes of CO_2, slightly less than the annual carbon emission

[1] See https://stlpartners.com/research/the-coordination-age-a-third-age-of-telecoms/

of all international aviation in 2018. We describe these scenarios in more detail in the methodology section as well as detail numerically in the appendix.

Figure 1: Faster 5G roll-out would have a material impact on greenhouse emissions



Source: STL Partners

5G networks will contribute to containing (and then reducing) carbon emissions from mobile networks in several ways. However, the most significant contribution will come from 5G New Radio, massive MIMO and mmWave. **The energy load – the average amount of energy required to transmit data (e.g. kWh/GB, GWh/EB, Joule/bit) - of a 5G cell site is 8-15% that of a like-for-like 4G cell site**. **With mmWave, this has the potential to fall to 1-2% of a 4G macro site**. In practice, these theoretical "optimal" energy loads are not achievable across entire networks and we have accounted for this in our modelling which reflects **relative** performances.

Recommendation: 5G sooner, faster, wider

Faster 5G network deployment is a big part of the answer to the question: ***How should mobile network operators deal with the rapid rate of growth in data, and seek to curtail the associated energy consumption and CO_2 emissions?***

Alongside self-generation of greener electricity or by under-writing others' generation of power from green energy sources, rolling out 5G networks can be a key component of operators' and national authorities' ambitions to reduce the emission of greenhouse gases from the operation of mobile networks. **As we have seen, rolling out 5G networks quickly (rather than slowly) could save the**

world over 1bn tonnes of CO_2 cumulatively between 2020 and 2030 – more than one year of greenhouse gas emissions from all maritime shipping or all aviation globally.

This leads us to offer the following guidance to the stakeholders in the mobile network in order to achieve these vital sustainability targets:

- **Network operators** should see 5G network deployment not only as an investment in their services, but also as part of a strategy to contain growing energy demands of escalating data volumes. Rolling out 5G networks as soon as possible will limit the network operators' CO_2 emissions and will make a major contribution to operators' own sustainability targets. This is doubly true for operators running networks in countries with carbon-intense energy grids, or in situations where operators are relying on diesel generators to run their base stations in remote areas.
- **National authorities** have a key role in ensuring the sustainability of the networks they oversee:
  - Setting realistic low-carbon operational targets within license terms (on energy loads, adoption of specific standards, use of renewables, carbon-intensity of network power);
  - Incentivising the accelerated roll-out of 5G through policy and licensing through smart coverage requirements rather than high spectrum pricing;
  - Establishing and enforcing rights of way, access to ducting, nationwide frameworks for use of power / lighting poles and streamlining other planning processes;
  - Reducing or eliminating import duty on 5G infrastructure;
  - Encouraging efficient and low-carbon practices: network sharing and the use of low-carbon energy sources (e.g. through lower energy taxation);
  - Incentivising migration off 2G/3G and early decommissioning of these networks.
- **Tower and power suppliers:** As well as ensuring that energy is low-carbon and optimised, they will increasingly have an influence on the selection of active component technology (antenna) in the future as they deliver shared infrastructure to multiple telco operators. They should support operators' carbon emissions objectives by adopting stringent reporting and carbon accounting practices.
- **Technology providers** supply operators with equipment, software and services for their 5G networks. Ultimately, they will need to ensure that 5G meets its promise of lower emissions:
  - Setting out clear performance standards and benchmarks, ideally at a global industry level (not unlike the energy ratings on white goods);
  - Pro-actively engaging regulators and authorities to make the case for 5G's energy performance;

- Pursuing new business models with operators (e.g. similar to the ESCO energy saving companies who introduce a range of measures in exchange for a share in the reduction in energy costs);
- Committing to better energy performance through SLAs to ensure their network equipment adheres to strict KPIs.

The one Watt challenge

Telecoms' long-term objective will be to achieve carbon neutrality. In the mid-term, the industry, investors, regulators, and analysts need to adopt a common language and set objective performance objectives. We propose four:

- By 2025, all mobile operators should report on and aim to achieve:

    1. An average end-to-end network load of **10W/Mbps** (or 10J/Mb)
    2. CO2 emissions of **1mg/Mb**

- By 2030, all mobile operators should report on and aim to achieve:

    3. An average end-to-end network load of **1W/Mbps**
    4. CO2 emissions of **30mg/Gb**

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Introduction

In 2009, mobile phone networks carried 91 Petabytes (that's 9.1×10^{16} bytes) of data per month[2]. Ten years later, mobile networks are estimated to carry around 30 Exabytes of data per month. That's 30 $\times 10^{19}$ bytes or 15 billion HD movies, or an average of 2.5 movies for the 6 billion smartphone users on the planet. This represents an increase of over 330-fold in data traffic. This rapid increase in data carried by mobile networks is projected to slow, but even a reduction in CAGR to 30% a year would see volumes reaching over 130 Exabytes a month in 5 years.[3]

This increase in data travelling over mobile networks reflects the increasingly data-heavy applications running on mobile devices as well as the increasing penetration of smartphones in many developing markets. Although enterprises and public sector firms will also drive demand for mobile data, this is minor compared to consumer user demand. As mobile device penetration rates continue to increase and mobile device owners adopt more data heavy applications such as video streaming and immersive experiences, growth in volumes will continue far past 2024 and we could easily still see a 20-fold increase over current levels over the next 10 years.

In many ways this is exciting, as more computing power reaches the hands of more people around the world delivering applications that help billions of people in their daily lives. But this comes with a caveat – there is an input inherent in delivering this data traffic: the energy needed for running the network infrastructure.

The electrical energy required to power networks represents a cost to operators, but it also represents CO_2 emissions arising from burning fossil fuels to power the network (either directly from local dedicated generators or through the power grid). Greenhouse gas emissions therefore also risk increasing significantly as a result of data growth, particularly in countries heavily dependent on fossil fuels for their electricity production. Previously, this has been managed by the fact that mobile networks have been optimised to support larger amounts of data with a similar topology in terms of infrastructure, if slightly higher energy needs and costs. However, as spectrum is a limited resource, continued growth of mobile traffic over current LTE networks would quickly lead to densification – an increased amount of antenna and network infrastructure – by some estimates this would be an increase of 160% by 2025.[4]

Even with improvements in hardware performance, growth in mobile data over LTE networks would result in significant growth in energy consumption which represents a significant source of emissions. This is at odds with the goals that operators have set for themselves in terms of greenhouse gas emissions and risks breaching the standards to which (consumer, public and private sector) customers are increasingly holding their suppliers. Investors are also factoring in the higher risk profile

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[2] Cisco Visual Networking Index, 2019
[3] Ericsson Mobility Report, 2019
[4] A playbook for accelerating 5G in Europe, BCG, 2018

associated with companies with high carbon emission exposure[5]. Finally, this also matters to employees – particularly younger ones with the digital skills-sets that operators are looking to attract[6].

The key question posed by this dilemma then is: ***How should mobile network operators deal with this rapid rate of growth in data and the associated energy consumption and CO_2 emissions?***

In this report, we focus on one part of the answer – accelerating the adoption of more energy efficient 5G technologies and associated operational practices. A faster roll-out of 5G networks is a key weapon in operators' arsenal of measures for de-coupling energy costs and carbon emissions arising from data growth.

Scope of this report

Network operators need to mitigate the ever-increasing energy costs and carbon footprint of their networks resulting from the forecast data growth in some way. There are six ways that the **accelerated adoption of 5G** can do this:

1. **Direct curtailment of energy** consumption in **mobile access networks** through the better energy "performance" of 5G network equipment and operational practices relative to 4G.

2. **Direct curtailment of energy** consumption in **5G core networks** through the better energy "performance" of network equipment and operational practices relative to 4G core networks.

3. **Reduced energy consumption** by devices (particularly smartphones and IoT devices).

4. **Decarbonising the grid:** indirectly enabling lower levels of national carbon emissions from electricity generation through 5G supported "smart-grid" applications, increasing the proportion contributed by renewables and improving wider efficiencies in distribution and non-renewables generation.

5. **Indirectly improving energy efficiency across all sectors** through reducing waste and improving operations. Reduced emissions are largely a by-product of improved productivity and process efficiencies.

6. **Reducing carbon emissions from travel** through reducing the number of journeys (e.g. remote monitoring and management, virtual meetings) and reducing the emissions per journey.

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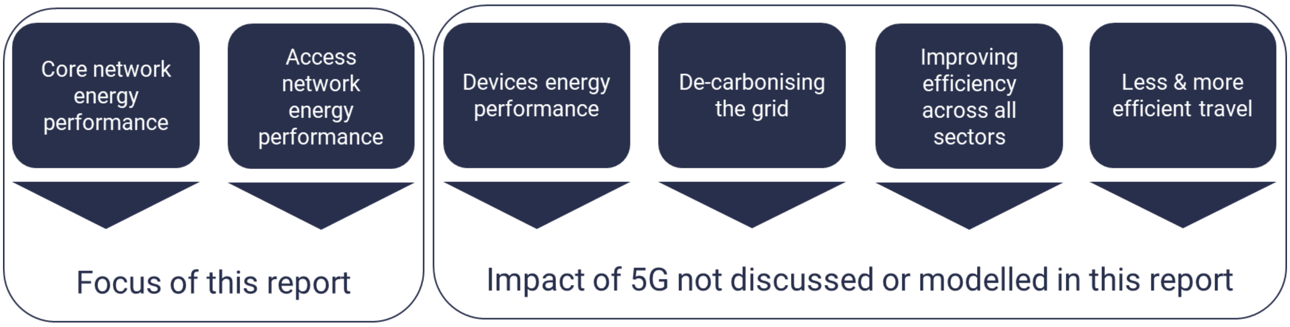
[5] UNEP Finance Initiative (2017) Portfolio Investment in a Carbon Constrained World: The Third Annual Progress Report of the Portfolio Decarbonisation Coalition

[6] https://www.fastcompany.com/90306556/most-millennials-would-take-a-pay-cut-to-work-at-a-sustainable-company

Figure 2: Areas where 5G could impact global carbon emissions



Source: STL Partners

In this report, we focus on the first two – the management of energy consumption via increasing the carbon performance of the network (expressed as a reduction in the tonnes of CO_2 per TB of data transmitted). While we see significant potential upside in "de-carbonising the grid", in enabling greater energy efficiencies and reducing waste across the economy, these are not in operators' direct control. They are also more challenging to estimate. We would recommend this form part of a future study.

For nearly all operators, over 90% of the direct energy usage of network operators is accounted for via electricity drawn from the grid to service their own networks. Limiting the growth of this would represent the largest direct reduction in future greenhouse gas production for a mobile network.

Four scenarios modelled

We have modelled our analysis around four 5G scenarios. We treat each of these scenarios differently in our model and scenario assumptions vary by country type.

No 5G roll out

No 5G roll out assumes that there is no roll out of 5G radio access or core technologies. This scenario shows emissions growth well below the growth in data volumes. This is because we anticipate reductions from lower-carbon power generation (e.g. renewables) and significant performance improvements in 4G core and access networking. These are discussed at length in this report.

Slow 5G rollout

A slow roll out of 5G would see the most delayed launch dates for 5G (between 2021 and 2024) and assumes that 5G accounts for the lowest share of data volumes over time (10-25% by 2025 and 60-80% by 2030).

Medium 5G rollout

A medium roll out of 5G can be considered a base-case. This would see an average launch date of 2019-2022. There would see a significant volume of data running over 5G – up to 60% by 2025 and 85% by 2030. Implicitly, we would expect decommissioning of 2G or 3G (or even 4G) networks with spectrum re-farming to 5G.

Fast 5G rollout

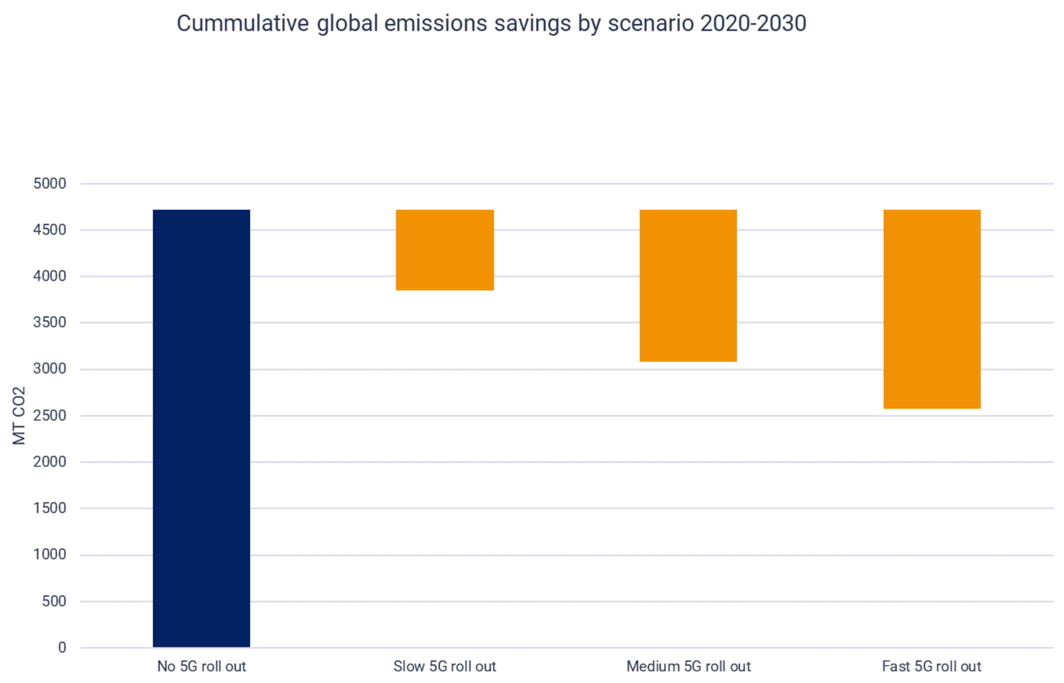
A fast roll out would see the highest and quickest realisation of the benefits of 5G to energy efficiency. It would see 5G launch between 2019 and 2021, and the highest percentage of the access network run on 5G networks (up to 99% in 2030 for advanced economies). Consequently, we have also assumed the highest energy efficiency levels by 2030 as 2/3/4G networks are decommissioned. It would also see the highest roll-out of millimetre wave cells.

Our findings

Faster 5G roll out could reduce cumulative carbon emissions by 0.5 billion tonnes of CO_2 globally by 2030

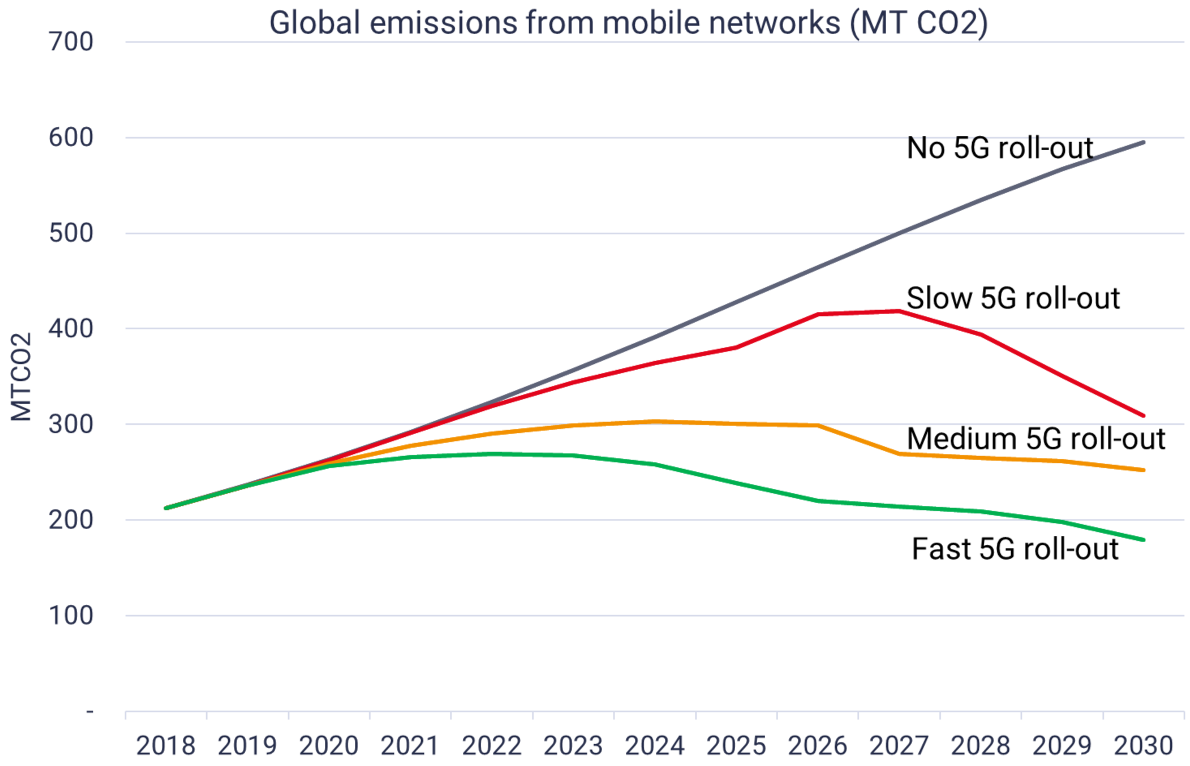
Our findings suggest that quickly rolling out fast 5G networks could reduce the cumulative CO_2 footprint of mobile networks globally by over a third, compared with a slow roll-out. The difference between a quick roll-out and medium "base-case" roll-out of 5G networks is also significant – cumulative global savings (2020-2030) would be 0.5 billion tonnes of CO_2, slightly less than the annual carbon emission of all international aviation in 2018. If we turn to the yearly carbon footprint of mobile networks, the only scenario that would see an actual reduction in annual carbon footprint of the mobile network would be our fast roll-out scenario. We describe these scenarios in more detail in the methodology section as well as detail numerically in the appendix.

Figure 3: Cumulative reduction in emissions under different roll-out scenarios



Source: STL Partners projections

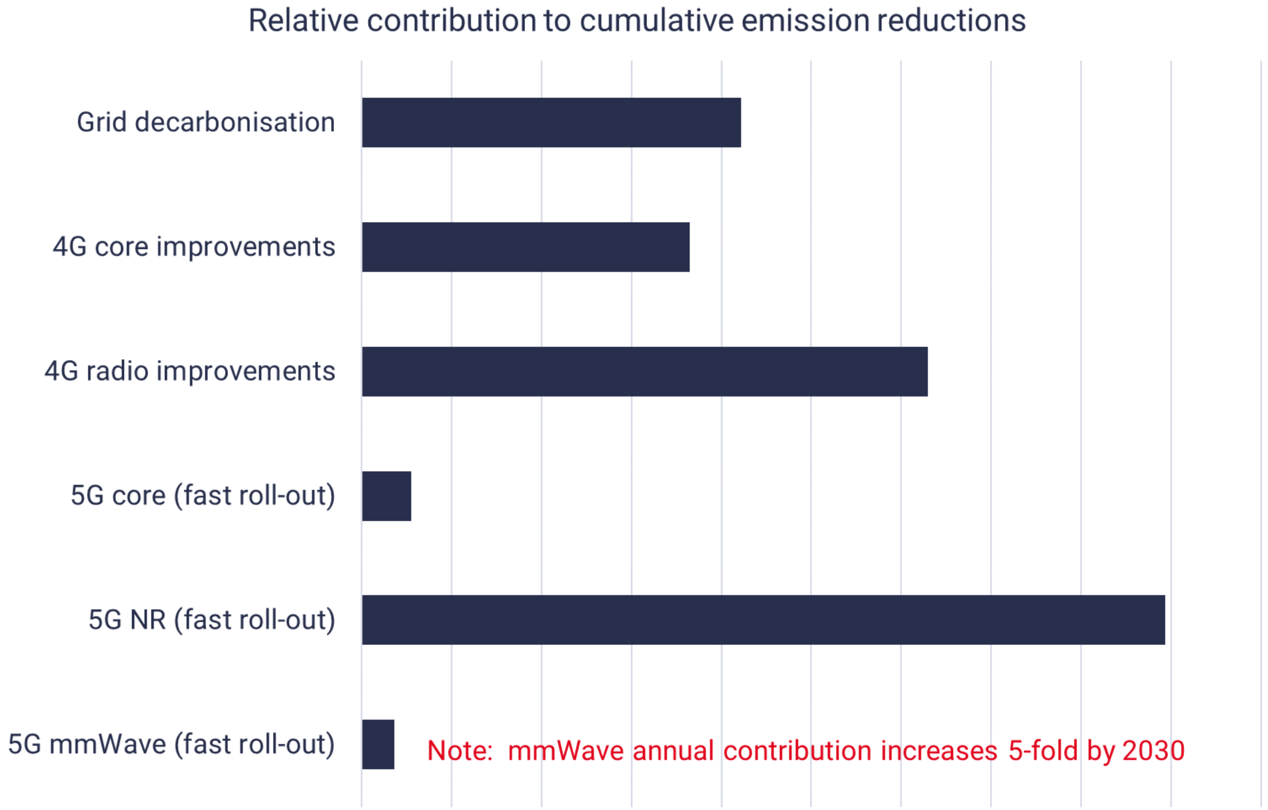
Figure 4: Projected CO_2 emissions from mobile networks under 4 scenarios



Source: STL Partners projections

Behind these high-level figures, we can drill down into the different effects on net emissions in Figure 3. About half of the carbon reduction can be accounted for by “non 5G” effects. Essentially, these are improvements that are expected to occur under 4G anyway: improvements to the core network (virtualisation, function optimisation, hardware performance) which will occur in a 4G-only scenario and de-carbonisation of electricity grids via a move to more environmentally friendly energy sources. The other half of cumulative carbon “savings” are accounted for by 5G technologies. These are discussed in more detail below. The largest saving is accounted for by mmWave radio access technologies highlighting the jump in efficiency compared to lower spectrum frequencies.

Figure 5: Where do emissions reductions come from[7]



Source: STL Partners projections

By accelerating the roll-out of 5G networks, national authorities and operators can set (and meet) tougher emission targets: in terms of total emission ($MtCO_2eq$), network carbon efficiency (tCO_2/PB) and network energy efficiency (GWh/EB). Improvements to the 4G networks alone will not produce the same results.

In summary, accelerated roll-out of 5G offers a means to prevent escalating network energy demand and CO_2 emissions arising from ever-increasing data volumes. Even with improvements to 4G technology, the only way to decrease yearly energy increases is 5G rollout – including the use of mmWave.

[7] Values in chart show the reductions in cumulative global emissions relative to the previous steps. For example, introducing 4G radio improvements would result in 32% less emissions than the emissions levels after Grid decarbonisation and 4G core improvements have been applied. All benefits are therefore multiplicative rather than additive.

How will accelerating 5G roll-out reduce carbon emissions from mobile networks?

As can be seen from the charts above, most of the energy savings arising from 5G can be accounted for by other expected changes to the technology within mobile networks. We drew these conclusions via interviews and literature reviews into the energy costs and efficiency gains of different mobile network technologies. For this exercise, we have divided and modelled networks into two parts:

- **Core network and IT**, mostly located in distributed and centralised technical sites (essentially datacentres and transmission)
- **Radio access**, mostly located at or near base stations.

Historically, radio access accounts for around two-thirds of most networks' energy consumption and so this is where we might expect most energy savings to occur and where changes in technology should make the largest difference. In practice, our modelling work suggests that this is set to change, partly due to greater gains being made in radio access technologies versus core networking and partly due to adoption of caching, break-out and "edge compute" developments which should reduce the proportion of mobile traffic being carried over core networks.

We have not estimated the energy consumed for caching and "edge compute" from our analysis as this is relatively small and/or largely displacing workloads that would otherwise have occurred elsewhere.

5G technologies as drivers of sustainability

The core network

The core network is expected to see improvements in energy efficiency through advances in technology combined with changes in underlying architecture. Edholm's Law[8] (which has parallels with Moore's Law[9]) predicts that improvements in compute and transmission technologies mean that data rates double every 18 months. As consumers, we have all experienced this first-hand in growth in data allowances offered to us on broadband plans. Although Phil Edholm did not specifically discuss energy, the implication is that there is little or no growth in resources (including energy) needed to support growth in bandwidth.

Increasing improvements in optical transmission, higher performance chipsets used in network equipment and the "cloudification" of network functions (writing for virtualised/containerised infrastructure) will continue to deliver more "bang for buck" (or GB per kWh).

[8] https://en.wikipedia.org/wiki/Edholm's_law
[9] https://en.wikipedia.org/wiki/Moore's_law

These trends will affect core networks regardless of whether a 5G-specific core is deployed – and most initial 5G deployments will use 4G cores anyway. However, several factors mean that accelerating roll-out of 5G will result in a further, albeit modest, improvement in energy efficiency in core networks:

- Investment in infrastructure, skills and operating practices will be brought forward, which means older (less efficient) equipment, software and practices will be "frozen" and then decommissioned sooner.
- The nature of 5G architecture means that far greater levels of automation will be possible, resulting in greater optimisation.
- End-to-end network slicing (only really possible through 5G) will result in more efficient use of core network resources, as only functions that are needed for a given application will be executed.
- As mentioned above, there is potential that adoption of caching, local break-out and "edge compute" could reduce core traffic volumes. Although these will also apply to 4G networks, we expect them to be more prevalent in 5G networks, partly because this should be easier to do and partly because of the need for densifications.

In practice – and this is reflected in our projections – 5G roll-out has a relatively modest impact on core network emissions and much of this is down to accelerated adoption of new technology and the business practices associated to this rather than 5G core technologies per se.

5G New Radio, new spectrum

There are three main improvements in the access network from 5G that will result in significant savings in the energy consumption of the network per bit of data transmitted:

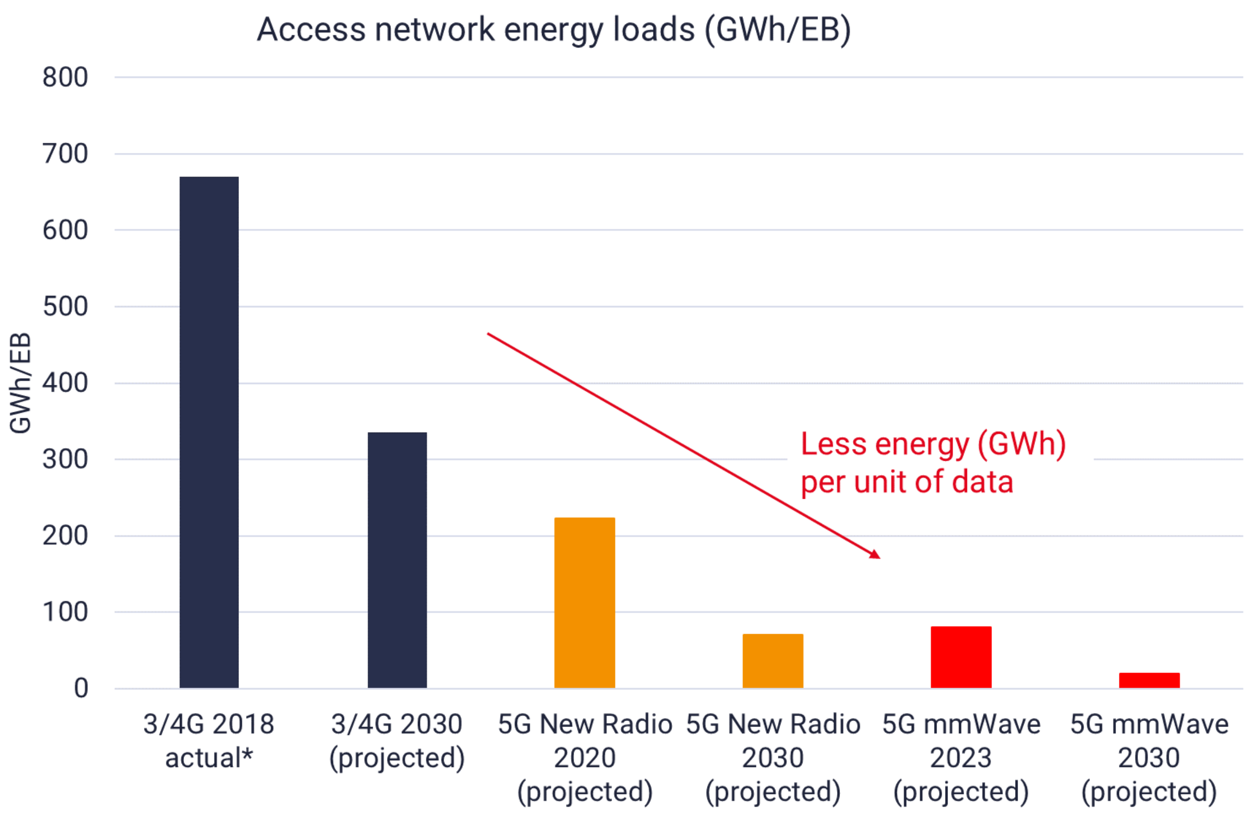
- A collection of technologies referred to as 'New Radio' (NR)
- New spectrum and higher array Massive MIMO antennas associated with this
- Millimetre wave (mmWave) spectrum

5G New Radio represents a collection of new 3GPP standards that provide higher spectral efficiency, Massive MIMO, beam forming technologies and new network protocols. These, alongside improvements in energy use such as automated sleep modes on base station functions, provide the basis for significant increases in energy performance. As networks are scaled and optimised, by 2030, we expect 5G New Radio (NR) to eventually fall to 10% of the energy consumption per bit of data transmitted with current 4G access technologies. This projection is drawn from a range of figures we collected from interviews with network equipment providers comparing power ratings for different cell site and antenna configurations. We assumed that in practice, actual performance levels would be much lower than the theoretical levels and converge to these over time (Fig. 5).

Millimetre Wave (mmWave)

Millimetre wave spectrum (for 5G, this is referred to as FR 2 and refers to spectrum above 24 GHz) is expected to see novel antenna devices, beam forming and network protocols, enabling a massively increased amount of data to be transmitted for less energy on smaller and cheaper-to-power cells. Perhaps more importantly, mmWave 'overlay' cells are expected to provide a far more efficient mechanism to support peaks in demand and thereby improve utilisation and energy performance of (3/4/5G) macro cells.

Figure 6: Access technologies' evolving energy performance



Source: STL Partners projection

However, millimetre wave technology is still being developed and with no deployments expected before 2023, estimates of energy performance are therefore informed by lab findings. We have drawn from a recent IEEE report[10] on the energy efficiency of millimetre wave in 3 different use case scenarios and conclude that by using the '50+mbps everywhere' use case scenario, which is a middle ground between high density city scenarios and scenarios with lower density of mobile devices, we project energy consumption that is under 2% of current 4G energy usage per bit transmitted.

[10] Performance, Power and Area Design Trade-Offs in Millimeter-Wave Beamforming Architectures. Han Yan, Sridhar Ramesh, Timothy Gallagher, Curtis Ling and Danijela Cabric. IEEE Circuits and Systems Magazine, Second Quarter 2019 1531-636X/19@2019IEEE

Since we anticipate millimetre wave to be rolled out in a scalable way only after 2025, the effect is only seen in the latter half of our projections. That being said, the savings are significant. We assume that to begin with, millimetre wave technology will be relatively inefficient due to limited cell size (and relative under-utilisation), interference and propagation barriers. However, once the technology matures we predict overall performance to pick up by 2030.

Network sharing, operational and competitive dynamics

In STL Partners' report we anticipate that 5G networks will see greater levels of network sharing across operators and more variety in the forms of network sharing than is possible (or needed) for 4G. As well as potential reduction in capital expenditure, we would expect that network sharing will result in even greater levels of network energy efficiencies. This is particularly true for mmWave deployments for the reasons set out above. This has not been explicitly modelled in our projections.

Devices

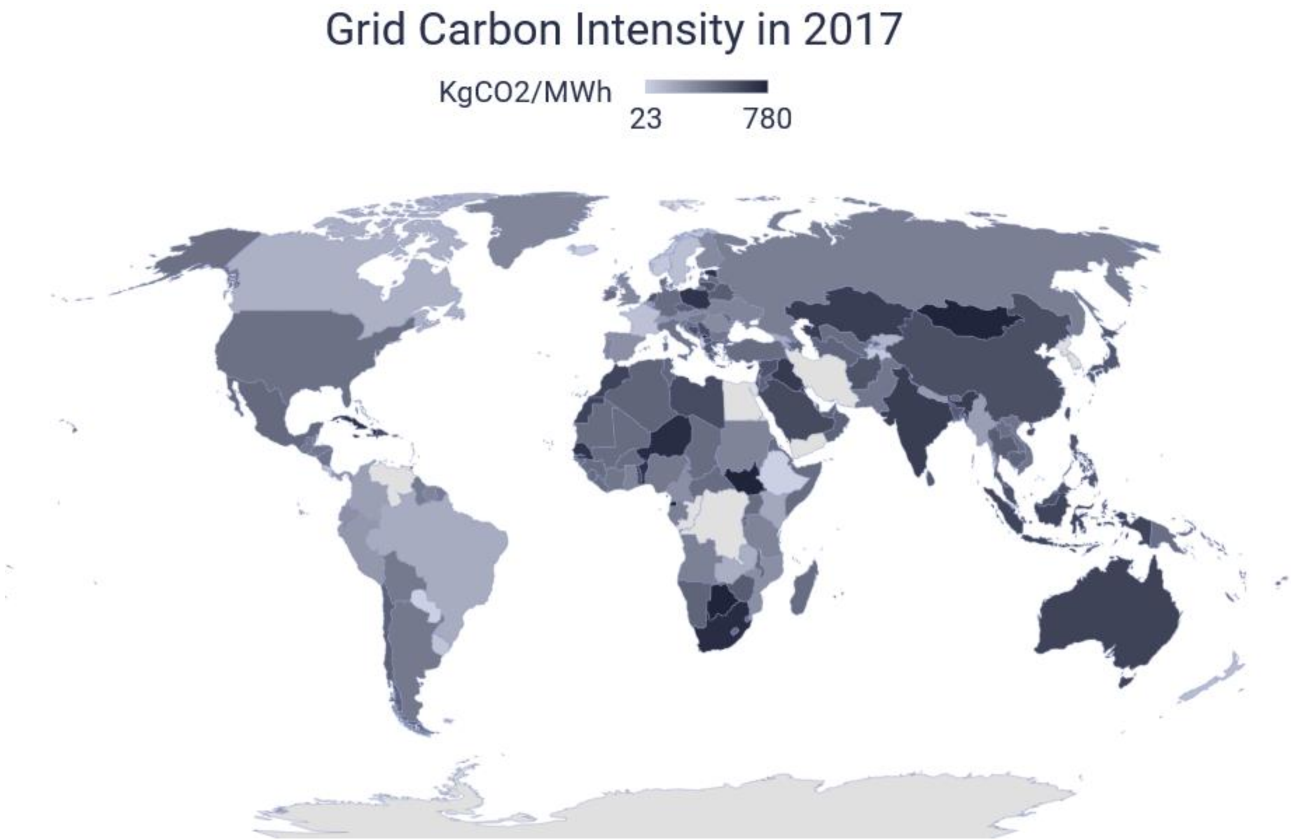
A further way that 5G networks will be more energy efficient falls outside of the network and onto the device. Because transmission of data between devices is so much more efficient, this can help reduce the battery consumption of IoT devices, smartphones and other devices. 5G technologies represent a potential saving in consumption of energy for 5G devices (smartphones and IoT devices alike).

This falls outside the scope of our report on the direct impact of the network on carbon emissions, so we do not include it in our calculations. However, rough estimates suggest that devices could potentially account for 2-3x the carbon emissions of the core and radio network.

Country level findings: Uneven distribution of carbon savings

Technology and new operating practices from transitioning to 5G are the most significant contributors to lowering the carbon footprint of mobile networks. What this also means is that the benefits of 5G roll out (in terms of carbon emissions) are not equally distributed. Networks that will save the most in in terms of CO_2 emissions are those that draw from more carbon-intense grids relying on power generation from fossil fuels such as coal and oil.

Figure 7: Carbon intensity of different countries used in modelling emissions

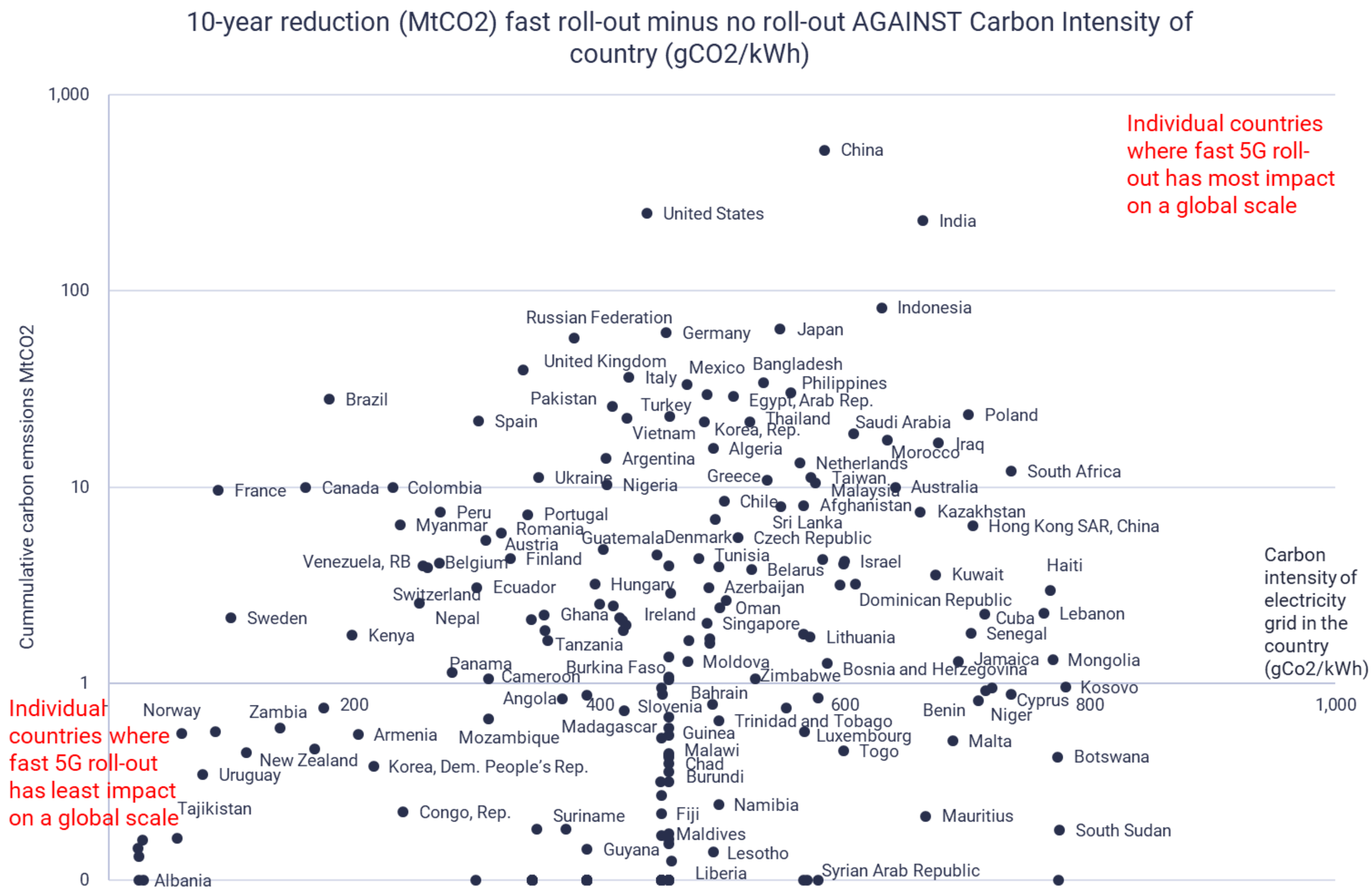


Source: STL Partners

This is set out in Figure 7 – the 10-year cumulative CO_2 savings resulting from a faster roll-out of 5G technology versus no 5G roll-out is concentrated in countries with the most carbon intense grids. Countries such as Indonesia could reduce the equivalent of 82 Million Tonnes of CO_2 between 2020 and 2030 in cumulative CO_2 emissions by rolling out 5G quickly, compared to not rolling out 5G at all.

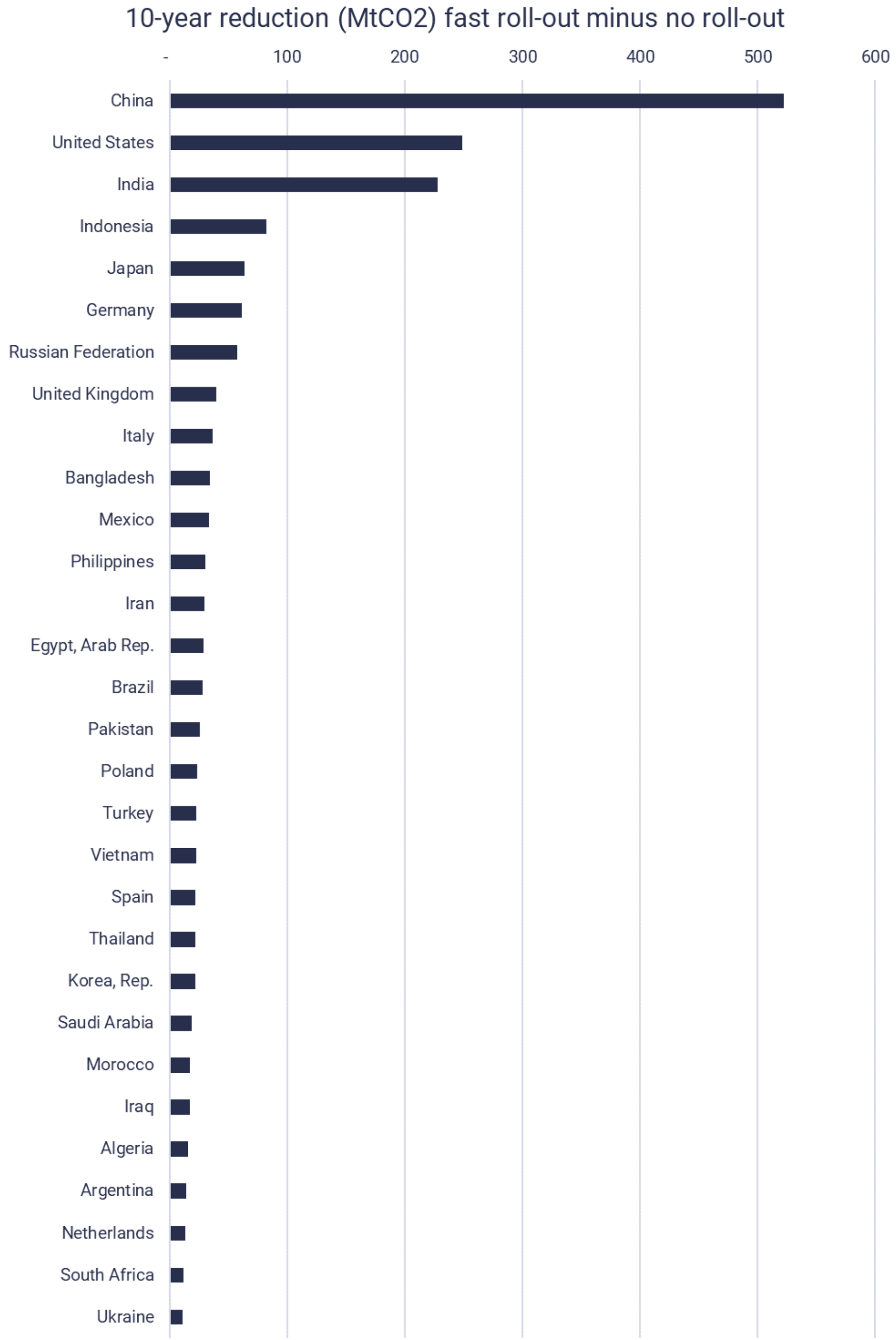
Figure 9 indicates the profile of the top 30 countries in terms of total cumulative savings between 2020-2030. A uniting factor between them all is having high-mobile-use populations with relatively carbon intensive grids.

Figure 8: Potential reduction in emissions from fast roll-out of 5G against carbon intensity of grid



Source: STL Partners projection

Figure 9: Top 30 Countries by potential reduction in emissions from fast 5G roll-out



Source: STL Partners projection

Even in the top 10 countries the carbon saved cumulatively is large – China for example would cumulatively save more carbon emissions from 5G roll out as the entire sub-Saharan Africa region would. This should not deter all countries from making their contribution to curtailing carbon emissions.

Conclusions and Recommendations

Faster 5G network deployment is a big part of the answer to the question we posed at the start of this report: ***How should mobile network operators deal with the rapid rate of growth in data, and seek to curtail the associated energy consumption and CO_2 emissions?***

Alongside self-generation of greener electricity or by under-writing others' generation of power from green energy sources, rolling out 5G networks can be a key component of operators' and national authorities' ambitions to reduce the emission of greenhouse gases from the operation of mobile networks. As we have seen, rolling out 5G networks quickly (rather than slowly) could save the world over 0.5 bn tonnes of CO_2 cumulatively between 2020 and 2030 – more than one year of greenhouse gas emissions from all maritime shipping or all aviation globally.

This leads us to offer the following guidance to the stakeholders in the mobile network in order to achieve these vital sustainability targets:

Operators

Network operators should see 5G network deployment not only as an investment in their services, but also part of a strategy to contain growing energy demands of escalating data volumes. Rolling out 5G networks as soon as possible will limit the network operators' CO_2 emissions and will make a major contribution to operators' own sustainability targets. This is doubly true for operators running networks in countries with carbon-intense energy grids, or in situations where operators are relying on diesel generators to run their base stations in remote areas.

We think that a single operator with data traffic of over 10 ectabytes per year in 2030 (for example the second operator in Saudi Arabia) would reduce CO_2 emissions by 7 million tonnes cumulatively between 2020 and 2030, which is equivalent to the annual emissions from over 800,000 US homes' energy use.

Regulators and other national authorities

Regulators and other national authorities have a key role in ensuring the sustainability of the networks they oversee by:

- Setting low-carbon operational targets within license terms (on energy performance, adoption of specific standards, use of renewables, carbon-intensity of network power)
- Incentivising the accelerated roll-out of 5G through policy and licensing
  - Set tough coverage requirements rather than high spectrum pricing
  - Establish and enforce rights of way, access to ducting, nationwide frameworks for use of power / lighting poles and streamlining other planning processes

  - Reduce or eliminate import duty on 5G infrastructure
- Encouraging efficient and low-carbon practices
  - Network sharing
  - Use of low-carbon energy sources (e.g. through lower energy taxation)
- Incentivising migration off 2G/3G and early decommissioning of these networks

Regulators have historically not held operators to meeting specific KPIs regarding network operators' sustainability. Making sure that operators meet target GWh/PB of data transmitted in their core and access networks would both ensure sustainability and also provide transparency – forcing operators to publish figures, for example, would help to cut through the obfuscation and provide customers with clearer information on the environmental impact of their mobile use. Tying 5G licenses and spectrum to efficiency standards should also be encouraged. Efficient 5G networks will require new legal environments around having the right to build much smaller but more efficient millimetre wave radio cells throughout cities. Similarly, building larger massive MIMO new radio masts will need to be supported by authorities to prevent planning laws from causing significant constraints to efficient deployment of 5G networks.

Tower and power suppliers

Independent tower businesses and energy suppliers operate more than two-thirds of the base station infrastructure and are responsible for the supply and management of power through grid, generators, batteries, wind and solar power. As well as ensuring that energy is low-carbon and optimised, they will increasingly have an influence on the selection of active component technology (antenna) in the future as they deliver shared infrastructure to multiple telco operators. They should support operators' carbon emissions objectives by adopting stringent reporting and carbon accounting practices.

Technology providers

Our final set of recommendations are for the technology community that supplies operators with equipment, software and services for their 5G networks. Ultimately, they will need to ensure that 5G meets its promise of lower emissions. Potential areas where they can support include:

- Set out clear performance standards and benchmarks, ideally at a global industry level (not unlike the energy ratings on white goods)
- Pro-actively engage regulators and authorities to make the case for 5G's energy performance
- Pursue new business models with operators (e.g. similar to the ESCO energy saving companies who introduce a range of measures in exchange for a share in the reduction in energy costs)
- Commit to performance through SLAs to ensure their network equipment adheres to strict KPIs
- Drive awareness and support industry-wide initiatives

Methodology

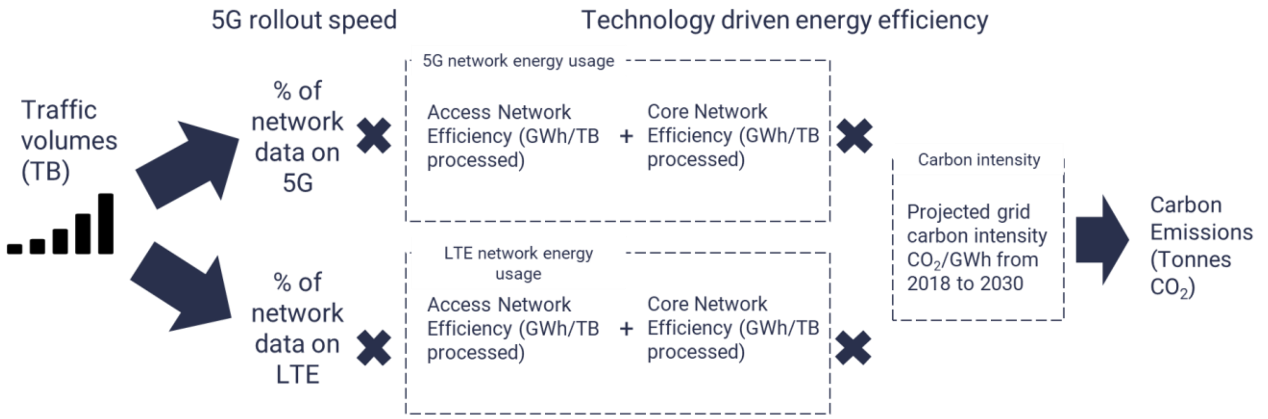
Projections

This section details how our forecasting model functions and where our assumptions and figures are drawn from. We urge readers to explore the appendices with key figures at a country level to get an idea of how the model works on a country level from scenario to scenario.

This exercise has required a number of simplifying assumptions and modelling approaches. We have consistently sought to ensure that these are conservative and that they understate rather than overstate the specific contribution of 5G technologies. In practice, the levels of energy consumption (and carbon emissions) from mobile networks are a function of many factors (network architecture and topology, spectrum availability, coverage requirements, operating policy, geography and demographics). Actual networks are composed of several overlaid "life cycles" of investment with each life cycle potentially achieving significant improvements in energy performance over the previous cycle. Ideally each investment cycle would need to be modelled over its life up to decommissioning. Furthermore, the cycles are not strictly independent (for example 5G coverage can be more effectively used to address peak loads, thereby ensuring a more constant loading of 4G networks and improving the resultant 4G energy performance). Attempting to model this at an operator level is both complex and requires making many assumptions. Extending this to 800 operators globally would be a gargantuan task.

The model works by taking a single projection for mobile network data growth for each country and running this through four scenarios of 5G deployment and adoption. We have taken actual mobile network figures for energy consumption for Core and Access networks. We then divide the energy consumption by the mobile network data and use this as our starting point for 2018 network energy efficiency.

Figure 10: STL's carbon emissions methodology



Source: STL Partners

We have generated theoretical maximum network energy efficiency values for 5G radio access technology (one for new radio technology and one for millimetre wave technology) that we have inferred from interviews and discussions with industry players as well as the sources set out in the footnotes. As we move along the timeline, we project that 5G technology will make up a larger percentage of the data transmitted, as well as moving closer to the theoretical maximum of energy performance from a fairly inefficient starting point. Once we have projected the theoretical energy used per unit of mobile data for each year, we then multiply this against the projected data for that year.

Our final step involves taking this energy used by a country's mobile networks and multiplying this with the CO_2 footprint per unit of (electrical) energy for that country. We assume that this electrical energy is drawn from the country's electricity grid and so assume that the carbon footprint per GWh of each countries' national grid functions as a suitable proxy for the environmental impact of the mobile network.

We have drawn data on the sources of electrical energy for each country from the IEA electricity report 2019 (for countries not featured in the report we use a regional average figure of countries included in the report – we use the following regional groupings: North America; Latin America; Western Europe; Central and Eastern Europe; North East Asia; South East Asia and Oceania; India, Nepal and Bhutan; the Middle East; and Sub-Saharan Africa), we then combine this with the carbon producing potential of each fuel type to derive a figure for the tonnes of CO_2 equivalent produced when creating a GWh of energy in each country. We then use this to determine a tonnes of CO_2 figure produced each year in each country through servicing mobile networks. Because we predict carbon intensity to decrease through time globally, we include a de-carbonisation factor that ranges from 30% decrease in tonnes of CO_2 per GWh of electricity generated for the most carbon-intense grids down to a 10% decrease for the least carbon-intense grids.

This is done on a country level and then summed up regionally and globally. Our data set contains 240 countries, which although not exhaustive contains every significant source of mobile data. We do this for every year between 2018 and 2030.

Scenarios

We propose there are 4 different scenarios for the future of mobile networks:

- No or negligible 5G roll out
- A slow 5G roll out
- A medium velocity 5G roll out
- A fast 5G roll out.

We treat each of these scenarios differently in our model and alter them by country type.

No 5G roll out

No 5G roll out assumes that there is no roll out of 5G radio access or core technologies. This scenario shows emissions growth well below the growth in data volumes. This is because we anticipate reductions from lower-carbon power generation (e.g. renewables) and significant performance improvements in 4G core and access networking. These are discussed at length in this report.

Slow 5G rollout

A slow roll out of 5G would see the most delayed launch dates for 5G (between 2021 and 2024) and assumes that 5G accounts for the lowest share of data volumes over time (10-25% by 2025 and 60-80% by 2030).

Medium 5G rollout

A medium roll out of 5G can be considered a base-case. This would see an average launch date of 2019-2022. There would see a significant volume of data running over 5G – up to 60% by 2025 and 85% by 2030. Implicitly, we would expect decommissioning of 2G or 3G (or even 4G) networks with spectrum re-farming to 5G.

Fast 5G rollout

A fast roll out would see the highest and quickest realisation of the benefits of 5G to energy efficiency. It would see 5G launch between 2019 and 2021, and the highest percentage of the access network run on 5G networks (up to 99% in 2030 for advanced economies). Consequently, we have also assumed the highest energy efficiency levels by 2030 as 2/3/4G networks are decommissioned. It would also see the highest roll-out of millimetre wave cells.

Country level differences

We group countries by World Bank income groupings – we use these groupings to assign status of High, Upper Middle, Lower Middle and Lower income economies to each country in our data base. We then assign scenario data relating to network energy assumptions and the adoption of 5G. Highest income countries are projected to show faster 5G adoption than other countries under all scenarios.

Other Assumptions

We have made simplifying assumptions, primarily with the aim of ensuring that scenarios are comparable.

- The data volumes projected are the same for all 5G roll-out scenarios. Essentially, we are projecting that demand is not affected by the presence of new 5G services. This is mainly to ensure that scenarios are comparable: increasing data volume forecasts for different scenarios (i.e. faster 5G roll-out generating more growth) would create confusion in interpreting findings. This approach implicitly accepts the 5G-sceptics' common assertion that 5G doesn't do much that 4G cannot do too. A possible refinement to the projection would be to factor in changes in data growth under the different scenarios.

- We have assumed that the carbon footprint embedded in equipment and generated in the installation of 5G networks is broadly comparable with that required for the equivalent 4G expansion and can therefore be excluded from our evaluation. In any case, embedded and installation carbon footprints are expected to be a small fraction (<5%) of the total lifecycle carbon footprint.

- We have applied the same assumptions for the starting points of energy consumption of 4G networks. In practice these will vary by country due to a number of market, geographic and technical factors. However, since our analysis is mainly concerned with the relative evolution of carbon emissions for different scenarios, rather than the absolute amount, this should not greatly affect our overall findings.

- Where data is not available for countries, we have made assumptions based on regional benchmarks.

- We have largely ignored 2G and 3G networks as in most countries, these carry a small proportion of data traffic. We would also expect most of these to be decommissioned before 2030 and that this should not vary by 5G roll-out scenario.

- Lastly, we assume that 4G and 5G networks are both predominantly drawing energy from the national grid and hence 5G networks use electricity that is no more efficient regarding carbon than the LTE network.

Appendix

Country data tables for all scenarios. Figures show cumulative carbon emissions from mobile networks 2020-2030 in millions of tonnes of CO_2.

Country	Fast 5G roll out	Medium 5G roll out	Slow 5G roll out	No 5G roll out
Afghanistan	14.2	16.6	18.3	22.3
Albania	0.1	0.1	0.1	0.1
Algeria	16.7	20.2	25.9	32.5
American Samoa	0.01	0.01	0.01	0.01
Andorra	0.03	0.04	0.1	0.1
Angola	1.1	1.3	1.5	1.9
Anguilla	-	-	-	-
Antigua and Barbuda	0.04	0.05	0.1	0.1
Argentina	15.0	18.0	23.1	29.0
Armenia	0.6	0.7	0.9	1.1
Aruba	0.03	0.04	0.1	0.1
Australia	9.0	11.1	15.1	19.0
Austria	4.6	5.8	7.8	10.0
Azerbaijan	3.5	4.2	5.3	6.6
Bahamas, The	0.1	0.1	0.1	0.2
Bahrain	0.6	0.8	1.1	1.4
Bangladesh	45.1	53.7	63.4	79.1
Barbados	0.1	0.1	0.1	0.2
Belarus	4.3	5.1	6.5	8.1
Belgium	3.4	4.2	5.7	7.3
Belize	0.1	0.1	0.2	0.2
Benin	1.5	1.8	2.0	2.4
Bermuda	0.02	0.02	0.03	0.03
Bhutan	0.2	0.3	0.3	0.3
Bolivia	3.1	3.7	4.4	5.6
Bosnia and Herzegovina	1.4	1.7	2.2	2.7
Botswana	0.5	0.6	0.7	0.9
Brazil	28.4	34.4	44.4	56.4
Brunei Darussalam	0.1	0.2	0.2	0.3
Bulgaria	2.8	3.3	4.2	5.3
Burkina Faso	2.0	2.3	2.6	3.1
Burundi	0.7	0.8	0.8	1.0

Country	Fast 5G roll out	Medium 5G roll out	Slow 5G roll out	No 5G roll out
Cambodia	5.2	6.2	7.3	9.1
Cameroon	1.3	1.6	1.9	2.4
Canada	8.2	10.3	14.2	18.2
Cabo Verde	0.1	0.1	0.1	0.1
Cayman Islands	0.02	0.03	0.04	0.05
Central African Republic	0.1	0.2	0.2	0.2
Chad	0.7	0.8	0.9	1.1
Chile	6.9	8.7	12.0	15.4
China	708.5	829.0	1032.9	1230.8
Cocos (Keeling) Islands	-	-	-	-
Colombia	10.1	12.2	15.8	20.0
Comoros	0.04	0.1	0.1	0.1
Congo, Dem. Rep.	0.3	0.3	0.4	0.4
Congo, Rep.	0.3	0.3	0.4	0.5
Cook Islands	-	-	-	-
Costa Rica	0.6	0.7	0.9	1.1
Cote d'Ivoire	2.7	3.2	3.8	4.8
Croatia	1.4	1.8	2.4	3.1
Cuba	2.4	2.9	3.7	4.6
Curacao	0.1	0.1	0.1	0.1
Cyprus	0.7	0.9	1.3	1.7
Czech Republic	4.8	5.9	8.1	10.3
Denmark	4.0	5.0	6.8	8.5
Djibouti	0.04	0.04	0.1	0.1
Dominica	0.02	0.02	0.03	0.04
Dominican Republic	3.4	4.1	5.3	6.6
Ecuador	3.2	3.9	5.0	6.3
Egypt, Arab Rep.	34.9	42.0	49.9	63.9
El Salvador	2.6	3.2	3.7	4.8
Equatorial Guinea	0.1	0.1	0.1	0.2
Eritrea	0.1	0.1	0.1	0.1
Estonia	0.8	1.0	1.4	1.8
Eswatini	0.1	0.2	0.2	0.2
Ethiopia	0.3	0.3	0.3	0.4
Fiji	0.3	0.3	0.4	0.5
Finland	3.7	4.6	6.3	8.0
France	8.0	10.1	13.8	17.7

Country	Fast 5G roll out	Medium 5G roll out	Slow 5G roll out	No 5G roll out
French Guiana	-	-	-	-
French Polynesia	0.1	0.1	0.1	0.1
Gabon	0.2	0.2	0.3	0.4
Gambia, The	0.3	0.4	0.4	0.5
Georgia	0.8	1.0	1.2	1.6
Germany	54.4	67.6	91.8	115.6
Ghana	2.9	3.4	4.0	5.1
Greece	9.7	12.0	16.3	20.6
Greenland	0.03	0.03	0.04	0.1
Grenada	0.03	0.03	0.04	0.1
Guadeloupe	-	-	-	-
Guam	0.04	0.05	0.1	0.1
Guatemala	5.1	6.2	7.9	9.9
Guernsey	-	-	-	-
Guinea	1.3	1.5	1.6	1.9
Guinea-Bissau	0.2	0.2	0.2	0.2
Guyana	0.2	0.2	0.2	0.3
Haiti	5.3	6.2	6.8	8.3
Honduras	2.3	2.7	3.2	4.1
Hong Kong SAR, China	6.6	8.1	10.7	13.0
Hungary	2.8	3.4	4.7	6.0
Iceland	0.02	0.02	0.03	0.04
India	409.0	473.4	545.3	636.8
Indonesia	108.7	129.6	153.0	190.9
Iran, Islamic Rep.	31.5	38.0	48.8	61.3
Iraq	17.8	21.5	27.6	34.7
Ireland	2.6	3.2	4.3	5.4
Isle of Man	0.04	0.05	0.1	0.1
Israel	3.4	4.3	5.9	7.6
Italy	32.3	40.2	54.5	68.7
Jamaica	1.4	1.7	2.1	2.7
Japan	66.1	80.4	106.3	129.8
Jersey	-	-	-	-
Jordan	2.8	3.4	4.4	5.5
Kazakhstan	8.8	10.5	13.3	16.3
Kenya	2.1	2.6	3.0	3.9
Kiribati	0.01	0.02	0.02	0.02

Country	Fast 5G roll out	Medium 5G roll out	Slow 5G roll out	No 5G roll out
Kosovo	1.1	1.3	1.6	2.0
Kuwait	2.9	3.7	5.0	6.5
Kyrgyz Republic	0.7	0.9	1.1	1.3
Lao PDR	1.3	1.5	1.8	2.2
Latvia	0.8	0.9	1.3	1.6
Lebanon	2.4	2.9	3.7	4.7
Lesotho	0.2	0.2	0.3	0.3
Liberia	0.3	0.3	0.4	0.5
Libya	4.3	5.2	6.6	8.3
Liechtenstein	0.02	0.02	0.03	0.04
Lithuania	1.5	1.8	2.5	3.2
Luxembourg	0.5	0.6	0.9	1.1
Macao SAR, China	0.9	1.1	1.4	1.7
Madagascar	1.1	1.3	1.4	1.7
Malawi	0.8	0.9	1.0	1.2
Malaysia	12.4	14.7	18.7	23.0
Maldives	0.2	0.2	0.3	0.4
Mali	2.0	2.3	2.5	3.0
Malta	0.5	0.6	0.8	1.0
Martinique	-	-	-	-
Mauritania	0.4	0.5	0.6	0.7
Mauritius	0.2	0.3	0.4	0.4
Mayotte	-	-	-	-
Mexico	35.7	43.0	55.2	69.2
Moldova	1.7	2.0	2.3	2.9
Monaco	0.01	0.02	0.02	0.03
Mongolia	1.7	2.1	2.5	3.1
Montenegro	0.4	0.4	0.5	0.7
Morocco	20.8	25.0	29.8	38.1
Mozambique	1.2	1.4	1.5	1.9
Myanmar	8.1	9.7	11.5	14.5
Namibia	0.3	0.3	0.4	0.5
Nepal	6.7	7.5	8.1	9.3
Netherlands	11.8	14.7	20.0	25.1
New Caledonia	0.1	0.1	0.1	0.1
New Zealand	0.4	0.5	0.6	0.8
Nicaragua	2.4	2.9	3.4	4.4

Country	Fast 5G roll out	Medium 5G roll out	Slow 5G roll out	No 5G roll out
Niger	1.7	1.9	2.1	2.5
Nigeria	13.1	15.7	18.6	23.4
Korea, Dem. People's Rep.	0.7	0.8	0.9	1.1
North Macedonia	0.8	1.0	1.3	1.6
Northern Mariana Islands	0.01	0.01	0.02	0.03
Norway	0.5	0.6	0.8	1.0
Oman	2.0	2.5	3.4	4.4
Pakistan	34.1	40.7	48.1	60.0
Palau	0.004	0.01	0.01	0.01
West Bank and Gaza	2.1	2.6	3.1	3.9
Panama	0.9	1.1	1.6	2.0
Papua New Guinea	0.7	0.8	1.0	1.2
Paraguay	0.1	0.2	0.2	0.3
Peru	7.7	9.4	12.0	15.2
Philippines	40.2	48.0	56.6	70.7
Poland	20.2	25.2	34.4	43.7
Portugal	6.3	7.8	10.7	13.5
Puerto Rico	0.7	0.9	1.2	1.6
Qatar	1.4	1.7	2.4	3.1
Reunion	-	-	-	-
Romania	6.4	7.7	9.8	12.2
Russian Federation	64.6	77.3	98.4	122.0
Rwanda	1.0	1.2	1.3	1.6
St. Kitts and Nevis	0.02	0.02	0.03	0.04
St. Lucia	0.04	0.1	0.1	0.1
Saint Pierre and Miquelon	-	-	-	-
St. Vincent and the Grenadines	0.03	0.03	0.04	0.1
St. Martin (French Part)	0.004	0.01	0.01	0.01
Samoa	0.03	0.03	0.04	0.1
San Marino	0.02	0.02	0.03	0.03
Sao Tome and Principe	0.02	0.02	0.02	0.03
Saudi Arabia	15.2	19.1	26.3	33.9
Senegal	2.3	2.8	3.3	4.1
Serbia	3.6	4.3	5.5	6.8
Seychelles	0.01	0.02	0.02	0.03
Sierra Leone	0.8	0.9	1.0	1.2
Singapore	1.8	2.3	3.0	3.8

Country	Fast 5G roll out	Medium 5G roll out	Slow 5G roll out	No 5G roll out
Sint Maarten (Dutch Part)	0.02	0.02	0.03	0.04
Slovak Republic	1.8	2.2	3.0	3.9
Slovenia	0.6	0.8	1.1	1.4
Solomon Islands	0.1	0.1	0.2	0.2
Somalia	0.8	1.0	1.0	1.3
South Africa	13.7	16.3	20.8	25.8
Korea, Rep.	22.3	27.2	36.0	43.9
South Sudan	0.3	0.4	0.4	0.5
Spain	18.8	23.4	32.0	40.6
Sri Lanka	9.3	11.1	14.1	17.2
Sudan	2.1	2.5	3.0	3.8
Suriname	0.2	0.2	0.3	0.4
Svalbard and Jan Mayen Is.	-	-	-	-
Sweden	1.8	2.3	3.1	4.0
Switzerland	3.5	4.4	6.0	7.6
Syrian Arab Republic	-	-	-	-
Taiwan	11.6	14.2	18.7	22.9
Tajikistan	0.3	0.3	0.4	0.5
Tanzania	3.5	4.0	4.4	5.3
Thailand	25.2	30.0	38.0	46.7
Timor-Leste	0.4	0.4	0.5	0.6
Togo	0.9	1.0	1.1	1.3
Tonga	0.03	0.03	0.04	0.1
Trinidad and Tobago	0.5	0.7	0.9	1.2
Tunisia	5.2	6.3	7.4	9.5
Turkey	24.2	29.2	37.5	47.1
Turkmenistan	1.9	2.2	2.8	3.5
Tuvalu	0.001	0.001	0.002	0.002
Uganda	2.6	3.0	3.3	3.9
Ukraine	14.3	17.1	20.2	25.5
United Arab Emirates	5.6	7.0	9.7	12.4
United Kingdom	34.0	42.4	57.8	73.4
United States	215.5	269.1	367.0	464.6
Uruguay	0.3	0.3	0.5	0.6
Uzbekistan	5.3	6.3	7.4	9.3
Vanuatu	0.1	0.1	0.1	0.1
Venezuela, RB	4.1	5.0	6.4	8.1

Country	Fast 5G roll out	Medium 5G roll out	Slow 5G roll out	No 5G roll out
Vietnam	29.6	35.3	41.7	52.0
Virgin Islands (U.K.)	0.01	0.01	0.02	0.02
Virgin Islands (U.S.)	0.03	0.04	0.1	0.1
Wallis and Futuna	-	-	-	-
Western Sahara	-	-	-	-
Yemen, Rep.	8.2	10.1	13.3	16.8
Zambia	8.2	10.1	13.2	16.8
Zimbabwe	8.1	10.1	13.2	16.7

Source: STL Partners

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