The WRC series

Study on Socio-Economic Benefits of 5G Services Provided in mmWave Bands

December 2018

The GSMA represents the interests of mobile operators worldwide, uniting more than 750 operators with over 350 companies in the broader mobile ecosystem, including handset and device makers, software companies, equipment providers and internet companies, as well as organisations in adjacent industry sectors. The GSMA also produces the industry-leading MWC events held annually in Barcelona, Los Angeles and Shanghai, as well as the Mobile 360 Series of regional conferences.

For more information, please visit the GSMA corporate website at **www.gsma.com.**

Follow the GSMA on Twitter: **@GSMA.**

TMG is a consulting firm specializing in the information and communication technologies (ICT) sector. For over 25 years, TMG has assisted public and private sector entities around the world on ICT policy and regulatory matters. Our team focuses on providing insight and developing strategies to assist clients on technology and market trends, the development mobile services; spectrum policy and management; broadband and ICT strategies; economic assessments and valuations, among other matters.

For more information, please visit **www.tmgtelecom.com.**

TMG wishes to thank Pantelis Koutroumpis, lead economist at the Oxford Martin School's Programme on Technological and Economic Change at the University of Oxford, Khuong Minh Vu, Associate Professor at the National University of Singapore, and Fernando Beltrán, Associate Professor with the Department of Information Systems and Operations Management at the University of Auckland Business School, for their helpful comments on this methodology.

Contents

1. Executive Summary

Mobile networks are an essential part of our everyday lives. They increase our working productivity, represent a central means of social interchange for our friends and family, assist in the management of our homes and businesses, enable financial transactions, and even facilitate how we manage our healthcare.

The global impact of 4G brought about increases in mobile usage and network performance. 5G will build on this momentum, bringing substantial network improvements, including higher connection speeds, mobility and capacity, as well as low-latency capabilities. In doing so, it enables new use cases and applications that will positively impact different industry sectors.

Spectrum plays a critical role in realising the full extent of these new capabilities. Thus, 5G's full socio-economic impact is dependent on access to a variety of spectrum resources, including millimetre wave (mmWave) bands between 24 GHz and 86 GHz. The mmWave spectrum allows for the increases in bandwidth and capacity that numerous 5G applications require. It will play a key role in meeting the demand for many enhanced mobile data services as well as new wireless broadband use cases such as remote object manipulation, industrial automation, virtual and augmented reality and next-generation connectivity for vehicles. These use cases will continue to increase the impact that mobile services have on societies and economies.

While the socio-economic benefits of mobile services and broadband connectivity have been studied for some time, quantifying the impact of high-capacity mmWave spectrum represents a new opportunity. To date, some of the mmWave bands have been made available for mobile services in some countries. Bands between 24 and 86 GHz are also under evaluation and will be considered for identification for International Mobile Telecommunications (IMT) at the ITU World Radiocommunication Conference in 2019 (WRC-19) in order to support 5G network development. The lengthy process to move spectrum from WRC agenda item to the day it is actually assigned underscores the need for all administrations to consider 5G spectrum needs now, especially in mmWave bands.

This emphasises the importance of a mmWave specific analysis, supporting the timely actions that administrations should take in order to realise the many opportunities afforded by 5G in the future. As such, this study leverages the wide variety of research done to date on the expected benefits of mobile broadband, the implementation of 5G and the role of mmWave in that implementation. This is done to forecast the contribution to gross domestic product (GDP) and tax revenue that is expected by making mmWave bands available for the deployment of 5G applications.

Global impact

During the last decade, numerous studies have focused on quantifying the socio-economic benefits of mobile broadband and 5G technologies on local, national, and regional economies. This study focuses on the impacts of making mmWave bands available for 5G.

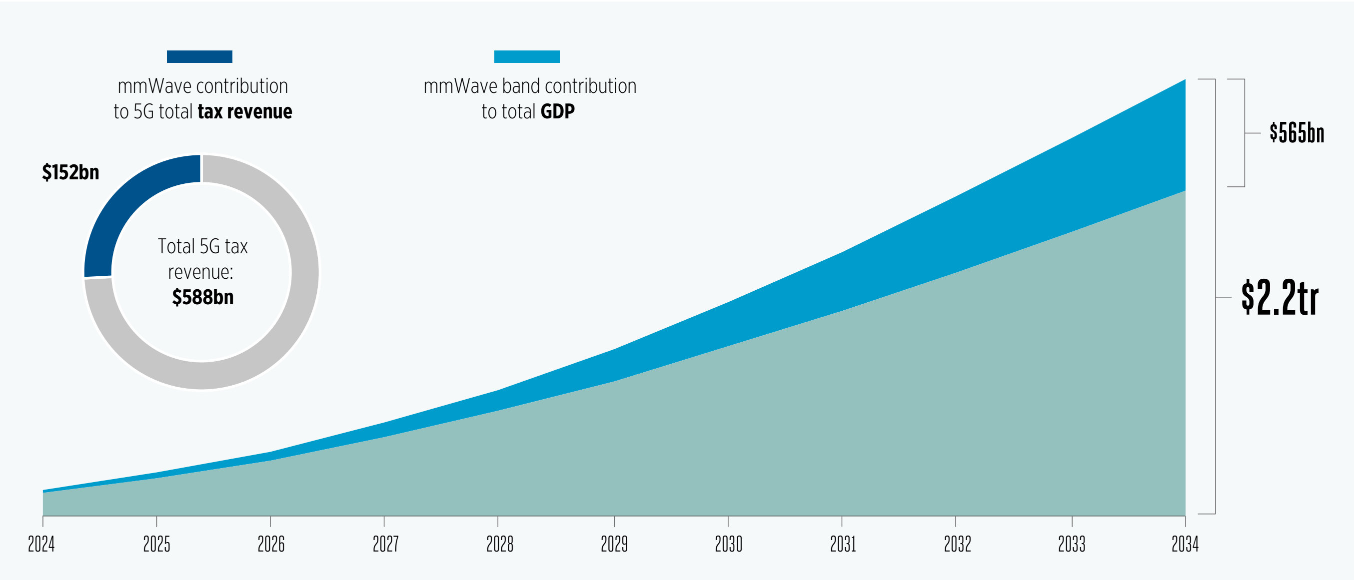
The economic impacts of mmWave spectrum are quantified over a 15-year period, 2020-2034, assuming mmWave bands are successfully identified at WRC-19 and made available in a timely manner at the national level.

The results of this study support three key findings:

- 5G is expected to provide important economic benefits globally,
- mmWave spectrum will grow to become a significant piece of this impact over time, and
- Although economic benefits are greater in the early adopting economies over the period studied, the rate of contribution of mmWave in later adopting economies outpaces that of early adopters in the later years of the study.

The study concludes, under conservative assumptions, that by 2034 mmWave spectrum will underlie an increase of $565 billion in global GDP and $152 billion in tax revenue, producing 25% of the value created by 5G (see Figure 1):

FIGURE 1. ESTIMATED IMPACT ATTRIBUTABLE TO MMWAVE SPECTRUM ON GDP AND TAX REVENUE



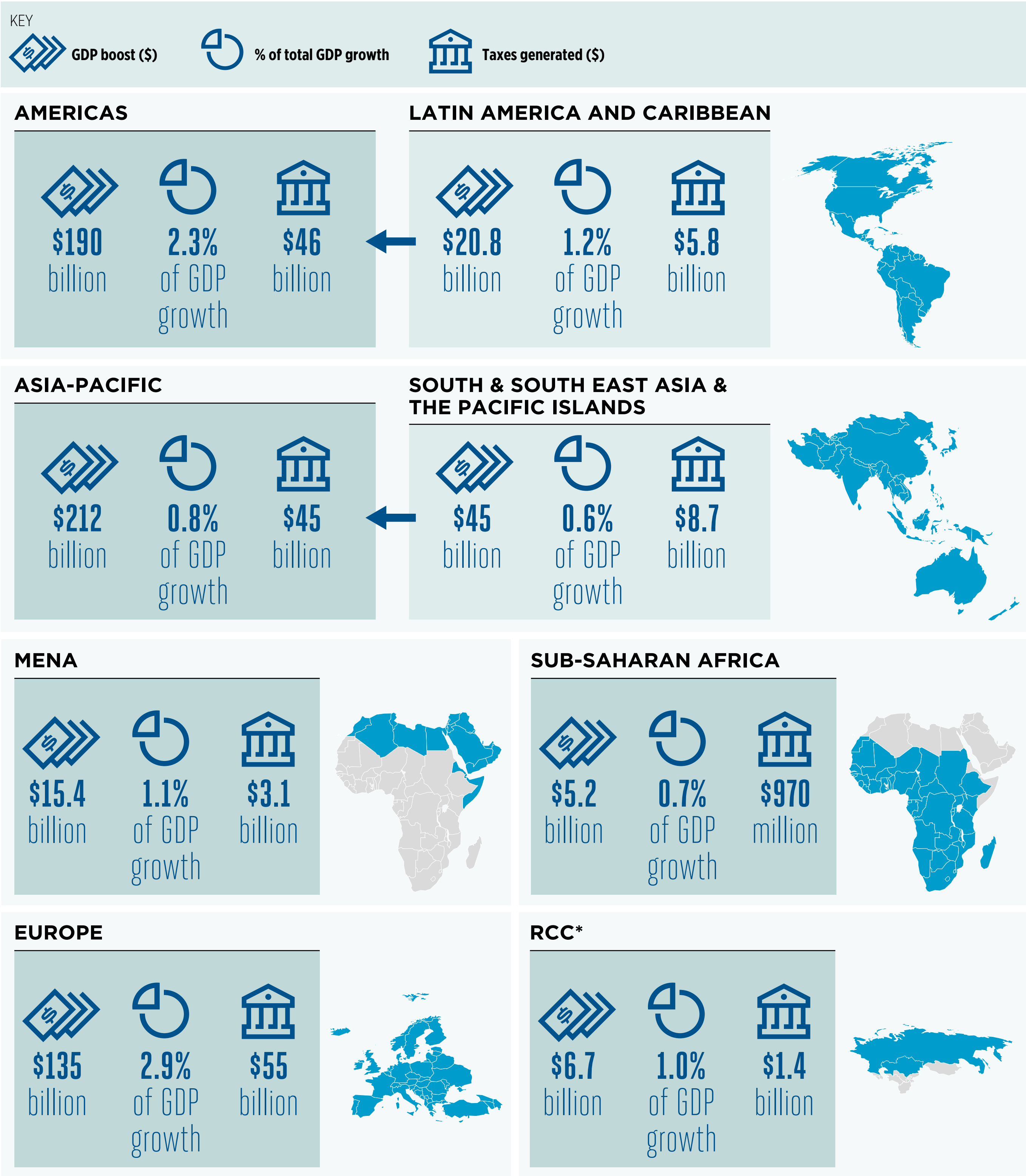
Source: TMG.

Regional breakdown

From a regional perspective, the study shows the following over the period 2020 to 2034 (see Figure 2 and Figure 4).

- The Asia-Pacific and Americas regions are expected to generate the greatest share of the total contribution of mmWave 5G to the GDP, $212 billion and $190 billion, respectively.
- One fifth ($45 billion) of the Asia-Pacific total ($212 billion) is the contribution made by the region after excluding early adopters China, Japan, the Republic of Korea, Australia and New Zealand.
- In the Americas region, a tenth ($20.8 billion) of the total ($190 billion) is contributed by the Latin-American and Caribbean countries.
- Europe has the highest percentage of GDP growth attributable to mmWave 5G than any other region (2.9%).
- The Americas region generates the second highest percentage of GDP growth attributable to mmWave 5G (2.3%).
- Once 5G has taken off in regions such as Sub-Saharan Africa, the annual gain from mmWave 5G will grow much faster from 2026 onwards, closing the gap between the early and late adopters.

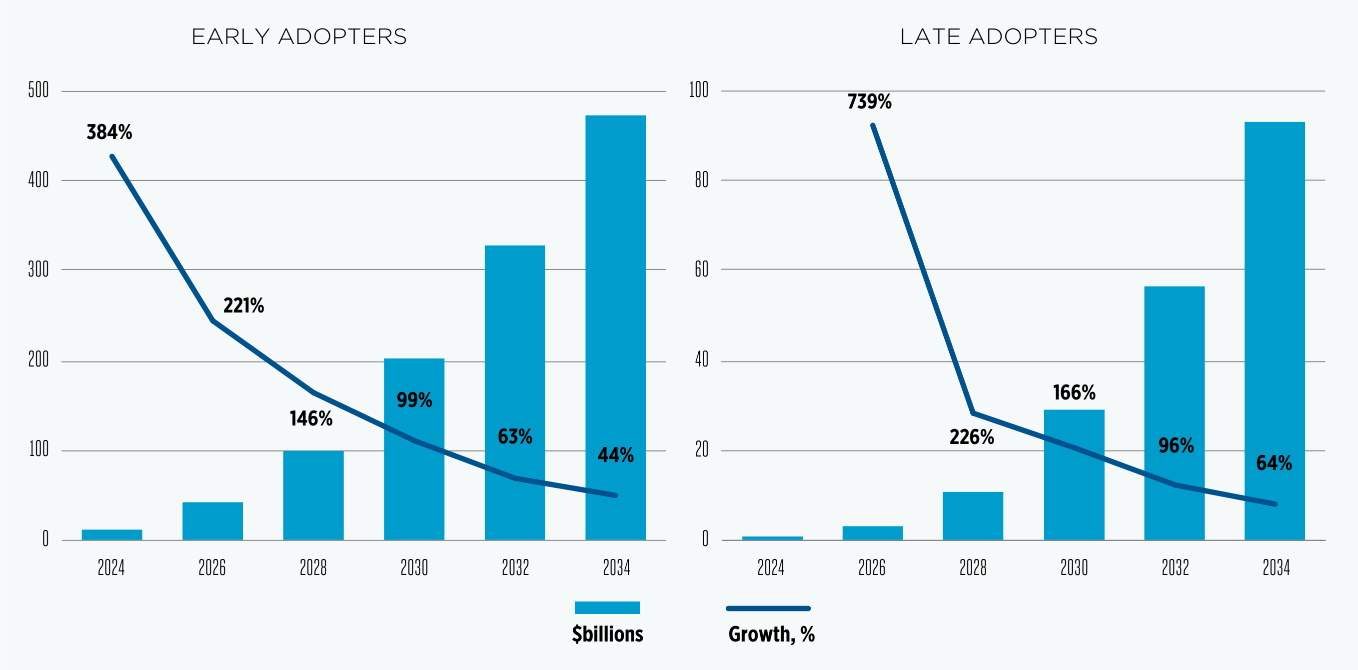
FIGURE 2. PROJECTED REGIONAL IMPACT OF MMWAVE SPECTRUM BY 2034



Source: TMG.
(*) Regional Commonwealth in the field of Communications, which includes eleven countries from the former Soviet Union.

While the greater share of the mmWave 5G contribution to GDP growth comes from larger economies, the economies that are adopting 5G at a later stage also have much to gain from backing mmWave bands for mobile. By 2034, the 5G ecosystem will have matured in terms of availability of equipment, deployment costs, and business case viability. These later adopters outperform the early adopters in terms of rate of growth in the later stage of the study period (see Figure 3).

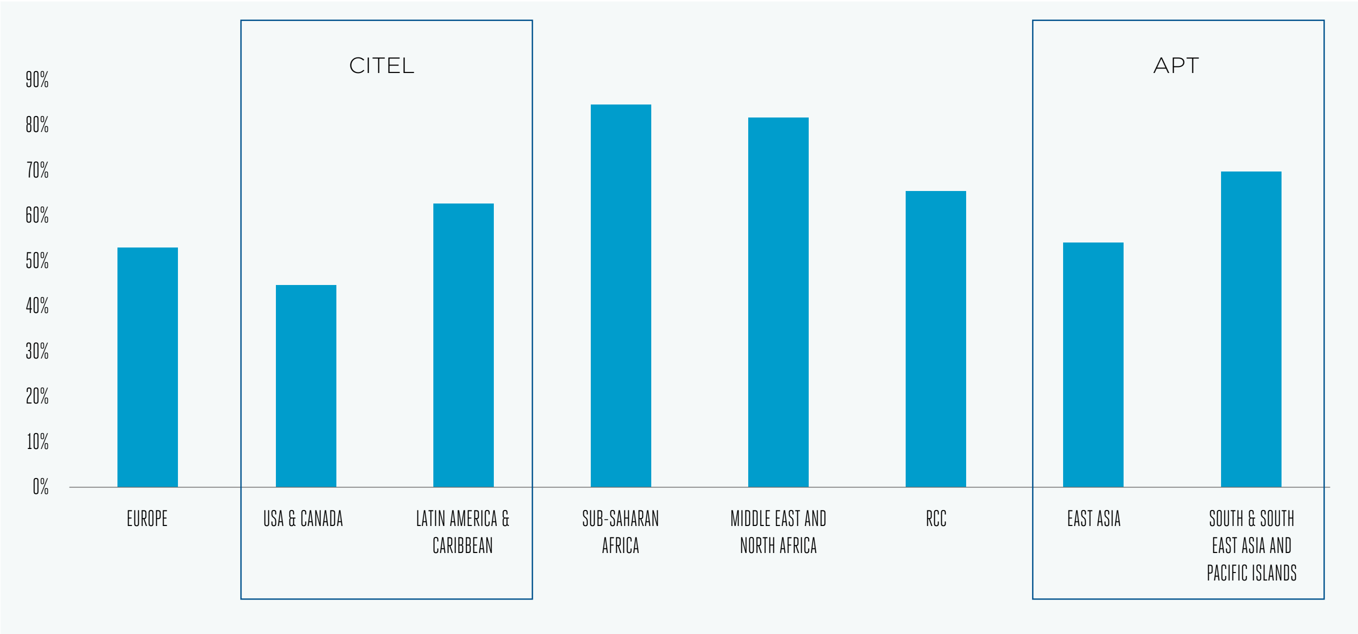
FIGURE 3. MMWAVE CONTRIBUTION TO GDP, FROM 2024-2034



Source: TMG

Figure 4 below shows this effect by region. Over the 2024-2034 period, the average annual growth in contribution of mmWave 5G to GDP is over 80% in Sub-Saharan Africa versus 53% in Europe.

FIGURE 4. ANNUAL AVERAGE GROWTH IN 5G-MMWAVE CONTRIBUTION TO GDP, 2024-2034



Source: TMG

Like previous generations of mobile technology, 5G has an impact on the daily lives of people, irrespective of where they live, in a number of different ways. However, not all of these benefits are reflected in GDP. According to the different use cases and verticals, additional potential benefits include increased access and availability to more advanced healthcare and education; reduced pollution and increased efficiency in transportation; and enhanced public safety response capabilities (see Figure 5).

FIGURE 5. ADDITIONAL BENEFITS OF MMWAVE 5G

Source: TMG

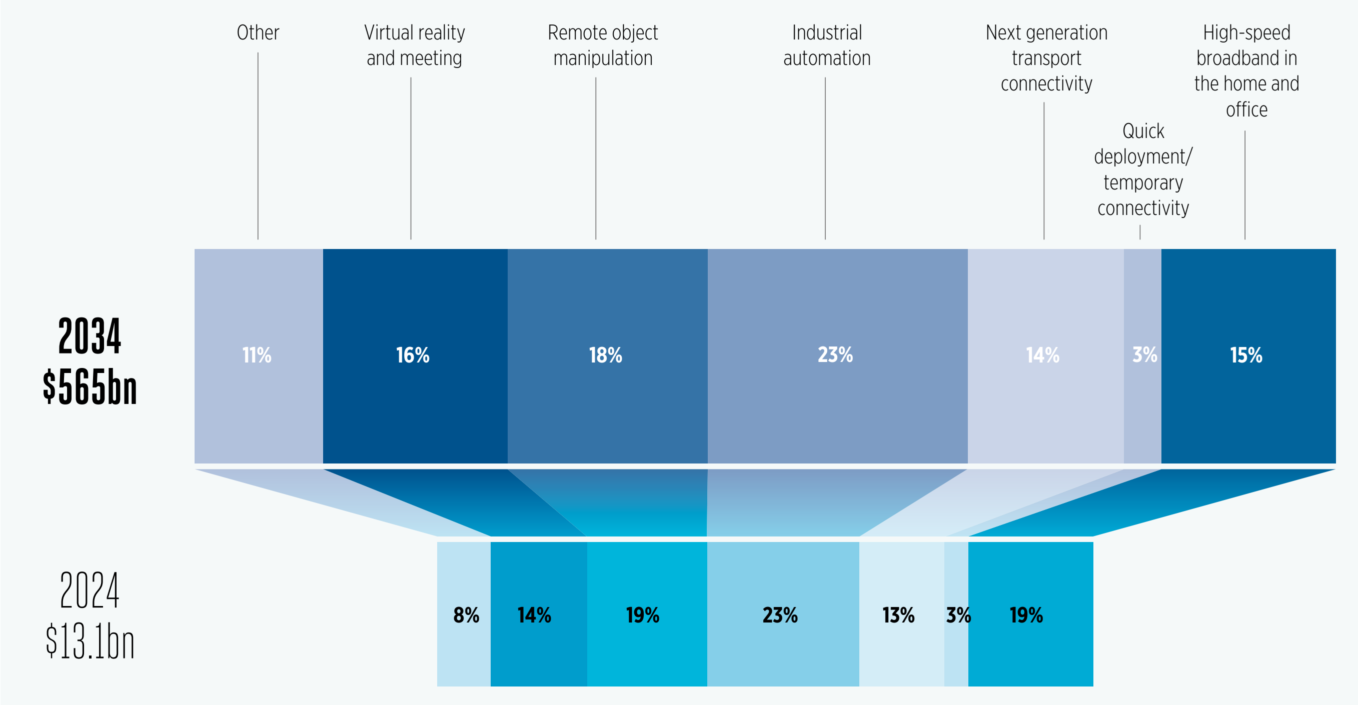
Use cases and industry verticals

In our personal and work lives, several use cases are likely to be the chief beneficiaries of mmWave 5G and will generate more value. These use cases generally require a large amount of data throughput in a small coverage area or face scarcity of spectrum in lower frequency bands.

To highlight the growth attributable to use cases and verticals, the study focuses on two key years: 2024, the year when 5G is expected to begin displaying a measurable impact on growth; and 2034, the final year of the study. Globally, remote object manipulation, industrial automation and virtual reality and meeting applications are expected to account for over 50% of the mmWave 5G contribution to GDP (see Figure 6). Over time, next-generation connectivity gains an increasing share.

The global impact of mmWave grows from $13.1 billion in 2024 to $565 billion in 2034. Remote object manipulation and industrial automation represent the biggest contributors to global output at both ends of the study period. The relative value of the use cases is anticipated to remain mostly stable over the ten-year period, with mmWave spectrum increasing its relative value in transport, the virtual space and other use cases as more sophisticated applications are introduced.

FIGURE 6. PROJECTED GLOBAL CONTRIBUTION OF MMWAVE SPECTRUM TO GDP BY USE CASE



Source: TMG.

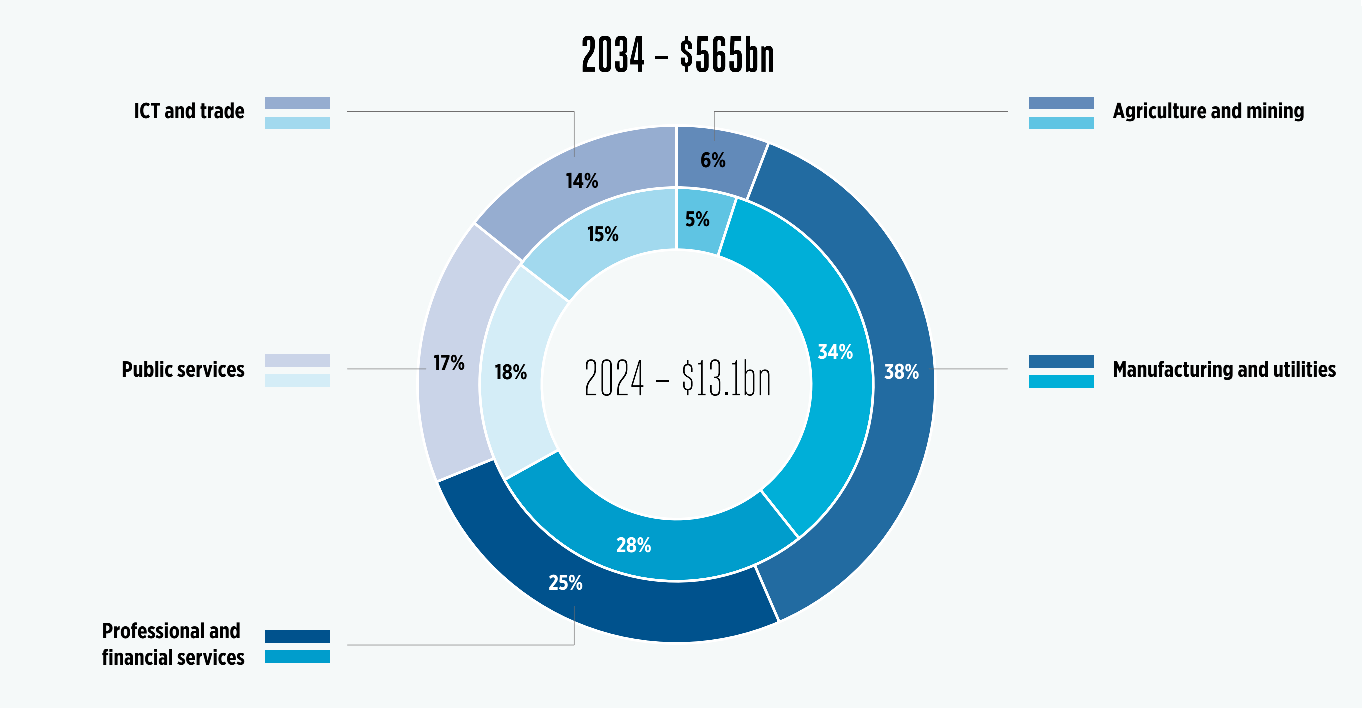
The growth in any particular vertical builds upon the diffusion and expansion of 5G through new and existing use cases. The study estimates the impact of mmWave 5G on 13 verticals of the economy, which are consolidated, for presentation purposes, into five sectors: manufacturing and utilities; professional and financial services; public services; ICT and trade; and agriculture and mining.

Within the five sectors, manufacturing and utilities is expected to be the largest beneficiary of 5G services which make use of mmWave spectrum. Contributions from manufacturing and utilities are projected to increase over the period 2024-2034. This is primarily due to two factors:

1. **The relatively large size of the sector in the global economy; and**
2. **The strong role expected to be played by industrial automation and remote object manipulation in this sector.**

Agriculture and mining are expected to represent the smallest share of growth (see Figure 7).

FIGURE 7. ESTIMATED GLOBAL CONTRIBUTION OF MMWAVE BANDS ON GDP BY SECTOR



Source: TMG.

Recommendations

The key findings of this study show that, by 2034, 5G can be expected to generate $2.2 trillion in GDP, and $588 billion in tax revenue, with an increasing share of this benefit related to mmWave spectrum. Beyond the measurable impacts of mmWave 5G technology and services, numerous other benefits are expected, including improved access to healthcare and education, increased public security and response times, safer driving conditions, and reduced pollution, among others. In order to realise the potential benefits analysed in this study, countries should plan accordingly for the timely availability of spectrum for mobile services, considering they are a key factor for their adequate deployment. Furthermore, the significant socio-economic benefits found by this study underscore the importance of mmWave spectrum for the development of the overall 5G ecosystem.

In this context, the consideration of a number of mmWave bands at the upcoming WRC-19 is a critical opportunity to identify this spectrum for IMT, helping 5G meet its full potential irrespective of where users are located and what mmWave-powered applications and services they want to use. It is recommended that governments take the following actions:

- Review and support the different conditions and proposals for WRC-19 related to 5G, particularly the recommendation to identify the 26 GHz, 40 GHz and 66-71 GHz bands for IMT.
- Support the regional and global process for the harmonisation of the use of these different bands, with due consideration for their frequency arrangements and minimum block sizes.
- Review the national regulatory frameworks with the goal of allowing these bands to be deployed within the country.
- Assign adequate amount of mmWave spectrum to operators, avoiding inflating 5G spectrum prices to allow for heavy network investments and continuous reduction of cost of devices.
- Aim to make available 80-100 MHz of contiguous spectrum per operator in prime 5G mid-bands (e.g. 3.5 GHz) and around 1 GHz per operator in millimetre wave bands (i.e. above 24 GHz).

2. 5G Spectrum Background

An understanding of the overall spectrum requirements for 5G services and applications is important because it helps set the stage for why mmWave bands are key to the future of 5G and how the benefits they bring can be realised.

5G spectrum bands

5G needs a variety of spectrum bands to support a wide range of applications and services, including mmWave bands. For the purposes of this study, the spectrum deployed for mobile services can be grouped into two broad categories: sub-6 GHz bands and above-24 GHz, or mmWave bands. Each has a different role to play in the overall 5G ecosystem (see Figure 8).

FIGURE 8. COMPARISON OF CHARACTERISTICS OF DIFFERENT 5G SPECTRUM BANDS

SUB-6 GHz BANDS	MMWAVE BANDS
Heavy incumbent use	Spectrum relatively available due to light incumbent use
Large contiguous blocks of spectrum may not be available	More contiguous blocks of spectrum available = Additional capacity
Lower throughput per Hz	Higher throughput per Hz
Wide coverage area	Small coverage area

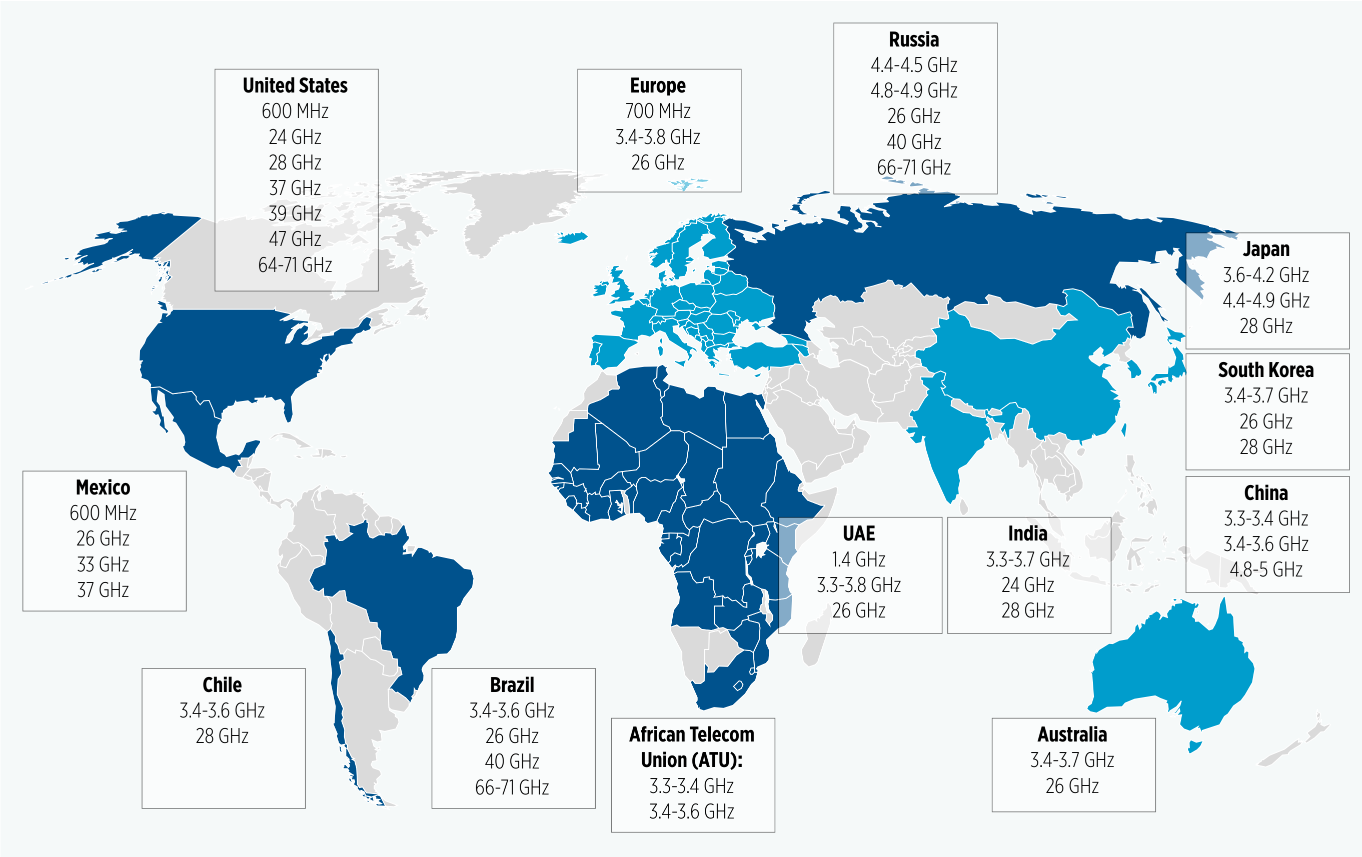
Source: TMG.

Over time, 5G is expected to use several different bands. Significant activity has already taken place in the 600 MHz, 700 MHz, and 3.5 GHz bands, for example. The latter is on its way to becoming a near-global 5G band.

Importantly, the range of spectrum from 24.25 to 86 GHz will be considered for IMT at WRC-19 in order to support the development of 5G networks. In the ITU process, the 26 GHz band (24.25-27.5 GHz) and the 40 GHz band (37-43.5 GHz) have received more attention and the greatest support for IMT identification. Interest is also growing to identify the 66-71 GHz range.

While the 28 GHz band is not included in the WRC-19 scope of work, it has emerged as a key 5G band due to its backing by some early-adopter countries. Japan, South Korea, India, Canada and the United States have already taken measures to assign it for mobile services. In the United States, the first commercial services using this band have already been launched. Figure 9 shows some of the priority bands being considered for 5G in select countries.

FIGURE 9. SUMMARY OF PRIORITY FREQUENCY BANDS FOR 5G IN SELECT COUNTRIES



Source: TMG.

International harmonisation

International coordination is essential to achieving widespread spectrum harmonisation for mobile services. Many benefits result from harmonising spectrum. First, spectrum harmonisation creates economies of scale by reducing deployment costs and making devices more affordable. Second, it helps deploy services into the market sooner. Third, it reduces cross-border interference and facilitates international roaming. Finally, the timely availability of spectrum for mobile services is a critical factor for adequate development of future technologies.

While variations among different countries' requirements for spectrum exist, the international process to make spectrum available is a long-term undertaking affecting all governments. As evidenced in the coordination processes for 3G and 4G spectrum, the ITU process is time-intensive. It takes years to study and agree on harmonised use and allocation of the bands, as well as additional time for national governments to adapt and adopt these bands into their national spectrum regulatory framework. An indicative timeline to complete this process is shown in Figure 10.

This lengthy process highlights the need for all administrations to consider their spectrum needs for 5G in the near term, especially in mmWave bands. Some countries are already adopting spectrum before harmonisation has taken place, further underscoring the urgency of considering 5G spectrum needs. Even if a country plans to award these bands at a later stage, action is required at WRC-19.

FIGURE 10. GENERAL TIMELINE FOR IDENTIFICATION OF IMT SPECTRUM

Source: TMG.

3. mmWave 5G Use Cases

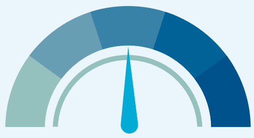
5G is not simply an access technology, which makes the estimation of its socio-economic benefits more complex. The progress of 5G roll outs will not be tracked by simply counting connections, as was the case with previous generations of mobile broadband. Most discussions regarding the role of 5G instead utilises a framework of use cases.[1] These use cases highlight either related applications that can be used in various economic activities or the enabling access technologies upon which such applications can operate.

The review of existing literature identified 14 key 5G use cases that are likely to be the most relevant based on their anticipated socio-economic benefits on the economy. To isolate the impact of mmWave spectrum specifically, a subset of six use cases was identified as having a dependency on the availability of mmWave spectrum in order to reach its full potential. These use cases are outlined below, along with their dependence on mmWave spectrum and the potential qualitative benefits that each are expected to bring to society.[2]

High-speed broadband in the home and office

Definition: This use case refers to the provision of ultra-high-speed broadband connectivity to households and office buildings. While mobility is possible in this situation, most often it is used as a fixed wireless broadband service. This service may also provide fixed links, including for backhaul solutions. The speeds made possible by 5G technologies allow wireless broadband to compete with wired connections, providing fibre-like user experiences. This is the main use case being considered in initial 5G commercial deployments.

Dependency on mmWave: While the offering of high-speed mobile broadband in the home and office is possible in other frequency ranges, it is highly dependent on mmWave due to its ability to utilise available blocks of contiguous spectrum to provide high-capacity service. The decrease in cost per Mbps resulting from the increased spectral efficiency will enable a wide variety of new business models such as portable home/office connections. Fixed fibre solutions are alternate technologies that could also provide similar speeds, but at higher costs. Areas without fibre deployments may benefit even more from this wireless alternative.



Potential societal benefits of high-speed broadband in the home and office applications

There are many potential applications in healthcare and education that are enabled by the provision of high-speed broadband. In healthcare, expanding remote treatment opportunities and using data analysis from wearables to drive better research and increasingly personalized treatment plans can increase access to and quality of healthcare. The provision of high-speed broadband is also expected to increase access to and quality of education, especially in cases where online learning opportunities are a better alternative to local classes, or where students were previously unable to access education.

1. ITU's IMT Vision outlined in Recommendation ITU-R M.2083 describes different new features these networks should fulfil, captured under three main usage scenarios: enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive machine type communications (mMTC or mIoT). This is further indication that 5G is expected to provide more enhanced capabilities than previous generations.

Quick deployment/temporary connectivity

Definition: This use case encompasses applications related to the provision of increased broadband capacity in certain ad-hoc circumstances. These could be special events, including one-way distribution of multimedia content or, in cases of disasters, the maintenance of mobile communication while an incapacitated network is being restored. This case relates to the provision of non-stationary and dynamic capacity to respond in real-time to demand at specific locations. These applications are expected to be used by public telecommunications operators and first responder organizations.

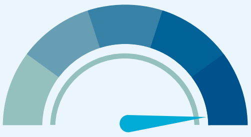
Dependency on mmWave: This case can be implemented in lower frequency bands, but benefits significantly from the increase in capacity provided by mmWave spectrum, as well as the decrease in cost per Mbps due to its higher spectral efficiency. Transmission of live events and disaster response efforts require high-speed and low-latency communications. Additionally, the transmission of multimedia content to several users in a targeted area requires high capacity. All of these are better accomplished with the use of mmWave spectrum.

Potential societal benefits of quick deployment/temporary connectivity applications
This use case is likely to improve disaster response by supporting enhanced, secure, mission-critical communications, as well as providing network capacity to support connected ambulances and unmanned ground and/or aerial vehicles. Additionally, it is also predicted to increase safety by maintaining network coverage in heavily trafficked areas—such as during emergencies where there are many outgoing calls in dense areas, and extending service to out-of-coverage areas by leveraging device-to-device connectivity in cases of infrastructure failure.

Industrial automation

Definition: This refers to the use of 5G networks to provide communications between devices and/or machines. It may or may not include human interaction and is expected to replace and enhance existing wired communications. Collaborative robots are included under this use case, and will be enabled by artificial intelligence (AI). New possibilities for industrial automation are emerging, aiming to increase the efficiency of production lines. Human interaction with robots will likely be related to the management and maintenance of these systems.

Dependency on mmWave: Widespread implementation of industrial automation, especially automation processes requiring a high degree of precision, will benefit from the low-latency associated with mmWave availability. The significant amounts of data that each autonomous robot is expected to generate, as well as the density of these robots in confined areas, should also be supported by mmWave 5G.



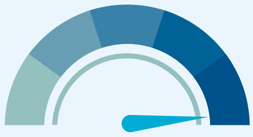
Potential societal benefits of industrial automation applications

This use case is anticipated to improve industrial production processes in a number of ways. First, industrial automation can enable various components of the production process to communicate wirelessly, thereby cutting down on outages and malfunctions. Additionally, the integration of high-speed imaging in machines can improve quality assurance and data collected by automated machines can be used to proactively prevent faults and modify processes. In the healthcare sector, the automation of objects such as smart syringes, supply cabinets, and hospital beds may lead to more efficient management of resources, and reduce the opportunities for errors in drug administration.

Remote object manipulation

Definition: This use case refers to the remote operation of different types of devices. This use case differs from the industrial automation use case as it involves a sophisticated interaction between the human operator and the equipment being used, instead of only machine-to-machine communication. Remote object manipulation often involves tasks requiring a high level of precision and allows operators to be in a completely different area from the device, thus supporting cases where certain services are unavailable or security applications where the setting is dangerous.

Dependency on mmWave: Given the low-latency and data rate requirements for this use case, mmWave band implementation is expected to play an important role. Most advanced applications of this use case are expected to need the best capabilities 5G can offer.



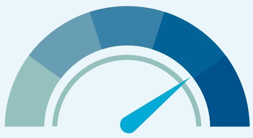
Potential societal benefits of remote object manipulation applications

In the healthcare sector, applications such as remote diagnosis and remote surgery may expand access and availability to healthcare by moving the care closer to patients and caregivers without requiring an in-person visit, especially in areas lacking local specialists. Additionally, the remote control of equipment and vehicles (including unmanned ground or aerial vehicles) is expected to increase safety by preventing human workers from operating machinery in dangerous situations, and providing first responders with new tools for reconnaissance and rescue in emergency situations.

Virtual reality and meeting

Definition: This use case refers to two groups of potential applications: virtual and augmented reality (VR/AR), and virtual meeting. Virtual reality is the experience of being virtually in another place (virtual reality), or having enhanced information on the actual environment (augmented reality).[3] Virtual meeting refers to next-generation videoconferencing or telepresence in which individuals can be virtually present by sending and receiving high-resolution details between two or more remote environments.

Dependency on mmWave: Given the latency and peak data rate requirements, mmWave developments are expected to play an important role in the mass adoption of virtual reality and meetings, inspections, and training. Educational applications of this use case will likely produce huge amounts of data (due to the decentralization of computing resources) that will be managed with the support of mmWave spectrum.



Potential societal benefits of virtual reality and meeting applications

Virtual reality and meeting applications allow skills usually taught in person, like fine motor skills, to be learned at a distance with the help of haptic feedback and high-speed broadband. Additionally, industrial/workplace education can improve worker safety by teaching skills used in dangerous situations in a safe VR/AR setting. Virtual applications are also predicted to improve production processes by enabling real-time high-quality assistance from remote experts supporting factories or construction sites to solve mechanical or technical issues, or by enabling virtual walk-throughs of buildings for architects and engineers.

3. Further discussion can be found in Orlosky, J., Kiyokawa, K. & Takemura, H. (2017). "Virtual and Augmented Reality on the 5G Highway," Journal of Information Processing, 25. 133-141. 10.2197/ipsjjip.25.133.

Next-generation transport connectivity

Definition: This use case includes two different types of transport connectivity: broadband access on transport and connected vehicles. These may apply both to public and private transportation networks. The first type of transport connectivity refers to the provision of ultra-high-speed broadband to end-users in moving vehicles or on public transport. The second group of applications included under this use case is associated with connected vehicles. This includes various types of direct vehicle communications (V2X), such as vehicle to vehicle (V2V), to pedestrians (V2P), to infrastructure (V2I), or to the network (V2N). Autonomous vehicles, for example, will depend heavily on reliable transport connectivity due to the high volume of data expected to be exchanged, such as in the use of high-definition maps and in communication with infrastructure for road conditions, among others.

Dependency on mmWave: Considering the need to address high data volumes and high-density real-time communications, this use case requires a combination of mmWave and lower bands to provide broadband and enhance data collection and safety, especially in urban scenarios. As such, in addition to the capabilities of mmWave, lower bands are required for long-range coverage and direct communications.

Potential societal benefits of next-generation transport connectivity applications

A number of societal benefits are expected from next-generation transport connectivity applications including increased mobility, shorter commute times, improved road safety, and reduced pollution. Autonomous driving could increase mobility for the elderly and disabled persons and improve road safety by limiting the potential for human error to cause accidents. Intelligent transportation systems that use data from connected vehicles and smart infrastructure could improve commute times and reduce pollution by optimizing pedestrian routes and public transportation. Additionally, autonomous vehicles or driving assistance for emergency responders could increase safety when driving in disaster areas or in hazardous terrain during rescue missions.

The different use cases underlie and structure the analysis of socio-economic benefits, both when considering the cases when mmWave spectrum is available for 5G networks and when it is not. For instance, the modelling of 5G adoption across the different regions considers the relevance of each use case by country type, considering existing technological readiness and demand. Additionally, the use cases are linked directly to sectors of the economy (also referred to as verticals), which facilitate a disaggregated view of the socio-economic benefits. Furthermore, the six use cases were key in highlighting the potential impact of mmWave spectrum in 5G networks. They do this by providing the means to estimate the lost benefit in the provision of mmWave-dependent services.

4. Economic Contribution of 5G and mmWave

During the last decade, numerous studies have focused on quantifying the socio-economic benefits of mobile broadband and 5G technologies on local, national, and regional economies. This study focuses on the impacts of making mmWave bands available for 5G. It draws on many of the conclusions from previous studies in order to forecast the benefits on economic activity, including GDP and tax collection. However, it is narrower than these other studies as it solely examines the impact of a particular enabler (mmWave) of a specific generation of broadband deployment and application (5G).

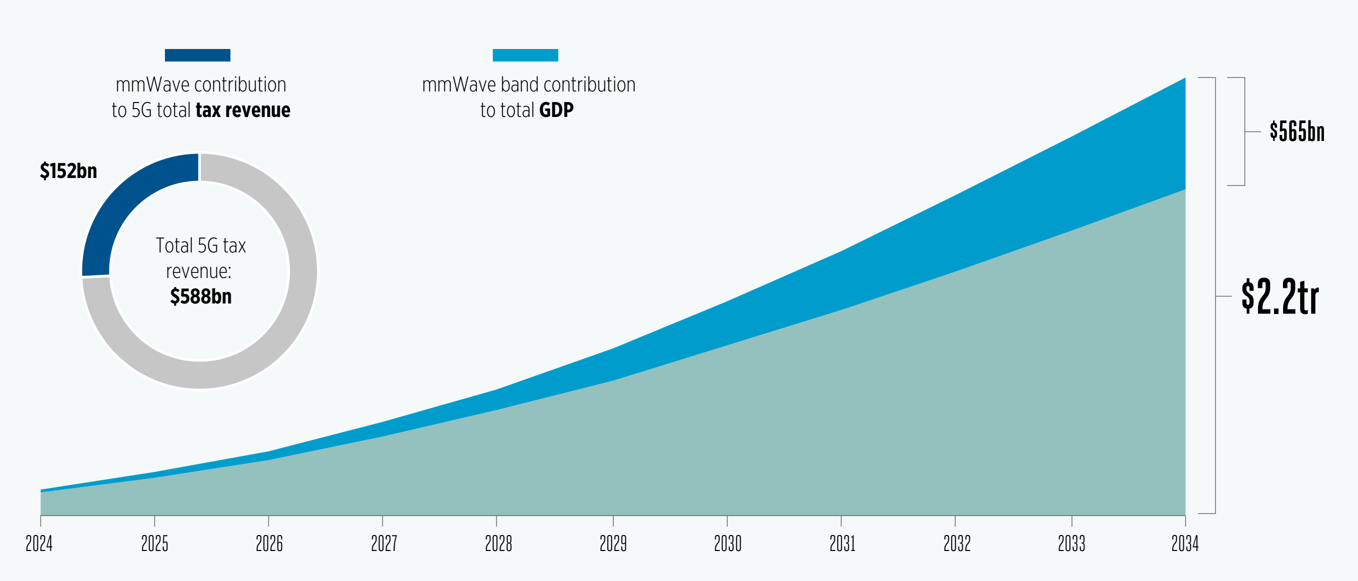
The results of this study support three key findings:

1. **5G is expected to provide important economic benefits globally,**
2. **mmWave spectrum will grow to become a significant piece of this impact over time, and**
3. **Although economic benefits are greater in the early adopting economies over the period studied, the rate of contribution of mmWave in later adopting economies outpaces that of early adopters in the later years of the study.**

Global results of 5G and mmWave 5G

This study estimates that 5G is expected to yield $2.2 trillion in GDP and $588 billion in tax revenue cumulatively over the period from 2020-2034. The mmWave 5G applications will make up an increasing proportion of the overall 5G contribution to global GDP, achieving around 25% of the cumulative total by 2034, which amounts to $565 billion in GDP and $152 billion in tax revenue (see Figure 11).

FIGURE 11. ESTIMATED IMPACT ATTRIBUTABLE TO MMWAVE ON GDP AND TAX



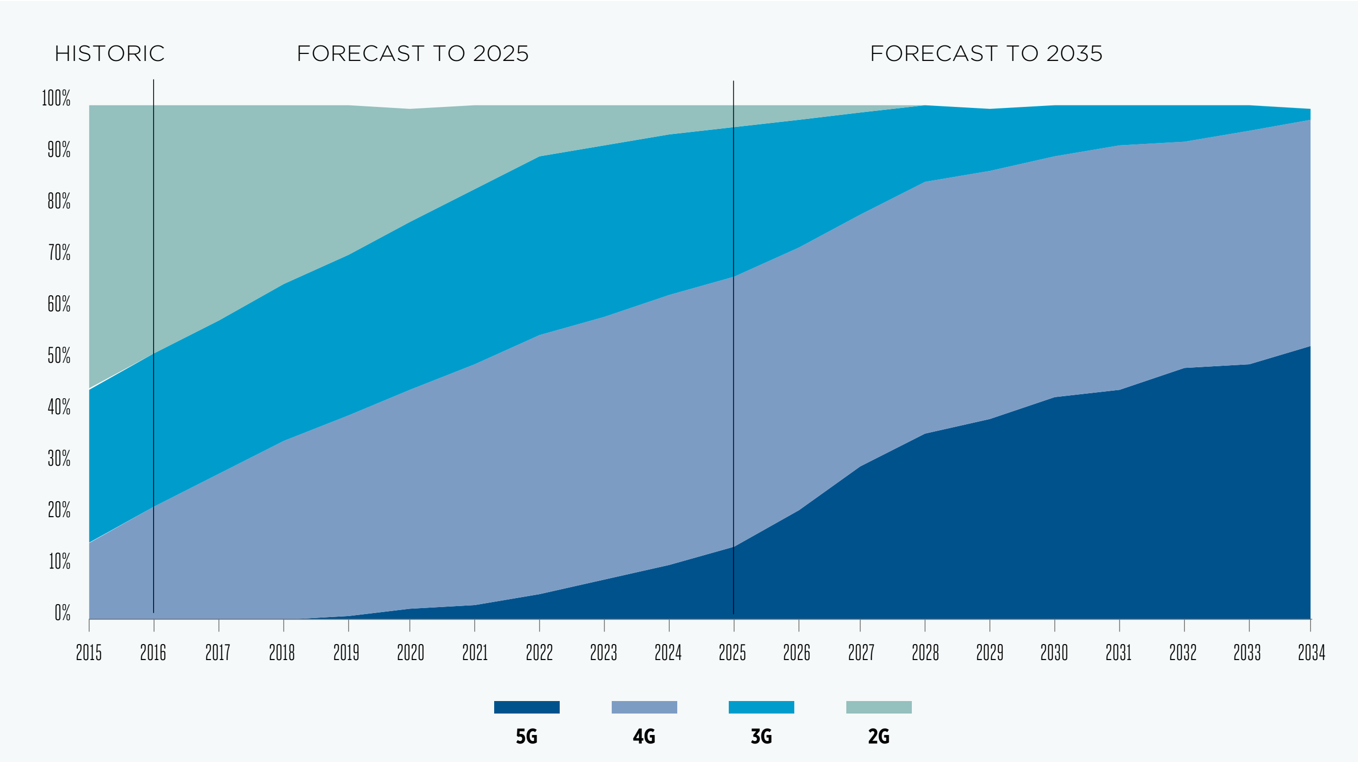
Source: TMG.

For any given economy, an important factor in determining the impact of 5G is the rate of adoption. Figure 12 presents a forecast for the global rate of roll outs for 5G over the period of study.

Globally, 5G mobile connections are expected to achieve between 40-50% of total connections by 2034.[4]

4. It should be noted that IoT devices will increase in relevance. A more comprehensive view of connections that would include such devices would significantly impact the shape of the adoption of 4G and 5G. However, this does not deny the wave-like pattern of adoption of generations of mobile broadband technologies – indeed of technological progress in general.

FIGURE 12. SHARES OF TOTAL MOBILE CONNECTIONS (EXCLUDING CELLULAR IOT), 2015-2034



Source: GSMA Intelligence (historic and forecast to 2025), TMG (forecast to 2034).

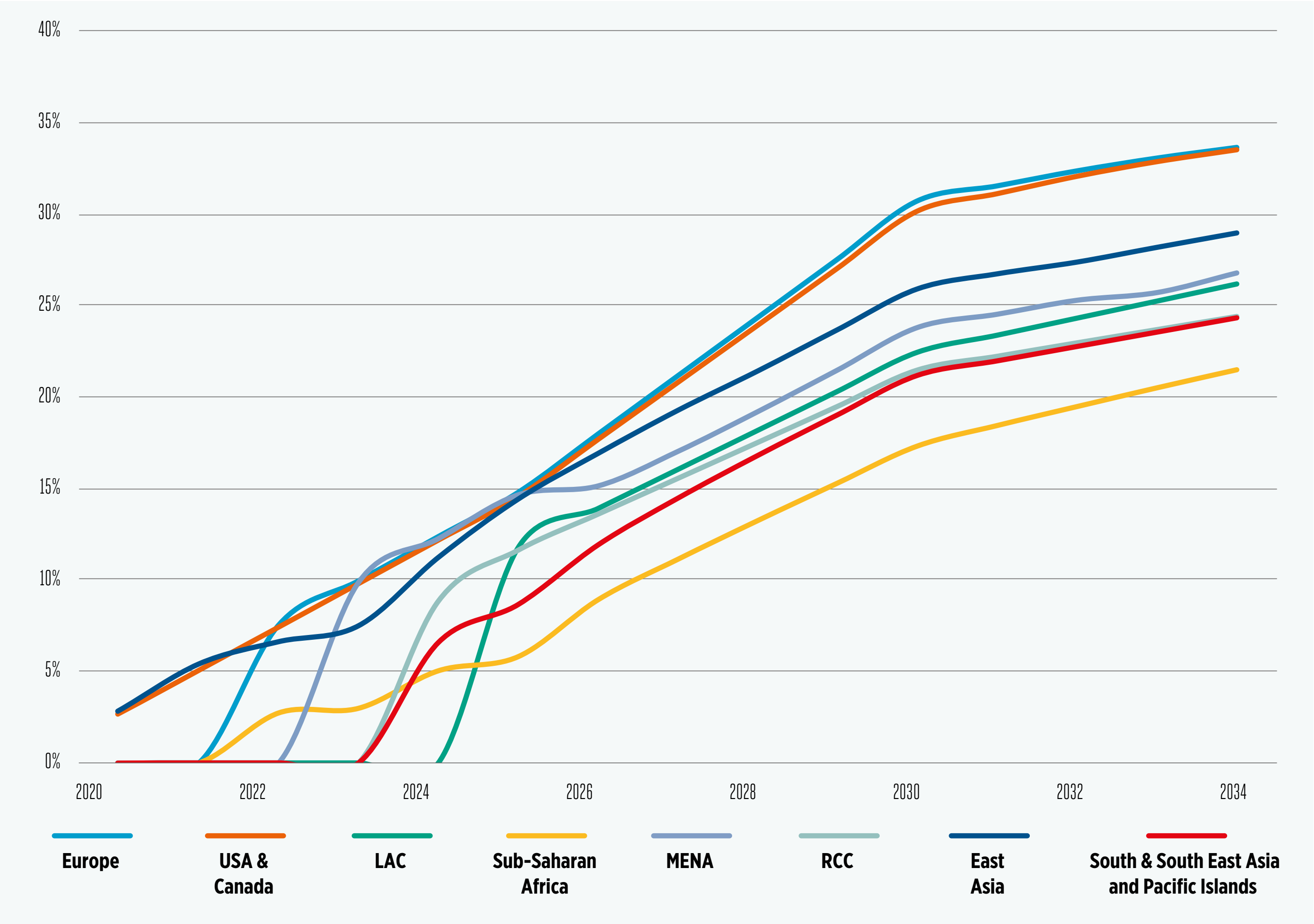
However, as mentioned above, 5G success will not be tracked by simply counting connections, as was the case with previous generations of mobile broadband. The rate of enablement of 5G and impact on an economy will be determined by:

- The evolution of technology supporting use cases;
- The readiness of an economy to adopt use cases; and
- The structure of the economy as use cases will have varying relevance to different verticals.

Figure 13 illustrates how all these factors influence the degree to which mmWave spectrum is expected to appear within the 5G service mix in different regions. It shows a forecast of the share of output attributable to 5G services that mmWave frequencies support, assuming spectrum is made available.[5]

5. The derivation of these forecasts is further discussed in Annex 3.

FIGURE 13. FORECASTED MMWAVE SHARE OF THE 5G SERVICE MARKET



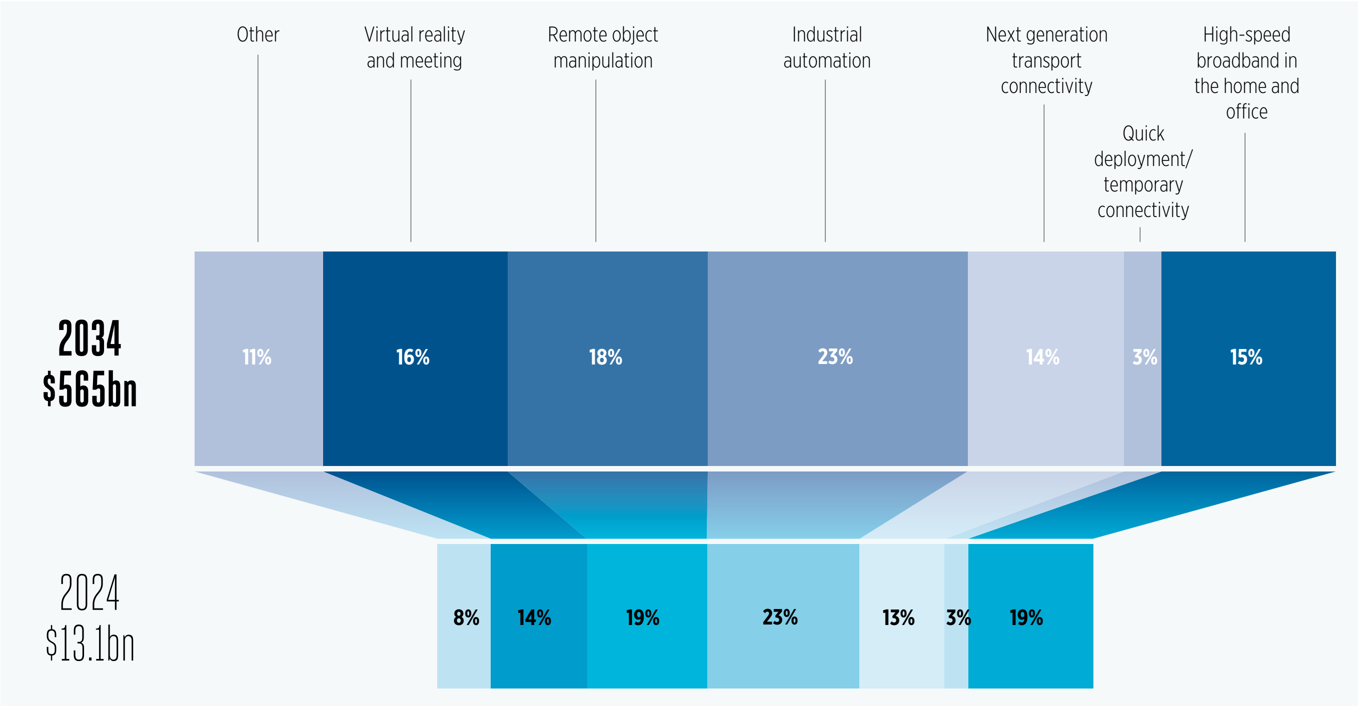
Source: TMG.

Global results by use case and vertical

As discussed earlier, how broadband technology is applied is particularly important when considering the economic impact of mmWave spectrum. The importance to GDP growth is a function of the dependence of particular use cases on the availability of this spectrum.

Globally, the relative value of the use cases is anticipated to remain relatively stable over time, with remote object manipulation and industrial automation being the biggest contributors to the output. Figure 14 illustrates how much each use case contributes to the global mmWave contribution to GDP.

FIGURE 14. DISTRIBUTION OF MMWAVE CONTRIBUTION TO GDP ACROSS USE CASES, IN 2024 AND 2034



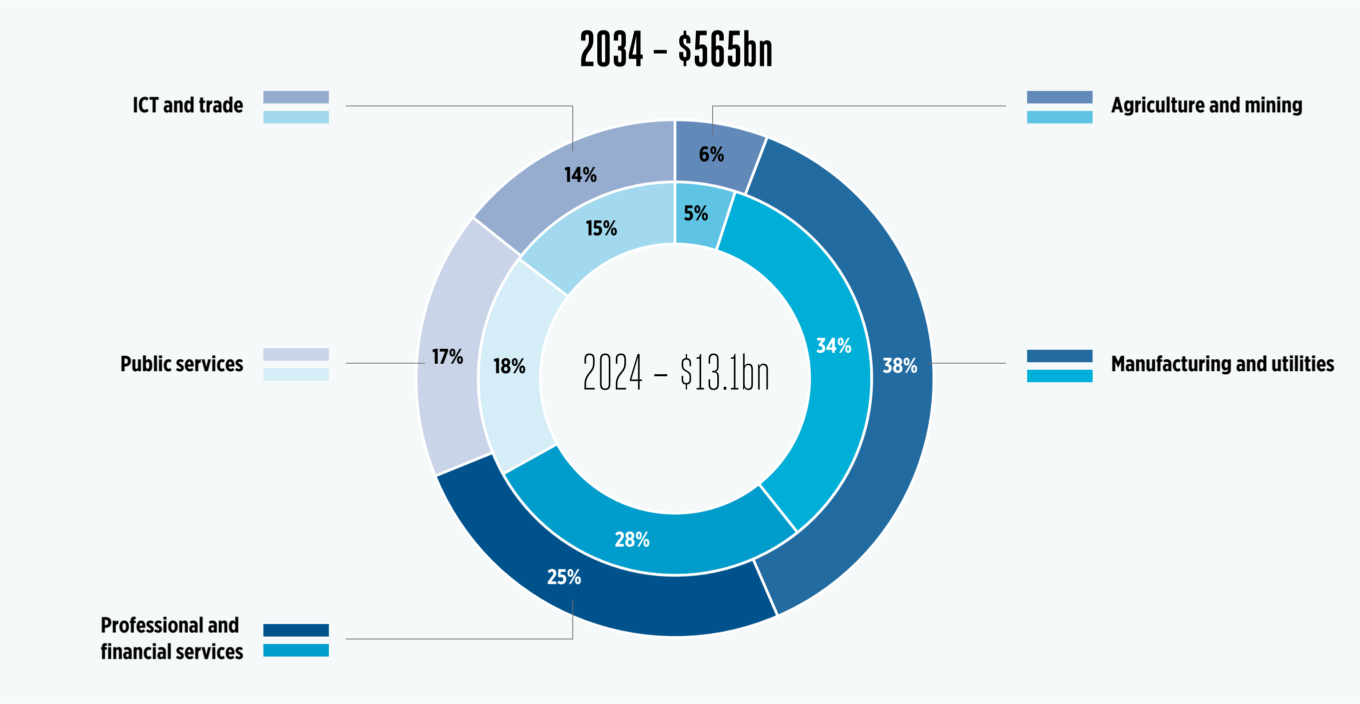
Source: GSMA Intelligence (historic and forecast to 2025), TMG (forecast to 2034).

These use cases reflect actual applications within verticals. Therefore, the forecasts of use case take-up lead to estimates of the contribution of mmWave 5G to GDP by vertical.

In order to present global forecasts, the verticals analysed were grouped into five sectors: (i) “agriculture and mining” composed of agriculture, forestry, fishing, mining and quarrying; (ii) “manufacturing” comprising manufacturing, utilities, construction and fossil fuel production; (iii) “professional services” covering professional and financial services; (iv) “public services” consisting of government, public services, education, health and social work; and (v) “ICT and trade” representing wholesale and retail trade, communications, and hospitality.

For contribution to GDP, as seen in Figure 15, the manufacturing, utilities and construction vertical is expected to become the chief beneficiary of mmWave spectrum usage. Its contribution to total GDP over the 10-year period is predicted to grow slightly to 38% of total vertical contribution. Professional and financial services, government, public services, education, health and social work, and wholesale and retail trade, communications and hospitality are expected to cumulatively provide over half of the contribution to global GDP both in 2024 and 2034. The agriculture and mining vertical are expected to provide the lowest contribution from mmWave 5G to global GDP. The contributions by vertical remain relatively stable over the period from 2024 to 2034.

FIGURE 15. DISTRIBUTION OF MMWAVE CONTRIBUTION TO GDP ACROSS SECTORS



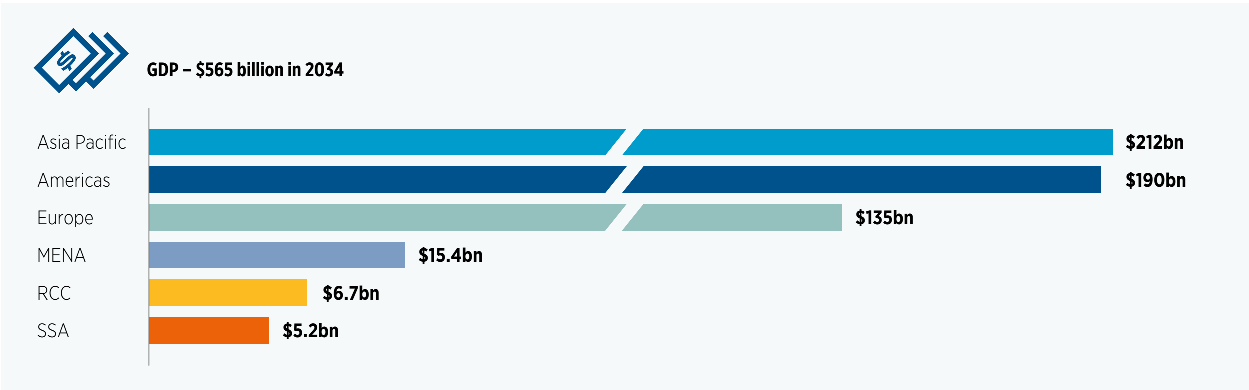
Source: TMG.

Regional results

The same key factors outlined earlier (the evolution of technology supporting use cases, the readiness of an economy to adopt use cases, the structure of the economy and the reliance of use cases on mmWave spectrum) also bring out the regional differences in the overall economic impact. These four factors may differ on a country-by-country basis, leading to different projections for the impact forecasted for each region.

Figure 16 presents the regional breakdown of GDP contribution of mmWave 5G services.[6] The Asia-Pacific, the Americas, and Europe contribute the most significant share of the total global contribution to GDP generated by mmWave 5G, followed by the Middle East and North Africa (MENA), the Regional Commonwealth in the field of Communications (RCC),[7] and Sub-Saharan Africa (SSA).

FIGURE 16. REGIONAL BREAKDOWN OF GDP CONTRIBUTION GENERATED BY MMWAVE 5G BY 2034



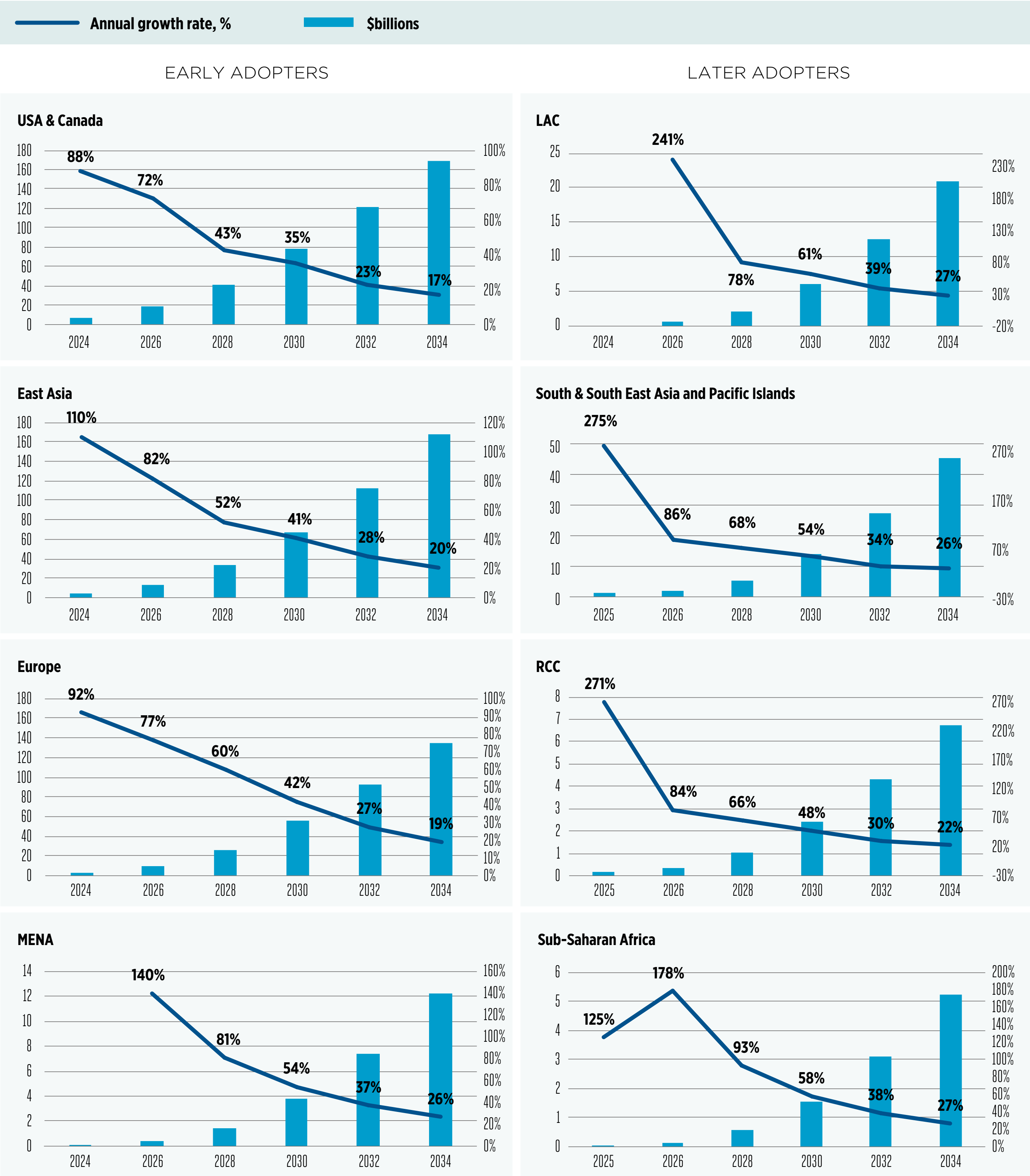
Source: TMG.

The larger economies comprise the lion's share of the mmWave 5G contributions to GDP growth. Still, the economies adopting 5G later in the study period are able to take advantage of a market that has matured in terms of availability of equipment, deployment costs, and business case viability. This group also outperforms the early adopters in terms of rate of growth in the later stage of the study period. Figure 17 shows the difference in growth rate from 2024 to 2034 for early adopter regions and those expected to adopt mmWave 5G later in the study period. Although MENA is included among early adopters in Figure 17, its results reflect a mix of early and later adopting countries.

6. Tax revenues generated follow uniformly from GDP in the modelling. More detail on tax results are given in Annex 2.

7. RCC includes eleven nations of the former Soviet Union: Azerbaijan Republic, Republic of Armenia, Republic of Belarus, Republic of Kazakhstan, Kyrgyz Republic, Republic of Moldova, Russian Federation, Republic of Tajikistan, Turkmenistan, Republic of Uzbekistan, Ukraine.

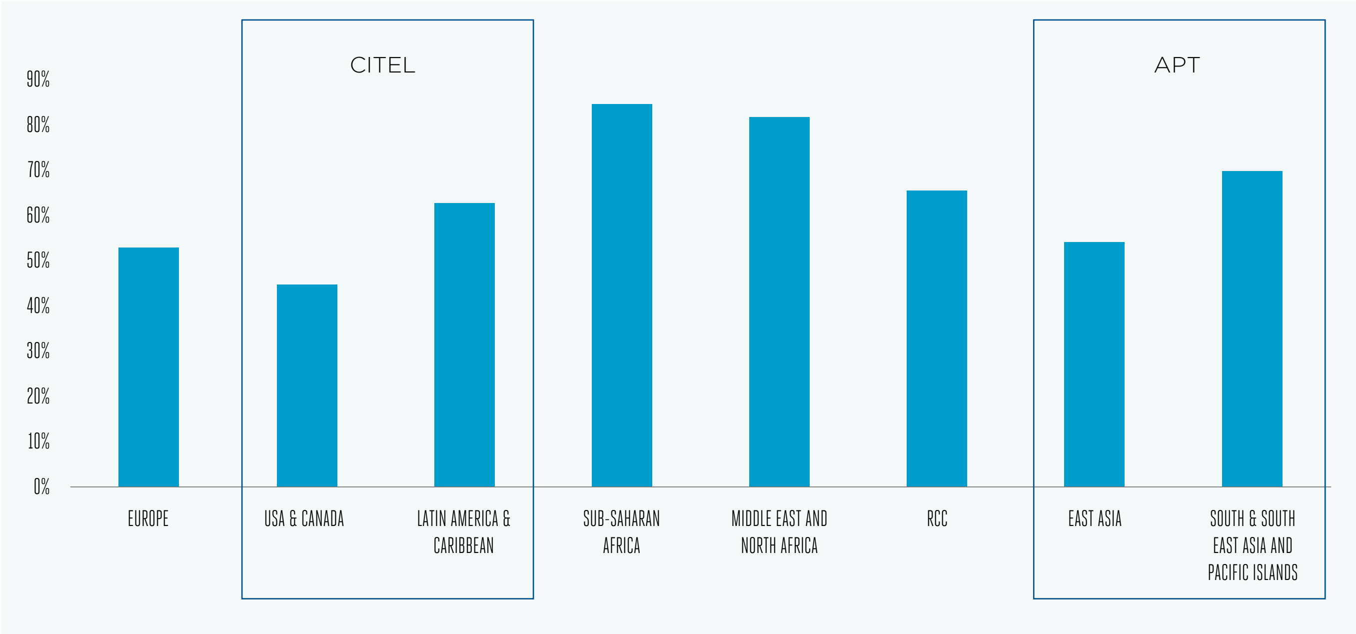
FIGURE 17. MMWAVE CONTRIBUTION TO GDP BY REGION, FROM 2024 TO 2034



Source: TMG.

Figure 18 shows the average effect by region. Over the 2024-2034 period, the average annual growth in the contribution of mmWave 5G to GDP is greater than 80% in Sub-Saharan Africa versus 53% in Europe.

FIGURE 18. ANNUAL AVERAGE GROWTH IN 5G-MMWAVE CONTRIBUTION TO GDP, 2023-2034

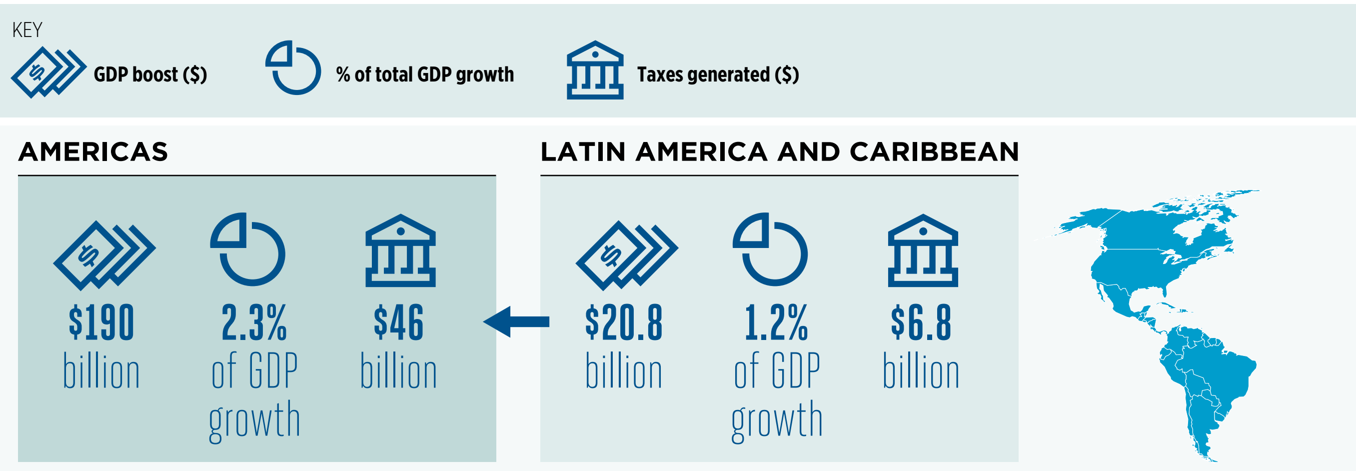


Source: TMG.

Americas

The Americas region is a large, diverse market. As the region's largest economy, the United States shapes the 5G market. Therefore, the specific benefits of the Latin American and Caribbean (LAC) region within the overall Americas region are separated. LAC is expected to contribute $20.8 billion out of the overall region's contribution of $190 billion to GDP as a result of mmWave 5G technologies (see Figure 19). The overall taxes collected represent around 24% of total output of the Americas, with taxes in LAC being significantly higher at 32% of its total output.

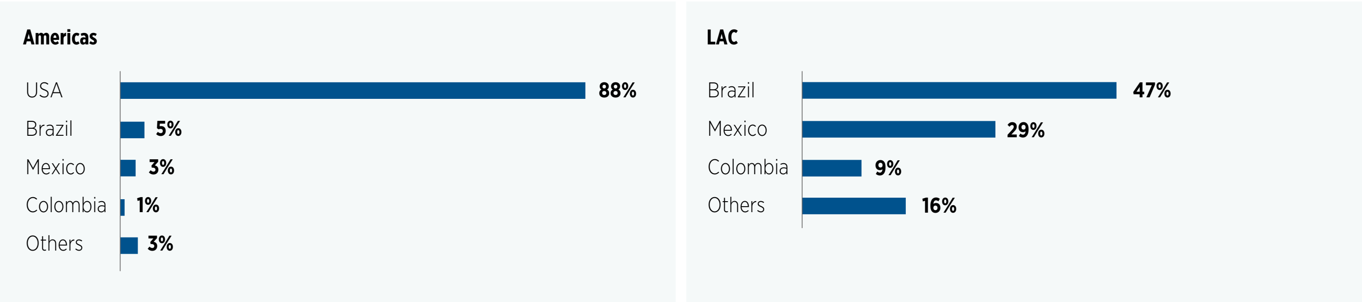
FIGURE 19. ECONOMIC RESULTS FOR THE AMERICAS AND LAC, 2034



Source: TMG.

Additionally, as shown in Figure 20, the United States is predicted to contribute 88% of the region's overall contribution to GDP from mmWave 5G. When looking at the LAC contribution of $20.8 billion in particular, Brazil and Mexico are expected to contribute 47% and 29%, respectively.

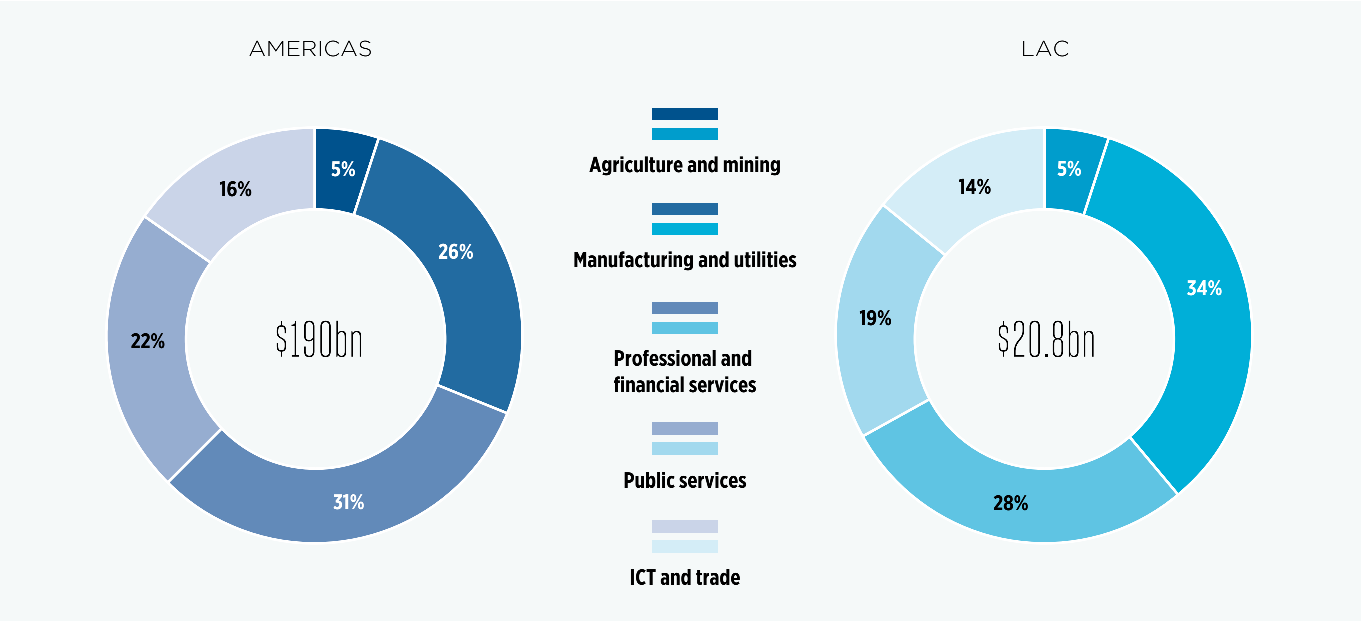
FIGURE 20. STRUCTURE OF GDP CONTRIBUTIONS TO AMERICAS REGION AS A WHOLE VERSUS LAC, 2034



Source: TMG.

In breaking these results down by industry, a fairly even split results across the manufacturing and utilities, professional and financial services and public services sectors. All three sectors are expected to each provide more than a quarter of the region's overall $190 billion contribution to GDP as a result of mmWave 5G (see Figure 21). Looking at the subset of LAC, the manufacturing and utilities sector contributes relatively more to GDP, whereas the professional and financial services sector and public services contribute slightly less than the Americas region as a whole.

FIGURE 21. STRUCTURE OF GDP CONTRIBUTIONS BY VERTICAL AMERICAS REGION AS A WHOLE VS. LATIN AMERICA, 2034

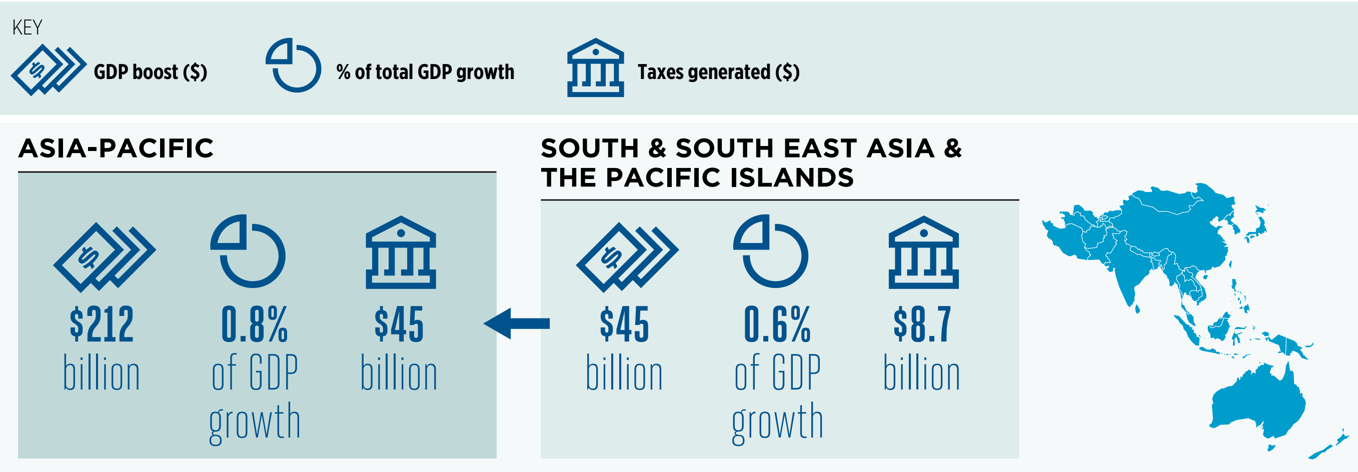


Source: TMG.

Asia-Pacific

Similar to the Americas, some regional players in the Asia-Pacific region are expected to have a particularly large influence on the nature of the economic benefits. In Figure 22, the economies of expected early adopters China, Japan, South Korea, Australia and New Zealand are shown to comprise approximately 80% of the region's contribution to GDP and taxes related to mmWave 5G. Overall, tax revenues represent more than 20% of the total GDP contribution related to mmWave of the region.

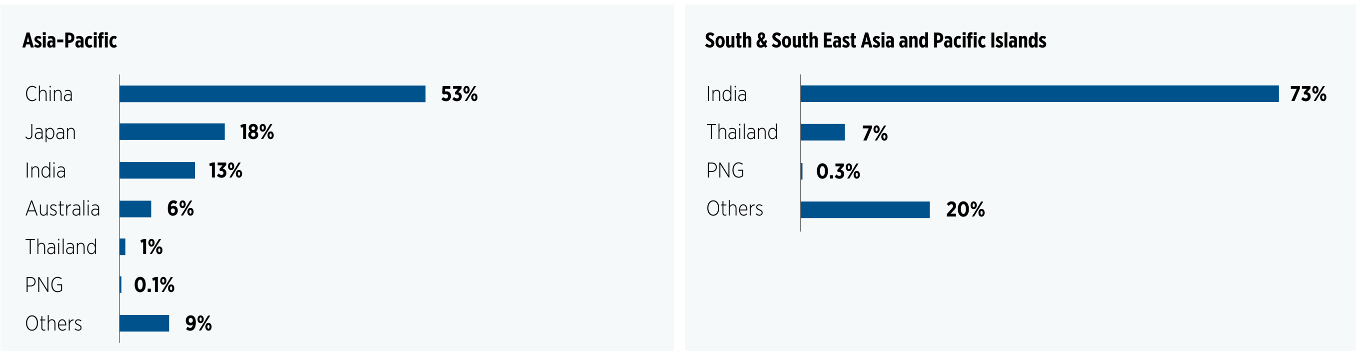
FIGURE 22. ECONOMIC RESULTS FOR THE ASIA-PACIFIC REGION AS A WHOLE AND SOUTH & SOUTH EAST ASIA AND PACIFIC ISLANDS, EXCLUDING CHINA, JAPAN, SOUTH KOREA, AUSTRALIA AND NEW ZEALAND, 2034



Source: TMG.

When excluding China, Japan, South Korea, Australia and New Zealand, India's significant contribution in the region is underscored (see Figure 23).

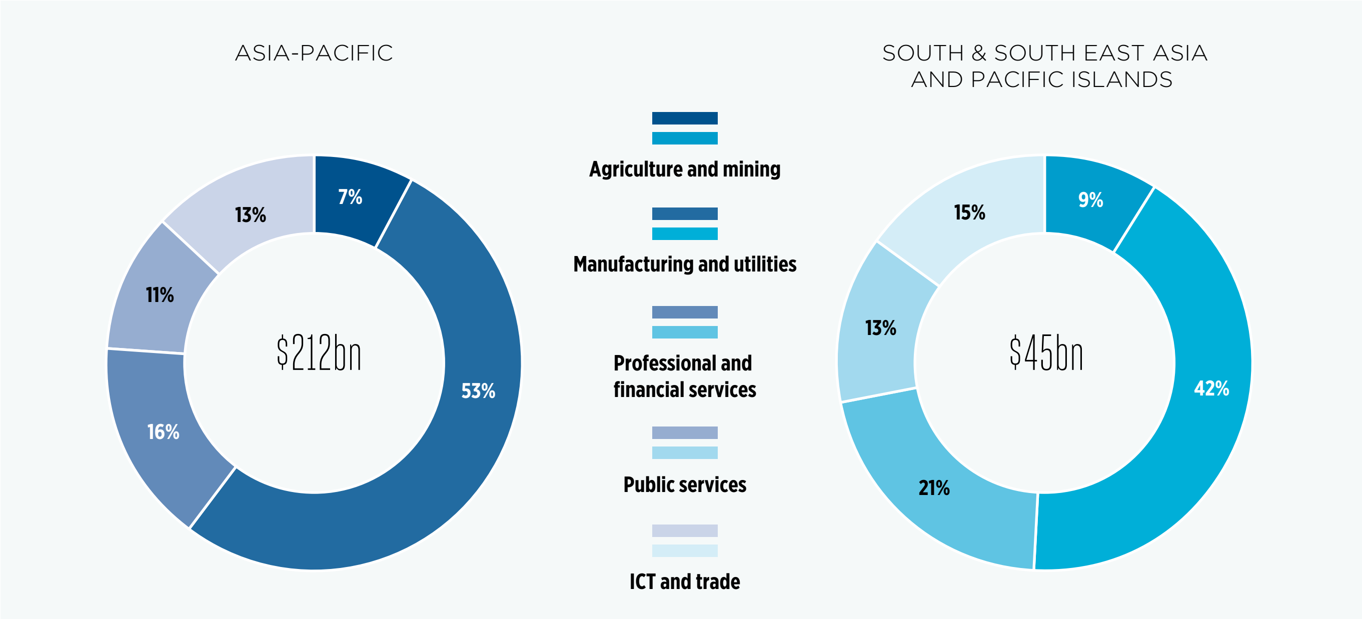
FIGURE 23. STRUCTURE OF GDP CONTRIBUTIONS FOR ASIA-PACIFIC AS A WHOLE VERSUS SOUTH & SOUTH EAST ASIA AND PACIFIC ISLANDS, 2034



Source: TMG.

Finally, the economic benefits overwhelmingly flow from the manufacturing and utilities sector, in which the sector accounts for 53% of the overall contribution to GDP of $212 billion as a result of mmWave 5G. Similarly, the manufacturing and utilities sector contributes the largest share of the contribution to GDP as a result of mmWave in South and South East Asia and Pacific Islands at 42%, although the professional and financial services sector is also an important contributor to sub-region's GDP contribution of $45 billion (see Figure 24).

FIGURE 24. STRUCTURE OF GDP CONTRIBUTIONS BY VERTICAL IN THE ASIA-PACIFIC REGION, 2034

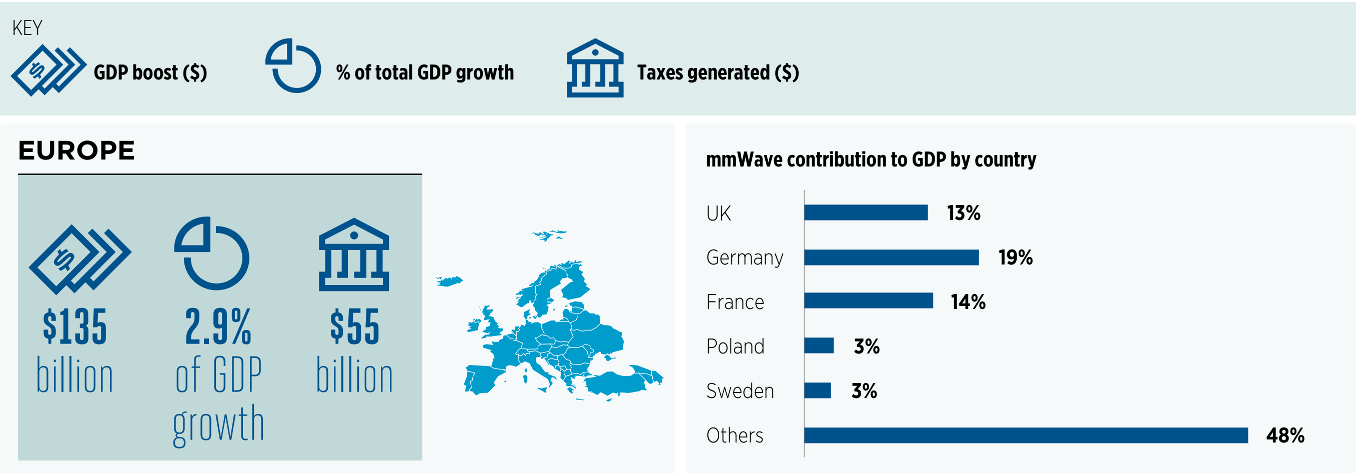


Source: TMG.

Europe

The European region will benefit from a $135 billion increase in GDP as a result of mmWave 5G. This is driven primarily by France, Germany, and the United Kingdom (see Figure 25). These three countries make similar contributions. A 40% share of GDP growth can be expected to go to the government in taxes.

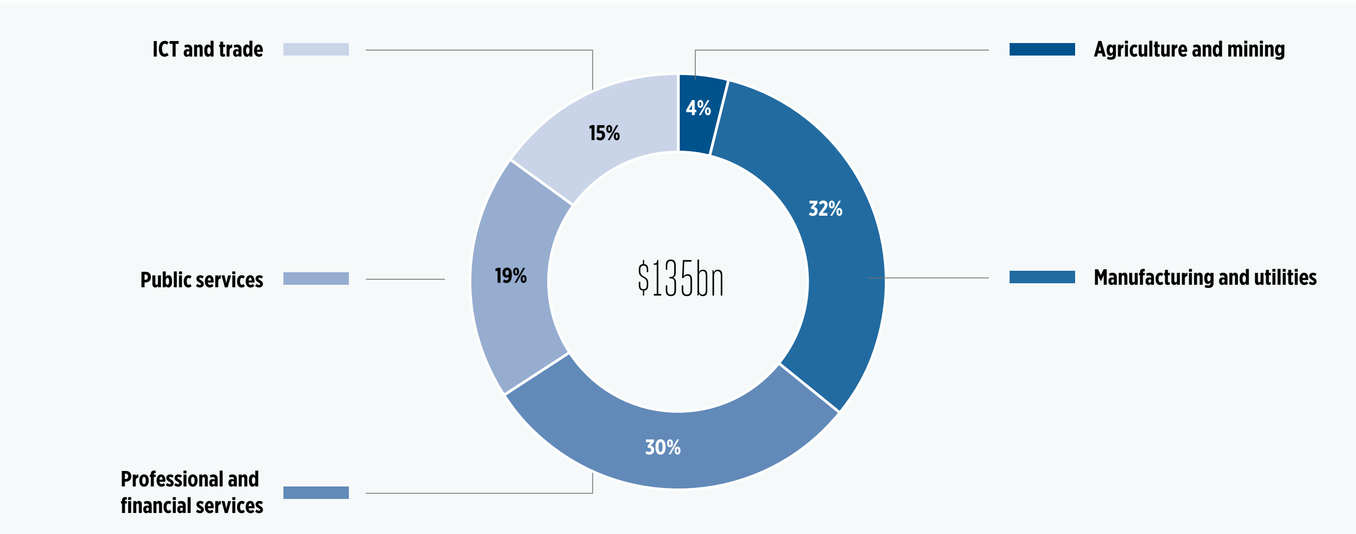
FIGURE 25. MMWAVE CONTRIBUTION TO GDP (BY SELECTED COUNTRY SHARE) AND TAX REVENUE COLLECTED IN EUROPE, 2034



Source: TMG.

As with other regions, the manufacturing and utilities sector is expected to contribute the largest share (32%) of the overall cumulative GDP contribution of $135 billion (see Figure 26).

FIGURE 26. STRUCTURE OF GDP CONTRIBUTIONS BY VERTICAL IN EUROPE, 2034

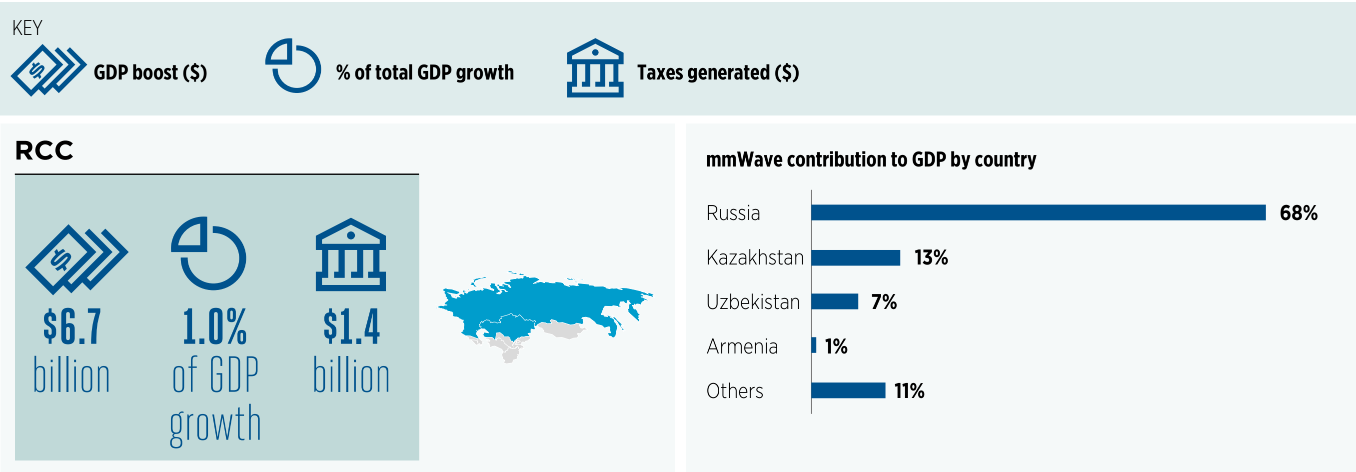


Source: TMG.

Regional Commonwealth in the field of Communications

For countries in the RCC region, mmWave 5G is estimated to increase GDP by $6.7 billion. Assuming current tax regimes stay stable, almost 15% of this GDP may pass through to the public treasury. The Russian Federation is the biggest player in this region, responsible for contributing 68% of the mmWave contribution to GDP, followed by Kazakhstan with 13% (see Figure 27).

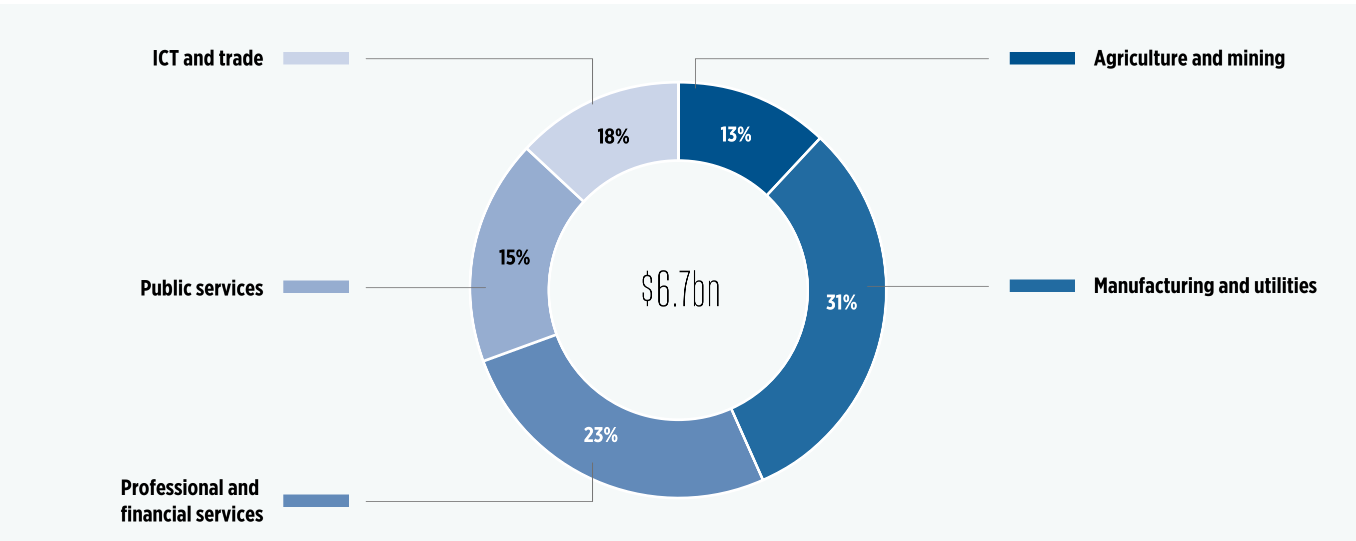
FIGURE 27. MMWAVE CONTRIBUTION TO GDP (BY SELECTED COUNTRY SHARE) AND TAX REVENUE COLLECTED IN THE RCC, 2034



Source: TMG.

The manufacturing and utilities sector contribute the largest amount to GDP, making up 31% of the total $6.7 billion contribution as a result of mmWave 5G. As fossil fuel and oil production fall under manufacturing and utilities, the dominance of this sector can be expected given the natural resource endowments of the economies in this region (see Figure 28). The services sectors of ICT and trade and professional and financial services also make significant contributions to the increase in GDP as a result of mmWave spectrum.

FIGURE 28. STRUCTURE OF GDP CONTRIBUTIONS BY VERTICAL IN THE RCC, 2034

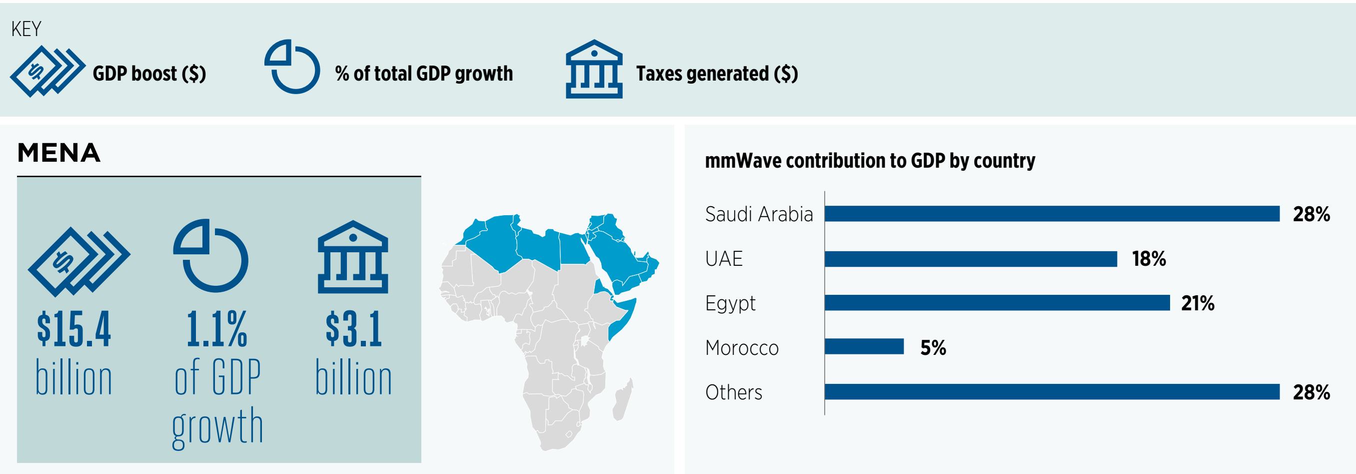


Source: TMG.

Middle East and North Africa

mmWave 5G will create an increase of $15.4 billion in GDP in the MENA region over the period of the study. The tax to GDP ratio for the region is slightly greater than 20%. MENA is comprised of various countries that actively promote technological adoption, such as Saudi Arabia, the United Arab Emirates, and other Gulf states, which represent a large share of the MENA economy (see Figure 29).

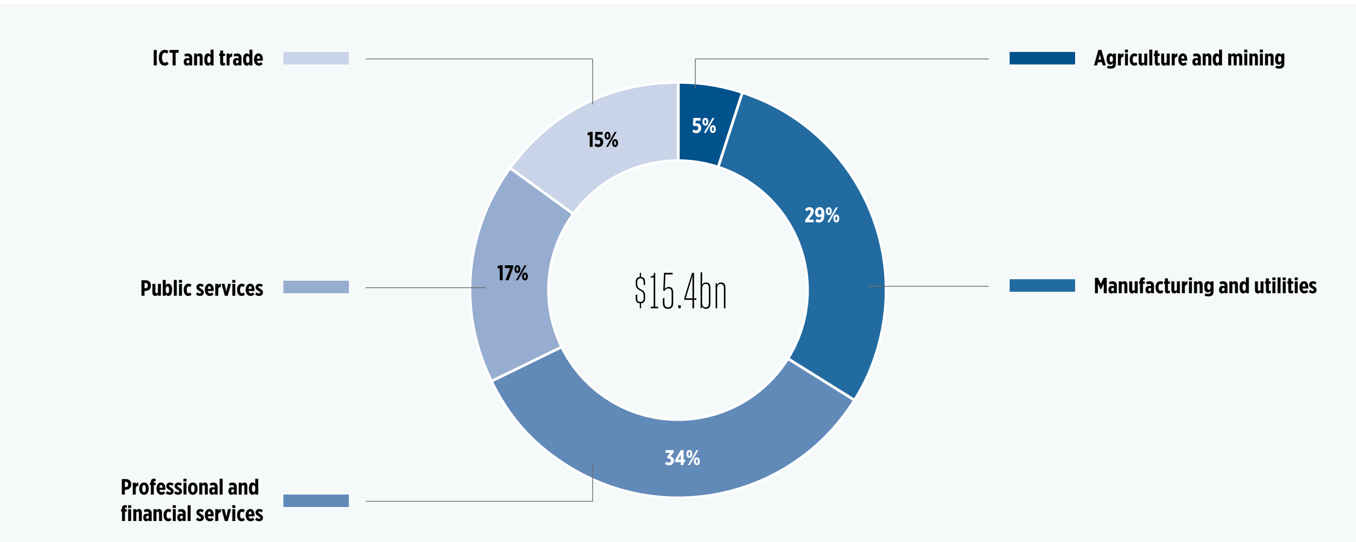
FIGURE 29. MMWAVE CONTRIBUTION TO GDP (BY SELECTED COUNTRY SHARE) AND TAX REVENUE COLLECTED IN THE MENA REGION, 2034



Source: TMG.

Professional and financial services contribute the most to GDP with 34% (see Figure 30). Many of the Gulf nations are fossil fuel rich, making this industry, captured in the manufacturing and utilities sector, one with significant economic impact in the region.

FIGURE 30. STRUCTURE OF GDP CONTRIBUTIONS BY VERTICAL IN MENA, 2034

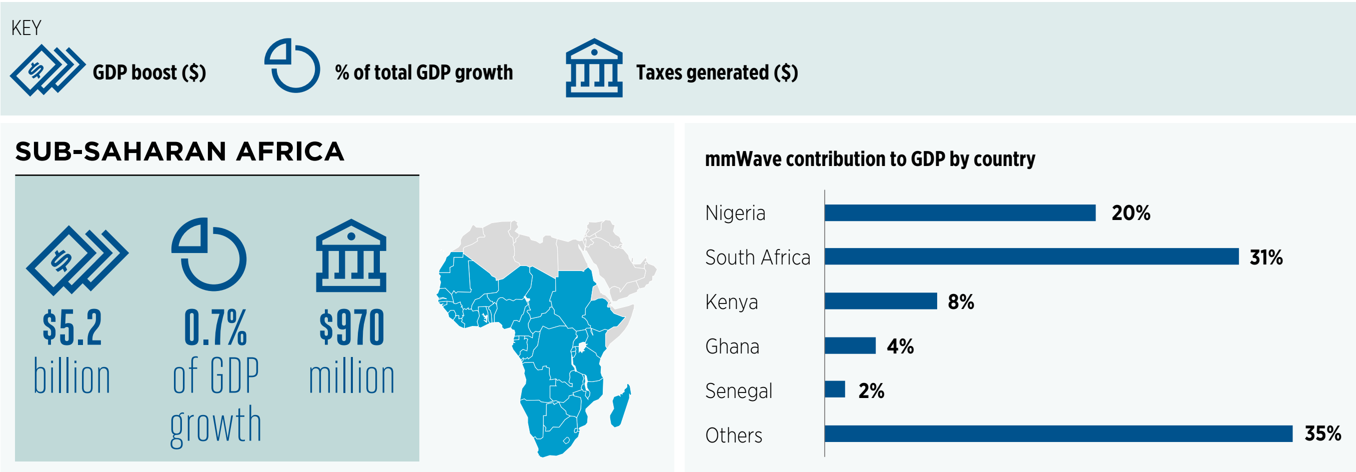


Source: TMG.

Sub-Saharan Africa

The Sub-Saharan Africa region has made great strides in recent years and continues making progress to increase the deployment of broadband infrastructure. In the medium term, the roll-out of 4G is expected to continue as the primary driver of economic benefit. Furthermore, in the near term, the use cases for Sub-Saharan Africa favour 5G applications that are less dependent on mmWave spectrum. However, the economic benefits of the mmWave spectrum will still be significant in the region at a later stage in the study period. The Sub-Saharan African region is expected to deliver $5.2 billion in GDP as a result of mmWave 5G, with Nigeria and South Africa combined providing approximately half of the total contribution (see Figure 31). Once 5G has taken off, the annual gain from mmWave 5G will grow much faster from 2026 onwards, closing the gap between the early and late adopters.

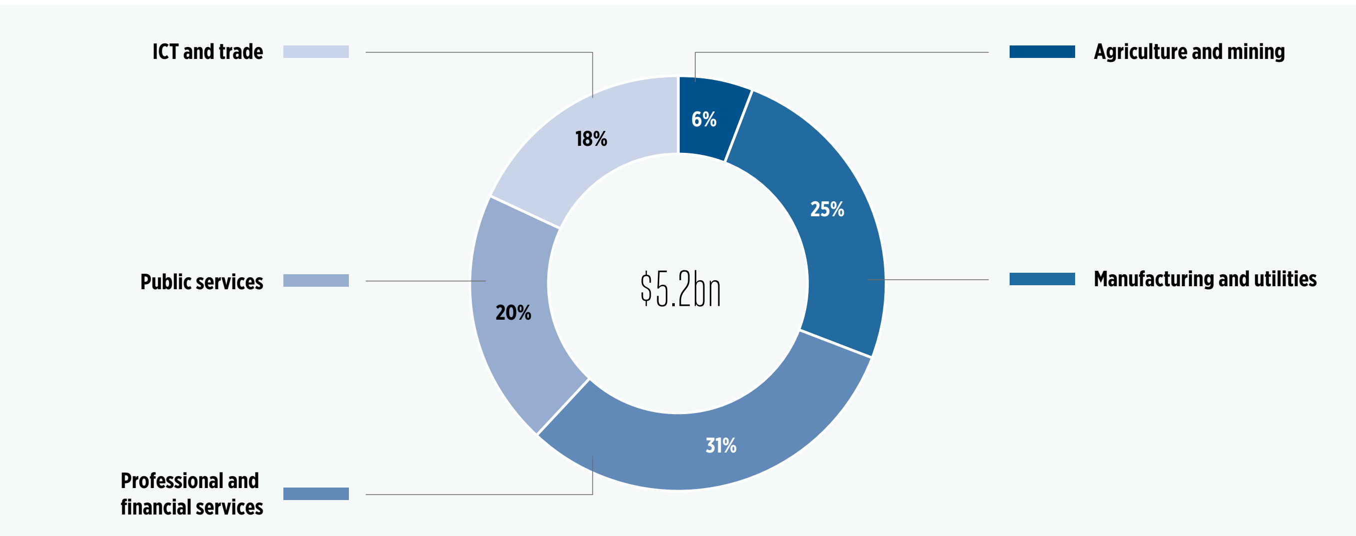
FIGURE 31. MMWAVE CONTRIBUTION TO GDP (BY SELECTED COUNTRY SHARE) AND TAX REVENUE COLLECTED IN SUB-SAHARAN AFRICA, 2034



Source: TMG.

The professional and financial services sector is expected to be the largest contributor to GDP making up 31% of the total $5.2 billion expected to be accrued over the period of the study. This is followed closely by the manufacturing and utilities sector providing a quarter of the impact on GDP, public services with 20%, and ICT and trade at 18%. (see Figure 32).

FIGURE 32. STRUCTURE OF GDP CONTRIBUTIONS BY VERTICAL IN SUB-SAHARAN AFRICA, 2034



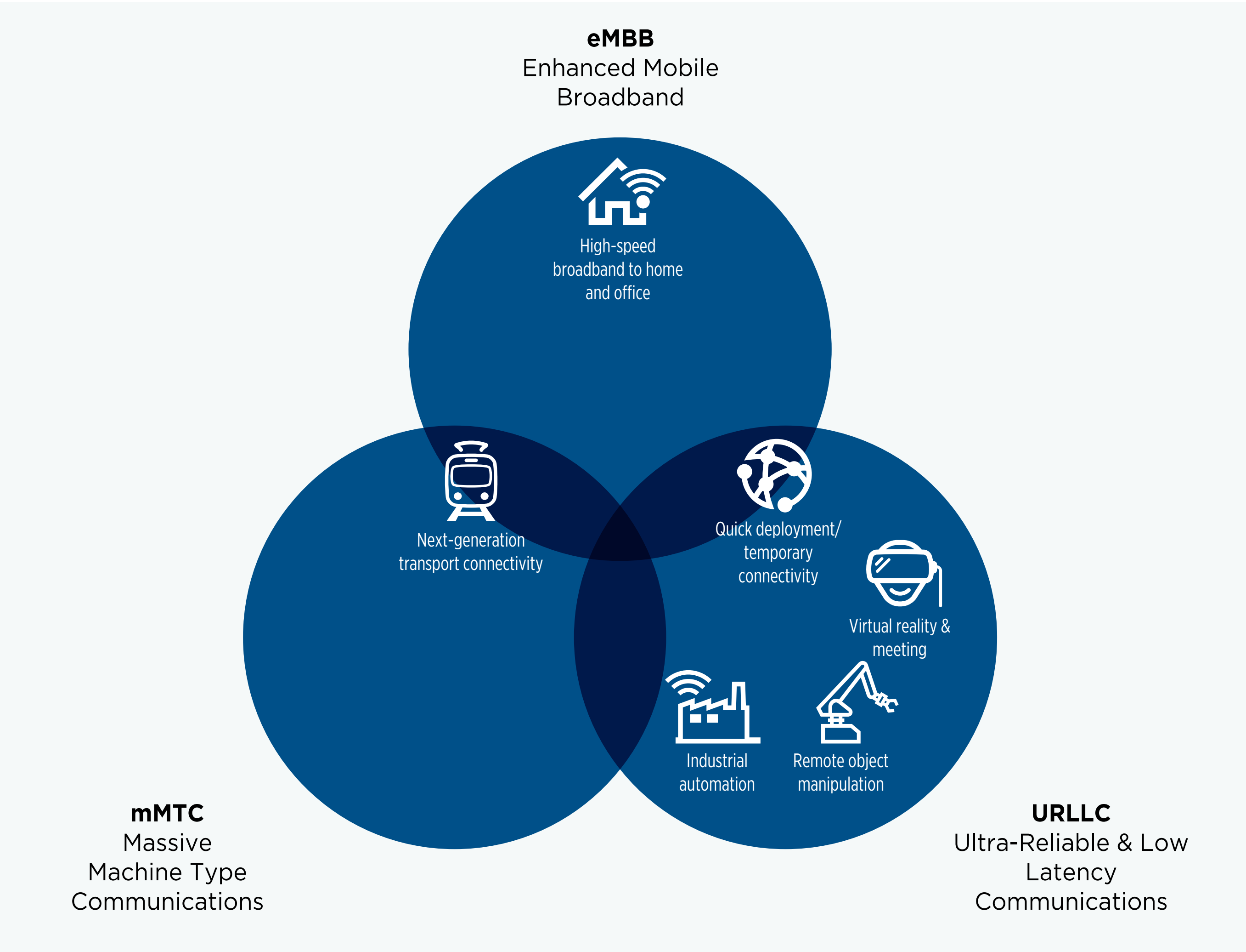
Source: TMG.

Annex 1: Use Case Requirements

This Annex provides a functional and technical description of the six mmWave 5G use cases addressed in this study: high-speed broadband in the home and office; quick deployment/ temporary connectivity; industrial automation; remote object manipulation; virtual reality and meeting; and next-generation transport connectivity. The term "use case" refers to possible business cases, enabled by mmWave spectrum within a broader 5G network deployment. Some of these use cases are specific applications that can be used in various industries, while others refer to access technologies upon which several applications can operate.

These six use cases can be mapped to the three 5G usage scenarios defined by the ITU: Enhanced Mobile Broadband (eMBB); Massive Machine Type Communications (mMTC) or Internet of Things (mIoT); and Ultra-Reliable and Low-Latency Communications (URLLC) for Mission Critical Services (MCS).[8]

FIGURE 33. MMWAVE USE CASES MAPPED TO ITU USAGE SCENARIOS



Source: TMG and ITU (2015), 'Recommendation ITU-R M.2083: IMT Vision'.

8. ITU (2015), 'Recommendation ITU-R M.2083: IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond', https://www.itu.int/rec/R-REC-M.2083-0-201509-I/en.

For example, high-speed broadband in the home and office, quick deployment/temporary connectivity, and next-generation transport connectivity are classified under the eMBB usage scenario, although some applications of the next-generation transport connectivity use case could also fall under the mIoT scenario. The industrial automation, remote object manipulation, and virtual reality and meeting use cases could fit under URLLC. However, as seen in Figure 33, some overlap may exist between usage scenarios, as some 5G mmWave use cases may apply to applications spanning more than one scenario.

From a technical perspective, the key capabilities used to classify the use cases, shown in Figure 34, were based on the ITU's IMT Vision described in Recommendation ITU-R M.2083.[9] These key capabilities were used to quantify the dependency of the use cases on mmWave spectrum.

FIGURE 34. KEY CAPABILITIES FOR EACH USE CASE

Source: TMG and ITU (2015), 'Recommendation ITU-R M.2083: IMT Vision'.

The dependency of mmWave spectrum is most relevant for capabilities such as peak data rate, user experience data rate, and latency. The larger spectrum bandwidths of mmWave spectrum improve throughput resulting in higher peak data rate and user experience data rate. The latency requirements also benefit from mmWave because the shorter wavelength facilitates the use of advanced antennas, including beam-forming and massive antenna arrays with multiple-input multiple-output (MIMO), bringing the network closer to the user.

The following sections contain a description of each use case including their related applications and required network capabilities. In each case, the applications are grouped to produce a quantifiable economic impact from the implementation of 5G in mmWave spectrum.

9. ITU (2015), 'Recommendation ITU-R M.2083: IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond', https://www.itu.int/rec/R-REC-M.2083-0-201509-I/en.

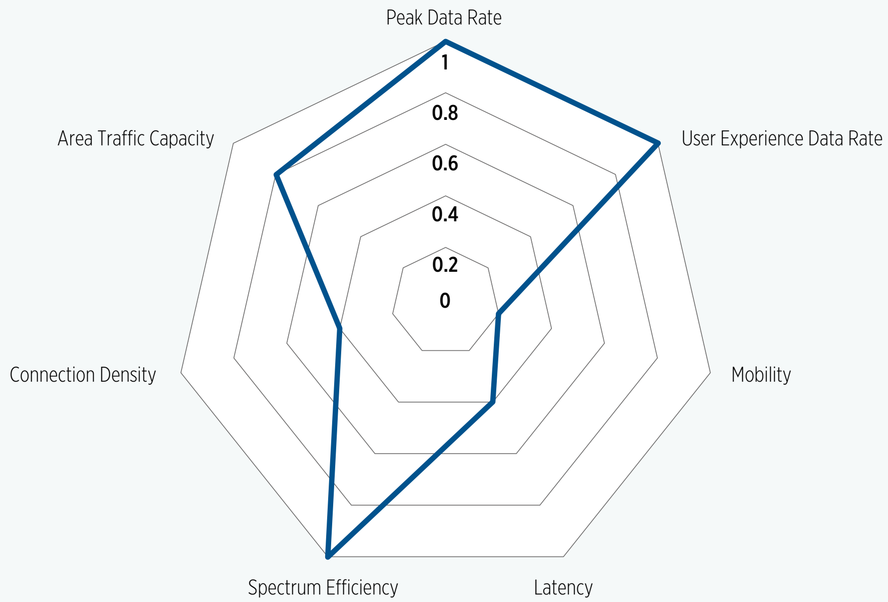
High-speed broadband in the home and office

Overview: The high-speed broadband in the home and office use case refers to the provision of ultra-high-speed broadband connectivity to households and office buildings. While mobility is possible in this situation, most often it is used as a fixed wireless broadband service. This service may also provide fixed links, including for backhaul solutions. The speeds made possible with 5G technologies allow wireless broadband to compete with wired connections, providing fibre-like user experiences. This use case in turn enables other applications and is part of the eMBB usage scenario.

Key Implementation Requirements: Some 5G technology critical components, like advanced radio access technologies and network slicing, are necessary to support this use case. The use of mmWave bands permits the provision of high-speed connections that can handle high volumes of traffic, consequently reducing the cost per Mbps.

As shown in Figure 35, capabilities like peak data rate and user experience data rate are particularly relevant for this use case.

FIGURE 35. KEY CAPABILITIES REQUIRED FOR HIGH-SPEED BROADBAND IN THE HOME AND OFFICE



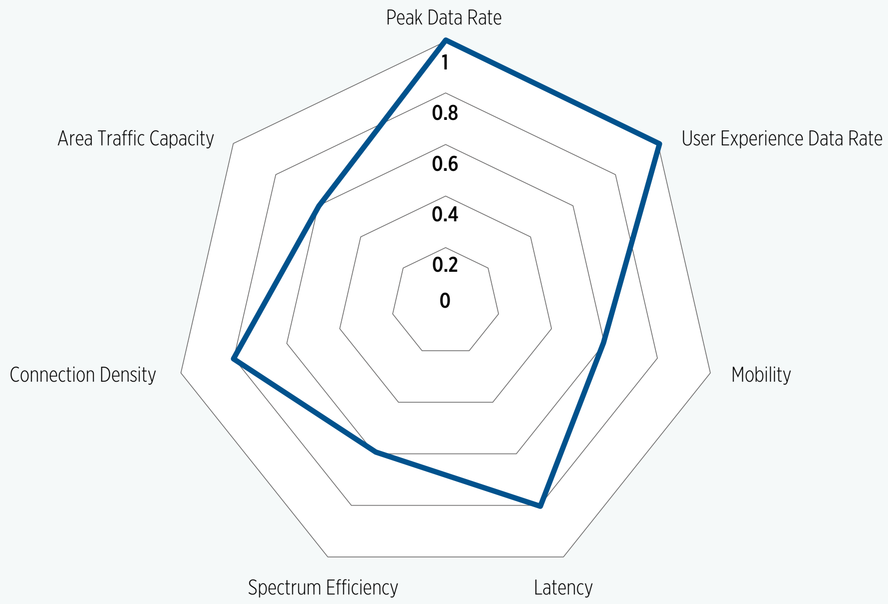
Source: TMG.

Quick deployment/temporary connectivity

Overview: This use case encompasses applications related with the provision of increased broadband capacity in certain cases. This could be for special events, including one-way distribution of multimedia content or, in cases of disasters, the maintenance of mobile communication while an incapacitated network is restored. This case relates to the provision of non-stationary and dynamic capacity to respond in real-time when increased capacity is needed at a specific location. Additionally, this use case also includes a variation of one-way distribution of multimedia content, in a broadcast-like mode. Broadcast-like applications will enable business models related to the provision of temporary services such as transmission of live events, emergency communications, and targeted retail ads, among others. These applications are expected to be used by public telecommunications operators and first responder organizations. This use case is part of the eMBB usage scenario.

Key Implementation Requirements: It will be necessary to deploy 5G key characteristics like advanced radio interface technologies and Massive MIMO antenna arrays to provide high throughput and manage high amounts of data in specific areas. For this use case, capabilities like peak data rate, user experience data rate, and connection density are particularly important, as shown in Figure 36.

FIGURE 36. KEY CAPABILITIES REQUIRED FOR QUICK DEPLOYMENT/ TEMPORARY CONNECTIVITY



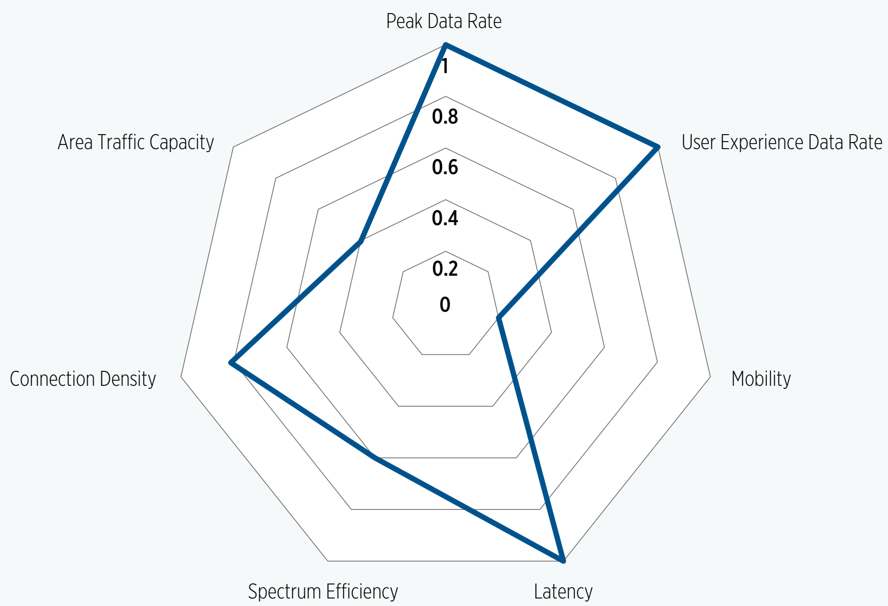
Source: TMG.

Industrial automation

Overview: This refers to the use of 5G networks to provide communications between devices/machines. It may or may not include human interaction and is expected to replace and enhance existing wired communications. Collaborative robots are included in this use case, and will be enabled by artificial intelligence (AI). New possibilities for industrial automation are emerging, with the aim to increase the efficiency of production lines based on the collaborative functions of a new generation of robots. Human interaction with robots will likely be limited to basic functions such as powering the machines on or off, managing software updates, physical installation, and repair. This use case is part of the URLLC usage scenario.

Key Implementation Requirements: For industrial automation, key capabilities like peak data rate and user experience data rate are highly relevant. Connection density and area traffic density become important in massive industrial automation processes. New generations of robots will produce large amounts of data and communicate with each other to improve manufacturing processes in real time. mmWave spectrum is expected to play an important role in the deployment of large-scale automation in concentrated areas (e.g., manufacturing facilities), with the key capabilities summarised in Figure 37.

FIGURE 37. KEY CAPABILITIES REQUIRED FOR INDUSTRIAL AUTOMATION



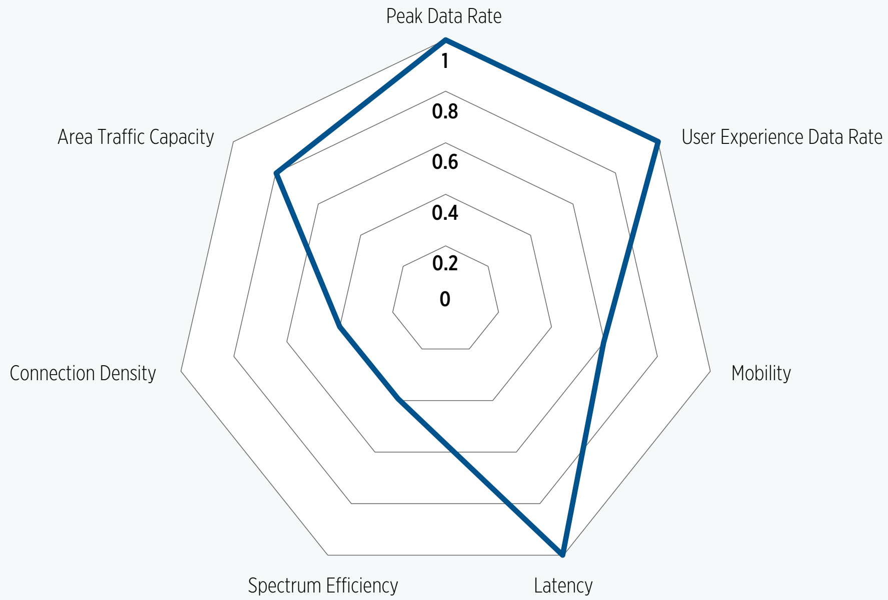
Source: TMG.

Remote object manipulation

Overview: This use case refers to the remote operation of different types of devices. Examples of applications are the operation of drones and healthcare, including remote surgery. This use case differs from the industrial automation use case as it involves a sophisticated interaction between a human operator and the equipment being used instead of machine-to-machine communication. Remote object manipulation can offer a high level of precision for an operator who is physically located far away from the device, thus supporting cases where basic services are unavailable or the setting is dangerous. Given the high degree of precision required for these tasks, this use case would fall under the URLLC usage scenario.

Key Implementation Requirements: For this use case, the 5G developments necessary for providing the correct control and feedback for high-precision devices involve very high requirements in terms of low-latency, reliability, and user experience data rate. The key capabilities are summarised in Figure 38.

FIGURE 38. KEY CAPABILITIES REQUIRED FOR REMOTE OBJECT MANIPULATION



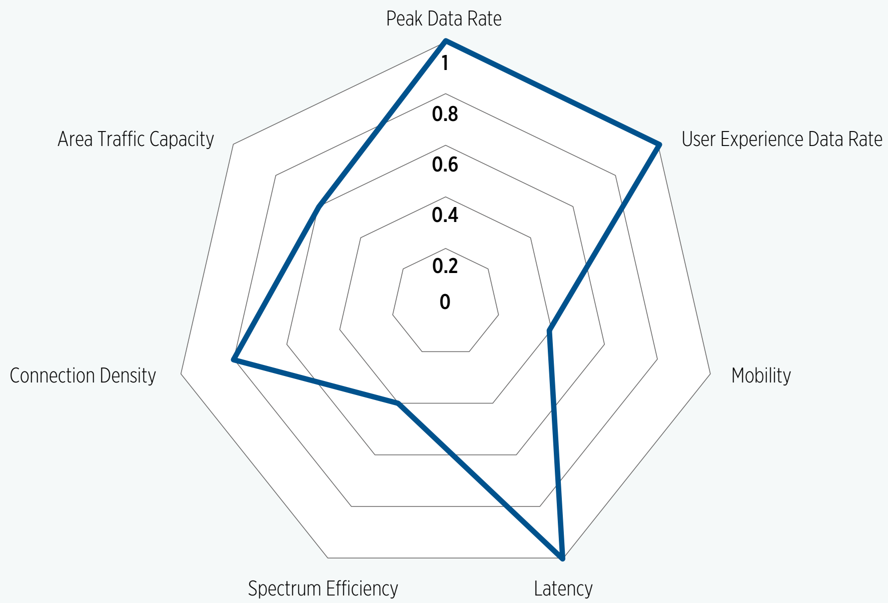
Source: TMG.

Virtual reality and meeting

Overview: This use case refers to two groups of potential applications: virtual and augmented reality, and virtual meeting. Virtual and augmented reality refers to the experience of being virtually in another place (virtual reality), or having enhanced information on the actual environment (augmented reality).[10] Virtual meeting refers to next-generation videoconferencing or telepresence in which individuals can be virtually present by sending and receiving high resolution details between two or more remote environments. Virtual reality applications have a wide range of possible uses, such as enhanced educational experiences for students, simulations for first responders training for disasters, virtual walk-throughs of buildings for architects and engineers, and virtual layouts of existing machinery for training or maintenance purposes. This use case overlaps with the eMBB and URLLC usage scenarios.

Key Implementation Requirements: For virtual reality and meeting applications, key 5G developments, such as advanced radio access technologies and network slicing, are necessary. Peak data rate, latency, and user experienced data rate capabilities are highly relevant for the successful implementation of these use cases. Connection density is also important considering the potential for massive adoption of these applications. Figure 39 summarizes the key capabilities required.

FIGURE 39. KEY CAPABILITIES REQUIRED FOR VIRTUAL REALITY AND MEETING



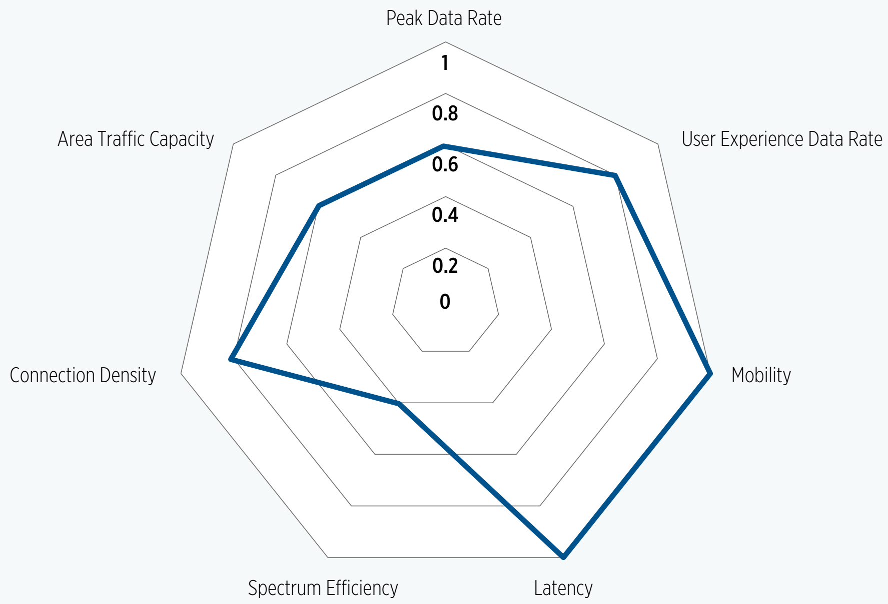
Source: TMG.

Next-generation transport connectivity

Overview: This use case includes two different types of transport connectivity: broadband on transport and connected vehicles. These may apply both to public and private transportation networks. The first type of transport connectivity refers to the provision of ultra-high-speed broadband to end-users in moving vehicles or on public transport. The second group of applications included under this use case is associated with connected vehicles. This includes various types of direct-vehicle communications (V2X), such as vehicle-to-vehicle (V2V), to pedestrians (V2P), to infrastructure (V2I), or to the network (V2N). Autonomous vehicles, for example, will depend heavily on reliable transport communications due to the high volume of data expected to be exchanged, such as in the use of high-definition maps and in communication with infrastructure for road conditions. Next-generation transport connectivity could be applied to both the eMBB and mIoT usage scenarios.

Key Implementation Requirements: This use case has a mix of requirements, from ultra-low-latency for control and warning signals, to higher data rates required to share video information between cars and infrastructure, as well as broadband requirements. 5G technology should provide the high reliability, low-latency, and high scalability required for these applications. The summary of key 5G capabilities for this use case is shown in Figure 40.

FIGURE 40. KEY CAPABILITIES REQUIRED FOR NEXT-GENERATION TRANSPORT CONNECTIVITY



Source: TMG.

Annex 2: Qualitative Benefits of mmWave 5G

Beyond the measurable impacts discussed in the previous section, it is important to emphasise the social impacts of mmWave 5G technology and services and how it will change society and the world we live in.

Users are more likely to focus on the observable impacts of the new technology, such as changes to how established services are delivered and how people and vehicles move around in their environment, and to notice improvements in the well-being of individuals and society overall. As mmWave 5G technologies are incorporated across verticals, it is possible to witness impacts such as increased access to education and healthcare expertise, increased independence, and shorter commute times, among many other benefits.

The sections below consider five sectors – healthcare, transportation, education, public safety, and industry (manufacturing, mining, and construction). These sectors are arguably among the most likely to experience qualitative improvements from mmWave 5G and the higher broadband capacities and lower latencies that it enables. Potential benefits within each sector are identified, including the relevant use cases and specific examples of improvements to the society well-being.

Healthcare

Several of the use cases introduced in the study may result in qualitative improvements in the healthcare sector. Expected benefits include increased accessibility and access to services, improved overall health of the population and a reduction of healthcare costs (Figure 41).

FIGURE 41. POSSIBLE BENEFITS FOR THE HEALTHCARE SECTOR

Availability and access	Lower healthcare costs	Improved overall health
Increased availability and access (e.g., via video/telemedicine, tactile internet) could lead to reduced expenditure of time and money on access to healthcare and specialists.	More preventative care and better medical resource management could lead to lower overall health costs.	Increased availability and access (e.g., via video/telemedicine, tactile internet) could lead to reduced expenditure of time and money on access to healthcare and specialists.

Source: TMG.

Several mmWave 5G use cases, such as high-speed broadband in the home and office, remote object manipulation, and industrial automation, may significantly benefit the healthcare sector. These cases often require high capacity, low-latency, and a high degree of precision, especially considering cases where they are applied to human health, resulting in a high dependency on mmWave spectrum. Some benefits that these use cases may bring to the healthcare sector as outlined in Figure 42. These benefits will be particularly impactful in rural and underserved areas.

FIGURE 42. USE CASES AND APPLICATIONS EXPECTED TO BENEFIT THE HEALTHCARE SECTOR

Lower healthcare costs

High-speed broadband in the home and office

Improved billing and care management systems via integration of data and services – are expected to give patients greater control over care and access to cost and billing information.

Industrial automation

Patients receive better care due to more reliable networks and use of smart machines that may be **less susceptible to breakdowns or downtime.**

Increased availability and access

Remote object manipulation

Remote diagnosis – 5G-enabled cameras, robotics, and other devices can enable distant medical professionals to diagnose some conditions without an in-person visit.

Remote surgery – Haptic feedback in remote surgery and deployment of remote surgery over longer distances. Improved healthcare in locations lacking trained specialists or populations without means to travel to top hospitals, moving care closer to patients and caregivers**.**

High-speed broadband in the home and office

Improved healthcare service delivery due to fast and intelligent networks, connected devices, back-end services, and extremely low-latency.

Expanded remote treatment opportunities – Patient monitoring and two-way device communication enabling automated and immediate treatment reactions (e.g., administering medication, neurostimulation or pacemakers).

Improved overall heath

High-speed broadband in the home and office

More widespread use of wearables consisting of multiple types of devices and sensors – Ultra-light, low-power, waterproof sensors integrated into clothing may enable heart rate/electrocardiography, blood pressure, blood glucose, body temperature, breathing rate and volume, skin moisture, and other measurements/monitoring.

Increased patient participation in care/wellbeing – Collection of patient data combined with patient and practitioner access to real-time and historical information may help emphasise early intervention and proactive solutions, as opposed to reactive treatments.

Updated care and research approaches due to data collection from more locations and larger populations enabled by wearables – Patient monitoring may reduce non-adherence to treatment instructions. Data capture and analysis benefits healthy consumers by improving research on healthy lifestyles and disease prevention. Data analysis may also drive increasingly personalized or precision treatment plans.

Industrial automation

Smart objects – 5G could enable smart devices in a medical setting, such as smart syringes, supply cabinets, and hospital beds. This may lead to more efficient management of medical resources, lower costs of providing healthcare, as well as reducing opportunities for errors such as incorrect drug dosages.

Sources: TMG based on SNS Research (2017), 'The 5G Wireless Ecosystem: 2017 – 2030: Technologies, Applications, Verticals, Strategies & Forecasts,'; 5G Americas (2017), '5G Services & Use Cases,'; Department of Communication and the Arts (2018), 'Impacts of 5G on productivity and economic growth,' ; NGMN Alliance (2015), 'NGMN 5G White Paper,'; DotEcon Ltd. and Axon Partners Group (2018), 'Study on Implications of 5G Deployment on Future Business Models,'; Ericsson (2018), 'The Industry Impact of 5G: Insights from 10 sectors into the role of 5G'.

Transportation

Qualitative impacts in the transportation vertical may bring a number of benefits to people and societies, such as increased mobility and autonomy, increased road safety, and shorter commute times, among others as outlined below (see Figure 43).

FIGURE 43. POSSIBLE BENEFITS FOR THE TRANSPORTATION SECTOR

Increased mobility

Expected increased mobility due to autonomous vehicles (e.g., transportation for mobility-challenged individuals).

Increased safety

Possible increased safety due benefits of autonomous vehicles (e.g., fewer traffic accidents, less impaired driving) and possible reduction of incidents between hired drivers and passengers.

Reduced pollution

Less pollution from transportation sector due to potentially more efficient driving and routing enabled by intelligent transportation.

Public transport

Potential for increased availability of public transport due to smart management of vehicle fleets and incorporation of data from commuters in route planning.

New businesses

Possibility for new business concepts and workplace locations.

Source: TMG.

Benefits for the transport sector, like increased mobility and increased efficiency of transport systems, will rely on the implementation of mmWave 5G services and technologies in the next-generation transport connectivity use case and the remote object manipulation use case. In particular, the transportation sector is expected to benefit from performance improvements such as low-latency communications, enabling autonomous driving and a more rapid adoption of intelligent transportation systems (ITS). Remote object manipulation, also relying on high-speed, low-latency broadband, is predicted to enable remote control of vehicles and assistance to drivers in complex traffic situations. The need for high speeds and low latencies makes mmWave spectrum important for the viability of these use cases. The greatest benefits from the implementation of mmWave 5G in vehicles and transportation systems are expected to accrue from increased road safety and traffic efficiency, both of which have potential to create noticeable societal change.[11]

11. Analysys Mason (2017), ‘Socio-economic benefits of cellular V2X,’ p. 64, http://www.analysysmason.com/contentassets/b1bd66c1baf443be9678b483619f2f3d/analysys-mason-report-for-5gaa-on-socio-economic-benefits-of-cellular-v2x.pdf.

FIGURE 44. USE CASES AND APPLICATIONS EXPECTED TO BENEFIT THE TRANSPORTATION SECTOR

Increased mobility

Next-generation transport connectivity

Autonomous driving – Truly connected autonomous driving, enabled by mission-critical reliability, low-latency, and high data rates, may become more widespread. A significant portion of data generated by autonomous vehicle will be processed in the cloud.

Remote object manipulation

Remote/assisted driving – Remote driving or driving assistance in environments inappropriate for autonomous driving, enhancing safety for the disabled and elderly, and addressing complex traffic situations.

Increased safety

Next-generation transport connectivity

Remote object manipulation

Autonomous and remote/assisted driving, as described, could limit the potential for human error to cause accidents or other traffic incidents.

Hired vehicles piloted remotely or autonomously could reduce the potential for confrontations or violence between drivers and passengers.

Reduced pollution and congestion

Next-generation transport connectivity

Intelligent transportation systems (ITS) leverage data from vehicles and smart infrastructure to optimize driving, railway, pedestrian, and other transport routes, as well as related services, such as parking availability.

More advanced, richer in-vehicle navigation systems, including road conditions and inputs from nearby sensors enable more efficient routing and less vehicle-generated pollution. This may result in lower congestion levels and reduction of commute times for citizens.

Increased availability of public transport

Next-generation transport connectivity

ITS can lead to more efficient planning of **public transportation routes and allocation of resources** in order to maximize the benefit and availability of public transportation.

Data from consumers, such as mobile devices or wearables, could be leveraged in the public transportation planning process for public transportation projects and routes.

Sources: TMG based on Analysis Mason (2017), 'Socio-economic benefits of cellular V2X,'; SNS Research (2017), 'The 5G Wireless Ecosystem: 2017 – 2030: Technologies, Applications, Verticals, Strategies & Forecasts,'; 5G Americas (2017), '5G Services & Use Cases,'; Anh Phan and Shoaib Tahir Qureshi (2017), '5G impact On Smart Cities.'

Education

There are high expectations for the impact of 5G networks to expand access to educational resources, and in particular to high-quality educational resources. Such benefits may be grouped into two broad categories: increased availability and access to educational opportunities and increased quality of education, including for educators (see Figure 45).

FIGURE 45. POSSIBLE BENEFITS FOR THE EDUCATION SECTOR

Availability and access	Increased safety
Expected increased availability and access due to high-quality, affordable internet options that enable distance learning, which could also help to close gaps between populations (e.g., developed and developing countries, urban and rural communities, households with different income levels, men and women) by providing equal opportunity to education.	May expand access to high-quality education and expert educators (e.g., distance-learning offerings from universities, native language speakers, and subject matter experts), including both academic and workplace education scenarios.

Source: TMG.

Leveraging the high-speed broadband in the home and office and the virtual reality and meeting use cases, high-speed, low-latency networks may enable new and improved opportunities for distance learning. While the provision of broadband could be accomplished using other spectrum bands, mmWave spectrum allows for a high quality at lower cost due to increased spectral efficiency, making it very beneficial to areas which may not have access to high-quality broadband options. The installation of new or upgraded broadband connections in a home, coupled with broadband at a school, university, or other educational campus can enable both real-time and time-shifted access to lectures, training, and other educational materials and opportunities. Further, workplace and vocational education can also benefit from remote access to training and continuing education resources that may currently be unavailable or prohibitively expensive (see Figure 46). Interactive lessons, or those using augmented or virtual reality technology could greatly expand and improve current distance-learning options. Such applications require high capacity and low-latency, which would benefit significantly from mmWave spectrum. These benefits will be particularly impactful in rural and developing regions.

FIGURE 46. USE CASES AND APPLICATIONS EXPECTED TO BENEFIT THE EDUCATION SECTOR

Increased quality

High-speed broadband in the home and office

Virtual reality and meeting

High-speed connectivity may **create and expand opportunities for remote access to experts and educators** that are impractical or impossible to reach in person.

Industrial/workplace education – New modes of teaching workers new or updated skills. Augmented Reality content delivery combined with haptic feedback could provide distance learning of fine-motor skills, such as surgery or industrial maintenance.

Increased availability and access

High-speed broadband in the home and office

Virtual reality and meeting

Distance learning – Evolution of distance learning, enabling a more immersive experience for educators and students in disparate locations.

Absence reduction – Virtual presence technology combined with robotics could allow students away from class (e.g., sick students, those with household obligations) to continue to attend class.

Improved access to high-speed, low-latency broadband at home may **expand educational opportunities for students** and potential students that were previously unable to access education, such as in less-developed countries, less-affluent communities, and individuals—often women and girls—with household obligations that prevented regular attendance at school.

Sources: TMG based on SNS Research (2017), 'The 5G Wireless Ecosystem: 2017 – 2030: Technologies, Applications, Verticals, Strategies & Forecasts,'; Ericsson (2018), 'The Industry Impact of 5G: Insights from 10 sectors into the role of 5G'.

Public-Safety

While 5G networks can be deployed in lower bands like the C-band, they are expected to provide the higher-capacity, lower-latency connectivity with the aid of mmWave spectrum, which may enable significant enhancements in communications for public-safety uses. Potential benefits include enhanced day-to-day safety for citizens stemming from increased capabilities and tools available to first responders and increased protection during disaster and emergency situations (see Figure 47).

FIGURE 47. POSSIBLE BENEFITS FOR PUBLIC-SAFETY

Increased safety

Day-to-day safety may be enhanced by broadband-enabled first responder communications, as well as new and improved tools to provide first responders with the data or support needed to address situations most effectively (e.g., patient data in ambulances, aerial footage from drones).

Disaster protection

May enable enhanced disaster responses, including communications in situations without adequate network infrastructure and use of remote devices to assist with rescue or emergency situations that are otherwise too difficult or dangerous.

Source: TMG.

Improvements for public-safety are anticipated to develop from the following use cases: quick deployment/temporary connectivity, next-generation transport connectivity, remote object manipulation, and industrial automation. mmWave spectrum brings new and improved capabilities including rapid delivery of richer time-sensitive and critical information, remote piloting of drones and other vehicles in response to emergencies, and improved options for emergency communications in cases where network infrastructure is unavailable or overtaxed. While some of these can be undertaken on existing mobile networks, the added capacity and increased speeds possible with mmWave spectrum will enable a more responsive and stable network infrastructure. These capabilities are expected to improve disaster response efforts and enhance safety (see Figure 48).

FIGURE 48. USE CASES AND APPLICATIONS EXPECTED TO BENEFIT PUBLIC-SAFETY

Increased safety for citizens

Quick deployment/ temporary connectivity

Enhanced, secure mission-critical communications – Improved push-to-talk (PTT) for voice, video, and data communications, instant PTT call setup times, group communications, call prioritisation, pre-emption, emergency calls, private/secure calls and HD voice quality to support a wide range of noise environments.

Connected ambulances may provide paramedics and other medical providers in the field relevant patient and/or reference information in order to improve emergency medical care.

Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs) may provide new tools to law enforcement for reconnaissance, rescue, and pursuit.

Next-generation transport connectivity

Ambulance drones – Ambulances that can maneuver without human drivers.

Remote/assisted driving – Remote driving or driving assistance for first responders and other emergency personnel. Applications could include disaster areas or hazardous terrain.

Enhanced response during disasters

Quick deployment/ temporary connectivity

Coverage extension of out-of-coverage areas – Commercialisation of the interface for device-to-device connectivity specified by 3GPP, improving connectivity in cases of infrastructure failure, emergencies, and special events.

As with law enforcement, **UGVs and UAVs** may provide first responders with new tools for reconnaissance and rescue.

Remote object manipulation

Sources: TMG based on NGMN Alliance (2015), 'NGMN 5G White Paper,'; SNS Research (2017), 'The 5G Wireless Ecosystem: 2017 – 2030: Technologies, Applications, Verticals, Strategies & Forecasts,'; Ericsson (2018), 'The guide to capturing the 5G industry digitalization business potential,'; DotEcon Ltd. and Axon Partners Group (2018), 'Study on Implications of 5G Deployment on Future Business Models,'; 5G Americas (2017), '5G Services & Use Cases'.

Industry (manufacturing, mining, and construction)

Industrial sectors, such as manufacturing, mining, and construction, may be able to leverage high-speed 5G connectivity to improve production processes and safety across the industrial sector (Figure 49).

FIGURE 49. POSSIBLE BENEFITS FOR INDUSTRY

Production processes	Enhanced safety
Potentially transform manufacturing, mining, and construction design and processes through the development of smarter factories and machinery enabling redeployment of human resources and higher-quality outputs.	Potentially enhance safety through remote control of equipment (e.g., construction, mining) in some high-risk scenarios.

Source: TMG.

By leveraging the industrial automation use case for mmWave 5G, companies have the potential to deploy smart factories and improve efficiencies, allowing for reconsideration of the best use of not only machinery, but also human labour. Similarly, the virtual reality and meeting and remote object manipulation use cases may enable workers in industrial sectors to obtain assistance and guidance from remote personnel or outside experts, as well as to limit human exposure to dangerous scenarios or locations. Given the high capacity and low-latency requirements of these use cases, they are highly dependent on the availability of mmWave spectrum.

FIGURE 50. USE CASES AND APPLICATIONS EXPECTED TO BENEFIT INDUSTRY

Improved production processes

Industrial automation

Smart factories

Replacement of wired connections with mmWave enables easier reconfiguration of production facility connections.

Cell automation – Assembly line devices, control units, and human interfaces communicating wirelessly. Autonomous vehicles transferring goods within a factory/campus.

Machine vision – High speed imaging enables analysis of products or processes to improve quality assurance processes.

Improvement of industrial processes

Use of Big Data, analytics and other technologies to drive actionable insights into factory operations – increased automation, improved process regulation, proactive or predictive prevention of malfunctions/faults. Leverages cloud intelligence and availability of data used to modify processes.

Virtual reality and meeting

Real-time assistance – High-quality video assistance from remote experts supporting factory or construction personnel. Factory workers and manufacturing engineers could stream AR content (e.g., renderings of parts, part numbers, and component assembly instructions) on smart glasses/devices.

Enhanced safety

Remote object manipulation

Remote control of equipment – Enable workers to control complex equipment (e.g., cranes, and excavators) remotely, making construction sites safer for people. Drone networks can also monitor and map construction sites.

Remote control of vehicles within closed facilities or on public roads.

Sources: TMG based on NGMN Alliance (2015), 'NGMN 5G White Paper,'; SNS Research (2017), 'The 5G Wireless Ecosystem: 2017 – 2030: Technologies, Applications, Verticals, Strategies & Forecasts,'; Ericsson (2018), 'The guide to capturing the 5G industry digitalization business potential,'; DotEcon Ltd. and Axon Partners Group (2018), 'Study on Implications of 5G Deployment on Future Business Models,'; 5G Americas (2017), '5G Services & Use Cases'.

Annex 3: Methodology

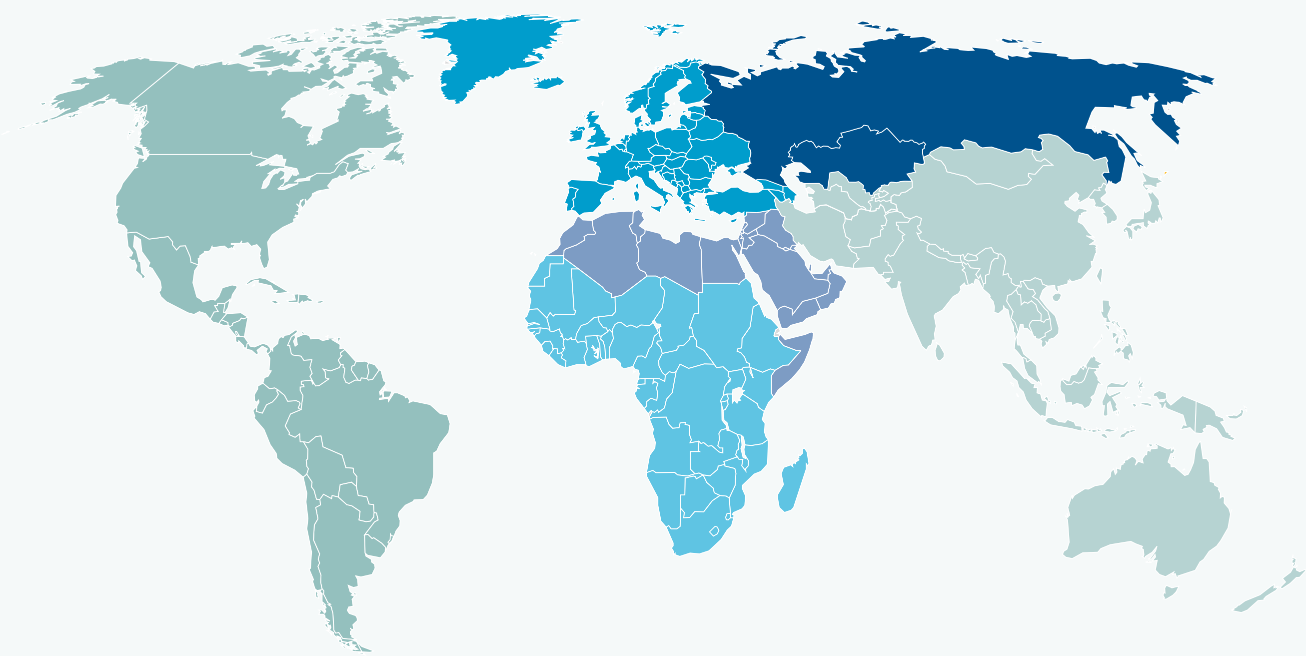
This benefit study is framed around forecasting economic contributions in terms of GDP and tax revenue resulting from the deployment of 5G networks and services and then identifying the contribution attributable to mmWave 5G services.

As opposed to a cost-benefit study, this study measures the contributions expected from 5G, but makes no assessment of the financial or opportunity costs involved in the 5G deployment. There is serious debate regarding the cost involved in making 5G services widely available. This study assumes that when demand matures for these higher functionality services, market conditions will enable demand to be met (i.e., the costs will be recoverable).

Significantly, however, this analysis implies that one critical market condition may not be met—the allocation of mmWave spectrum for those 5G applications that require it. The main differentiating characteristic of this study from other recent 5G-impact analyses is that it identifies the contribution that mmWave services make to the economy. This contribution can be similarly characterised as the lost benefit of not making mmWave spectrum available for 5G deployment.

The analysis is conducted in a bottom-up fashion using data at the country level. Four to six target countries per region were identified to be analysed individually, as well as six blocks of the remaining countries to treat as an aggregate rest of the region.

FIGURE 51. REGIONS AND KEY COUNTRIES SELECTED FOR IN-DEPTH ANALYSIS



Americas (4) Brazil, Colombia, Mexico, United States	**Europe (5)** France, Germany, Poland, Sweden, United Kingdom	**Asia-Pacific (6)** Australia, China, India, Japan, Papua New Guinea, Thailand
Americas (4) Egypt, Morocco, Saudi Arabia, UAE	**Africa (5)** Ghana, Kenya, Nigeria, Senegal, South Africa	**RCC (4)** Armenia, Kazakhstan, Russia, Uzbekistan

Source: TMG.

Inputs

For each of the target countries (28 target countries from 6 regions), the following country-specific information was gathered:

1. **GDP in USD from 2017;[12]**
2. **Annual GDP growth rate forecast;[13]**
3. **Structure of the economy in terms of output in 13 verticals;[14] and**
4. **Tax revenue as a percentage of GDP.[15]**

In addition to the 28 target countries, analogous attributes for the six rest of the region economies were generated based on the residual GDP of the relevant region and a representative GDP growth rate and economic structure.

For any given economy, 5G's contribution to GDP will be driven by trend lines for the rate of 5G enablement and the structure of the economy. As significant uncertainty remains regarding the impact of 5G within use cases, the dispersion of use cases within industries, and the timeframes of adoption, a consensus approach was adopted to derive the estimates for the overall impact and distribution of 5G's impact within the economy.

To estimate the increasing impact of 5G on the economy, trend lines were estimated using the GSMA forecast on 5G adoption rates,[16] considering historic experience with 4G adoption, and seeking opinion from a panel of experts from leading global manufacturing companies developing 5G technology.

These experts were provided a list of fourteen fully defined use cases. They were then asked to give their view on markets differentiated by region and degree of economic development. In particular, with respect to 5G they were requested to provide for each use case:

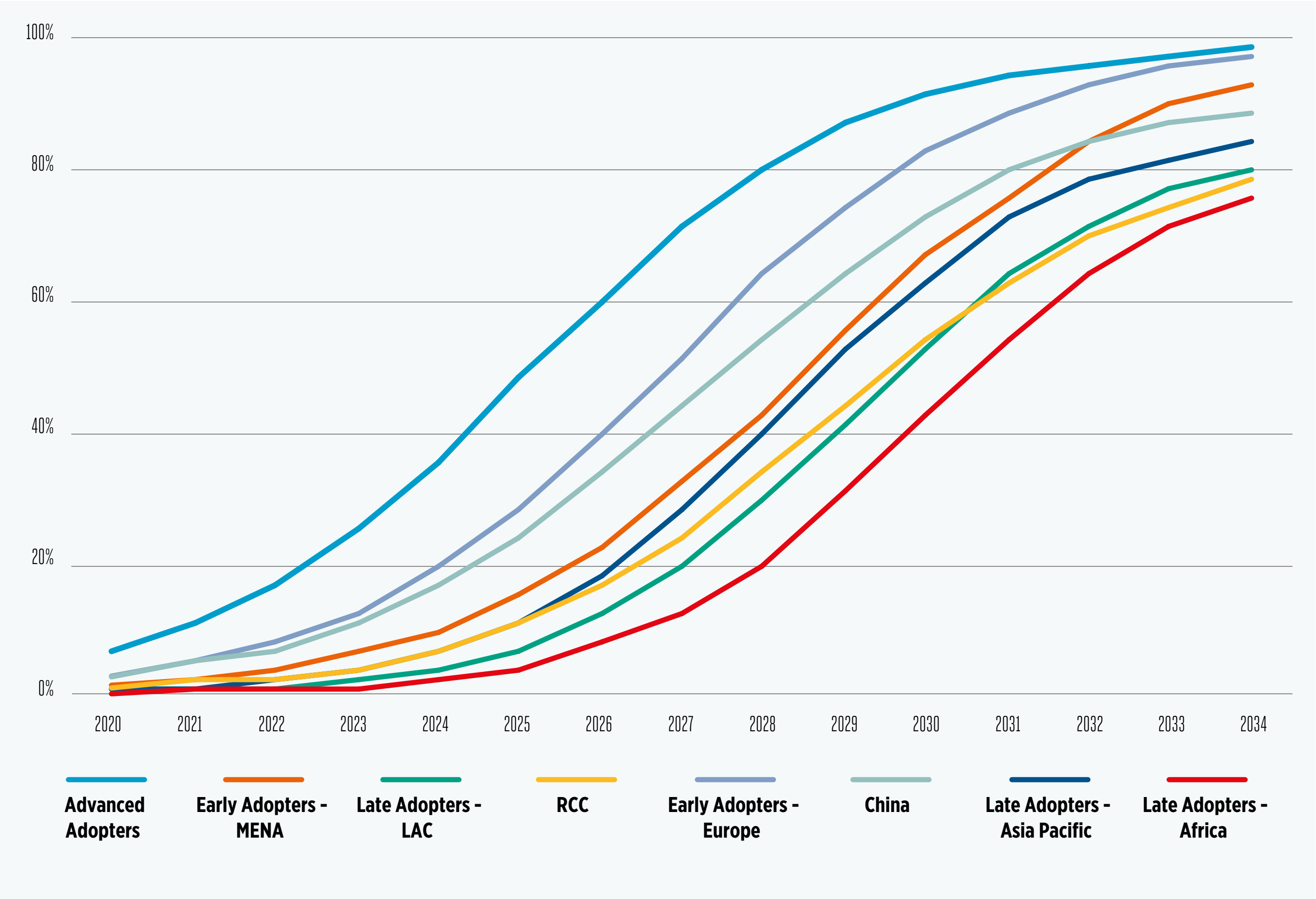
- In what year the expert thinks each use case will be initially deployed using 5G in these markets. It was explained that "initially deployed" meant the date when the 5G use case would likely be first commercially launched in the market.
- In what year the expert thinks each use case will reach maturity using 5G in these markets. It was explained that "reach maturity" meant the date when the growth rate in the 5G use case began to decline.

Eight distinct trends or economy types were recognized based on a combination of factors – the GSMA forecasts, historic experience, and key threshold years as identified by the experts. Figure 52 presents the 5G enablement assumed for each economy type. Table 1 provides the disaggregated example for advanced adopters.

One of the eight trend lines was applied to each country (target and residual) depending on the region and, within the region, based on the country's level of development, current status of 5G adoption, and previous experience with 4G adoption.

12. International Monetary Fund (2017), 'World Economic Outlook Database: Gross Domestic Product, current prices (U.S. Dollars),' https://www.imf.org/external/pubs/ft/weo/2017/02/weodata/index.aspx.
13. International Monetary Fund (2018), 'Real GDP Growth,' https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/OEMDC/ADVEC/WEOWORLD.
14. World Input-Output Database (2016), 'Release 2016, Socio Economic Accounts: All countries,' http://www.wiod.org/database/seas16; Eora (2014), 'Multi-region input-output table: 2014,' http://worldmrio.com/.
15. U.S. Central Intelligence Agency (2017), 'The World Factbook: Taxes and other revenues,' https://www.cia.gov/library/publications/the-world-factbook/fields/2221.html.
16. The Mobile Economy: Asia-Pacific 2018, p.18; The Mobile Economy: Europe 2018, p. 10; The Mobile Economy: Latin America and the Caribbean 2017, p. 16; The Mobile Economy: Middle East and North Africa, 2017, p. 17; The Mobile Economy: North America, 2018, p. 12; and The Mobile Economy: Sub-Saharan Africa 2018, p. 12.

FIGURE 52. UNWEIGHTED AVERAGE 5G ENABLEMENT BY ECONOMY TYPE



Source: TMG.

TABLE 1. ADVANCED ADOPTERS 5G ENABLEMENT ASSUMPTIONS

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
High-speed Broadband in the Home	0%	2%	4%	6%	11%	18%	29%	43%	57%	71%	82%	89%	94%	96%	98%
High-speed Broadband in the Office	0%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%	96%	97%
Ultra-Low Cost Networks in Rural Areas	0%	1%	1%	2%	3%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%
Dynamic Hot Spots	0%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%	96%	97%
Broadband to Special Events	0%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%	96%	97%
Broadband to Public Transport	0%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%	96%	97%
Broadcast-Like Services	0%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%	96%	97%
Connected Vehicles	0%	2%	4%	8%	14%	25%	40%	57%	73%	85%	92%	96%	98%	99%	99%
Smart Wearables	0%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%	96%	97%
Stationary or Near-Stationary Monitoring Networks	0%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%	96%	97%
Collaborative Robots/Complex Automation	0%	2%	3%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%
Remote Object Manipulation	0%	2%	4%	8%	14%	25%	40%	57%	73%	85%	92%	96%	98%	99%	99%
Virtual or Augmented Reality	0%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%	96%	97%
Virtual Meeting	0%	5%	8%	13%	20%	29%	40%	52%	65%	75%	83%	89%	93%	96%	97%

With respect to mmWave enablement, an analogous set of trend lines, based on expert opinion, were similarly developed. These trend lines represent how mmWave spectrum use is expected to grow by use case to become an increasing share of the 5G ecosystem. It was assumed that share would grow according to a linear progression to a given maximum. The experts were requested to provide for each use case by market type:

- What year the expert thinks mmWave spectrum would be used in the deployment of 5G for each use case.
- What percentage of the 5G business in each use case could be attributed to mmWave (vs. sub-6 GHz) in 2025.
- What percentage of the 5G business in each use case could be attributed to mmWave (vs. sub-6 GHz) in 2030.

The patterns identified by the experts appeared to follow kinked linear trends. One linear trend was identified for each of the eight economy types. Table 2 provides the simple average of the trend lines for the use cases for each of the eight country types. Table 3 provides an example of the disaggregated trend lines for the advanced adopters.

TABLE 2: UNWEIGHTED SHARE OF 5G MARKET ATTRIBUTABLE TO MMWAVE

	2020	2025	2030	2034
Advanced Adopters	3%	15%	32%	36%
Late Adopters LAC	0%	11%	22%	25%
Late Adopters Africa	0%	9%	19%	22%
Early Adopters MENA	1%	25%	32%	36%
RCC	0%	11%	22%	24%
China	0%	12%	21%	23%
Europe	3%	15%	32%	36%
Late Adopters Asia-Pacific	0%	11%	22%	25%

TABLE 3: EXAMPLE OF SHARE OF 5G MARKET ATTRIBUTABLE TO MMWAVE BY USE CASE: ADVANCED ADOPTERS

	2020	2025	2030	2034
High-speed Broadband in the Home	4%	20%	30%	38%
High-speed Broadband in the Office	4%	20%	30%	38%
Ultra-Low Cost Networks in Rural Areas	0%	1%	10%	10%
Dynamic Hot Spots	1%	3%	10%	10%
Broadband to Special Events	3%	20%	40%	50%
Broadband to Public Transport	4%	20%	40%	50%
Broadcast-like Services	3%	20%	40%	50%
Connected Vehicles	3%	15%	30%	42%
Smart Wearables	1%	3%	10%	10%
Stationary or Near-Stationary Monitoring Networks	1%	3%	10%	10%
Collaborative Robots/Complex Automation	4%	25%	50%	50%
Remote Object Manipulation	4%	25%	50%	50%
Virtual or Augmented Reality	4%	20%	50%	50%
Virtual Meeting	4%	20%	50%	50%

With respect to the structure of the economy, the relative size of verticals (extracted from WIOD and EORA databases) was used and the relative impact of 5G on the verticals was estimated. Because of the different impacts that broadband in general and 5G in particular will have across sectors, one cannot assume that the overall impact of 5G can be distributed across the economy in proportion to the respective economic shares of each vertical. Therefore, a coefficient was required to account for the relative impact of 5G on vertical output. To derive this coefficient, the literature on the historic impact of broadband and forecasted 5G impact by vertical was consulted. No study was completely satisfying in this regard. However, from Koutroumpis (2018) it was possible to test the relationship between the structure of the economy and the historic impact of broadband speed on GDP growth.[17]

17. Running multiple regressions using Koutroumpis (2018) results and OECD country data, we were able to establish that manufacturing, professional services, public service and EHS (Education, Health and Social Work) appeared more likely to benefit strongly from increasing broadband speeds. Agriculture, mining, utilities, construction and hospitality were less likely to enjoy a strong benefit.

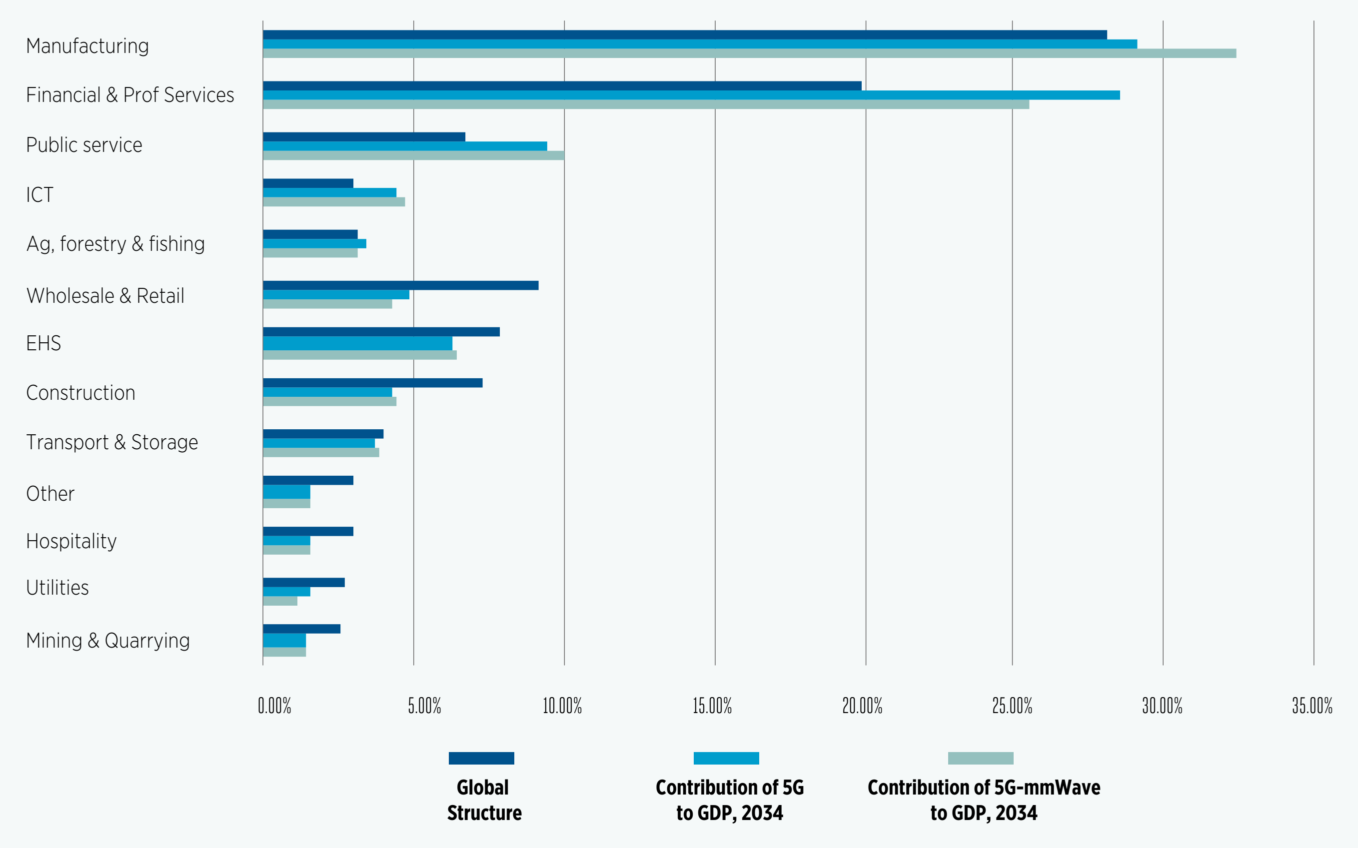
IHS Economics (2017) presented a forecast of the relative impact of 5G in the form of sales growth anticipated by various sectors of the economy resulting from 5G.[18] From these rankings, coefficients were derived that were most consistent with many of the vertical impact estimates found in the literature, e.g., IHS (2017) and Ericsson (2017).

Thus, the contribution of mmWave 5G in any given vertical is a function of two factors:

1. **The relative size of any particular sector within an economy; and**
2. **The relative impact the use case will have in the vertical.**

As shown in Figure 53, some verticals, like manufacturing and financial and professional services, which can productively use mmWave 5G use cases, contribute a disproportionately high amount to global GDP, and vice versa.

FIGURE 53. CONTRIBUTION OF 5G AND MMWAVE 5G TO GDP COMPARED TO STRUCTURE OF THE GLOBAL ECONOMY



Source: TMG.

18. IHS economics (2017) forecasts suggests that ICT is likely to benefit significantly more than its share in the output of the economy. IHS data show that agriculture, professional services and public services are likely to benefit somewhat more and the others somewhat less than their share of economic output.

The relevance of 5G use cases to verticals was also calculated. Again, based on recent studies of the significance of each 5G use case for each vertical, coefficients were developed that allowed the distribution of the 5G impact by vertical use case categories (See Table 4).[19]

The maximum annual growth rate, or peak impact of 5G contribution to economic growth was used as a reasonableness constraint. The maximum annual growth rate was set to 0.28% as this was the level estimated in a number of studies as the contribution of broadband and mobile telecommunications in general. For this analysis this made a reasonable conservative assumption for the limit of impact on GDP for next-generation mobile broadband.[20]

TABLE 4. USE CASE RELEVANCE BY VERTICAL

Use Case	Ag, forestry & fishing	Mining & Quarry-ing	Manu-fac-tur-ing	Utilities	Con-struction	Whole-sale & Retail	Transport & Stor-age	Hospi-tality	Info & Commu-nications	Fin & Profes-sional services	Public service	Health & Social work
High-speed Broadband in the Home	5%					5%			20%	10%	2%	5%
High-speed Broadband in the Office	5%	5%	5%	5%	5%	5%	5%	5%	20%	14%	5%	5%
Ultra-Low Cost Networks in Rural Areas	5%	5%							5%	7%		10%
Dynamic Hot Spots									5%			
Broadband to Special Events	5%	5%			5%				5%		15%	
Broadband to Public Transport							20%		5%	5%		
Broadcast-like Services						5%		5%	5%		5%	
Connected Vehicles	5%	13%				5%	23%		5%	17%	20%	
Smart Wearables		5%				20%			5%	17%		15%
Stationary or near-stationary monitoring Networks	34%	23%	20%	82%	34%	30%	23%	40%	5%	17%	30%	15%
Collaborative Robots/Complex Automation		15%	50%		5%	5%	11%		5%	3%		5%
Remote Object Manipulation	21%	16%	22%	10%	38%		15%		5%		15%	25%
Virtual or Augmented Reality	10%	10%			10%	22%		40%	5%	5%	5%	
Virtual Meeting	10%	3%	3%	3%	3%	3%	3%	10%	5%	5%	3%	20%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Source: TMG.

19. Sources include Ericsson (2018) The Industry Impact of 5G, pp. 6-7; and IHS Economics (2017, Appendix A.

20. See, page 17 and Appendix B of Australian Government (2018).

Workings and results

The foregoing assumptions allowed the study to calculate an increase in each country's GDP attributable to 5G, including the GDP increase attributable to mmWave spectrum. Note that this is an incremental increase in GDP above the baseline growth rate. Thus, at the end of the period, the next-generation scenario result will be greater than the GDP predicted on the basis of the IMF forecast.

The cumulative impact of these increments above baseline GDP represent the total contribution of 5G to the economy in any given year.

The GDP results (for both 5G generally, and mmWave 5G specifically) are top-down distributed through to verticals and use cases based on their relevance to technologies.

Based on the tax-to-GDP ratio, estimates of the contribution of 5G and mmWave 5G services to taxes collected in each country were calculated. The tax results were distributed through to verticals. These do not include spectrum fees and payments.

All of these country results were then summed to provide regional and global outcomes.

Floor 2, The Walbrook Building
25 Walbrook, London EC4N 8AF UK
Tel: +44 (0)207 356 0600

spectrum@gsma.com
www.gsma.com