The Socio-Economic Impacts of 5G

Prepared for TELUS Communications Inc.

Full Report

Deetken Insight

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Executive Summary

5G provides the network foundation for the next generation of digital technologies and services that will advance Canada's standard of living and help address key challenges including climate change.

Deetken Insight was commissioned by TELUS to complete a comprehensive review of published research about 5G and its potential socio-economic impacts, with a particular focus on Canada. The research highlights a compelling value case for a robust nationwide 5G network. Because of its 10-fold performance improvements over 4G, 5G will drive economic growth across sectors and improve quality of life across communities. Given the right conditions, 5G and 5G-enabled technologies will:

- Increase economic growth across **all sectors**, delivering an estimated 16% of GDP growth by 2036 while supporting growth in high-paying digital economy jobs
- Reduce **greenhouse gas emissions** up to 20% and deliver other environmental benefits such as more sustainable agricultural practices
- Increase the productive capacity of **rural communities** through the deployment of 5G fixed wireless access (FWA) where last-mile fibre is not feasible
- Improve **healthcare** system performance, including enabling the expansion of rural and virtual care models
- Deliver new interactive capabilities built on augmented and virtual reality and artificial intelligence that enhance the **quality of life** for older Canadians and those living with disabilities
- Increase crop yields and optimize water, pesticide, herbicide, and fertilizer use for the **agriculture** sector

The report presents an exhaustive overview of emerging use cases and the potential economic and socio-economic benefits of 5G in 11 sectors. It also describes what steps the public sector, mobile network operators, and other industry stakeholders should take to accelerate the successful deployment and adoption of 5G. Chief among these steps are:

- The **speedy release of spectrum** that enable the majority of high value use cases that bring benefits to all sectors and to rural and other underserved communities; and
- The development of a **digital infrastructure strategy and three-year roadmap**, led by the federal government, that lays a path toward achieving success targets with respect to 5G infrastructure deployment and adoption across urban and rural communities.

An ambitious yet coordinated approach to the rollout of 5G is critical to ensuring the benefits are achieved while also ensuring Canada's 5G networks and the applications that run on them are reliable and resilient. And yet Canada, despite the benefits of 5G, is behind its global peers in its deployment and adoption to date. Urgent action is required to get Canada back on track and demonstrate global leadership in 5G. Digital innovation, enabled by 5G, should be a **cornerstone of Canada's prosperity and sustainability agendas**.

Key Takeaways

5G is the fifth-generation wireless mobile network technology that delivers substantial performance improvements over the current 4G technology.

Launched in early-adopter markets in 2018, 5G technology will provide 10 times or greater performance in data speed, latency, traffic capacity and other characteristics compared to 4G. Because of these performance advantages, 5G widens the scope of what is possible in terms of new digital services such as artificial intelligence and augmented and virtual reality. It also provides the capability to massively scale connectivity between a multitude of devices and sensors, enabling the Internet of Things (IoT) and related applications such as self-driving vehicles.

The capabilities of 5G will unlock fundamentally new sources of value across *all* sectors of the economy.

The improvements of 5G over 4G provide for value-generating use cases across sectors. Whereas 4G enhanced the consumer experience and brought benefits mostly to industries that served applications to smartphone devices (such as online shopping, online advertising, and ride-hailing services), 5G promises benefits to health, agriculture, energy, manufacturing, government, and other sectors. It enables technologies such as autonomous vehicles, remote-operated robots, virtual and augmented reality, artificial intelligence, and machine learning to be deployed safely and with precision in urban and remote locations.

5G could deliver an estimated 16% of Canada's Gross Domestic Product (GDP) growth by 2036.

5G and the innovation it enables will create economic growth through increases in productivity, the efficiency with which inputs are used to create output. Productivity matters because it is by far the most significant driver of Canada's standard of living as measured by growth in GDP per capita, which itself is strongly correlated over the long run with wage growth. In a 2021 forecast, the OECD places Canada last among advanced economies in GDP per capita growth between 2020 and 2030. Finding ways to increase productivity, including the deployment and adoption of 5G, is critical to correcting this course. 5G drives productivity growth by making it easier and cheaper to use technologies that run on mobile and fixed networks. For example, 5G is a necessary factor to make it economical to build self-driving vehicle systems or deploy remote-operated robots for mineral extraction. Based on published estimates and independent modelling by Deetken, 5G will enable real GDP growth in Canada of $30 billion to $50 billion by 2030 and $100 billion to $120 billion by 2036. The midpoints of these ranges represent roughly 14% of economic growth by 2030 and 16% of growth by 2036.

5G also helps enable high-quality job growth.

According to the Information and Communications Technology Council (ICTC), employment growth in the digital economy will continue to outpace employment growth in the general economy and will account for roughly 11% of total employment in Canada by 2025. Average earnings in the wireless sector are almost 25% higher than in the wider business sector.

5G will help reduce greenhouse gas emissions by up to 20%.

Many 5G use cases have commercial viability because they reduce energy requirements, such as smart electricity grids, smart transportation systems to optimize traffic patterns and reduce congestion, smart buildings to optimize energy use, and enhanced capabilities for remote work and machine operation. A corollary benefit of the reduction in energy usage is a decline in GHG emissions to the extent these energy requirements are currently met by burning fossil fuels. Put simply, without universal connectivity to high-quality networks, Canada will be unable to meet its climate targets.

5G will deliver health and other social benefits.

Social benefits of 5G include more effective and efficient healthcare service delivery and higher agricultural productivity to feed a growing global population. 5G also creates opportunities for new software applications to enhance the quality of life for traditionally disadvantaged populations, including older citizens and those living with disabilities.

5G will help reduce digital divides impacting rural and other underserved communities.

5G-enabled fixed wireless access (FWA) will allow network operators to deliver wireless ultra-high-speed broadband internet to homes and businesses in rural, remote, and Indigenous regions where last-mile fibre is unfeasible. This infrastructure will help ensure the same level of performance and access to leading digital services is available to all communities. 5G FWA eliminates the need for costly deployment of deep-fiber fixed access infrastructure while also offering peak rates that few fixed technologies can match. By delivering broadband over newly available 5G networks, telecommunications operators can help bridge the digital divide and offer connectivity to a broader population and reach underserved areas.

Canada is lagging its peers in the deployment of 5G.

Despite its market-leading performance in 4G and the transformational benefits of 5G, Canada is lagging its peers in the deployment of 5G. Compared to the U.S., Germany, Japan, Italy, Australia, and South Korea, Canada's 5G spectrum allocations for mid- and high-band frequencies are one to five years behind. 5G deployment in Canada has been limited to low-band networks, largely due to low-band 5G networks being cheaper to deploy on a non-standalone basis alongside existing 4G networks, and because, until recently, only low-band 5G spectrum has been available for use.

5G adoption and harnessing the value of 5G depends on a host of factors, such as innovation partnerships to test new technologies and a robust workforce with relevant skills.

Most of the use cases reviewed for this report are in their infancy. There are complementary technologies such as edge computing that will need to be integrated into the 5G ecosystem. Partnerships between government, regulatory bodies, mobile network operators, other industry sectors, and research institutions will be critical to build and test new ideas using 5G as the platform. Mechanisms to ensure network resiliency and access to critical services in case of outages are required to build business and consumer confidence. A reskilling of the workforce for a digital economy is essential to success. Organizations will need to experiment and adjust their

business and operating models to leverage new technologies. These and other factors are necessary to achieve the value proposition of 5G. Deployment of the underlying network infrastructure presents a separate set of challenges, including the need for mobile network operators to make the necessary capital investments. Estimates suggest the total cost of ownership for Canadian 5G networks could be over 50% more expensive than for 4G networks.

To ensure that Canadians realize the full benefits of 5G, Canada urgently needs a national digital infrastructure strategy. The federal government in collaboration with key 5G ecosystem stakeholders and other levels of government, should develop a comprehensive and integrated three-year digital roadmap to enable the 5G network. This roadmap should **address seven key outcomes for 5G deployment and adoption**:

1. **Timely access to 5G relevant spectrum** across all bands with **expedited clearing/repurposing of bands** that are currently in use by other services
2. Reinforcement of **resilient network infrastructure** with appropriate coverage, bandwidth, latency and reliability, supported by government investments to achieve key objectives such as equitable access and performance across urban, rural and remote communities
3. Availability of **connected devices, software and applications** to take full advantage of the capabilities of 5G that are compatible with local spectrum allocation and in line with harmonized global standards.
4. Regulatory flexibility to support network operators' development of **tiered services** with differentiated pricing and service levels that are targeted to different market segments and key sectors through partnership models among 5G ecosystem participants
5. Creation of **unified national standards** for spectrum, network hardware, endpoint devices, security, privacy, software and applications that are strongly interlocked with global standards to support the timely and responsible deployment and adoption of 5G
6. Intensification of current **network security and data privacy** policies to address new vulnerabilities introduced with 5G (e.g., unintended leaks of personal or security data, authentication attacks, location discovery, etc.)
7. Definition and implementation of a **performance management framework,** including operational and sector specific metrics, to track the performance and socio-economic contributions of 5G with the leadership of federal agencies including the Canadian Radio-television and Telecommunications Commission (CRTC) and Statistics Canada who can design, coordinate and monitor progress.

This report provides detailed actions that key stakeholders such as government and mobile network operators should undertake to achieve these outcomes. Similar coordinated approaches as proposed in this report are currently in place in jurisdictions such as the United Kingdom, Finland, and China. The report also outlines a set of metrics to form the basis of a performance measurement framework per outcome #7 above.

Moving forward with this strategy will demonstrate Canada's continued global leadership and competitiveness in telecommunications services.

Canada has proved itself a global leader in 4G performance and nationwide availability. The stakes are high for Canada to achieve the same level of excellence in the future with next-generation 5G technology. This technology is at the heart of the next wave of digitalization that will drive much-needed productivity gains while also reducing GHG emissions and delivering other socio-economic benefits. The scale of transformation is significant. For example, Canadian wireless network operators will need to spend approximately $26 billion to deploy 5G infrastructure.

Conclusion

It is crucial that government and stakeholders understand the importance of 5G in enabling the next wave of digital innovation. A coordinated approach to develop a three-year roadmap with key success measures is a necessary next step for Canada to catch up to its peers and achieve the considerable economic, environmental, and social benefits made possible by 5G networks.

1 Introduction

1.1 Objectives and Rationale

Mobile networks play a critical role in how economies and societies function. They are depended upon by government and businesses alike to deliver products and services and by citizens to access core public services, engage with their communities, and participate in the economy.

5G is the fifth-generation wireless mobile network that will succeed fourth-generation (4G) technology. Because of its substantial performance improvements over its predecessor, 5G will create opportunities for new and enhanced capabilities, services and experiences delivered to the mobile device.

Achieving the very best that 5G can enable – including economic, environmental and social benefits – is a matter of public interest. To that end, TELUS Communications Inc. commissioned Deetken Insight to prepare a report that presents an evidence-based, thorough, and balanced perspective on the most important questions pertaining to 5G and its potential contributions to economic performance and environmental and social welfare.

Further, the report aims to provide a firmer foundation for policy discussions and evidence-based decision-making among government, industry, and other stakeholders. Finally, the research supports TELUS's thought leadership at a national level to advance Canada's aspirations to lead in the responsible deployment and adoption of next-generation telecommunication infrastructure and enabled services.

1.2 Report Structure

Section 2 provides background on 5G: what it is, how it is different from 4G, its capital and operating cost requirements, and how its roll-out in Canada compares to that in other countries.

Section 3 presents overviews of emerging use cases of 5G in eleven sectors based on a systematic review of available research. Both economic and socio-economic (environment, social, governance) impacts are described for each sector. Additional "deep dive" detail is provided for three sectors – Health, Agriculture and Energy.

Section 4 presents estimates of 5G's potential contribution to Canada's economy in terms of gross domestic product (GDP) over the next 15 years. The estimates draw on published reports as well as independent modeling by Deetken.

Section 5 summarizes the potential environmental and other socio-economic benefits that 5G can enable, using ESG (Environment, Social and Governance) as an organizing framework for the findings.

Section 6 outlines recommended actions that government, mobile network operators and other key stakeholders should take in collaboration to ensure the successful deployment and adoption of 5G technology. It also includes a proposed performance measurement framework to measure deployment and adoption success.

1.3 Methodology, Scope, and Limitations

Deetken undertook a systematic review of research studies, whitepapers, and articles related to 5G future deployment, economic, environmental, social and regulatory impacts to create this report. Systematic review refers to any effort that synthesizes a body of literature in a logical, transparent, analytical, and repeatable manner whether that literature includes studies that use quantitative or qualitative methods.[1] It includes appraising the quality of the data and a synthesis of research data. A systematic review entails five stages:

1. **Framing objectives, rationale, and corresponding questions(s) to design a useful systematic review:** Best practice recommends publishing the protocol of the review before initiating it. Protocol describes the rationale, hypothesis, and planned methods of the review.
2. **Searching and identifying relevant data sources:** Create a predetermined plan for the search for relevant data from research that matches certain criteria in developing a rigorous systematic review. Relevant criteria can include only selecting research that is good quality and answers the defined question.
3. **Selecting relevant data from the data sources according to the review method**: Study quality assessment is relevant to every step of a review. Question formulation (Step 1) and study selection criteria (Step 2) should describe the minimum acceptable level of design.
4. **Analyzing and combining the data:** This step provides an overall result from all the data. Because this combined result uses qualitative or quantitative data from all eligible sources of data, it is considered more reliable as it provides better evidence.
5. **Interpreting the findings:** The conclusions of the systematic review, along with policy change recommendations and implications should be clearly linked to the research findings and outcomes.

The rationale for undertaking a systematic review approach is its usefulness in promoting evidence-based policy decisions. The approach summarizes the results of multiple studies, allowing policymakers to understand both the average effect across studies and its variability, thus leading to more informed decisions about important policy issues.

For this report, Deetken developed a comprehensive set of research questions based on the objectives and rationale, to inform the protocol of the review. The team then conducted a rigorous desktop literature search by leveraging search engines such as Google Scholar, Microsoft Academic, Educational Resources Information Center (ERIC), ResearchGate, COnnecting

[1] Refer to the following resource for more information about conducting a system review: https://journals.sagepub.com/doi/full/10.3102/0034654319877153.

REpositories (CORE) and Semantic Scholar to name a few. The search was systematic in the sense that the search used terms, strings, databases, limiters, and tools that were sensitive enough to capture all relevant studies associated with our topic of interest – including the attributes, socio-economic benefits, challenges, and government and regulatory policy implications of 5G.

To select the relevant studies from the searches, the Deetken team undertook two reviews of the literature identified from the searches. A pre-screening was completed to decide which literature to retrieve in full, and the second review focused on deciding which literature should be included in our study. The criteria for report selection for our study were:

1. exclusion of unrelated, duplicated, unavailable full texts, or abstract-only papers. These exclusions were stated in advance to refrain the researcher from bias.
2. inclusion of literature which contained information answering our research questions. Most importantly, it included reports that had clear and sufficient information, including positive or negative, to answer our question.
3. ensure that the selection of eligible literature was based on similar study designs, the depth and breadth of analysis, and the credibility of the source based on prior research as well as the reputation of the source in government, regulatory and business circles.

Throughout the review, prioritization, and selection of literature for this study, the Deetken team was mindful of potential biases that would otherwise compromise the findings of our report. There are several biases that can cause distortions in the literature investigation and analysis and conclusions in a systematic review. However, there are certain types of bias to which systematic reviews are more susceptible to. These biases can be classified in the following categories:

1. selection bias – occurs when a systematic review does not identify all available data and points of view on a topic. It is also closely related to confirmation bias, publication bias or reporting bias; and
2. information bias – any systematic difference from the truth that arises in the collection, recall, recording and handling of information in a study, including how missing data is dealt with. Major types of information bias are misclassification bias, observer bias, recall bias and reporting bias.

Literature assessment and synthesis were carried out by two reviewers and consensus on the selection of the literature was reached through discussion. In all, the team drew on over 250 research studies, whitepapers, and articles related to 5G future deployment, economic, environmental, social and regulatory impacts for this report. Studies and research papers are included in the bibliography, while footnote citations include links to all cited sources.

The limitations of our study are as follows:

1. **Data limitations:** While the Deetken team adhered to the guidelines for a systematic review, any methodological deficiencies in our sourced literature will impact the quality of our findings and conclusions in this report. Accordingly, we provide no opinion, attestation, or other form of assurance with respect to the completeness, accuracy, fair presentation, and findings from research of others that are presented in this report.

2. **Reliance on English language secondary data:** This report may not have captured non-English literature on our topic of interest.
3. **Availability of new data:** The report relies on all literature that is currently available in both the public and to a great extent in the private domain (subscription-based literature) as of the finalization of this report. While the focus is on Canada, the research extends beyond Canada, and for some topics, research published about Canada is limited or non-existent.
4. **Forward-looking information, statements, and conclusions:** This report contains forward-looking statements within the context of the 5G technology evolution. Statements that are not historical facts, including statements about deployment and customer uptake expectations as well as future socio-economic impacts of this technology, are forward-looking statements. These forward-looking statements have been based largely on expectations and projections about future events and are therefore subject to several uncertainties that could potentially cause actual results and experience to differ materially from any forward-looking statements in this report.

2 5G Analysis and Current Status

Key Takeaways

- Fifth-generation (5G) technology standards for broadband mobile networks are an integral part of Next-Generation Communication Networks that are steering a significant redesign of advanced, high-speed communication access network infrastructures. At peak performance, 5G will 1) be 10 to 20 times faster than fourth-generation (4G) technology standards; 2) have 10 times lower latency than 4G; and 3) support 100 to 1000 times higher traffic capacity than 4G.
- 5G's capabilities enable a diverse range of use cases that can be categorized across four main types of connected services: 1) enhanced mobile broadband (eMBB); 2) ultra-reliable and low-latency communications (URLLC); 3) massive Internet of Things (mIoT); and 4) fixed wireless access (FWA). Together, these services provide a variety of benefits, such as increased productivity and better rural-urban integration and reduced greenhouse gas emissions.
- Key requirements for seamless *deployment* of 5G network infrastructure are 1) alignment on regulatory standards; 2) availability of the appropriate type and quantity of spectrum; 3) collaboration among participants in the digital ecosystem; and 4) significant capital and ongoing operating investments.
- Major challenges to the *adoption* of 5G and related services enabled by 5G that will need to be addressed are 1) lingering security, privacy and health uncertainties in the minds of regulatory bodies and consumers; 2) the immaturity of 5G standards, ecosystem and technology; 3) collaborations and alignment amongst multiple stakeholders; and 4) investment requirements across the end-to-end 5G value chain.
- Canada's rollout of 5G has lagged that of other leading countries despite its leadership in 4G performance and availability. This is a result of 1) Canadian network operators facing higher capital expenditure requirements due to Canada's land mass, less dense and highly dispersed population, difficult topography and cold climate; 2) late spectrum auctions with the most expensive per-unit spectrum prices in the world; and 3) reduced revenues stemming from Canada's service-based competition incentives.

Economies are becoming increasingly dependent on advanced communication networks supported by Next-Generation Network[2] (NGN) technology. NGN's new tools and capabilities (e.g., fibre optics, software-defined networking, 5G) enable the provision of comprehensive

[2] As defined by the International Telecommunication Union, an NGN is "a packet-based network able to provide Telecommunication Services to users and able to make use of multiple broadband, quality of service-enabled transport technologies and in which service-related functions are independent of the underlying transport-related technologies. It enables unfettered access for users to networks and to competing service providers and services of their choice. It supports generalised mobility which will allow consistent and ubiquitous provision of services to users." (https://www.itu.int/en/ITU-T/gsi/ngn/Pages/definition.aspx).

broadband coverage that can support the increasing amounts of data generated by an expanding ecosystem of mobile devices, cloud-based applications, and artificial intelligence-enabled Internet of Things (IoT) sensors. NGN technology is enabling rapid digitalization and convergence of fixed and mobile broadband networks and services into a single seamless communication architecture and essentially paving the way for the Fourth Industrial Revolution, or "Industry 4.0". A nascent surge of NGN-based innovations is already beginning to unlock new avenues for economic growth across various industries.[3] To maintain this momentum, "governments at all levels must support research and development, and Canadian academic researchers, government labs, and enterprises must redouble innovation efforts to advance and commercialize Canadian-developed intellectual property in NGN."[4] As a core component of NGN, this applies especially to 5G technology.

5G is the fifth-generation wireless mobile network that will succeed fourth-generation (4G) technology. Launched in early-adopter markets in 2018, 5G technology significantly improves upon its predecessor in three key performance areas: data speed, latency and device connection density.[5] However, 5G is not simply an incremental evolution over 4G networks: while 5G technology improves upon the mobile device connectivity previously enabled by 4G networks, it goes a step further and enables connections between *everything else*. 5G will deliver entirely new ways of using mobile networks and thus serve as a platform for significant innovation. "In the same way that no one predicted an application such as ride hailing (e.g., Lyft, Uber) when operators first deployed 4G, … many applications for 5G remain to be invented."[6]

5G will play an integral role in NGNs and digitalization. The convergence between wireless and wireline networks that results from increased connectivity necessitates the development of robust 5G networks that provide ubiquitous geographic coverage and support various potential business use cases. 5G technology is especially crucial for the transition toward the Internet of Everything (IoE) that will enable the vast and reliable connectivity required for the future vision of the digital economy, from autonomous vehicles to wearable computing. 5G technology will be the key infrastructure upon which these applications are delivered.

2.1 Key 5G Network Components and Attributes

The various features and benefits directly and indirectly attributable to 5G technology are listed as follows:

[3] Link to source: https://www.cengn.ca/wp-content/uploads/2021/08/CENGN_ExecSummaryRecs.pdf.
[4] Ibid.
[5] Link to source: https://www.accenture.com/_acnmedia/PDF-130/Accenture-Greece-Race-to-5G-Full-Report.pdf#zoom=50.
[6] Link to source: https://www.5gamericas.org/wp-content/uploads/2022/01/Cellular-Communications-in-a-5G-Era-InDesign.pdf.

TABLE 2.1: KEY 5G NETWORK COMPONENTS AND ATTRIBUTES[7]

Feature / Benefit	Description
1. Faster data speed	5G is anticipated to be up to 100 times faster than current 4G networks. 5G will offer speeds up to 20 gigabits per second (Gbps) and the ability to download a full high-definition (HD) movie in under 10 seconds, which would otherwise take roughly 10 minutes on 4G. Files and applications will be able to be accessed instantly, without waiting. Higher data speeds will also allow for more intensive use of cloud computing and thus allow devices to rely less on internal processing. 5G networks will be better equipped to support the proliferation of big data analytics (BDA) and real-time artificial intelligence/machine learning (AI/ML) applications. Moreover, 5G's speed will enable wireless service providers to compete directly with fixed broadband in ways that were previously unfeasible with 4G.
2. Lower latency	Users on 5G networks will experience much less delay or lag while using their mobile devices. With 4G networks, latency is roughly 40 to 50 milliseconds. Latency under 5G networks may be one millisecond or less, which is undetectable to the user and will consequently enable near-instantaneous remote manipulation of processes that require even the utmost precision. Lower latencies will be further supported by edge cloud infrastructure, as well as cloud-native functions.
3. Greater application capacity	5G infrastructure will have greater overall capacity – between 10 to 100 megabits per second (Mbps)/m^2, compared to 4G's 0.1 Mbps/m^2. This will allow networks to handle many more high-demand applications at once, including connected vehicles, IoT devices, virtual reality experiences and ultra-HD video streaming.
4. Better reliability	5G networks are anticipated to be more reliable than 4G networks, implying no dropped calls or connectivity. This will enable more critical use cases such as those pertaining to digital healthcare, autonomous vehicles and remote manipulation.
5. High device connection density	5G will be able to support up to one million devices per square kilometre, compared to 100,000 devices per square kilometre that can be supported by existing 4G networks. 5G will be capable of supporting almost any type of connected device, including sensors, machines, wearables, vehicles or industrial robots. Advanced sensor and machine technologies can be leveraged to accurately create digital twin representations that allow for the analysis of different scenarios, both present and future.
6. Expanded operating frequency range	5G will operate in a variety of different frequency bands, including 700 megahertz (MHz), 2 gigahertz (GHz), 3.4-3.8 GHz and 26 GHz. In comparison, 4G only operates in the band between 2 and 6 GHz. 5G's ability to operate across various frequency ranges provides a level of flexibility that can be exploited by service providers to address different needs across the network.
7. Superior network flexibility	5G networks, in tandem with network slicing, enables users to enjoy requirement-specific tailored connectivity and data processing that adhere to a Service Level Agreement (SLA) agreed upon by mobile operators. Customisable network

[7] The following sources were used to inform the contents of this table: 1) https://www.accenture.com/_acnmedia/PDF-130/Accenture-Greece-Race-to-5G-Executive-Summary.pdf; 2) https://www.gsma.com/security/securing-the-5g-era/; 3) https://d1p0gxnqcu0lvz.cloudfront.net/documents/Big_Inversion_whitepaper_Bell_Labs_Consulting_2021.pdf; 4) https://foryou.ericsson.com/eso-network-slicing-value-potential-report.html; and 5) https://doi.org/10.1186/s13673-020-00258-2.

Feature / Benefit	Description
	capabilities include data speed, quality, latency, reliability, security and services. 5G network slicing use cases will include higher bandwidth for video, higher speeds, and wide-scale availability; extensive machine-type communication monitoring of transportation and control; and critical machine-type communication with remote operations. Moreover, 5G networks will better facilitate network-as-a-service business models that reduce upfront capital investments and mitigate business risk by scaling operations elastically as demand shifts and applications change.
8. Improved battery life	5G is anticipated to extend the battery life of devices by up to 10 times.
9. Enhanced security	5G will incorporate enhanced end-to-end security features, such as new mutual authentication capabilities and enhanced subscriber identity protection, to address the numerous threats faced in current 4G networks. 5G technology also enables additional preventative measures to protect its massively increasing threat surface, such as blockchain-based ledgers and machine learning-based pattern recognition in real-time.
10. Better private networking options	5G will also enable the usage of private networks that range from Standalone Non-public Networks (SNPNs), with minimal dependence on the external wide area network, to Public Network Integrated NPNs (PNI-NPNs), which share many access and core functions with external networks. These could use licensed, unlicensed, or shared-license spectrum and utilize network slicing to provide end-to-end service guarantees from the end device(s) to the edge cloud and between all the other application and service components.

Similar to how 4G improved upon third-generation (3G) networks, 5G's capabilities are an order of magnitude above those of 4G across various key metrics:

TABLE 2.2: PERFORMANCE CHARACTERISTICS OF 3G, 4G, 5G[8]

Characteristic	3G	4G	5G
1. Peak data rate	21 Mbps	1 Gbps	20 Gbps
2. Latency	100 milliseconds (ms)	10 ms	1 ms
3. Connection density	10,000 devices/km^2	100,000 devices/km^2	1,000,000 devices/km^2
4. Area traffic capacity	0.001 Mbps/m^2	0.1 Mbps/m^2	10-100 Mbps/m^2
5. Mobility[9]	N/A	350 km/h	500 km/h

[8] The following sources were used to inform the contents of this table: 1) https://doi.org/10.1186/s13673-020-00258-2; and 2) https://carrier.huawei.com/~/media/CNBGV2/download/program/Industries-5G/5G-Impact-on-Industry-Verticals.pdf.

[9] Maximum travel speed at which a user is able receive to satisfactory performance such as upload and download speed.

Characteristic	3G	4G	5G
6. Spectral efficiency[10]	0.6x	1x	3-4x
7. Network energy efficiency[11]	0.1x	1x	>10x

Together, 5G's various features and improvements over 4G enable a diverse range of new mobile wireless use cases that can be divided into four main categories:

TABLE 2.3: 5G USE CASE CATEGORIES[12]

Use Category	Description	Business Need	Verticals
1. Enhanced Mobile Broadband (eMBB)	The most obvious extension of mobile network capability, eMBB allows mobile network operators (MNOs) to deliver higher data throughputs and capacity for a range of consumer applications, such as streaming, web access, video calling and AR/VR, including during mass gatherings where current 4G technology is often stretched to its limits. Highest speeds will occur in small cells with lower user mobility. This is the focus of 5G's initial rollout and the use category with which end users are most familiar. A 2019 survey by Global System for Mobile Communications (GSMA) found that 72% of Canadians identify improved mobile data speed as 5G's biggest differentiator from 4G, while only 27% on average identify 5G's broader capabilities listed below.[13]	AR/VR 4K/8K streaming on mobile devices Increased service capacity Immersive media Private networks Remote work and education/training	Retail Public Administration Arts and events
2. Massive IoT (mIoT)	Also referred to as Massive Machine-Type Communications (mMTC), mIoT expands on Long-Term Evolution (LTE) technology's existing IoT capabilities to support huge numbers – tens of billions – of hyper-intelligent, autonomous devices with lower costs, enhanced coverage, and long battery life. As such, mIoT will enable numerous use cases across several industry verticals	Remote monitoring Smart manufacturing and connected factories Smart cities Smart infrastructure Precision agriculture	Agriculture Utilities Manufacturing Public administration

[10] Relative to 4G.

[11] Relative to 4G.

[12] The following sources were used to inform the contents of this table: 1) https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165916&file=051120-5G-in-Canada.pdf; 2) https://www.qualcomm.com/media/documents/files/ihs-5g-economic-impact-study-2019.pdf; and 3) https://www.accenture.com/_acnmedia/PDF-130/Accenture-Greece-Race-to-5G-Executive-Summary.pdf.

[13] Link to source: https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165916&file=051120-5G-in-Canada.pdf.

Use Category	Description	Business Need	Verticals
	that deliver production efficiencies and environmental benefits. Improved low-power requirements, greater spectrum flexibility and improved coverage will all drive significantly reduced costs within mIoT that will enable its immense scale and induce greater adoption of 5G technology.	Asset control Drone delivery, field service and maintenance	
3. Ultra-Reliable and Low-Latency Communications (URLLC)	URLLC enables new wireless "mission critical" applications requiring low latency and is driven by high dependability and extremely short network travel time. Industrial automation, drone control, medical remote applications and autonomous vehicles will all leverage URLLC. Many of these use cases are emerging markets; growth will be dependent on market innovation and development of appropriate regulation, as well as the comprehensive deployment of 5G networks. While growth in URLLC applications may take longer to accelerate, their overall impact to society is expected to be tremendous.	Autonomous cars and mass transit Safety-critical applications Remote robotics Real-time translation AR-assisted factory maintenance Remote patient monitoring and telehealth	Manufacturing Utilities Oil & gas Transportation Healthcare
4. Fixed Wireless Access (FWA)	5G will allow MNOs to deliver ultra-high-speed broadband internet to homes and businesses in lower density locales where last-mile fibre is unfeasible. 5G FWA eliminates the need for costly deployment of deep-fiber fixed access infrastructure while also offering peak rates that few fixed technologies can match. By delivering broadband over newly available 5G networks, operators will have the business opportunity to bridge the digital divide and offer connectivity to a broader population and reach the underserved areas ensuring the ubiquitous coverage necessary for all to benefit from the digital economy.	Residential, commercial, wholesale and rural broadband services Private networks Remote work and education/training	Education Healthcare Utilities Public Administration

Unlike 4G networks, 5G networks are capable of operating within a variety of different spectrum bands, with each playing a different role in realizing the full extent of 5G's benefits and use cases listed above. The various spectrum bands being made available for 5G use can be broadly categorized as low-, mid- and high-band. These three ranges each possess different strengths and weaknesses and would be generally deployed as follows:

TABLE 2.4: 5G FREQUENCY RANGES AND RELATED SPECTRUM BANDS[14]

[14] The following sources were used to inform the contents of this table: 1) https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf; 2)

Frequency Range	Use Cases	Spectrum Bands	Priority
1. **Low-band** *(sub 1 GHz)* Frequency bands that support the widest coverage and best indoor penetration at the expense of data speed. Low-band networks are ideal for attaining ubiquitous coverage and closing the urban-rural digital divide. Low-band performance is considered an improvement on current 4G capabilities.	Geographic coverage Consumer applications Transport connectivity	**700 MHz band** *(694 – 790 MHz)*	**High -** The sub 1 GHz spectrum is well-suited to the rollout of broad network coverage at relatively low cost. It provides deep and large coverage for eMBB, IoT and low latency applications and services and can be used in the 5G context to ensure adequate coverage.
2. **Mid-band** *(1 – 6 GHz)* Frequency bands that will be capable of providing a good mixture of coverage, capacity and data speeds. Mid-band spectrum is highly valued; networks deployed on these bands combine the positive attributes of low- and high-band frequencies and could, therefore, enable more demanding applications whose requirements exceed the capabilities of low-band networks while also covering larger areas than high-band networks.	Geographic coverage Consumer applications Autonomous driving Smart cities Smart infrastructure Smart wearables	**L-band** *(1427 – 1518 MHz)*	**Medium** - The L-band is a good complementary band to combine with the sub 1 GHz band (e.g., 700 MHz band). The band provides a good combination of capacity and coverage.
		2.3 GHz band *(2300 – 2400 MHz)*	**High** - The band provides wider bandwidths enabling enhanced mobile broadband and mission-critical communications.
		2.6 GHz band *(2500 – 2690 MHz)*	**High** – These bands increase the cost of coverage but are better-suited to providing the capacity necessary to meet demand for high-data rates from large numbers of users in urban areas, airports and other high traffic areas. It is likely the only band with the scope to give operators blocks of 2x20 MHz of contiguous spectrum, enabling them to operate high-speed LTE services at optimum performance.
		C-band *(3300 – 3600 MHz)*	**High** - The C-band is emerging as the primary frequency band for deployment of 5G with greatest potential for global harmonization. It provides an optimal balance between coverage and capacity for cost-effective network deployment.
3. **High-band** *(above 6 GHz)* Also referred to as "mmWave", these		**26 GHz band** *(24.25 – 27.5 GHz)*	**Medium** - The 26 GHz band is one of the bands in which early mmWave 5G deployments will take place to support

https://www.gsma.com/spectrum/wp-content/uploads/2019/10/mmWave-5G-benefits.pdf; and 3) https://www.gsma.com/spectrum/wp-content/uploads/2022/02/mid-band-5G-spectrum-benefits.pdf.

Frequency Range	Use Cases	Spectrum Bands	Priority
frequency bands support the fastest 5G speeds and highest capacity at the expense of coverage and indoor penetration. High-band networks would be best implemented in dense urban areas or individual buildings and would enable the most data demanding, low-latency 5G use cases. However, high-band networks are the most expensive, as they require a large number of small cell installations due to their limited coverage and penetration. It would be economically challenging to cover large areas with high-band 5G networks.	Mass gatherings and events Autonomous driving Remote object manipulation Industrial automation VR/AR Transport connectivity		ultra-high capacity and delivery of extremely high data rates and low latency required by some 5G enhanced mobile broadband (eMBB) applications. The 26 GHz band is most suitable for outdoor hotspot, in-building coverage, and fixed wireless access (FWA) with outdoor customer-premises equipment (CPE). The band is important in the overall 5G ecosystem as it will address specific 5G eMBB use case requirements and demands.
		40 GHz band *(37 – 43.5 GHz)*	**Low** - The 40 GHz band is harmonized globally for deployment of International Mobile Telecommunications (IMT). IMT-2020 is a standard and set of specifications for 5G networks established by the International Telecommunication Union (ITU). It is a promising band for the early deployment of 5G millimetre wave systems. It provides extreme bandwidths for ultra-high broadband speeds. It may be used for private 5G networks by verticals, though the ecosystem has not yet matured.
4. **Other mmWave**	Ultra-fast wireless broadband	**Other 40/50 GHz bands**	**Low** - The band is identified for deployment of IMT in a few countries. It provides extreme bandwidths for ultra-high broadband speeds. It may be used for private 5G networks by verticals, though the ecosystem has not yet matured.
		66 – 71 GHz band	**Low** - The 66 - 71 GHz band is identified for IMT for flexible use for 5G systems enabling both IMT and non-IMT technologies and shared with WiGig systems (which allows devices to communicate without wires at multi-gigabit speeds). The band provides extreme bandwidths for ultra-high broadband speeds.

The ongoing rollout of 5G has prompted many to hypothesize about the future of 6G – the inevitable next generation of wireless network – and how it will improve upon its predecessor. While these figures are largely speculative, experts predict that the trend of exponential improvement in mobile communications will continue beyond the transition from 4G to 5G. It is

anticipated that international standardization bodies will determine 6G's standards by the year 2030.[15]

TABLE 2.5: 5G VS 6G PERFORMANCE CHARACTERISTICS[16]

Characteristic	5G	6G
Peak data rate	20 Gbps	>1000 Gbps
Latency	1 ms	0.1 ms
Connection density	1,000,000 devices/km^2	10,000,000 devices/km^2
Area traffic capacity	10-100 Mbps/m^2	1,000 Mbps/m^2
Mobility	500 km/h	>1000 km/h
Spectral efficiency[17]	3-4x	>15x
Network energy efficiency[18]	>10x	>100x

2.2 5G Deployment and Adoption Factors and Challenges

5G deployment and adoption[19] face several challenges due to regulatory and market forces. The extent to which these challenges are effectively addressed by the stakeholders involved can lead to 5G services varying greatly from country to country, which would in turn directly impact the adoption and subsequent socio-economic benefits of 5G and global competitiveness. Countries that prioritize and incentivize the efficient deployment of 5G networks will reap the many benefits of 5G technology sooner than those that do not.

The success of 5G *deployment* can be influenced by a number of factors:

[15] Link to source: https://doi.org/10.1186/s13673-020-00258-2.

[16] The following sources were used to inform the contents of this table: 1) https://doi.org/10.1186/s13673-020-00258-2; and 2) https://carrier.huawei.com/~/media/CNBGV2/download/program/Industries-5G/5G-Impact-on-Industry-Verticals.pdf.

[17] Relative to 4G.

[18] Relative to 4G.

[19] Deployment refers to the installation of the 5G network infrastructure, while adoption refers to the use of 5G and the applications that run on it.

TABLE 2.6: 5G DEPLOYMENT CHALLENGES[20]

Deployment Challenge	Description
1. Spectrum allocation and availability	Spectrum within all three key frequency ranges (low-, mid- and high-band) is a critical resource in 5G; availability and cost will have major impacts on the feasibility of 5G deployment. Most telecommunications regulators are making spectrum available for 5G in conventional ways, such as through nationwide auctions or by granting exclusive licenses. However, some regulators have "set-aside" a portion of spectrum within valuable mid-band frequencies (e.g., a portion of the 3.5 GHz range) for exclusive use by smaller regional carriers or users. Set-aside policies are controversial because they reduce the amount of spectrum made available to national service providers that require large contiguous frequency bands to support the data demands of their large consumer bases. Reduced spectrum availability is associated with: 1) higher prices paid at spectrum auctions; 2) slower, more expensive 5G rollouts; and 3) reduced coverage, capacity and data speeds.[21]
2. Service-based competition incentives	Similar to spectrum set-asides, the adoption of policies to promote service-based competition in the telecommunications industry can have adverse effects on the rollout of next-generation network infrastructure. Such policies encourage the entry of new telecom operators that, rather than invest in their own physical infrastructure, purchase and/or lease network capacity from existing facilities-based MNOs. The goal of these policies is to increase retail price-based competition in telecommunications. However, this approach has had mixed effects on pricing but has typically reduced the industry's average revenue per user (ARPU), thereby impacting the facilities-based MNOs' ability to invest in and deploy network infrastructure.[22] Historically, countries that lagged in 4G network deployment and adoption (e.g., Italy and Germany) did so, in part, because of their efforts to promote service-based competition, which reduced the incentives for facilities-based MNOs to invest in 4G infrastructure. Conversely, countries that did not implement policies to promote service-based competition (e.g., Canada, the United States, the United Kingdom and Australia) enabled an economic environment that was more encouraging of facilities-based MNOs to invest in high-quality 4G infrastructure. As

[20] The following sources were used to inform the contents of this table: 1) https://www.pwc.com/ca/en/communications/publications/761378-the-importance-of-a-healthy-telecommunications-industry-to-canadas-high-tech-success.pdf; 2) https://www.gsma.com/spectrum/wp-content/uploads/2021/04/5G-Spectrum-Positions.pdf; 3) https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf; 4) https://www.pwc.com/ca/en/communications/publications/the-evolution-of-canadas-telecom-industry-and-the-growing-digital-economy.pdf; 5) https://www.accenture.com/_acnmedia/PDF-130/Accenture-Greece-Race-to-5G-Executive-Summary.pdf; and 6) https://www.mckinsey.com/~/media/mckinsey/industries/technology%20media%20and%20telecommunications/telecommunications/our%20insights/connected%20world%20an%20evolution%20in%20connectivity%20beyond%20the%205g%20revolution/mgi_connected-world_discussion-paper_february-2020.pdf.

[21] Link to source: https://www.gsma.com/spectrum/wp-content/uploads/2021/04/5G-Spectrum-Positions.pdf.

[22] Link to source: https://www.pwc.com/ca/en/communications/publications/761378-the-importance-of-a-healthy-telecommunications-industry-to-canadas-high-tech-success.pdf.

Deployment Challenge	Description
	a result, 4G deployment and adoption in these countries was much faster.[23] The difference in 4G adoption between countries with and without service-based competition incentives remained for years after 4G coverage became near-universal, suggesting that it is difficult and takes longer to close the gap in adoption once a country falls behind in network deployment.
3. Increased competition and complexity in the digital value chain	The new digital ecosystem made possible by 5G will introduce competition to MNOs from other hardware, software and service providers whose offerings are supported by connectivity but who do not invest directly in the national network infrastructure they use. As a result, Canadian MNOs are forecasted to receive a mere 11% share of the total value pool generated by 2026 from the entire digital economy technology stack. The remaining 89% is expected to flow toward leading multinational solution providers, such as Google, Siemens, ASEA Brown Boveri, and General Electric.[24] Connectivity's smaller share of value makes the business case for network investment more uncertain for Canadian MNOs, but greater scale could help them better compete with these multinationals and capture a larger share of value in the digital economy, which would help fund network investments. The integrated nature of this new ecosystem will also require multiple players who may have never collaborated previously to cooperate to deliver a given 5G use case. This will introduce the need to align technical standards across industries and firms.
4. Network deployment and regulatory approaches	The use of high-band mmWave frequencies will require breakthroughs in network designs. Moreover, 5G small cells will require a new regulatory and deployment approach for planning, permitting, right of way access and fee structure updates. In some instances, it has been difficult for MNOs to find the physical space to install new 5G equipment. For example, MNOs have been unable to turn on their new C-band equipment within two miles of any airports because airplane instruments also operate within C-band frequencies. Moreover, high-band 5G is unable to travel far distances or penetrate walls, which necessitates strategic placement of numerous small cells in dense urban locales where there is already little free space available.
5. Potential technological disruptions	MNOs can expect two significant technological disruptions in the coming years. First, the deployment of Low Earth Orbit satellites will be used to provide satellite broadband internet. This will enable satellite providers to provide high-speed connectivity in existing markets as well as reach unserved markets, which would allow these providers to compete in the direct-to-consumer market and serve new business-to-business customers. Second, the introduction of embedded SIM (eSIM) technology will remove the need to physically swap SIM cards to change a device's profile. This technology could be leveraged by equipment manufacturers, such as Apple or Samsung, to effectively disintermediate telecom operators, own the customer relationship and dictate revenue splits.

To hasten their deployment of 5G networks, many MNOs have initially taken a non-standalone (NSA) approach, where 5G acts as a supplementary capacity overlay to the existing 4G network. This approach reduces overall investment requirements by avoiding the need for a new set of base stations and therefore increases the rate of return from incremental revenues stemming from less-intensive 5G use cases, such as ultra-HD video streaming. In addition, this further

[23] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

[24] Link to source: https://www.pwc.com/ca/en/communications/publications/the-evolution-of-canadas-telecom-industry-and-the-growing-digital-economy.pdf.

benefits MNOs by allowing for some 4G data traffic to be offloaded onto the new 5G networks. In contrast, standalone (SA) 5G deployment involves the implementation of entirely separate 5G core infrastructure. Though it is more expensive and resource-intensive, SA deployment will allow for the full scope of 5G's potential capabilities to be realized, including network slicing and use cases requiring URLLC. While NSA networks are cheaper in the short-run, SA networks may offer long-run capital efficiencies while also avoiding the need to go through subsequent rounds of hardware and software upgrades that would be required for NSA networks that eventually migrate to SA.[25]

TABLE 2.7: 5G STANDALONE AND NON-STANDALONE MODELS[26]

Dimension	Standalone	Non-standalone
1. Deployment period	2021 onwards; primarily 2022 and beyond	2019 onwards
2. Network core	New 5G core controlling 5G radio access network (RAN)	4G core controlling 4G RAN and 5G RAN
3. Use Case	eMBB, mIoT, and URLLC	eMBB and limited mIoT
4. Spectrum	5G RAN deployed in new frequency bands	Existing 4G network provides coverage, with 5G RAN deployed in new frequency bands.

While the success of 5G deployment is largely a function of regulatory and government policy and underlying market forces, the success of 5G *adoption* will be influenced by a variety of logistical and demand-side factors, such as those in the following table:

TABLE 2.8: 5G ADOPTION CHALLENGES[27]

Adoption Challenge	Description
1. Security concerns and data complexity	While 5G will implement additional security measures that address the shortcomings of existing 4G networks, the significantly increased volume of and connectivity between devices under 5G networks creates additional vulnerability to security threats, whether malicious or inadvertent. Moreover, many 5G use cases

[25] Link to source: https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165916&file=051120-5G-in-Canada.pdf.

[26] The following source was used to inform the contents of this table: https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165916&file=051120-5G-in-Canada.pdf.

[27] The following sources were used to inform the contents of this table: 1) https://www.accenture.com/_acnmedia/Accenture/Redesign-Assets/DotCom/Documents/Global/2/Accenture-Accelerating-5G-Future.pdf; 2) https://www.jabil.com/dam/jcr:e51424bb-b754-4665-93ff-0d631eef2194/2022-5G-technology-trends-report.pdf; 3) https://www.healthline.com/health/is-5g-harmful#false-claims. 4) https://itif.org/publications/2020/04/27/us-national-strategy-5g-and-future-wireless-innovation; 5) https://www.accenture.com/_acnmedia/PDF-130/Accenture-Greece-Race-to-5G-Executive-Summary.pdf; and 6) https://www.mckinsey.com/~/media/mckinsey/industries/technology%20media%20and%20telecommunications/telecommunications/our%20insights/connected%20world%20an%20evolution%20in%20connectivity%20beyond%20the%205g%20revolution/mgi_connected-world_discussion-paper_february-2020.pdf.

Adoption Challenge	Description
	will require data sharing and device interoperability across firm and industry boundaries. As a result, many experts have concerns surrounding 5G's overall security, especially with regards to user privacy and IP theft. There is additional concern within some government circles that foreign-sourced 5G equipment could be used for state-level espionage and sabotage.
2. User equipment investment costs	Many existing user devices – cell phones, tablets, etc. – are incapable of receiving 5G signal. New devices will be required to take advantage of 5G's capabilities, such as improved spectral efficiency and reduced latency. As a result, businesses face potentially large upfront costs to pay for the device upgrades necessary to leverage the capabilities of 5G eMBB technology. To make use of mIoT, businesses would be required to invest in large volumes of devices, such as sensors, drones, robots, etc., as well as the software, applications and expertise required for effective device management.
3. Lack of skills and knowledge to leverage 5G	Like any new technology, the incorporation of 5G technology into day-to-day business operations may require substantial training for existing staff and management to ensure efficient utilization and/or interoperability with existing legacy hardware. Shortages of the skill sets necessary to implement new 5G solutions may suppress 5G adoption in the short-term. Company executives, particularly those in companies that have yet to embark on their digital transformation, may lack the knowledge and vision to properly incorporate 5G solutions into their business operations and may therefore be reluctant to do so.
4. Adapting business models	MNOs have had difficulty determining how best to sell 5G to customers. Without proven use cases, business customers are reluctant to invest in 5G technology. Moreover, these customers may be required to re-evaluate their existing business models to adapt to potential disruptions induced by 5G technology. As a result, there currently exists little to no demand for solutions that explicitly require the capabilities of 5G technology, which is forcing some MNOs to rethink their own 5G business models in order to determine willingness to pay.
5. Early-adopter concerns	Many businesses are afraid of being first adopters of 5G technology and getting it wrong or earning an insufficient return on investment. As outlined above, incorporating 5G into existing business operations involves large upfront costs with largely unknown payoffs. Until such time when a broader range of 5G pilot projects have been completed, businesses may remain reluctant to adopt 5G solutions.
6. Misaligned incentives	Businesses that invest in the necessary infrastructure to utilize 5G technology may not be the ones to capture the ultimate financial gains. For example, hospitals and healthcare providers could invest in the required infrastructure, train their workers, and change their day-to-day operations to incorporate 5G use cases only to see the financial benefits accrue to health insurers or consumers. Such misalignment would have negative impacts on 5G use case adoption.
7. Supply chain disruptions	Supply chain disruptions could negatively impact shipments of 5G devices and hardware, which would slow the adoption of 5G solutions once demand accelerates.

2.3 Capital and Operational Costs of 5G Deployment

The total cost of ownership for Canadian 5G networks is forecasted to be between 23% and 71%[28] more expensive than for 4G networks, depending on the speed and scope of deployment. This increase in overall costs is creating uncertainty among facilities-based MNOs and is largely driven by three factors:

TABLE 2.9: MNO 5G CAPITAL AND OPERATING COST IMPLICATIONS[29]

5G Cost Driver	Description
1. The capital expenditures (CapEx) associated with purchasing and installing new infrastructure	The capital cost of more macro cells and small cells – which are expected to grow by 3% and 25% in numbers by 2025, respectively – along with the increased need for backhaul infrastructure will necessitate significant investment by MNOs. By 2025, global MNOs' capital expenditure (CapEx) is expected to increase up to 217% from 2018 levels.[30] From 2021 to 2026, the global telecom industry is anticipated to allocate roughly $890 billion of CapEx to 5G rollouts – nearly as much as the $1.03 trillion in annual revenue generated by the entire mobile industry in 2019.[31] Among Canadian MNOs specifically, CapEx between 2020 and 2026 (excluding expenditure on spectrum licenses) is estimated to be roughly $26 billion.[32]
2. Providing equitable and ubiquitous access to 5G networks	Ubiquitous 5G coverage across all locales – urban and rural – will be necessary to enable equitable access to the various features and benefits offered by 5G. This extensive coverage requires additional CapEx by MNOs into the necessary infrastructure. Different deployment scenarios lead to varying increases in anticipated CapEx. Under the more aggressive 5G vision in which high-band networks are more frequently deployed across all locales, CapEx between 2025 and 2027 could increase up to 317% from 2018 levels. Under a more conservative estimate that accounts only for capacity expansions required for increasing data traffic, CapEx between 2025 and 2027 could increase up to 107% from 2018 levels.[33]
3. Increased costs to operate 5G networks	5G equipment is more energy efficient on a per-GB rate, but the increase in overall data demand will lead to higher energy costs for MNOs. Required network densification will increase maintenance costs as a greater volume of small cells will need to be continuously maintained and upgraded. In addition, existing 4G infrastructure will also need to be maintained as the transition to 5G takes place.

[28] Link to source: https://www.pwc.com/ca/en/communications/publications/the-evolution-of-canadas-telecom-industry-and-the-growing-digital-economy.pdf.

[29] The following sources were used to inform the content of this table: 1) https://www.pwc.com/ca/en/communications/publications/the-evolution-of-canadas-telecom-industry-and-the-growing-digital-economy.pdf; and 2) https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

[30] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

[31] Link to source: https://www.f5.com/solutions/service-providers/protect-your-4g-investment-with-your-5g-strategy.

[32] Link to source: https://www.5gcc.ca/wp-content/uploads/2018/06/CWTA-Accenture-Whitepaper-5G-Economic-Impact_Updates_WEB_06-19-2018.pdf.

[33] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

The uncertainty surrounding the costs associated with 5G deployment and operation is further compounded within Canada: Canadian MNOs have historically been required to make higher infrastructure investments, on average, than international peers. From 2016 to 2018, 18.6% of revenue earned by large Canadian MNOs was spent on CapEx on average, compared to 13.3% by large MNOs outside of Canada.[34] This is largely due to four factors:

TABLE 2.10: CANADIAN 5G CAPITAL EXPENDITURE DRIVERS[35]

Canadian CapEx Drivers	Description
1. Low population density and high dispersion	Unlike in most European countries, Canadian MNOs serve a small population and a large geographic area. Per 2018 data, the United Kingdom and Germany have population densities of 275 and 237 people per square kilometre, respectively. In contrast, Canada and Australia have densities of 4 and 3 people per square kilometre, respectively. However, Australia's small population is primarily concentrated in fewer, larger cities, while Canada's small population is dispersed among thousands of small communities across the country. This is an important distinction between these two markets: Canadian MNOs have built roughly 51% more cell towers per capita and invested 33% more on capital (excluding spectrum) per wireless subscriber than Australian MNO's, despite both countries having similar population densities.[36]
2. High per-unit rates for spectrum	Historically, Canadian MNOs have paid much higher per-unit prices for wireless spectrum than those in other jurisdictions. This stems from factors such as the competitive bidding process and the regulator's decision to implement spectrum set-asides. During the 2014 auction of 700 MHz bandwidth, Rogers paid almost CA$3.3 billion for 12 MHz of paired bandwidth – roughly CA$3.50 per MHz per unit population served and one of the highest rates paid globally. Canadian MNOs spent approximately US$178.50 on spectrum per capita during this auction, which is roughly 77% more than American MNOs spent during a similar 2008 spectrum auction.[37]
3. Lower scale and less bargaining power	Economies of scale generate various efficiencies, including bargaining power with upstream suppliers of goods and services. Relatively speaking, Canadian MNOs are smaller than those in other countries. In terms of average revenue between 2016 to 2020, US-based AT&T is roughly 4.3 times larger than Bell, Rogers and TELUS combined. Similarly, Canadian MNOs are smaller than the suppliers upon whom they rely for key products and services, such as network-related companies like Cisco and Ericsson, and device suppliers like Google, Apple, and Samsung. Using the same metric as above, Cisco and Apple are roughly 1.3 and 6.4 times

[34] Link to source: https://www.pwc.com/ca/en/communications/publications/761378-the-importance-of-a-healthy-telecommunications-industry-to-canadas-high-tech-success.pdf.

[35] The following sources were used to inform the content of this table: 1) https://www.pwc.com/ca/en/communications/publications/761378-the-importance-of-a-healthy-telecommunications-industry-to-canadas-high-tech-success.pdf; and 2) https://www.pwc.com/ca/en/communications/publications/the-evolution-of-canadas-telecom-industry-and-the-growing-digital-economy.pdf.

[36] Link to source: https://www.pwc.com/ca/en/communications/publications/761378-the-importance-of-a-healthy-telecommunications-industry-to-canadas-high-tech-success.pdf.

[37] Ibid.

Canadian CapEx Drivers	Description
	larger, respectively, than Bell, Rogers and TELUS combined.[38] These revenue disparities are largely driven by Canada's relatively small population and result Canadian MNOs having a reduced ability to negotiate lower prices, which often results in less-favourable contract terms. Larger scale MNOs are better positioned to generate the cash flow and take on debt to deploy 5G networks at pace.
4. Weather challenges	Canada experiences extreme cold during the year that essentially halts underground construction in many parts of the country. As such, underground fibre lines or wireless backhaul can only be laid during the parts of the year that are conducive to construction. Furthermore, Canada frequently experiences losses resulting from extreme weather events; in 2018, Canada recorded a total of US$2 billion in losses triggered mostly by windstorms, hailstorms and flooding. As a result, non-life insurance premiums per capita in Canada that year were roughly US$2,000, second only to the United States (US$2,700) and comparable to Australia (US$2,000).[39]

2.4 Current Developments in 5G Deployment and Adoption

A 2021 survey of various MNOs across the globe by F5 provides an informative outlook on the state of global 5G deployment. The surveyed providers accounted for 40% of the global mobile subscriber base and operated primarily in developed markets. 82% of surveyed providers running a 4G network claimed that they were either managing a transition to 5G non-standalone (NSA) or already had some form of operational 5G NSA network. 8% were running a 4G network without either a planned transition to 5G NSA or an already operational 5G NSA. 52% expected to complete their transition to 5G NSA by the end of 2021, 44% by the end of 2023 and 4% by the end of 2025. Approximately 18% of surveyed providers were in the process of deploying 5G standalone (SA) networks with 26% claiming that they were planning to transition to 5G SA. 38% expected to complete their transition to 5G SA by the end of 2021, 52% by the end of 2023 and 9% by the end of 2025.[40] As of 2021, commercial 5G was available in 1,336 cities across 61 countries around the world – a 350% increase from 2020.[41]

5G deployment in Canada began in 2020 with TELUS, Rogers and Bell rolling out 5G NSA networks in major cities across Canada. They have continued to expand their 5G coverage to additional cities throughout 2021. Rogers launched Canada's first 5G SA network in 2022. Other regional providers, such as SaskTel, Videotron and TeraGo, began deploying 5G networks in their respective territories between 2020 and 2021. Xplornet launched Canada's first rural 5G standalone network with fixed wireless access in 2021 in New Brunswick, with plans to expand to

[38] Link to source: https://www.pwc.com/ca/en/communications/publications/the-evolution-of-canadas-telecom-industry-and-the-growing-digital-economy.pdf.

[39] Link to source: https://www.pwc.com/ca/en/communications/publications/761378-the-importance-of-a-healthy-telecommunications-industry-to-canadas-high-tech-success.pdf.

[40] Link to source: https://www.f5.com/solutions/service-providers/protect-your-4g-investment-with-your-5g-strategy.

[41] Link to source: https://www.viavisolutions.com/es-es/literature/state-5g-deployments-2021-posters-en.pdf.

250 additional communities throughout 2022.[42] In total, Canada's MNOs are expected to invest $26 billion by 2026 to install 5G networks across the country.[43]

As of 2021, 5G deployment in Canada has been limited to low-band networks, largely due to two reasons: 1) low-band 5G networks are cheaper to deploy on a non-standalone basis alongside existing 4G networks; and 2) until recently, only low-band 5G spectrum was available for use.[44] As a result, Canadian 5G networks have only seen incremental improvements over existing 4G networks, with 5G download speeds ranging between 91 Mbps to 156 Mbps (as of February 2022).[45] For comparison, average Canadian 4G download speeds range between 59 Mbps and 80 Mbps (as of February 2022).[46]

TABLE 2.11: 5G COUNTRY COMPARISONS

Country	Average 5G download speed[47]	Average 5G upload speed[48]	Coverage (by pop.)[49]	First mid-band auction[50]	First high-band auction[51]
South Korea	368-467 Mbps	28-38 Mbps	98%	June 2018	June 2018
United States	49-150 Mbps	10-18 Mbps	82%	August 2020	January 2019
Germany	104-144 Mbps	18-21 Mbps	81%	June 2019	January 2021
Australia	153-272 Mbps	13-17 Mbps	77%	December 2018	April 2021
Canada	91-156 Mbps	18-21 Mbps	50%	July 2021	2023 (expected)
Japan	140-224 Mbps	8-32 Mbps	48%	April 2018	April 2019
Italy	65-274 Mbps	10-24 Mbps	47%	October 2018	October 2018
United Kingdom	73-132 Mbps	9-14 Mbps	30%	April 2018	TBD

[42] Figures are sourced from the following article that compiles data from multiple MNO websites, confirmed by Deetken: https://www.lifewire.com/5g-canada-4582444.

[43] Link to source: https://www.5gcc.ca/wp-content/uploads/2018/06/CWTA-Accenture-Whitepaper-5G-Economic-Impact_Updates_WEB_06-19-2018.pdf.

[44] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

[45] Link to source: https://www.opensignal.com/reports/2022/02/canada/mobile-network-experience-5G.

[46] Link to source: https://www.opensignal.com/reports/2022/02/canada/mobile-network-experience.

[47] Opensignal, 2021-2022; ranges include highest and lowest average 5G download speed across providers. Link to source: https://www.opensignal.com/global. Select a country under "Market Insights by geography" and select "5G Experience Report" by date.

[48] Ibid; ranges include highest and lowest average 5G upload speed across providers.

[49] As of Q2, 2021. Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

[50] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

[51] Ibid.

Country	Average 5G download speed[47]	Average 5G upload speed[48]	Coverage (by pop.)[49]	First mid-band auction[50]	First high-band auction[51]
France	98-273 Mbps	9-19 Mbps	10%	October 2020	TBD

Compared with other 5G-leading countries, Canada's rollout of 5G has been poor – a stark contrast to Canada's leading performance in 4G. In a report from 2018, OpenSignal, a market research company, found 4G in Canadian markets across major providers (TELUS, Bell, Rogers) to be market-leading in terms of nationwide availability and performance, concluding that "there's no question Canada is a global 4G superpower today. That likely means there are few other countries better prepared than Canada to deploy the 5G networks of the future."[52] In a 2021 report, PwC found that despite Canada ranking highest in network build cost index amount compared to its G20 peers (primarily driven by its low population density, high spectrum costs, and relatively smaller scale MNOs), it ranked highest in terms of network speed and among the top countries for 4G availability and video experience.[53] As of the second quarter of 2021, Canadian 5G coverage by population ranks fifth among G7 countries, Australia, and South Korea at 50%. Furthermore, Canada's 5G coverage still has yet to expand into regional and rural locales, which limits its potential impact. In contrast, 5G networks in the U.S. have extended into more rural areas: T-Mobile's 5G network covers 92% of interstate highway miles.[54]

While Canada's 5G download and upload speeds perform modestly when compared against these countries, reliance on low-band infrastructure will ultimately limit further speed growth as well as 5G's ability to handle high throughput cases such as Industrial IoT, 4K live broadcasting, AR/VR entertainment and immersive services in large public venues. As other nations continue to deploy mid- and high-band networks, their average 5G data speeds will experience tremendous growth, and wider adoption of advanced 5G use cases will take place. For example, high-band network coverage is still very limited in the United States, but it can deliver much faster speeds that range from 245 Mbps to 618 Mbps.[55]

Canada only concluded its first mid-band (3.5 GHz) spectrum auction in July 2021 after being delayed due to COVID-19. CA$8.9 billion[56] was paid by Canadian MNOs to obtain a total of 200 MHz, of which roughly 50 MHz were set aside for regional operators. As a result, 150 MHz of mid-band spectrum was divided between Canada's three national facilities-based MNOs – TELUS, Bell and Rogers – despite the International Telecommunications Union (ITU) recommendation of

[52] Link to source: https://www.opensignal.com/reports/2018/02/canada/state-of-the-mobile-network.

[53] Link to source: https://www.pwc.com/ca/en/communications/assets/understanding-the-cost-and-quality-of-networks-across-the-g20-en.pdf.

[54] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

[55] Ibid.

[56] Link to source: Government of Canada. "3500 MHz Auction – Process and Results." 2021. Data accessed at: https://www.canada.ca/en/innovation-science-economic-development/news/2021/07/3500-mhz-auction--process-and-results.html.

100 MHz minimum per operator.[57] This auction resulted in the most expensive 5G spectrum prices (measured as average price per MHz/pop) in the world, nearly twice what U.S. providers paid and between 9 and 21 times more than what was paid by MNOs in European peer countries.[58] Lower prices could have provided for more investment by MNOs in physical 5G infrastructure. Canada's high-band spectrum auctions are not expected until 2023.[59]

Compared to the G7, Australia, and South Korea, Canada's 5G spectrum allocations for mid- and high-band frequencies are years behind. Currently, Canada is the last country among this group to issue mid-band spectrum and one of only three countries (the others being the U.K. and France) that have yet to issue high-band frequencies.[60] Furthermore, the 200 MHz of mid-band spectrum Canada has so far issued is considerably less than that issued in other countries, such as the United States (360 MHz), Japan (500 MHz) or most European countries (300 to 400 MHz).[61] Allocating sufficient amounts of all three spectrum band categories is crucially important; for 5G to fully enable the digital economy, each band is required to facilitate the unique requirements of each use case, foster subsequent innovation and deliver ubiquitous geographic coverage.

Global 5G subscriptions grew by 70 million during the first quarter of 2022 to around 620 million, and that number is expected to surpass 1 billion by the end of 2022.[62] Global 5G uptake – which has been faster than that of 4G – has been fueled by strong demand in China and North America and impacted partially by timely availability of 5G devices from multiple vendors and falling prices. As of the third quarter 2021, Northeast Asia has the highest 5G subscription penetration (24%), followed by North America (20%), the Gulf Cooperation Council countries (9%) and Western Europe (6%).[63] Due to their heavy CapEx investment since 2019/2020, China and South Korea are currently leading the world in 5G adoption and have reached 5G subscription penetration levels of 46%[64] (as of January 2022) and 39%[65] (as of December 2021), respectively.

5G adoption is expected to rapidly proliferate over the next five years. By the end of 2027, it is forecasted that global 5G subscriptions will grow to 4.4 billion (implying a 41% compound annual growth rate from the end of 2021) and account for 48% of all mobile subscriptions. It is projected that North America will have the highest 5G penetration rate at 90%. In addition, 5G FWA will

[57] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.
[58] Link to source: https://www.pwc.com/ca/en/communications/assets/understanding-the-cost-and-quality-of-networks-across-the-g20-en.pdf.
[59] TELUS.
[60] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.
[61] Link to source: https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165916&file=051120-5G-in-Canada.pdf.
[62] Link to source: https://www.ericsson.com/49d3a0/assets/local/reports-papers/mobility-report/documents/2022/ericsson-mobility-report-june-2022.pdf.
[63] Ibid.
[64] Link to source: https://www.marbridgeconsulting.com/marbridgedaily/2022-02-21/article/114902/chinas_three_main_telcos_add_28_mln_5g_subs_in_january_2022.
[65] Calculated using Dec. 2021 5G subscription figures from Statista divided by 2022 South Korea population projections by the United Nations. Link to Statista: https://www.statista.com/statistics/1108022/south-korea-number-5g-subscribers-by-month/#:~:text=As%20of%20December%202021%2C%20South,approximately%2020.92%20million%205G%20subscribers. Link to population estimate: https://worldpopulationreview.com/countries/south-korea-population.

provide broadband connectivity to roughly 110 million people and the number mobile IoT connections will grow to roughly 5.5 billion by the end of 2027.[66]

Many 5G pilot use cases have been conducted in countries around the world, particularly in those where 5G network deployment has further progressed. For example, China has explored 5G use cases across numerous industry verticals, including industrial manufacturing, mining, transportation, energy infrastructure, healthcare and content creation, that cover a variety of practical scenarios, technical features and development opportunities for 5G technology.[67] The table below provides brief overviews of some of the 5G pilots that have been conducted across various 5G-leading countries:

TABLE 2.12: EXAMPLE 5G PILOTS IN OTHER JURISDICTIONS

Country	Examples of 5G Pilots
United States[68,69]	**Military / Smart City:** The United States Navy and other stakeholders have allocated US$4 million to establish the 5G Living Lab at Marine Corps Air Station Miramar in San Diego. The goal of the program is to experiment with 5G-enabled systems that will improve overall safety and efficiency on base, such as automated package delivery shuttles. However, the pilot also seeks to develop a framework of best practices that will serve smart communities in the future. **Agriculture:** In 2019, the Department of Agriculture, together with corporate partners Microsoft and Esri, launched the Data Innovations project to pilot the use of IoT in farming applications. They deployed sensors, drones, and IoT-enabled farm equipment on a 7,000-acre farm to automate data collection and aggregation on several metrics that would give farmers better intelligence on their crops with respect to insect levels, disease, weeds, water, and nutrient dynamics, and help make farms more efficient.
China[70]	**Mining:** In 2019 and 2020, respectively, the Xinyuan and Pangpangta coal mines implemented industrial 5G networks to enable automated inspections, unmanned mining operations, comprehensive data collection and interconnected production management. These projects have resulted in significant annual cost savings and production efficiency improvements. **Healthcare:** Since 2019, Shenzhen Futian Medical Consortium has deployed 5G technology to develop and test applications for remote emergency, remote consultation, mobile diagnosis and treatment, community first aid guidance and smart wards across seven hospitals and 83 community health centres.

[66] Link to source: https://www.ericsson.com/49d3a0/assets/local/reports-papers/mobility-report/documents/2022/ericsson-mobility-report-june-2022.pdf.
[67] Link to source: https://www.gsma.com/greater-china/wp-content/uploads/2021/02/5G-Use-Cases-for-Vertical-China-2021-EN.pdf.
[68] Link to source: https://www.us-ignite.org/program/miramar-5g-testbed/.
[69] Link to source: https://federalnewsnetwork.com/big-data/2019/10/usda-pilots-data-driven-smart-farms-powered-by-internet-of-things-ai/.
[70] Link to source: https://www.gsma.com/greater-china/wp-content/uploads/2021/02/5G-Use-Cases-for-Vertical-China-2021-EN.pdf.

Country	Examples of 5G Pilots
	Manufacturing: Guangdong Midea Kitchen Appliances Manufacturing Co., Ltd., a manufacturing plant that engages 9,000 employees and has 59 assembly lines, initiated a multi-phase 5G pilot project in 2019 to apply 5G-based IoT to enhance warehouse management and logistics, campus security monitoring, production inspection and production line transformation. **Energy:** In 2018, China Southern Power Grid Co. applied 5G technology to experiment with smart electricity grids. They leveraged improved automation and edge computing to increase inspection efficiency of transmission lines by 80 times and power transformation equipment by 2.7 times. 5G technology has also reduced construction costs by 50%.
South Korea[71]	**Public Administration:** The Ministry of the Interior and Safety launched a six-month 5G trial in June 2020 within its Digital Government Bureau to verify the security and quality of communications capabilities enabled by 5G. The results from this study will inform broader adoption of 5G services within government complexes and municipal governments. **Immersive Media:** The Ministry of Science and ICT launched the 5G Contents Flagship Project in April 2019 to support the development of 5G immersive media and AR/VR use cases. As of April 2020, the ministry supported 28 use cases such as AR arthroplasty surgery training. The ministry also created a seed money investment fund equal to roughly US$27 million and built 5G experience centres in the United States and Vietnam.
Germany[72]	**Manufacturing:** Nokia has deployed a private 5G standalone wireless network for Volkswagen at its main plant in Wolfsburg, Germany. The private network provides reliable, secure, real-time connectivity and enables Volkswagen to trial new smart factory use cases, such as wireless upload of data to manufactured vehicles and intelligent networking of robots and wireless assembly tools, that seek to improve efficiency and productivity.
Canada[73,74]	**Smart City:** The City of Kelowna, in partnership with the University of British Columbia and Rogers, launched a pilot project to explore how 5G-enabled LiDAR traffic cameras can be used to study traffic patterns and improve driver and pedestrian safety. The cameras capture consistent data throughout the day that is uploaded and stored on Microsoft Azure and later assessed by researchers. The City of Montréal has also initiated a pilot project to install 5G microcells on traffic lights and lamp posts within the downtown core. Supported by a health and social acceptability committee, the project aimed to evaluate the potential of 5G technology, as well as the functionality and feasibility of this installation method.

These pilot use cases are integral not only for establishing frameworks to promote greater 5G adoption, but also for identifying future avenues of 5G research and innovation that could enhance – or at least maintain – a nation's competitive advantages in various industry verticals. Thus, swift deployment of high-quality comprehensive 5G networks that can facilitate research into all of 5G's capabilities should be among the top priorities of any developed nation.

[71] Link to source: https://openknowledge.worldbank.org/bitstream/handle/10986/35780/Entering-the-5G-Era-Lessons-from-Korea.pdf.

[72] Link to source: https://www.nokia.com/about-us/news/releases/2021/12/06/nokia-deploys-5g-private-wireless-network-for-volkswagens-pilot-project-in-germany/.

[73] Link to source: https://cities-today.com/canadas-first-5g-smart-city-project-launched-in-kelowna/.

[74] Link to source: https://montreal.ca/en/articles/5g-urban-pilot-project-9155.

3 Vertical Deep Dives and Snapshots

Key Takeaways

5G will enable innovative applications for various industry verticals by facilitating increased productivity, product/service differentiation and new business models. It will also provide non-economic benefits to help address environmental, social and governance (ESG) objectives and similar UN Sustainable Development Goals (SDG) such as global climate change mitigation, environmental sustainability, and safety.

While the majority of 5G use cases are still being developed and tested with 4G LTE or 5G lite networks to make them ready for commercial deployment, research confirms 5G will have broad applicability across the economy. For MNOs to realize the full potential of 5G, it will be critical for them to embrace new business models, focus efforts on select underserved verticals and become adept at managing global partnerships.

The following table summarizes key challenges faced by the 11 sectors evaluated for this report and provides select operational and ESG benefits of 5G-enabled solutions.

Industry Sectors	Key Challenges	Example 5G Solutions and Associated Benefits
Health	▪ Escalating healthcare expenditures ▪ Fewer medical resources ▪ Aging global population ▪ Climate induced health crisis ▪ Rural and remote populations still encounter barriers to healthcare	▪ More affordable healthcare solutions ▪ Improved real-time patient monitoring, preventative care and predictive analytics ▪ Enhanced remote diagnosis, imaging, and surgery ▪ Faster and more reliable data sharing ▪ Improved medical training, surgical planning, patient care management and mental health treatment
Agriculture	▪ Population growth and food wastage straining natural resources ▪ Changing weather patterns reduce crop yields ▪ Soil degradation and water scarcity	▪ Real-time data collection and analysis of soil moisture, temperature, diseases and insects ▪ Increased crop/ livestock yields and reduce waste ▪ Increased food traceability for safety ▪ Reduced usage of raw materials and fuel ▪ Enhanced predictive maintenance of assets
Energy	▪ Electrification, decentralized generation and renewable energy generation ▪ Increasing consumption	▪ More accurate demand prediction and adjustment of supply from distributed grids ▪ Reduced peak demand

Industry Sectors	Key Challenges	Example 5G Solutions and Associated Benefits
	▪ Shift from the traditional utility model to align to a more distributed energy network ▪ Demanding ESG goals and increased regulatory oversight ▪ Physical/cyber attacks	▪ Increased efficiency of electricity transmission ▪ Improved diagnostics and maintenance ▪ Enhanced employee training and productivity ▪ Improved physical and cyber security and privacy
Manufacturing	▪ Competition from lower-cost markets ▪ Intensifying regulatory and environmental oversight ▪ Heightened supply chain weaknesses ▪ Aging workforce and skill shortages ▪ Changing customer needs	▪ Reduced costs of raw materials and energy ▪ Fewer product defects ▪ Improved availability and throughput of machines ▪ Increased operational flexibility and shortened lead times for factory floor changes and alterations ▪ Improved sales growth through reduced time to market for new product designs and faster response to customer demand and customization capability ▪ Increased human productivity and performance
Government	▪ Dynamic population changes ▪ Rapid urbanization pressurizing infrastructure and services in cities ▪ Scaling back of social services due to fiscal constraints ▪ Balancing natural resource expansion and GHG emissions reduction	▪ Real-time equipment monitoring, preventative maintenance and improved asset utilization ▪ Hands-on learning in a safe, structured, and interactive environment for hazardous jobs ▪ Better warehouse optimization, scalability, adaptability and lower operational costs ▪ Increased operational flexibility, enhanced employee productivity, efficiency, performance, communication, innovation and satisfaction
Finance and Insurance	▪ Increasing economic uncertainties ▪ Intense competition ▪ Technology disruptions ▪ Rising customer expectations and waning customer loyalty ▪ Legacy processes, systems and skills	▪ Reduced cost of financial advisory services ▪ Streamlined credit processing and allow faster insurance analysis ▪ A more granular view of a customer's behaviour and health ▪ Increased customer stickiness and wallet share ▪ Lower fraud and improve data security and privacy

Industry Sectors	Key Challenges	Example 5G Solutions and Associated Benefits
		▪ Enhanced mobile payments, online acquisitions and banking processes
Real Estate	▪ Large carbon footprint ▪ Rising construction costs ▪ Shortage of skilled labour ▪ Increased project complexity ▪ Increasing regulation and environmental policies ▪ Supply chain vulnerabilities ▪ Complex documentation ▪ Elevated property and liability risks due to aging properties ▪ Changing customer needs	▪ Smart heating, ventilation, air conditioning (HVAC), lighting and windows ▪ Automated system optimization (ASO) of building automation systems (BAS) and energy management and information systems (EMIS) ▪ Smart maintenance, traffic, and security management ▪ Remotely controlled autonomous machinery ▪ 3D building models ▪ Construction processes management ▪ Automated advertising, lead generation and engagement ▪ Smart blockchain contracts
Education	▪ Inaccessible environments ▪ Shortage of teachers and poor quality of instruction ▪ Safety risks	▪ Augmented reality (AR), virtual reality (VR) and extended reality (XR) teaching and training ▪ Artificial intelligence (AI) ▪ 5G fixed wireless access (FWA) ▪ Intelligent campus management
Retail	▪ Changing customers needs and behaviour ▪ Intensifying competition ▪ Increasing costs ▪ Supply chain vulnerabilities ▪ Shortage of retail talent ▪ Increasing use of the digital mobile wallet	▪ Consumer 3D calls and holograms ▪ Consumer augmented, virtual and mixed reality ▪ Automated digital and contactless checkout ▪ Indoor position systems (IPS) ▪ Artificial intelligence (AI) and big data analytics (BDA) ▪ RFID Asset Tracking, Video Surveillance Powered by ML and Shelf Sensors and Point-of-Sale technologies; shelf sensors and cameras monitor inventory and alert staff for re-stocking ▪ Smart heating, ventilation and air conditioning (HVAC)

Industry Sectors	Key Challenges	Example 5G Solutions and Associated Benefits
Logistics	▪ Intensifying competition ▪ Increasing fuel and labour costs ▪ Economic uncertainties ▪ Low supply chain visibility ▪ Inadequate vendor and supplier collaboration ▪ Poor customer experiences ▪ Labour shortage ▪ Increasing environmental regulation	▪ Smart logistics transportation, warehousing, loading/unloading, packaging, and distribution
Communications	▪ Intensifying competition ▪ Slowing growth in core offerings ▪ Rising cybersecurity and privacy threats ▪ Mounting operational and technological complexity ▪ Escalating capital requirements and investment risk ▪ Shortage of skilled labour ▪ Increasing government regulation and environmental issues	▪ Big data analytics ▪ Chatbots ▪ Smart heating, ventilation, and air conditioning (HVAC) ▪ Camera-equipped drones ▪ Smart logistics and warehousing

Below are snapshots of the potential impact of 5G in select industry sectors. Each snapshot contains an overview of the industry sector, including its share of global and Canadian GDP where estimates are available. Key economic, operational and ESG challenges faced by each industry sector are highlighted, and the following are provided: 1) a list of potential industry-specific digital solutions supported by 5G; 2) types of 5G capabilities leveraged by these digital solutions (only provided for the health, agriculture and energy industries); 3) potential operational and ESG benefits and related SDGs produced through the deployment of 5G solutions; 4) estimated economic benefits realized by the deployment of these digital solutions (measured in terms of additional GDP generated); and 5) potential 5G-specific and industry metrics that must be tracked and reported to assess whether these benefits are being realized. Given the nature of this section's objectives and the nascency of the research, the report has had to rely more on articles.

3.1 Deep Dives and Case Studies for TELUS Priority Verticals

3.1.1 Health

Industry overview: Access to an effective and efficient healthcare ecosystem is crucial to how individuals perceive their quality of life. The healthcare sector accounts for approximately 10% of

total global GDP.[75] In Canada, total health expenditure as a proportion of GDP has risen to 12.7% in 2021[76] from 7.0% in 1975.[77] Today, insufficient public funding is challenging Canadian healthcare providers and recipients. Three studies indicate that Canada's healthcare does not compare favorably to peer countries, as highlighted in the key findings summarized below.[78]

Challenges faced by the healthcare industry:

1. **Escalating healthcare expenditures:** According to the World Health Organization (WHO), there is a worldwide health worker shortage that is jeopardizing social services and sustainable health systems. "The world will need 18 million additional health workers by 2030, primarily in low- and middle-income countries, including 9 million nurses and midwives."[79] A Fraser Institute study of 28 OECD countries[80] suggests that "there is an imbalance between the value Canadians receive and the relatively high amount of money they spend on their healthcare system. Although Canada ranks among the most expensive universal-access healthcare systems in the OECD, its performance for availability and access to resources is generally below that of the average OECD country, while its performance for use of resources and quality and clinical performance is mixed."[81] The study finds that, after adjusting for age, "Canada ranks second highest for healthcare expenditure as a percentage of GDP and 10th highest for healthcare expenditure per capita."[82]

2. **Fewer human and capital medical resources per capita:** Canada has fewer human and capital medical resources per capita when compared to other high-income OECD countries with universal healthcare. The Fraser Institute Study finds that, after adjusting for age, "Canada ranks 26th for physicians, 13th for nurses, 26th for curative (acute) care beds (out of 27), and 25th for psychiatric care beds per thousand population."[83]

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[75] Link to source: https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS

[76] Link to source: https://www.cihi.ca/en/national-health-expenditure-trends-2021-snapshot/.

[77] Link to source: https://www.cihi.ca/sites/default/files/document/nhex-trends-narrative-report-2019-en-web.pdf.

[78] Link to sources: 1) https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf; 2) https://www.commonwealthfund.org/publications/fund-reports/2021/aug/mirror-mirror-2021-reflecting-poorly; 3) https://www.fraserinstitute.org/sites/default/files/waiting-your-turn-2020-execsum-national.pdf. The challenges identified for the healthcare sector are more specific to Canada as opposed to other industry sectors in this report where the challenges are more generalized. Key factors that may be responsible for this underperformance are: 1) 5th highest rural population among G10 nations; 2) lowest population density among G10 nations; 3) highest population growth amongst G10 nations; and 4) 2nd highest migrant population amongst G10 nations.

[79] Link to source: https://www.who.int/news-room/photo-story/photo-story-detail/urgent-health-challenges-for-the-next-decade.

[80] The countries included for comparison in this study were chosen based on the following three criteria: 1) must be a member of the OECD; 2) must have universal (or near-universal) coverage for core-medical services; 3) must be classified as a "high-income" country by the World Bank. Of 35 OECD members in 2017 considered for inclusion, the OECD (2017) concluded that six countries - Chile, Greece, Mexico, Poland, the Slovak Republic, and the United States did not have universal (or near-universal) coverage for core medical services. Of the 29 countries remaining for consideration, Turkey does not meet the criteria of being classified in the high-income group (in 2017) according to the World Bank (2019). The remaining 28 countries that meet the three criteria above are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom.

[81] Link to source: https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf.

[82] Ibid.

[83] Ibid.

3. **Fewer technology and diagnostic imaging resources:** Canada has, on an age-adjusted basis, fewer medical technologies than the average high-income OECD country with universal healthcare for which comparable inventory data is available. The Fraser Institute Study finds that, on a per million population basis and after adjusting for age, "Canada ranks 21st (out of 26) for MRI units, 21st (out of 27) for CT scanners, 17th (out of 22) for PET scanners, 2nd (out of 21) for Gamma cameras, and 12th (out of 19) for Mammographs."[84]

4. **Mediocre performance on use of resources:** Canada's performance in terms of resource efficiency is mixed. The Fraser Institute Study finds that, after adjusting for age, "Canada ranks 9th (out of 26) for the number of doctor consultations per capita, 28th (out of 28) for hospital discharge rates per 100,000 population, 14th (out of 25) for MRI examinations per thousand population, and 12th (out of 25) for CT scans per thousand population."[85]

5. **Low performance on timeliness and access to resources:** Canada's timeliness of healthcare access ranks relatively low against other countries with universal healthcare systems. According to the Fraser Institute study, "Canada is tied for last place (out of 10) for the percentage of patients able to make a same-day appointment when sick and ranks 4th (out of 10) for the percentage of patients who report that it is very or somewhat easy to find care after hours. Canada placed last among 17 countries … on the percentage of patients who reported waiting more than four weeks for an appointment with a specialist. Canada also ranked worst (10th out of 10) for the percentage of patients who reported waiting two months or more for a specialist appointment and worst (10th out of 10) for the percentage of patients who reported waiting four months or more for elective surgery."[86] Moreover, "Canada performed worse than the 10-country average on the indicator measuring the percentage of patients who found that cost was a barrier to access, ranking 7th out of 10."[87] Canada also has the lowest hospital discharge rate per 100,000 population of the 28 countries evaluated in the study.[88]

6. **Aging global population puts yet another pressure on the healthcare system:** Populations in the West and the East are aging rapidly. The number of people aged 65+ years is projected to increase from 8.5% of total global population in 2015 to 12% of total global population by 2030 and to 16.7% by 2050.[89] According to the 2021 Census, roughly 22% of working age Canadians are aged 55 to 64 – an all-time high in the history of Canadian censuses.[90] As a growing number of workers leave the workforce in the years ahead, a smaller cohort of the working-age population will need to work harder to maintain

[84] Ibid.
[85] Ibid.
[86] Ibid.
[87] Ibid.
[88] Ibid.
[89] Link to source: https://www.researchgate.net/profile/Paul-Kowal/publication/299528572_An_Aging_World_2015/links/56fd4be108ae17c8efaa1132/An-Aging-World-2015.pdf.
[90] Link to source: https://www150.statcan.gc.ca/n1/daily-quotidien/220427/dq220427a-eng.htm?CMP=mstatcan.

Canada's standard of living, to support the production of goods and services and bear the financial burden of the increasing social service needs, including healthcare, for the aged.

7. **Climate change will continue to aggravate the health crisis we are currently facing:** According to the WHO, "air pollution accounts for approximately 7 million deaths every year, while climate change causes more extreme weather events, exacerbates malnutrition and fuels the spread of infectious diseases such as malaria. The same emissions that cause global warming are responsible for more than one-quarter of deaths from heart attack, stroke, lung cancer and chronic respiratory diseases."[91]

8. **Medication errors and adverse drug events continue to drive unnecessary costs, decreased patient satisfaction and a growing lack of trust in the healthcare system:** Unsafe medication is responsible for considerable and potentially avoidable morbidity and mortality. Medication safety issues can adversely impact health outcomes, increase time spent in the hospital, increase re-admission rates, and increase overall costs to an already-expensive healthcare system.[92] It is estimated that preventable medication hospitalizations cost more than CA$140 million in direct and indirect healthcare expenditures, with an additional CA$12 million in costs stemming from lost productivity. Globally, these costs are estimated to exceed CA$55 billion.[93]

9. **Rural populations continue to encounter barriers to healthcare that limit their ability to obtain the care they need:** Access to quality healthcare in remote/rural areas is another critical challenge for the world. According to the Canadian Institute for Health Information, "significant differences exist between urban and rural populations in terms of health status, health behaviors, health service use, costs and outcomes. In general, rural residents have direct access to a much smaller number and scope of health services and providers than urban residents. Decision-makers and planners frequently face challenges regarding the availability, capacity, sustainability and performance of rural health systems."[94] In Canada, rural populations in Canada are generally older, less affluent and sicker. Almost one-fifth of Canadians (18%) live in rural communities, but they are served by only 8% of the physicians practicing in Canada.[95,96] These communities face ongoing challenges in recruiting and retaining family physicians and other healthcare professionals. People in rural areas face more difficulty accessing the healthcare system than their urban counterparts, and when they do access healthcare, they have poorer outcomes.[97]

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[91] Link to source: https://www.who.int/news-room/photo-story/photo-story-detail/urgent-health-challenges-for-the-next-decade.

[92] Link to source: https://www.patientsafetyinstitute.ca/en/NewsAlerts/News/pages/medication-without-harm-2018-09-14.aspx.

[93] Ibid.

[94] Link to source: https://www.cihi.ca/en/rural-health-care-in-canada

[95] Link to source: Canadian Institute for Health Information. Supply, distribution, and migration of physicians in Canada 2015-data tables. Ottawa, ON: Canadian Institute for Health Information; 2016. Data accessed at: https://secure.cihi.ca/estore/productSeries.htm?pc=PCC34.

[96] Link to source: https://www.cfpc.ca/CFPC/media/Resources/Rural-Practice/ARFM_BackgroundPaper_Eng_WEB_FINAL.pdf.

[97] Link to source: https://www.doi.org/10.25318/82-003-x201900500001-eng.

10. **Persistent and growing socio-economic gaps are driving major discrepancies in the quality of people's health:** According to the WHO, "the global rise in noncommunicable diseases, such as cancer, chronic respiratory disease and diabetes, has a disproportionately large burden on low- and middle-income countries and can quickly drain the resources of poorer households."[98] The world spends far more money responding to disease outbreaks, natural disasters and other health emergencies than it does on preparation and prevention. It is not a matter of *if* another COVID-19 type pandemic will strike, but rather *when*. Meanwhile, climate change is inducing the migration of mosquito populations into new areas and consequently causing further spread of vector-borne diseases such as dengue, malaria, Zika, chikungunya and yellow fever.[99]

11. **Patients demand similar experience levels with healthcare as they do with other services:** Quality of care has become very important to patients, and they have more options today as to how and with whom they get their care. They are demanding transparency of data and processes, and privacy and security assurances for personal records. Patient advocacy groups and the patients themselves, armed by social media, are pushing for deeper investigations of matters such as medication errors and hospital-acquired infections.

12. **Other healthcare challenges:** There are numerous other healthcare challenges, including a lack of transportation to healthcare centres, cumbersome hospital registration systems, and a hierarchical medical system. Another common phenomenon in developing countries and regions is overcrowding in hospitals, resulting in overloaded medical staff. An imbalance of health resources, including medical equipment and well-trained practitioners, causes large numbers of patients to travel from rural areas to urban areas seeking high-quality health service. Medical staff, in the provision of healthcare services, rely heavily on their own experience rather than data.

Enhancements to services enabled 5G such as remote robotic surgery, remote patient monitoring, telemedicine, clinical collaboration and communication, medical sensors, connected ambulances, computer-aided diagnostics, and medical imaging will allow both patients and the healthcare ecosystem to mitigate or possibly eliminate these challenges. Enhancement of current technologies and applications and the introduction of innovative technologies and applications like 5G are revolutionizing patients' ability to prevent, diagnose and treat many diseases. This new 5G enabled ecosystem will align with the recent phenomenon of 4P medicine – predictive, preventative, personalized and participatory. 5G will also allow more rural/remote post-acute care and home-based models, with savings greater than 30% and better patient outcomes.[100]

Potential Digital Solutions Supported by 5G	Types of 5G Capabilities Leveraged

[98] Link to source: https://www.who.int/news-room/photo-story/photo-story-detail/urgent-health-challenges-for-the-next-decade.
[99] Ibid.
[100] Link to source: https://www.accenture.com/_acnmedia/PDF-146/Accenture-5G-WP-US.pdf.

1. **Continuous monitoring** via wearable and other 5G-enabled sensory devices will "facilitate continuous monitoring of patients. Superior monitoring capability means that 5G can substantially increase the effectiveness of preventative care. By doing so, it can lower the burden of chronic disease [on] healthcare systems in the developed world."[101] 2. **Predictive analytics** capability harnesses the data generated from continuous monitoring and augments it further. "While continuous monitoring will power the development of new data streams, the use of distributed computing – the processing of patient data nearer to the patient – will power predictive analytics and intelligent care based on those new data streams."[102] 3. **Remote diagnosis and imaging** enable the application of virtual reality, "which can have important benefits in the delivery of medical care (e.g., in the diagnosis and treatment of critical medical episodes such as strokes)." [103] 4. **Remote surgery,** also known as telesurgery, enables a doctor to perform surgery on a patient even though they are not physically in the same location. It is a form of telepresence; a robot surgical system generally consists of one or more arms (controlled by the surgeon), a master controller (console) and a sensory system giving feedback to the user.[104] 5. **Image transfer** enables medical image sharing to facilitate transfers between other care facilities that may or may not be on the same network and to referring physicians in the community, as well as directly to patients.[105] 6. **AR/VR-enabled healthcare** enables applications including medical training, surgical planning, pain management, patient care management and mental health treatment.[106] 7. **Drone-enabled medical service delivery** enables the fast delivery of vaccines, medications and supplies right to the source. This capability could help avoid unnecessary direct contact between	1. **Ultra-low and predictable latencies with quality-of-service guarantees (URLLC)** - even with a heavy load and many users. 2. **Extremely high bandwidth for data transmission (eMBB)**, enabling transfer and download of massive data files, high-resolution images, videos and supporting AR/VR. 3. **Massive IoT (mIoT)** - 5G will be able to facilitate a large network of IoT devices and sensors. 4. **Fixed wireless access (FWA)** - ubiquitous and low-cost networks in rural areas. 5. **More deployment flexibility** for sparse and dense options. **6. Mobility capabilities to ensure a smooth handover** between base stations. 7. **Reliability of device interoperability** and low device cost at scale. 8. **Location awareness** for navigating, real-time locating, and positioning.

[101] Link to source: https://haas.berkeley.edu/wp-content/uploads/5g-mobile-impact-on-the-health-care-sector.pdf.

[102] Ibid.

[103] Ibid.

[104] Link to source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7136105/.

[105] Link to source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8764898/.

[106] Link to source: https://healthtechmagazine.net/article/2020/11/what-does-future-hold-ar-and-vr-healthcare.

individuals and limit outbreaks of life-threatening communicable diseases.[107] 8. **Equipment monitoring** enables "hospital management [to] continuously monitor technology readiness and functional status of devices. … Additionally, the hospital equipment management system gathers other parameters such as localization of the tools, intrahospital mobility and usage rates."[108] 9. **Interactive smart pharmaceuticals** promote medication compliance. "Smart inhalers or insulin pens and similar devices equipped with an embedded subscriber identity modules (eSIM) can record their application. Additionally, these devices might implement sensors and algorithmic functions to estimate the medication effect on the patient and consequently predict critical situations. These devices may also support personalized medication dose management and precision medicine."[109] 10. **Digital twin** enables location-independent patient assessment by retrieving patient data from different repositories, including "ad hoc retrieval and volume rendering of extensive image volume data and bidirectional communication for dynamic and interactive research of dedicated aspects on remote devices."[110] 11. **Distributed AI** enables services for personalized medicine by leveraging AI and patient data algorithms to provide personalized treatment.[111] 12. **Tele-assistance and telecare** allow healthcare operators to provide service to individuals in logistically challenging areas, particularly remote/rural areas. "5G-based, hands-free augmented reality technology has a strong potential for remote medical consultations in real-time under hygienic conditions."[112]	
Potential Operational Benefits	**Potential ESG Benefits**
1. **Facilitate a transition from volume-based fee-for-service models of medical delivery to outcome-based models** with the support of superior health informatics.	1. **Delivery of healthcare services to rural and underserved communities** which have poor access to healthcare; Doctors, especially specialists, have limited areas in which they practice, but by using telemedicine, primary care

[107] Link to source: https://healthmanagement.org/uploads/article_attachment/autonomous-deliver-of-medical-material-through-drones-in-a-future-pandemic.pdf.
[108] Link to source: https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf.
[109] Ibid.
[110] Ibid.
[111] Ibid.
[112] Ibid.

2. **Decrease medication and medical errors** while simultaneously increasing medication compliance with enhanced informatics and interactive smart pharmaceuticals. 3. **Train new surgeons or guide a surgeon in a remote area through a complex operation in real-time** with the support of high-resolution image feeds from operating room cameras. 4. **Allow physicians and researchers to access aggregated information and accumulated knowledge on the latest evidence, diagnosis, and treatment trends** through the transfer of high-resolution scans, tests and data-heavy files instantly using cloud-based solutions like Share XR. This creation and rapid movement of data, combined with predictive analytics and machine learning, will not only advance the state of medicine and health outcomes but our understanding of the human condition itself. 5. **Save money for hospitals and healthcare facilities by** helping medical practitioners work from home for some tasks; This frees up facility office space, provides access to doctors and nurses who work outside of the area, and facilitates online training and collaboration opportunities. 6. **Reduce costs through higher usage, lower downtime and more effective and efficient equipment maintenance** through real-time monitoring and diagnosis of hospital equipment and devices. 7. **Eliminate some human steps** by delivering medicine to the bedside of a patient from the pharmacy with the help of small indoor drones. This would lead to more rapid and less error-prone administration of medications. Nurses and pharmacists can work more efficiently as supplies can be summoned to the bedside instead of the time-consuming task of gathering necessary items. Drones could also deliver medications and supplies to patients being cared for in the home instead of in a hospital-based setting. The future will see more outpatient care and even home-based care that used to be delivered in the hospital. For many conditions, drone technology may make it easier and safer to provide this home-based care.	doctors on-location can consult with specialists anywhere in the world. 5G enables safe, secure and state-of-the-art telesurgery. [U.N. SDG - 1, 2, 5, 8, 10 and 14] 2. **Decrease medical waste, energy use and, thereby, GHG emissions** with better supply chain forecasting, more efficient facilities and equipment maintenance, and climate controls. [U.N. SDG - 12] 3. **Improved worker health and safety** by using robots and drones for tasks where human involvement may be tedious or dangerous. [U.N. SDG - 3] 4. **Shift of skills** and access to better professional jobs; empower patients, informal carers and lesser qualified professionals; in-field AR support for e-learning and expert advice in remote areas. [U.N. SDG - 8] 5. **Improved patient outcomes and satisfaction while potentially reducing readmissions** by interlinking health and social care and engaging care in proactive healthcare and wellness. [U.N. SDG - 3] 6. **Increased transparency of data, treatment and decisions** (access, audit trail, better reporting of data security, third party access); ability to restrict information to needs. [U.N. SDG - 3]
Estimated Economic Benefits	**Example Metrics Potentially Impacted by 5G**
1. 5G applications in healthcare could add an estimated US$530 billion[113] to global GDP by 2030. Extrapolating the study's results to Canada,	1. Access to the 5G network

[113] Link to source: https://www.pwc.com/gx/en/tmt/5g/global-economic-impact-5g.pdf.

estimated productivity gains could be between CAN$10 billion to $15 billion by 2030.[114] 2. Virtual care can generate up to $150 million on cost savings annually for Canada, by reducing travel times to appointments, missed appointment, and unnecessary emergency room visits.[115]	2. Number of 5G-enabled digital solutions implemented 3. Estimated total value realized from 5G enabled digital solutions implemented 4. Decrease in patient wait times 5. Decrease in the number of mistake events 6. Decrease in readmission rate 7. Decrease in medication errors 8. Decrease in the rate of complications 9. Decrease in the post-procedural death rate 10. Decrease in the average length of stay 11. Increase in bed/room turnover 12. Decrease discharge process time 13. Increase in equipment utilization rate 14. Decrease in equipment maintenance costs 15. Decrease in response times for patient transport services 16. Increase in patient confidentiality 17. Decrease in energy usage 18. Decrease in average cost per discharge 19. Decrease in average treatment cost 20. Decrease in the number of patient complaints filed 21. Increase in overall patient satisfaction 22. Increase in percentage of medical documents translated 23. Increase in training per department and percentage of employees that find internal training useful 24. Increase in care access to remote/rural areas

Select case studies:

Virtual Reality Training for Healthcare Workers[116]	
Background	▪ A 2017 survey of 107 orthopaedic surgeons found that 80% would like to use VR frequently for training and 90% would suggest VR training to their peers. ▪ The Johnson & Johnson Institute has launched a new global VR training programme for surgeons and nurses, with more than 50 sets of VR equipment worldwide. The programme includes VR training modules that allow surgeons to improve their techniques across three types of orthopaedic surgery: total knee replacement; total hip replacement with direct anterior approach; and hip fracture treatment with a proximal femoral nail.

[114] Based on World Bank and Statistics Canada data, and Deetken analysis.

[115] Link to source: https://www.rand.org/content/dam/rand/pubs/research_briefs/RBA1200/RBA1274-1/RAND_RBA1274-1.pdf.

[116] Link to source: https://www3.weforum.org/docs/WEF_The_Impact_of_5G.pdf.

Virtual Reality Training for Healthcare Workers[116]	
Improvement areas	▪ 5G mobile broadband capabilities allow for the simulation of a real-world experience in the operating room, including anatomical accuracy, via all the instruments and implants featured in VR training. ▪ VR training is highly scalable and can thus reduce time and resources spent on training overall. ▪ VR training programs reduce the need to travel to receive training.
Economic and societal impacts	▪ VR training provides cost savings for patients due to greater local availability of medical skills. ▪ VR training modules provide advanced skill enhancement for doctors and support staff and drive greater patient outcomes. [U.N. SDG 3] ▪ The acquisition of new professional skills can lead to increased revenue opportunities. ▪ The use of VR reduces carbon emissions due to reduced travel requirements to attend training programmes.
5G capabilities used	▪ eMBB
CapEx requirements	▪ VR headsets, motion control devices, surgical training tools and digital infrastructure.
Maturity timeline	▪ Current state: 4K streaming and faster delivery of training programmes. ▪ Short-term: gamified training simulations that lead to immersive surgery techniques. ▪ Long-term: enhanced remote training opportunities using the internet of medical skills combined with haptic feedback and robotics

5G-enabled Healthcare Solutions for Hospitals[117]	
Background	▪ Hospitals have rigid demands to improve patient healthcare services. More than 20 new services, with more demanding requirements, are expected to enter the new medical ecosystem. ▪ Clinical information is not shared across medical institutions due to inconsistent information system standards, thereby resulting in low utilization of medical data resources. ▪ Futian Medical Consortium (FMC), China Mobile, Huawei and other organizations have jointly developed a variety of 5G smart healthcare projects in Shenzhen since 2019. These projects have been carried out in all medical institutions – seven hospitals and 83 community health centres – across the district.

[117] Link to source: https://www.gsma.com/greater-china/wp-content/uploads/2021/02/5G-Use-Cases-for-Vertical-China-2021-EN.pdf.

5G-enabled Healthcare Solutions for Hospitals[117]	
Improvement areas	▪ 5G technology, along with multi-edge computing and network slicing, has allowed FMC to utilize a virtual private network that runs on the public network. This solution allows hospitals to quickly scale their services and meet the real-time transmission needs of the large volume of medical devices and applications supported by the network. ▪ Use of 5G-enabled tablets and medical carts allow medical staff to perform ward rounds and other daily routines efficiently and conveniently, as well as quickly send and receive medical images and data. ▪ Regionally connected smart emergency carts in community health centres support one-click activation and enable users to request remote rescue guidance from experts in superior institutions. ▪ 5G networks enable ambulances to offer in-hospital-like services such as patient registration and medical record setup. A patient's vital signs and electrocardiogram, as well as the ambulance's location information, can be transmitted to the hospital's emergency command centre in real-time so that hospital staff can be ready prior to the patient's arrival. ▪ 5G-enabled devices allow experts to provide remote consultations anytime and anywhere, thus breaking restrictions in time and location and improving healthcare access for those in more rural locales.
Economic and societal impacts	▪ The telemedicine market was valued at roughly US$80 billion in 2020 and is expected to grow to US$397 billion by 2027.[118] ▪ 5G networks expand medical coverage to rural/remote areas and allow medical personnel and specialists to provide immediate care to patients. [U.N. SDG 3] ▪ Transport of patients is reduced due to the availability of 5G-enabled healthcare services from experts at local satellite facilities. ▪ 5G technology increases capacity for research and innovation. [U.N. SDG 9]
5G capabilities used	▪ eMBB ▪ URLLC ▪ Security critical
CapEx requirements	▪ Backbone connectivity, AI and big data solutions, data analytics applications, robotics and wearables.
Maturity timeline[119]	▪ Current state: faster data processing for enhanced and efficient remote patient monitoring. ▪ Short-term: AR/VR-based healthcare solutions using multi-edge computing. ▪ Long-term: real-time health systems leveraging the internet of medical skills and machine learning.

[118] Link to source: https://www.fortunebusinessinsights.com/industry-reports/telemedicine-market-101067.

[119] Link to source: https://www3.weforum.org/docs/WEF_The_Impact_of_5G.pdf.

3.1.2 Agriculture

Industry Overview: The agriculture and agri-food industries, which account for approximately 9.7% of total global GDP[120] and 6.8% of Canadian GDP and in Canada employs 2.1 million people[121], will need to evolve rapidly over the next few years to meet the demands of global population growth and climate change. According to the IPCC, between 21% and 37% of total global GHG emissions are attributable to the food system, including up to 14% from activities within the food gate, 14% from land use changes, and 10% from supply chain issues, notably from food loss and waste.[122] Over the next decade, 5G will play a critical role in the agriculture and livestock industries by enabling devices and solutions that can improve crop yields, crop quality and health of the livestock. Smart farming/precision agriculture will allow farmers and ranchers to be more informed and productive. Internet of Everything-based cloud computing service in the 5G network provides flexible and efficient solutions for smart farming that will allow the automated operation of various agricultural machines for the plowing, seeding and management phases of crop farming. In turn, this will make farming operations more secure, reliable, sustainable and energy efficient. According to a McKinsey study, "if connectivity is implemented successfully in agriculture, the industry could tack on $500 billion in additional value to the global GDP by 2030. … This would amount to a 7 to 9% improvement from its expected total."[123] Extrapolating to Canada, the GDP impact of these technologies could be between $2.7 billion and $3.5 billion.[124]

Challenges faced by the agriculture industry:

1. **Population growth:** The United Nations (U.N.) estimates the global population will increase to 9.7 billion by 2050 and could peak at roughly 11 billion by 2100.[125] A 2009 study by the Food and Agriculture Organization of the U.N. (FAO) estimates that food production would need to increase by 70% to feed their forecasted world population of roughly 9 billion by 2050, based on an evaluation of farming practices, techniques and technology at that time.[126]

2. **Changing weather patterns:** The variability of temperatures and precipitation and the rise in the frequency of floods and droughts because of climate change will likely have negative impact on crop yields.[127]

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[120] Link to source: https://www.slideshare.net/IFPRI-PIM/beyond-agriculture-measuring-agrifood-system-gdp-and-employment.

[121] Link to source: https://agriculture.canada.ca/en/canadas-agriculture-sectors/overview-canadas-agriculture-and-agri-food-sector.

[122] Link to source: https://www.ipcc.ch/srccl/chapter/chapter-5/.

[123] Link to source: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth.

[124] Based on applying the 2010 to 2020 compound annual growth rate of 'Crop and animal production' sector GDP (chained (2012) dollars) to estimate annual GDP for 2021 to 2030. The range provided is based on applying the 7% and 9% impacts to the estimated 2030 value. Link to source: Statistics Canada. Table 36-10-0434-03 Gross domestic product (GDP) at basic prices, by industry, annual average (x 1,000,000).

[125] Link to source: https://www.un.org/en/global-issues/population.

[126] Link to source: https://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf.

[127] Link to source: https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf.

3. **Soil degradation:** The world's farmlands are becoming increasingly unsuitable for production. According to a study by the FAO, "the majority of the world's soil resources are in fair, poor or very poor condition. Today, 33% of land is moderately to highly degraded due to the erosion, salinization, compaction, acidification and chemical pollution of soils."[128]

4. **Water scarcity**: Water resources are also highly stressed, which places additional pressure on the agri-ecosystem and exacerbates rural poverty in certain parts of the world. According to a study by the FAO, "3.2 billion people live in agricultural areas with high to very high water shortages or scarcity, of whom 1.2 billion people – roughly one-sixth of the world's population – live in severely water-constrained agricultural areas."[129]

5. **Wastage of food:** Despite roughly 925 million people suffering from hunger globally, estimates compiled by the U.N. suggest that approximately 1.3 billion tonnes of food produced annually is lost or wasted across the entire food value chain (i.e., production, processing, distribution and end-customer consumption).[130] Analyses indicate that much of the pre-consumer waste could be avoided by refining production, manufacturing and distribution processes. Wasted food consumes approximately 30% of global agricultural land area[131] and 25% of globally freshwater.[132] A study by Value Chain Management International Inc. finds that in Canada, approximately 58% of commodities entering the food system are wasted. Of that, 24% of total waste occurs at the production level, 34% at the processing level and 13% at the manufacturing level. Distribution and retail waste accounts for 6% of total food waste and hotel, restaurant and institution waste accounts for 9%.[133]

Smart farming is expected to drive significant enhancements in food planning, production, logistics and tracking. Technologies such as the IoT, AI, ML, and BDA, supported by a ubiquitous and resilient 5G network, can help harness the value of data. This would help avert the expected future food sustainability crisis while supporting the achievement of environmental and sustainability goals of enhanced productivity, water and fertilizer optimization, and GHG emission and food wastage reduction. Mobile wireless technologies, including 5G, applied to the primary agriculture industry could abate 10% of its emissions, or 2% of Canada's total emissions.[134]

Potential Digital Solutions Supported by 5G	Types of 5G Capabilities Leveraged

[128] Link to source: https://www.fao.org/3/i5199e/I5199E.pdf.

[129] Link to source: https://www.fao.org/3/cb1447en/cb1447en.pdf.

[130] Link to source: https://www.un.org/en/chronicle/article/feeding-world-sustainably.

[131] Link to source: https://www.un.org/en/observances/end-food-waste-day/background.

[132] Link to source: https://comparecamp.com/food-waste-statistics/.

[133] Link to source: https://www.secondharvest.ca/getmedia/58c2527f-928a-4b6f-843a-c0a6b4d09692/The-Avoidable-Crisis-of-Food-Waste-Technical-Report.pdf.

[134] Based on sources and Deetken analysis. Link to sources: https://www.cwta.ca/wp-content/uploads/2020/10/5G_Role_In_Fight_Against_Climate_Change.pdf; https://www.farrpoint.com/uploads/store/mediaupload/492/file/Digital_Policy_and_Climate_Change_Report_FarrPoint_2022.pdf.

1. **Distributed soil sensors** that monitor and measure soil parameters such as moisture or temperature, identify issues such as diseases or insects, and enable informed farming decisions.[135] 2. **RFID, bar code and other identification technologies** that build a safe traceability system for agricultural products and enhance the added value of agricultural products.[136] 3. **Weed and crop monitoring** to track positive and negative dynamics of crop vegetation development in real-time.[137] 4. **Routing and monitoring of livestock** supports real-time management of herds to track the location, health and needs of individual animals and to adjust their nutrition, thereby preventing disease and enhancing herd health. With this information, farmers can also identify sick animals so they can be separated from the herd to prevent the spread of disease.[138, 139] 5. **Smart irrigation** through the use of controllers and devices which reduce water usage by using precise real-time and location-dependent information about site conditions. Data generated from IoT soil sensors and drones can help generate heat maps that highlight problem areas. Advanced machine learning algorithms can process this data and distribute water where it's needed most. 5G's speed and throughput facilitate the real-time transmission of these large data sets.[140] 6. **Connected farming machinery** that use GPS-enabled auto-steer to automate machine use and deployment, thereby leading to optimized operation and substantial fuel savings.[141] Automated farming equipment (e.g., smart milking equipment) and vehicles (e.g., harvesting trucks) can be controlled remotely by a central operator (human or AI), with 5G facilitating the real-time transfer of the massive amounts of data generated.[142, 143]	1. **Ultra-low and predictable latencies with quality-of-service guarantees (URLLC)** even with a heavy load and many users. 2. **Extremely high bandwidth for data transmission (eMBB),** enabling the transfer and download of massive data files, high-resolution images, videos and supporting AR/VR. 3. **Massive IoT (mIoT)** - 5G will be able to facilitate a large network of IoT devices and sensors. 4. **Fixed wireless access (FWA)** - ubiquitous and low-cost networks in rural areas. 5. **More deployment flexibility** for sparse and dense options. 6. **Mobility capabilities to ensure a smooth handover** between base stations. 7. **Reliability of device interoperability** and low device cost at scale. 8. **Location awareness** for navigating, real-time locating and positioning.

[135] Link to source: https://www.mdpi.com/1424-8220/21/5/1693/pdf?version=1614850188.
[136] Link to source: https://www.barcodesinc.com/news/bar-coding-and-rfid-enable-food-supply-chain-traceability-and-safety/.
[137] Link to source: https://www.5gradar.com/features/ways-5g-will-change-farming-and-agriculture.
[138] Ibid.
[139] Link to source: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth.
[140] Link to source: https://www.5gradar.com/features/ways-5g-will-change-farming-and-agriculture.
[141] Link to source: https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf.
[142] Link to source: https://www.5gradar.com/features/ways-5g-will-change-farming-and-agriculture.
[143] Link to source: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth.

7. **Building and equipment management** through "prescriptive maintenance and real-time environmental adjustments, aimed at improving performance and extending the useful life of farm equipment and other assets as well as decreasing the risk of mold, fire and other threats."[144] 8. **Drones for farming** for surveillance and remote interventions based on image analysis and connected sensors. Data from the drone allows users to monitor fields, livestock or autonomous machinery (e.g., driverless harvesting trucks). Drones can help isolate problem areas on a large farm and also enable autonomous, targeted (reduced) application of pesticides and herbicides.[145, 146] They have the ability to spray fertilizers, pesticides and herbicides 40 to 60 times faster than is possible with manual application.[147] **9. Smart greenhouses** that "leverage IoT and connected devices to create a self-regulating microclimate conducive to crop production. These controlled environments eliminate the struggles of inclement weather and predators while delivering real-time insights to farmers for optimum efficiency. Farmers using smart greenhouse crop monitoring systems can leverage insights from big data and analytics to regulate crop spraying, irrigation, lighting, temperature, humidity, and more."[148]	
Potential Operational Benefits	**Potential ESG Benefits**
1. **Increase in farmland productivity** by "an estimated 4% as a result of current precision agriculture adoption and has the potential to further increase 6% with broader precision agriculture adoption."[149] 2. **Improved fertilizer application (right source, right rate, right time and right place) efficiency** by "an estimated 7% and has the potential to further improve an additional 14% with broader adoption of precision agriculture technologies."[150]	1. **Ensured food security and resilience and reduced dependency on imports** by increasing crop and livestock yields, decreasing food spoilage and waste, and increasing food quality and access. [U.N. SDG - 1 and 2] 2. **Decrease in fossil fuel use** by "an estimated 6% as a result of current precision agriculture adoption [with] the potential to further decrease 16% at full precision agriculture adoption."[154] [U.N. SDG - 12]

[144] Ibid.
[145] Ibid.
[146] Link to source: https://www.5gradar.com/features/ways-5g-will-change-farming-and-agriculture.
[147] Link to source: https://www.businessinsider.com/smart-farming-iot-agriculture.
[148] Ibid.
[149] Link to source: https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf.
[150] Ibid.
[154] Link to source: https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf.

3. **Significant savings and simultaneous protection of the fragile farm ecosystem.** For example, a study conducted by the European Parliamentary Research Service finds that early, accurate detection and localized pest and disease treatment have the potential to reduce pesticide costs by up to 85%.[151] A study by the Association of Equipment Manufacturers et al. finds that herbicide usage "has been reduced by an estimated 9% as a result of current improved precision agriculture application practices and has the potential to further decrease 15% at full precision agriculture adoption."[152] Broader precision agriculture adoption enabled by 5G is also expected to result in a decrease in seeding, fuel and energy, labor and asset maintenance costs.[153] 4. **Increased human productivity and performance** and decreased level of unnecessary human intervention. Creation of new jobs by 5G in data analytics and farm management. 5. **Enhanced cyber and physical security** through real-time security monitoring and threat assessment via drones and industrial cameras.	3. **Reduced water use** by "an estimated 4% as a result of current precision agriculture adoption [with] the potential to further decrease by 21% at full precision agriculture adoption."[155] [U.N. SDG - 6] 4. **Improved worker health and safety** with the use of autonomous agriculture vehicles and drones for tasks where human involvement may be tedious or dangerous. [U.N. SDG - 3] 5. **Improved access to connectivity and integration into the end-to-end food value chain** will drive an increase in food safety and traceability and a reduction in food waste, thereby reducing GHG emissions and supporting global climate change goals. [U.N. SDG - 2, 8, 9, 10, 12 and 14] 6. **Shift of skills** and access to better professional jobs; in-field AR support for e-learning and expert advice in remote areas. [U.N. SDG - 8]
Estimated Economic Benefits	**Example Metrics Potentially Impacted by 5G**
1. 5G applications in agriculture could add an estimated US$500 billion to global GDP by 2030, and $2.7 billion to $3.5 billion to Canada GDP in 2030. [156]	1. Access to the 5G network 2. Number of 5G-enabled digital solutions implemented 3. Estimated total value realized from 5G enabled digital solutions that are implemented 4. Increase crop and livestock yield 5. Decrease in fertilizer, pesticide, and herbicide use per output 6. Decrease in water and energy use per output 7. Decrease in crop storage and transportation costs 8. Increase in farmland utilization rate 9. Decrease in food crop wastage and improved livestock health 10. Decrease in GHG emissions 11. Decrease in workplace injuries 12. Increase in labor force skills index

[151] Link to source: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf.

[152] Link to source: https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf.

[153] Link to source: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth.

[155] Ibid.

[156] Based on sources and Deetken analysis. Link to sources: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth; Statistics Canada. Table 36-10-0434-03 Gross domestic product (GDP) at basic prices, by industry, annual average (x 1,000,000).

Select case studies:

Precision Agriculture in Canola Farming[157]	
Background	▪ In 2018, Saskatchewan harvested over 12 million acres of canola, with total production of over 10.9 million tonnes. Roughly 90% of Canada's total canola production is exported to foreign markets.[158] ▪ Canola operations make use of fertilizers and pesticides to combat invasive plants, harmful insects and disease and promote higher crop yields. Larger operations use several tractors or manned aircraft to administer fertilizers and pesticides, which often under- or over-spray certain areas and consequently place crops, human health and the environment at risk.
Improvement areas	▪ Aerial scanning and detection by unmanned drones, in combination with large-scale IoT sensor networks, allow for autonomous, targeted application of fertilizers and pesticides – thereby reducing overall usage.
Economic and societal impacts	▪ A study by the European Parliamentary Research Service suggests that early, accurate detection and localized pest and disease treatment can reduce the use of pesticides by up to 85%.[159] In addition to cost savings, these precision agriculture techniques would result in health and environmental benefits, as well as higher crop yields. [U.N. SDG 12] ▪ For Saskatchewan's canola industry, an 85% reduction in pesticide usage would equate to roughly $360 million in annual savings. Once 5G networks are deployed and precision agriculture practices become more widely adopted, the average Saskatchewan oilseed farmer could expect to realize up to $40,000 in annual savings.[160]
5G capabilities used	▪ eMBB ▪ mIoT ▪ Power efficiency
CapEx requirements	▪ Unmanned drones, IoT devices and data analytics applications; other potential purchases include edge computing and private network infrastructure.
Maturity timeline[161]	▪ Current state: Connectivity requirements of precision agriculture can be supported by existing 4G networks; however, the implementation of large-scale IoT sensor networks and real-time video analysis will require 5G's bandwidth and speed capabilities. ▪ Short-term: Fixed wireless access and network slicing will allow 5G networks to support additional IoT applications in rural areas.

[157] Link to source: https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.
[158] Ibid.
[159] Link to source: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf.
[160] Link to source: https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.
[161] Link to source: https://www3.weforum.org/docs/WEF_The_Impact_of_5G.pdf.

Precision Agriculture in Canola Farming[157]	
	▪ Long-term: autonomous machine learning and satellite, content-based analytics that further augment the benefits of precision agriculture.

Viticulture Disease Mitigation[162]	
Background	▪ In 2019, Canada's viticulture industry earned roughly $1.5 billion in total revenue and provided over 45,000 full-time equivalents jobs.[163] ▪ Grapevine Leafroll Disease (GLD) is one of the most common viruses impacting vineyards globally and can be difficult to identify from the ground. The disease can reduce berry weight and delay time to maturity by up to four weeks.[164] ▪ A Halifax-based vineyard has initiated a digital vineyard pilot project, which involves flying a 4G-enabled drone over a winery to conduct real-time analysis of vineyard health.
Improvement areas	▪ An automated approach to vineyard monitoring would enable the timely identification, isolation and treatment of infected or at-risk vines necessary to mitigate adverse outcomes from GLD. ▪ Unmanned aerial reconnaissance using 5G-enabled communications networks would allow for greater volumes of data and imagery to be transmitted in real-time so farmers can quickly take action to mitigate losses attributable to crop disease.
Economic and societal impacts	▪ An Accenture study finds that "for an average 50-acre Okanagan vineyard, [GLD] could impact yield by as much as 30%. If left undetected and untreated in a timely manner via targeted [vine replacement], this would result in an economic loss on average of $18,000 annually.[165] 5G-enabled unmanned aerial drone reconnaissance enables farmers to quickly detect and treat GLD such that crop yields are improved. [U.N. SDGs 2 & 12]
5G capabilities used	▪ eMBB
CapEx requirements	▪ Unmanned drones and data analytics applications; other potential CapEx purchases include edge computing and private network infrastructure.
Maturity timeline[166]	▪ Current state: Connectivity requirements of aerial drone monitoring can be supported by existing 4G networks, however, real-time high-resolution video analysis will require 5G's bandwidth and speed capabilities.

[162] Link to source: https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.

[163] Link to source: https://www.winegrowerscanada.ca/wp-content/uploads/2022/08/RPT-Canadian-Wine-Economic-Impact-2019-1.pdf.

[164] Link to source: https://brocku.ca/ccovi/wp-content/uploads/sites/125/2016-03-02.-CCOVI-Lecture-Series.-Urbez-Torres-Grapevine-viruses-in-BC.pdf.

[165] Link to source: https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.

[166] Link to source: https://www3.weforum.org/docs/WEF_The_Impact_of_5G.pdf.

Viticulture Disease Mitigation[162]	
	▪ Long-term: autonomous machine learning that further augments the benefits of drone reconnaissance

3.1.3 Energy

Industry Overview: In Canada, energy production was equal to 10% of total Canadian GDP in the first quarter of 2022.[167] The current transformation underway in the energy sector is one of the most important challenges facing humankind. According to the U.S. Energy Information Administration (EIA), fossil fuels (petroleum and other liquids, natural gas, and coal) still accounted for 80% of global primary energy consumption in 2018. Nuclear energy and renewables accounted for the remainder of energy consumption at 5% and 15%, respectively.[168] The overall demand for energy is expected to continue growing as the global population is anticipated to reach 9.7 billion by 2050.[169] Improving standards of living in developing markets will also play a critical role in the growth of energy consumption in these markets. The EIA projects nearly a 50% increase in world energy usage by 2050, led by growth in Asia.[170] Their projections indicate that, by 2050, fossil fuels will account for roughly 69% of global primary energy consumption, while nuclear energy and renewables will account for 4% and 28%, respectively.[171] The Intergovernmental Panel on Climate Change (IPCC) states that to limit global warming to 1.5 degrees, "global net human-caused emissions of carbon dioxide would need to fall by about 45% from 2010 levels by 2030 [and reach] 'net zero' around 2050."[172] This dichotomy puts the energy and electric utility sectors in the centre of a massive energy transition which will last for multiple decades as the world strives to wean itself off fossil fuels. In Canada, the oil and gas and electricity sectors together account for approximately 35% of total GHG emissions. As a point of comparison, emissions from transportation across all modes (aviation, rail, truck, passenger vehicles) account for 24% of total emissions.[173]

Given the oil and gas and electric utility sectors' highly diversified and complex operations, processes, infrastructure and technical workforce, as well as the magnitude of their economic and environmental footprint, it is expected these industries will drive the migration from Industry 3.0 to Industry 4.0 using 4G- and 5G-enabled digital solutions.[174] Widespread use of digital technologies in the oil and gas sector could decrease production costs between 10% and 20%, including

[167] Link to source: https://energy-information.canada.ca/en/subjects/energy-and-economy.

[168] Link to source: https://www.eia.gov/todayinenergy/detail.php?id=41433.

[169] Link to source: https://www.un.org/en/global-issues/population.

[170] Link to source: https://www.eia.gov/todayinenergy/detail.php?id=41433.

[171] Ibid.

[172] Link to source: https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments.

[173] Based on figures from 2020, Environment and Climate Change Canada (2022) National Inventory Report 1990-2020: Greenhouse Gas Sources and Sinks in Canada. Link to source: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html.

[174] Link to source: https://www.frost.com/frost-perspectives/5g-a-critical-enabler-for-digitalization-in-oil-and-gas-emerging-use-cases-and-opportunities/.

through advanced processing of seismic data, the use of sensors and enhanced reservoir modelling.[175] According to the International Energy Agency (IEA), "technically recoverable oil and gas resources could be boosted by around 5% globally, with the greatest gains expected in shale gas."[176] The IEA estimates that "the overall savings from these digitally enabled measures could be in the order of US$80 billion per year over 2016-2040, or about 5% of total annual power generation costs."[177] Extrapolated to Canada, the cost savings would be approximately CAN$1 billion to $2 billion a year.[178] While power asset lifetime extensions enabled by digitalization are not yet known, the IEA estimates that if the lifetime of all global power assets were extended by five years, "close to US$1.3 trillion of cumulative investment could be deferred over 2016-2040, or about 7% of total power sector investment in the [status quo] scenario."[179]

Challenges faced by the energy and electric utility industries:

1. **Increase in energy demand from population growth and rising living standards in developing economies:** As the global population continues to grow, it will drive increased energy demand from emerging markets and developing economies. Across all fuels and technologies, emerging markets will be instrumental in shaping global trends in the coming decades. According to the IEA's Stated Policies Scenario (STEPS)[180], "oil demand in these economies [will be] 12 million barrels per day higher in 2030 than in 2020 (an increase of nearly 30%), gas demand [will be higher] by 520bcm (a near 25% increase), and coal demand [will be higher] by 160 million tonnes of coal equivalent (a 4% rise)."[181] According to their Announced Pledges Scenario (APS),[182] "demand for fossil fuels in advanced economies falls … but announced pledges do not bend projected demand trends across much of the developing world."[183]

2. **Transitioning to renewable energy sources:** Converting the current energy system to one led by renewable energy will require significant flexibility in all parts of the power system from generation to transmission and distribution systems, storage and demand. Production of heat and synthetic gas (e.g., hydrogen) from renewable electricity will also

[175] Link to source: https://www.pwc.com/ca/en/media/release/digitization-decrease-production-cost-for-oil-and-gas-companies.html.

[176] Link to source: https://iea.blob.core.windows.net/assets/b1e6600c-4e40-4d9c-809d-1d1724c763d5/DigitalizationandEnergy3.pdf.

[177] Ibid.

[178] Based on Canada accounting for approximately 2% of total global GDP.

[179] Ibid.

[180] The Stated Policies Scenario reflects current policy settings based on a sector-by-sector assessment of the specific policies that are in place, or have been announced, by governments around the world.

[181] Link to source: https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf.

[182] The Announced Pledges Scenario, introduced this year, aims to show to what extent the announced ambitions and targets, including the most recent ones, are on the path to deliver emissions reductions required to achieve net zero emissions by 2050. It includes all recent major national announcements of 2030 targets and longer-term net zero and other pledges, regardless of whether these have been anchored in implementing legislation or in updated NDCs. In the APS, countries fully implement their national targets to 2030 and 2050, and the outlook for exporters of fossil fuels and low emissions fuels like hydrogen is shaped by what full implementation means for global demand.

[183] Link to source: https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf.

be key for energy system decarbonization in the long-term, and, once in place, it can be a significant additional source of flexibility for the power system.

3. **Shift away from the traditional utility business model, in which monopolist power companies distribute their energy from large power plants to the end-user:** Decentralization of the energy utility market will look like a distributed energy network with a democratic business model in which energy consumers manage their own energy portfolios. Decentralization requires several technologies with different implications for the grid: distributed generation from renewable sources (primarily photovoltaic solar), which reduces demand during sunny hours of the day; distributed storage, which collects electrical energy locally for use during peak periods or as backup, flattening demand peaks and valleys; energy efficiency, which allows for reduced energy use while providing the same service, reducing overall demand; and demand response, which enables control of energy use during peak demand and high pricing periods, reducing peak demand. According to the World Economic Forum, "as more distributed energy resources come online, demand response programmes may become even more flexible and by some estimates could reduce necessary annual investments in U.S. grid infrastructure by 10%."[184] Moreover, "demand flexibility creates value for customers and the grid by shrinking customer bills (by as much as 40%), reducing peak demand and shifting consumption to lower price, off-peak hours."[185] This new decentralized model, when fully scaled, should optimize renewable energy while also cutting transmission and distribution costs.[186] Unlike a centralized system where power is supplied when demand peaks, a decentralized system uses demand responses to manage supply and grid stability. However, this system would require coordination of an immense number of energy consumers, equipment and demand responses.[187]

4. **Increased variability caused by demand and supply of different energy sources:** New energy sources are creating complex dynamics between electricity, fuels and storage markets, and will continue to do so moving forward. These complex interactions will generate considerable variability on both the demand and supply sides of the energy market. For example, rising shares of wind and solar photovoltaic electricity generation will further necessitate robust grids and other flexible sources of supply due to the additional variability that these generation methods introduce.[188]

5. **Demanding ESG goals and increased regulatory oversight:** International agencies, governments and policy makers have intensified their scrutiny of the energy and electric utility sectors because of the environmental challenges related to these sectors. The oil and gas and electricity sectors are major consumers and producers of energy and are subject to increasingly stringent environmental regulations. These sectors are increasingly

[184] Link to source: https://www3.weforum.org/docs/WEF_Future_of_Electricity_2017.pdf.
[185] Ibid.
[186] Link to source: https://utilityanalytics.com/2021/08/energy-decentralization-why-its-a-big-deal-for-every-business/.
[187] Link to source: https://solutions.mhi.com/blog/the-energy-transition-depends-on-these-three-trends/.
[188] Link to source: https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf.

confronted with the need to develop and report their ESG targets that align with national and or international regulatory standards. This additional oversight is driving operators to redesign their extraction, production and transportation systems and processes to enhance their operational and regulatory effectiveness. Operators are also required to provide transparency in the environmental management of their activities. These considerations have become critical as these two sectors face accelerating change and increased activism.

6. **Wastage of energy during generation and consumption:** According to the EIA, approximately 60% to 66% of energy used for electricity generation is lost in conversion.[189] It is estimated that of the 66% lost, roughly 59 percent points are due to inefficiencies in the process of converting primary energy to electricity, 5 percent points are due to power plant operations and the remaining 10 percent points are lost during the delivery of electricity through the transportation and distribution system.[190]

7. **Reducing costs to remain globally competitive:** One of the major challenges of the energy industry is the high cost to produce crude oil, gas and refined products. Optimizing extraction, conversion and distribution systems and processes is a priority for both energy and utility operators.

8. **Increasing operational complexity from distributed smaller scale energy solutions:** The move from centralized to decentralized energy generation is accelerating. As more renewable energy sources connect to the grid, they are creating hundreds or thousands of power generation points and types and are making the power grid more complex to operate. This is resulting in reduced revenue for operators, increased transmission and distribution system costs, and increased risk regarding grid reliability and cyber-security.

9. **Outdated extraction, generation and distribution plants and systems:** Both Canada's and the U.S.'s electric utility sectors face a pressing need to maintain aging facilities, and operators are tasked with integrating more intermittent generation from renewable sources and incorporating smarter grid systems. There are more than 35 electrical transmission interconnections between the Canadian and U.S. power systems with the two systems forming a highly integrated grid. This integration is set to continue expanding, with multiple cross-border transmission projects currently in various stages of development. Every Canadian province along the U.S. border is electrically interconnected with one or more neighboring U.S. states. For utilities, the aged infrastructure is causing frequent tripping and breakdown because of a poor distribution system. The oil and gas sector faces a similar challenge in the form of fugitive emissions[191] that account for approximately 5% of global emissions. Roughly 60% of fugitive emissions come from leaky valves; servicing,

[189] Link to source: https://www.eia.gov/todayinenergy/detail.php?id=44436.

[190] Link to source: https://www.enerdynamics.com/Energy-Currents_Blog/How-Much-Primary-Energy-Is-Wasted-Before-Consumers-See-Value-from-Electricity.aspx.

[191] Fugitive gas emissions are leaks or unwanted releases of gases and vapours into the atmosphere that can originate from storage tanks, pipelines, appliances, and other industrial pressurized equipment.

updating and replacing valves, as well as implementing new automation and monitoring technology, could address much of these fugitive emissions.[192]

10. **Climate change and the increase in natural disasters:** Increasing potential for incidents such as pipeline bursts and natural calamities like floods and earthquakes owing to climate change may also cause interruptions to electricity and energy supplies, as well as major spills and leaks.

11. **Asset protection from physical and cyber attacks:** The economic importance of oil and gas infrastructure means that they are a key target for terrorism and piracy, which can lead to high levels of damage.

Current oil and gas and electric utility business models will use 5G-enabled digital machines, devices, and technologies like AI, ML, BDA, digital twins, blockchain and others to optimize their operations and infrastructure. These new machines, devices, technologies and applications will improve the design, construction, and maintenance methods of oil and natural gas pipelines and electricity generation plants while simultaneously enhancing asset integrity and cost-efficiency and extending service life expectations. These innovative technologies will also further reduce environmental and work and safety incidents.

The proliferation of renewable energy sources will make our energy networks more complex. This increased complexity will be driven by factors such as multiple energy sources and decentralized grids. To manage this complexity, the energy and utility sectors will require intelligent solutions to monitor and manage fluctuating demand and supply, environmental impacts and operational performance. 5G-enabled digital tools will help energy and utility operators overcome these acute challenges and make the necessary changes.

5G technology enhances critical awareness and decision-making for a variety of situations. As an example, drone-mounted cameras can help monitor seismic changes, fires, and natural disasters more effectively; they can help terminal operators proactively inspect container ships before they even reach the port and operators of wind farms proactively detect problems with turbines. Video analytics could significantly enhance the security, and efficiency in the field by enabling intrusion detection, automatic fault detection, and control of robots. Similarly, search and rescue operations could leverage camera drones and video analytics to survey remote areas without human intervention.

Potential Digital Solutions Supported by 5G	Types of 5G Capabilities Leveraged
1. **VR, AR and MR (Mixed Reality)** can be used to support collaboration for diagnostics and maintenance, enhance employee training and productivity, and recreate real-life scenarios for workers to safely practice their skills. These digital solutions could even support remote work by allowing collaboration among employees in virtual spaces. Additionally, they could allow interaction	1. **Ultra-low and predictable latencies with quality-of-service guarantees (URLLC)** even with a heavy load and many users by using network edge to optimize network traffic flows; Decentralization will drive the need for real-time control of the grid, and low latency requirements, which will also drive the

[192] Link to source: https://www.reuters.com/article/sponsored/capturing-fugitive-emissions-can-create-greener-more-cost-effective-operations.

with data, applications and the environment in new ways. Digital twins could create a virtual model of an oil and gas or power plant or even an entire grid, allowing employees to model different scenarios, make better decisions and improve efficiencies.[193] 2. **AI and predictive analytics** can be used to accelerate data clean-up and analysis of the massive volumes of data and reports generated by operational processes related to logistics, supply, and production. They can also be used to analyze and predict demand and adjust where power is drawn from on distributed grids.[194] 3. **Smart grids** can detect local changes in power usage and react automatically without the need for human intervention. They allow reliable real-time communication between consumers and utilities so consumers can tailor their energy consumption based on individual preference, such as price and/or environmental concerns. They enable more efficient transmission of electricity; quicker restoration of electricity after power disturbances; reduced peak demand; increased integration of large-scale renewable energy systems; better integration of customer-owner power generation systems, including renewable energy systems; and improved security.[195, 196] 4. **Smart fleet management** with GPS, sensors and enhanced 5G connectivity will enable enhanced maintenance and fuel management; driver safety; telematics; geo-fencing and tracking; smart surveillance; vehicle-to-vehicle communications; optimal real-time routing; speed/idling real-time feedback; real-time cargo monitoring; and collision avoidance. "Through integrated planning, improved vehicle utilization, and route and speed optimization, oil companies have demonstrated 10% to 30% reductions in overall transportation costs."[197] 5. **Smart contracts stored on blockchain** are "self-executing, customizable and tamper-proof [in] nature [and] seen as a key technology for enabling the transition to a more efficient, transparent and transactive energy market. The applications of smart contracts include coordination of smart electric vehicle charging, automated demand-side response, peer-to-peer energy trading and	need for more capable edge computing to support required latencies. 2. **Extremely high bandwidth for data transmission (eMBB),** which will enable the transfer and download of massive data files, high-resolution images, videos and supporting AR/VR. 3. **Massive IoT (mIoT)** - 5G will be able to facilitate a large network of IoT devices and sensors. 4. **Fixed wireless access (FWA)** - ubiquitous and low-cost networks in rural areas. 5. **More deployment flexibility** for sparse and dense options. 6. **Mobility capabilities to ensure a smooth handover** between base stations. 7. **Reliability of device interoperability** and low device cost at scale. 8. **Resilience and high availability** - All deployment scenarios must be able to ensure an elevated level of resilience and availability. To satisfy utilities' requirements, carriers may need to dedicate spectrum, radios, packet core instances and edge computing to utility customers. These dedicated resources can be enabled through the 5G slicing feature set. **9. Location awareness** for navigating, real-time locating, and positioning.

[193] Link to source: https://www.frost.com/frost-perspectives/5g-a-critical-enabler-for-digitalization-in-oil-and-gas-emerging-use-cases-and-opportunities/.

[194] Link to source: https://www.analyticsinsight.net/top-10-applications-of-ai-and-robotics-in-the-energy-sector/.

[195] Link to source: https://www3.weforum.org/docs/WEF_The_Impact_of_5G_Report.pdf.

[196] Link to source: https://www3.weforum.org/docs/WEF_Future_of_Electricity_2017.pdf.

[197] Link to source: https://ihsmarkit.com/research-analysis/upstream-oil-and-gas-meeting-its-challenges-through-innovation.html.

allocation of the control duties amongst the network operators."[198] 6. **Drone video surveillance, notification and analytics** to manage the security of campuses of oil and gas and electric utility companies and drilling, generation and distribution infrastructure; alerting systems that send notifications directly to mobile devices. 7. **Supervisory control and data acquisition (SCADA) systems that can proactively detect leaks and other issues** provide an abundance of data about the functionality and health of equipment. They can indicate the level of pressure within each pipe, monitor durable valves, measure tank level, track flow monitoring and much more. In addition to alarm notifications, operators can create preventative maintenance alerts so they can be proactive about their equipment. 8. **Digital workforce management** with seamless real-time collaboration; connecting employees across locations and time zones, allowing instant access to document and file sharing, and streamlined communication. Digital workforce management will also enhance remote work support, sustainability and better AI integration. 9. **Electric vehicles** (EVs) – 5G will be critical to guaranteeing safety and reliability via network slicing, which will play an essential role in guaranteeing connectivity. Network slicing will allow the creation of individual network slices with their own SLA-grade requirements for EVs and their charging infrastructure. This will require operators to be better equipped to guarantee the low latency and reliability they need to adapt to changing scenarios. EVs will be able to automatically switch to 5G without disrupting or interrupting communication with charging stations and management systems; they will dynamically switch back to fixed connectivity. **10.** **Smart meters** that will expose information about end-point energy consumption and generation and the quality of energy that is received from the distributor.[199] When this information is fed into the latest grid optimization tools, it shows distributors how to reconfigure their grids to reduce losses to heat and vibration and better use available capacity.	
Potential Operational Benefits	**Potential ESG Benefits**

[198] Link to source: https://www.sciencedirect.com/science/article/pii/S1364032121012764.

[199] Link to source: https://www.telit.com/blog/how-5g-enables-advanced-metering-infrastructure-smarter-utilities/.

1. **Optimized and automated drilling** with advanced analytics could increase drilling operations productivity by improving drilling speed by 25% or more.[200] Remote or semi-automatic drilling should also reduce the number of people required on the rig, driving down cost per well. Productive drilling time would increase to 94% from the current 90%. Together, drilling optimization and automation should drive a combined 5% to 10% reduction in cost per barrel of oil equivalent.[201] 2. **Reduced unplanned downtime** – "Oil and gas producers suffer 32 hours of unplanned downtime each month, on average, at the cost of $220,000 per hour – amounting to $84 million [annually] per facility. In refineries alone, losses to Fortune Global 500 constituents are estimated to total $47 billion from 213,000 downtime hours [annually]. 82% of oil and gas respondents [say] predictive maintenance [is] a strategic objective, the most of any sector surveyed."[202] Considering that 70% of companies lack awareness of when assets require maintenance, application of real-time asset condition monitoring and pre-emptive anomaly identification to pumps and compressors could reduce maintenance sessions and unplanned downtime by 25% and 32%, respectively, in addition to extending equipment lifetime by 25%.[203] Overall, this optimization could reduce maintenance costs by 20% to 40% and increase production by 3% to 5%.[204] 3. **Enhanced field operations and reduced operations costs driven by connected workers -** Digital twins, mobile device-accessible schematics and plans combined with features like push-to-video and smart integrated modeling will make workers more efficient both on and offsite. The increased	1. **Optimized and automated drilling** would reduce emissions from drilling activity by approximately 10%.[206] [U.N. SDG - 9 and 13] 2. **Optimized production** – Enhanced SCADA technologies will enable timely data collection across production systems substantially improving the performance of the plant, reducing the risk of leaks, and increasing public health safety. They should also create value by increasing throughput while also reducing the energy consumed and emissions produced.[207] [U.N. SDG - 9 and 13] 3. **Reduced health and safety incidents** – Augmenting workers with digital solutions can improve both their productivity as well as their workplace safety. A digitally enabled workforce can be 8.5% more productive while also reducing loss from health and safety incidents by 48%.[208] [U.N. SDG - 3 and 8] 4. **Reduced carbon dioxide emissions** by up to 12% with the Smart Grid.[209] [U.N. SDG - 12] 5. **Shift of skills** and access to better professional jobs; in-field AR support for e-learning and expert advice in remote areas. According to PWC's 22nd Annual Global CEO Survey, "76% of respondents from the energy, utilities and resources space expressed concern about the availability of skills, particularly digital skills, in the marketplace. It's becoming increasingly difficult for energy operators to find – and retain and engage – talent with key skill sets, including digital business strategy and data analytics."[210] [U.N. SDG - 8]

[200] Link to source: https://www.mckinsey.com/industries/oil-and-gas/our-insights/how-tapping-connectivity-in-oil-and-gas-can-fuel-higher-performance.
[201] Ibid.
[202] Link to source: https://pressreleases.responsesource.com/news/101458/world-s-largest-manufacturers-lose-almost-trillion-a-year-to/.
[203] Link to source: https://www.ericsson.com/en/industries/offshore-and-processing.
[204] Link to source: https://web-assets.bcg.com/img-src/BCG-Going-Digital-Is-Hard-for-Oil-and-Gas-Companies-but-the-Payoff-Is-Worth-It-Mar-2019_tcm9-215951.pdf.
[206] Link to report: https://www.mckinsey.com/industries/oil-and-gas/our-insights/how-tapping-connectivity-in-oil-and-gas-can-fuel-higher-performance.
[207] Link to report: https://www.mckinsey.com/industries/oil-and-gas/our-insights/how-tapping-connectivity-in-oil-and-gas-can-fuel-higher-performance.
[208] Link to source: https://www.ericsson.com/en/industries/offshore-and-processing.
[209] Link to source: https://www.frontiersin.org/articles/10.3389/fenrg.2021.681244/full.
[210] Link to source: https://www.pwc.com/ca/en/industries/energyvisions/publications/774843-forward-together-whats-ahead-for-canadas-oil-and-gas-industry-part-3.pdf.

effectiveness of digitally enhanced workers can result in an 8% reduction in operational spending.[205] 4. **Streamlined end-to-end supply and logistics** with improved demand management, transparent materials tracking and more efficient logistics operations. 5. **Reduced electricity theft, losses from transmission, distribution, etc.** from the development of smart grids. Smart grids can also reduce electricity costs, meter reading costs, operations and maintenance costs, and equipment failures by using automatic operation based on varying load conditions. The demand response of smart grids should decrease the stress on smart grid systems during peak conditions, which will reduce the probability of failure. Smart grids are also capable of meeting increased consumer demand without adding infrastructure. 6. **Digitization and standardization of regulatory compliance** processes should allow energy operators to support new business models and meet regulatory requirements while remaining competitive in the marketplace. It should also improve operating efficiencies and reduce the time for administrative regulatory tasks, thereby enabling legal and compliance functions to redirect their efforts to strategic initiatives and managing regulatory risk.	
Estimated Economic Benefits	**Example Metrics Potentially Impacted by 5G[211]**
1. 5G applications in smart grids and meters could add US$209 billion to global GDP by 2030.[212]	1. Access to the 5G network 2. Number of 5G-enabled digital solutions implemented 3. Estimated total value realized from 5G enabled digital solutions that are implemented 4. Decrease in GHG emissions 5. Decrease in number/size of oil and/or gas leaks 6. Decrease in waste and fresh water used 7. Decrease in health and safety incidents 8. Decrease in physical and cyber attacks 9. Increase in workforce training and development 10. Increase in compliance with regulatory standards and reporting 11. Decrease in cost per megawatt produced

[205] Link to source: https://www.ericsson.com/en/industries/offshore-and-processing.

[211] The following sources were used to inform the contents of this list: 1) https://www.sciencedirect.com/science/article/pii/S2351978917303785; and 2) https://www.spiderstrategies.com/kpi/industry/utilities/.

[212] Link to source: https://www.pwc.com/gx/en/tmt/5g/global-economic-impact-5g.pdf.

	12. Decrease in maintenance cost per mile of pipe/line/cable 13. Decrease in average number of labor hours to complete a maintenance task 14. Decrease in average response time to fix breaks 15. Increase in crew productivity 16. Decrease in equipment failure or unavailability 17. Decrease in mean time to repair 18. Decrease in number of complaints received 19. Decrease in number of power failures per year 20. Decrease in number of staff per 1,000 customer connections 21. Decrease in outage time per event 22. Increase in billing accuracy and timeliness

Select case studies:

VR Training for Oil & Gas Operators[213]	
Background	▪ Saudi Aramco has established a "Fourth Industrial Revolution Centre", where technological and digital solutions are being developed to transform the ways in which the company runs its operations. ▪ Their "VR Zone" is used to develop, prototype and train for AR/VR applications. These applications enable plant assets to be visualized and provide workers with a live sense of the plant experience from a simulation booth. ▪ Their "3D Operator System Training Centre" provides real-world incident training in a safe and engaging VR-simulated environment. The system uses VR headsets and standard controls that allow operators to virtually walk through three generic plant types: a gas-oil separation plant, a gas and condensate processing plant, and a water injection plant. During these training scenarios, operators encounter several process disruptions that they must address.
Improvement areas	▪ 5G-enabled immersive VR training for the workforce ensures accuracy and effectiveness in day-to-day operations. ▪ VR training is highly scalable and can thus reduce time and resources spent on training overall. ▪ VR training programs reduce the need to travel to receive training. ▪ Innovative learning through VR helps to uphold job satisfaction and retention.
Economic and societal impacts	▪ Reduction in training budgets and operational downtime, leading to increased profitability ▪ Increased skill capacity and job satisfaction of the workforce [U.N. SDG 8] ▪ Mitigation of risk and safety concerns

[213] Link to source: https://www3.weforum.org/docs/WEF_The_Impact_of_5G.pdf.

VR Training for Oil & Gas Operators[213]	
	[U.N. SDG 3] ▪ Reduced carbon emissions due to reduced travel requirements for training programmes.
5G capabilities used	▪ eMBB ▪ URLLC
CapEx requirements	▪ VR headsets, motion control devices, knowledge management platforms and digital infrastructure
Maturity timeline	▪ Current state: 4K streaming that ensures faster delivery of training programmes ▪ Short-term: gamification that leads to more immersive training programmes ▪ Long-term: volumetric video that further augments the immersion and effectiveness of VR training programmes

5G Smart Grids[214]	
Background	▪ China Southern Power Grid Co., Ltd. (CSG) operates power grids in five Chinese provinces and has connections with national or regional power grids in four neighbouring countries. CSG's total service area spans 1 million square kilometres and serves more than 254 million people. ▪ CSG and its digital partners have jointly pursued the innovative application of 5G smart grid technologies, and they have achieved breakthroughs in several technologies and services.
Improvement areas	▪ 5G networks enable drones to inspect power transmission lines and make the process up to 80 times more efficient. ▪ 5G technology allows power transformation substations to operate nearly three times more efficiently and enables accurate remote monitoring of equipment status. ▪ 5G technology minimizes fault detection and isolation times from minutes to milliseconds. ▪ Unlike 4G, 5G is capable of handling power consumption data collection from tens of millions of users and opens new avenues to create value for customers. ▪ 5G-enabled end-to-end network slicing and chip encryption technology facilitates security isolation of power grids.
Economic and societal impacts	▪ Shortened power failures, improved power supply efficiency and lower electricity costs can minimize losses to society and save operating costs. [U.N. SDG 7]

[214] Link to source: https://www.gsma.com/greater-china/wp-content/uploads/2021/02/5G-Use-Cases-for-Vertical-China-2021-EN.pdf.

5G Smart Grids[214]	
	▪ Rollout of these 5G-enabled smart grid innovations to the five provinces served by CSG is expected to generate economic and societal benefits of at least RMB 5 billion.[215]
5G capabilities used	▪ eMBB ▪ URLLC
CapEx requirements	▪ Unmanned drones, data analytics applications and digital infrastructure.
Maturity timeline	▪ Current state: grid infrastructure monitoring via unmanned drones and remote technology ▪ Short-term: integration of decentralized power grids and smart meters that provide additional information to end-users ▪ Long-term: predictive analytics that anticipate demand fluctuations and service outages and react accordingly in real-time

3.2 Snapshots for Other Verticals

3.2.1 Manufacturing

Industry Overview: The manufacturing industry accounts for approximately 16% of global GDP[216] and more than 10% of Canada's total GDP.[217] 5G's ability to enhance connectivity quality, speed, latency, and bandwidth will be critical to the industry's use cases. A report by STL Partners expects that the manufacturing industry will benefit the most from 5G technology compared to other industries because of the large impact it will have on operations and because of the large size of the manufacturing industry vertical.[218]

The key challenges faced by the manufacturing sector are its carbon footprint (approximately 30% of global GHG emissions[219]); continued competitive pressures from lower-cost markets and increased business cycle volatility; intensifying regulatory and environmental oversight; supply chain vulnerabilities; rapid technology evolution; data security; an aging workforce; a current skills shortage; medium and long-term skills set mismatches; and changing customer needs and behaviors.

To compete globally, the manufacturing sector will need to continue to reduce costs by improving its efficiency and effectiveness through new process and systems innovations. 5G networks offer

[215] Ibid.

[216] Link to source: https://data.worldbank.org/indicator/NV.IND.MANF.ZS.

[217] Link to source: https://www.ic.gc.ca/eic/site/mfg-fab.nsf/eng/home.

[218] Link to source: https://carrier.huawei.com/~/media/CNBGV2/download/program/Industries-5G/5G-Impact-on-Industry-Verticals.pdf.

[219] Link to source: https://ourworldindata.org/emissions-by-sector (energy use in industry of 24.2% plus direct industrial processes emissions of 5.2%).

manufacturing companies the ability to build smart factories and take advantage of technologies such as automation, artificial intelligence, augmented reality for troubleshooting, and the IoE.

Potential Digital Solutions Supported by 5G & Their Operational Benefits (OB) and ESG Benefits (ESGB) [220, 221]

1. **Advanced predictive maintenance and machinery setup**
   - **OB** - Improved performance of machines through better prediction of equipment's operational status; lowered costs through reduced raw material and energy consumption, increased asset efficiency, decreased product defects; increased operational flexibility and shortened lead times for factory floor layout changes and alterations, allowing manufacturers to maximize production capacity and facilitate customization.
   - **ESGB** - Improved access to connectivity and the ability to integrate it into industrial processes, thereby allowing manufacturers to improve their access to and use of capital assets and drive innovation.
2. **Augmented reality and remote experts**
   - **OB** - Increased human productivity and performance and decreased level of unnecessary human intervention.
   - **ESGB** - Shift of skills and access to better professional jobs.
3. **Precision monitoring and control**
   - **OB** - Better planning, timely delivery and quality control through BDA, AI and M2M communications; reduced variances in actuals versus forecasts and enhanced on-time delivery of products with the right specifications.
4. **As-a-service model**
   - **OB** - Growth in sales and revenue through reduced time to market for new product designs and faster response to customer demand; enhanced customer experience and support with BDA, AI and ML.
5. **Automated Guided Vehicles (AGVs) and Automated Mobile Robots (AMRs)**
   - **OB** - Continued efficiency gains from asset tracking through precise indoor localization compared to manual asset tracking.
6. **Automated tracking of inventory and assets**
   - **OB** - Reduce scrap by using AGVs, and AMRs to improve materials handling.
   - **ESGB** – Reduced quantity of natural resources used and scrap/waste produced during operations; reduce energy consumption in production, warehousing and transportation of final products at a smart factory; and improve worker health and safety by using AMRs, AGVs and drones for tasks where human involvement may be tedious or dangerous.
7. **Remote security monitoring and control**
   - **OB** - Enhanced cyber and physical security through real-time security monitoring and threat assessment via drones and industrial cameras.

[220] Link to source: https://www.ericsson.com/497d92/assets/local/internet-of-things/industry-4.0/docs/ericsson-tallinn-factory_case_study.pdf.
[221] Link to source: https://link.springer.com/content/pdf/10.1007/s12652-020-02521-x.pdf.

Estimated Economic Benefits	Example Metrics Potentially Impacted by 5G
1. 5G applications in manufacturing could add between US$134 billion to global GDP and US$15 billion to U.S. GDP by 2030.[222]	1. Access to the 5G network 2. Number of 5G enabled solutions implemented 3. Estimated total value realized from 5G enabled digital solutions that are implemented 4. Decrease in energy and GHG emissions 5. Decrease in workplace injuries 6. Decrease in successful cyber security incidents 7. Increase in labor force skills index

3.2.2 Government

Industry Overview: Global government sector expenditures accounted for approximately 18% of global GDP in 2020 based on data from 161 countries.[223] In Canada, public sector expenditures accounted for approximately 23% of total Canadian GDP in 2020.[224]

Today, all levels of governments across the globe are facing rapid and profound challenges, including dynamic population changes (e.g., aging, migrations, etc.); rapid urbanization; persistent social disparities; climate change and increasing consumption which is straining finite resources; a scaling back of social services and a failure to invest for the future due to fiscal constraints.[225] Scrutiny of government practices has intensified with the advent of the information age. To meet the evolving demands of citizens, public administrators will need to rethink current organizational structures and capacity, processes, practices, technologies and policy tools to better tackle both old and new challenges in ways that earn the public's trust.

To address these significant challenges the current telecommunications regulatory frameworks and policies should be modified to ensure stronger alignment with the digital transformation taking place in all industries. The deployment of 5G-enabled digital technologies will play a critical role in helping the public sector to deliver better health and education outcomes; promote energy conservation; promote efficient use of scarce natural resources; bridge the digital divide; and close inequality gaps.[226]

[222] Link to source: https://www.pwc.com/gx/en/industries/technology/publications/economic-impact-5g.html#explorer.
[223] Link to source: https://www.theglobaleconomy.com/rankings/government_size.
[224] Ibid.
[225] Link to source: https://napawash.org/grand-challenges/the-12-grand-challenges.
[226] Link to source: https://www.un.org/en/un75/impact-digital-technologies.

Potential Digital Solutions Supported by 5G & Their Operational Benefits (OB) and ESG Benefits (ESGB)[227]

1. **Enhanced public safety**
   - **ESGB** - Reduced crimes and increased public safety by enabling first responders to address threats proactively and make faster, more informed decisions with video analytics; facilitate critical infrastructure, and environmental monitoring with sensors and camera drones.[228]
2. **Asset tracking and management**
   - **OB** - Reduced costs of equipment loss; real-time equipment condition monitoring, preventative maintenance, and improved asset utilization.
3. **Telemedicine**
   - **ESGB** - Reduced patient wait times, travel costs and pollution by allowing healthcare professionals to assess, diagnose and treat patients from a distance.
4. **AR/VR- based training**
   - **OB** - Hands-on learning in a safe, structured, and interactive manner via AR/VR for more hazardous jobs.[229]
5. **Autonomous driving**
   - **ESGB** - Reduced accidents, traffic congestion and CO^2 emissions; increased lane capacity and transportation accessibility; reduced travel time and cost; more efficient parking.
6. **Smart warehouse**
   - **OB** - Better warehouse optimization, scalability, adaptability, and lower operational costs through enhanced inventory and asset management; faster and more accurate order processing.[230]
7. **Digital workforce management**
   - **OB** - Increased operational flexibility, and enhanced employee productivity, efficiency, performance, communication, innovation, experience, and satisfaction; improved talent recruitment and retention.[231]
   - **ESGB** - Promote new skills and access to better professional jobs.
8. **Smart energy.**
   - **ESGB** - Reduced energy costs and a lower carbon footprint, ensuring tighter compliance with regulations and standards.[232]
8. **Smart defense bases**
   - **OB** - Enhanced Intelligence, Surveillance, Reconnaissance (ISR) systems that provide timely access to actionable intelligence data and improve operational decision-making; enablement of augmented or virtual

[227] Link to source: https://www2.deloitte.com/us/en/insights/industry/public-sector/future-of-5g-government.html.

[228] Link to source: https://assets.ctfassets.net/rz9m1rynx8pv/5xKzLUrfrCAqsCH0e5dNqx/c02b93c43c84fc7bb2243d2fef77d656/TELUS-Samsung-Whitepaper-Public-Safety-Feb22-English.pdf.

[229] Link to source: https://www.hurix.com/benefits-of-using-ar-vr-technology-in-employee-training/.

[230] Link to source: https://www.hopstack.io/blog/smart-warehouse-benefits.

[231] Link to source: https://www.lumapps.com/solutions/digital-transformation/digital-workplace-benefits/.

[232] Link to source: https://www.digiteum.com/internet-of-things-energy-management/.

reality environments that could enhance training; improved command and control systems and facial and license plate recognition software, which will improve perimeter security.[233]

9. **Smart cities**
   - **ESGB** - Improved transportation services and traffic management; better lighting, waste and water management; enhanced efficiency of public services, greater digital equity, increased economic development, job opportunities, and advanced public infrastructure;[234] more connected communities and civic engagement; simplified digital government tools and forms; public access to open data; improved and collaboration within/between cities, private-public-sectors, national-regional-local governments and agencies.[235] According to McKinsey Global Institute (MGI), smart city applications could reduce fatalities by 8% to 10%, accelerate emergency response times by 20% to 35%, cut the average commute by 15% to 20%, lower the disease burden by 8% to 15%, and cut greenhouse gas emissions by 10% to 15%, among other positive outcomes.[236]
10. **Smart ports**
   - **OB** - Increased handling capacity with automatic identification and detection of containers; faster docking, unloading, and loading times; better processing of cargo information and payments, including the processing of trade licenses, import and export permits, and customs clearances; improved coordination of traffic flow between ports and cargo destinations.[237]
   - **ESGB** - Fewer accidents and safer working environment with AI and automation.
11. **Smart public transportation**
   - **OB & ESGB** - Increased convenience and efficiency in traveling; enables transit operators to consolidate fleet management, streamline and monitor daily operations and improve passenger safety.[238]

Estimated Economic Benefits	Example Metrics Potentially Impacted by 5G[239]
1. 5G applications in smart city could add US$10 trillion[240] to global GDP by 2026.	1. Access to the 5G network 2. Number of 5G enabled solutions implemented 3. Estimated total value realized from 5G enabled digital solutions that are implemented 4. Increase in percentage of facilities incorporating energy and water efficient upgrades 5. Increase in percentage of infrastructure projects completed on time 6. Increase in percentage of fire and emergency medical service response time within the goal 7. Increase in percentage of commuters using public transportation

[233] Link to source: https://cyberdefensereview.army.mil/Portals/6/Documents/CDR%20Journal%20Articles/Smart%20Bases%20Smart%20Decisions_Arata_Hale.pdf?ver=2018-07-31-093711-343.
[234] Link to source: https://www.aplustopper.com/smart-city-advantages-and-disadvantages/#Advantages_of_Smart_City.
[235] Link to source: https://www.oecd.org/cfe/regionaldevelopment/Smart-Cities-FINAL.pdf.
[236] Link to source: https://www.mckinsey.com/business-functions/operations/our-insights/smart-cities-digital-solutions-for-a-more-livable-future.
[237] Link to source: https://www.adv-polymer.com/blog/smart-port#ch3.
[238] Link to source: https://www.nexcom.com/applications/DetailByDivision/smart-public-transit.
[239] Link to source: https://www.clearpointstrategy.com/143-local-government-kpis-scorecard-measures/#sect9.
[240] Link to source: https://www.caba.org/wp-content/uploads/2020/04/IS-2018-215.pdf.

	8. Increase in number of active municipal mobile app users 9. Increase in satisfaction with municipal services 10. Increase in number of businesses 11. Decrease in GHG emissions per capita 12. Decrease in water usage per capita 13. Decrease in number of water line breaks 14. Decrease in number of roadway accidents 15. Decrease in number of fires 16. Decrease in number of violent and non-violent crimes

3.2.3 Finance and Insurance

Industry Overview: The global finance and insurance sectors account for approximately 20% to 25% of global GDP.[241] In Canada, the financial and insurance sectors accounted for approximately 7.5% of total Canadian GDP in 2021.[242]

Today, both sectors are facing significant challenges, including economic uncertainty; a restrictive regulatory environment; intense competition; rising customer expectations and waning customer loyalty; technology-driven disruptions; as well as legacy processes, systems and skill sets that are not configured to meet changing customer demands.[243]

The financial and insurance sectors need to transform their current business models, processes, systems, and skill sets to thrive in the future. 5G digital solutions, in addition to other connected technologies such as edge computing, AR/VR and the Internet of Things (IoT), will support the transformation of these sectors and allow them to create innovative services that are secure, private and customer-centric.

Potential Digital Solutions Supported by 5G & Their Operational Benefits (OB) and ESG Benefits (ESGB)
1. **Personalized banking and financial advice based on AI enabled Bots and Robo-Advisors** ▪ **OB** - Increased customer engagement, stickiness and wallet share as financial institutions use 5G-enabled applications and AI-enabled BDA to offer regular financial advice to customers. Permission-based monitoring of spending habits related to location, corresponding suggestions on how to cut costs, and other nudges will encourage clients to save and invest.[244] Also, AI and machine learning equipped customer bots will help financial institutions more quickly resolve administrative and less complex financial issues and

[241] Link to source: https://www.investopedia.com/ask/answers/030515/what-percentage-global-economy-comprised-financial-services-sector.asp.
[242] Link to source: Statistics Canada. Table 36-10-0434-03 Gross domestic product (GDP) at basic prices, by industry, annual average (x 1,000,000); (Finance and insurance [52] / All industries [T001]).
[243] Link to source: https://www.wns.com/Portals/0/Documents/Articles/PDFFiles/600/180/Top%20Trends%20in%20Banking%20&%20Financial%20Services%20Final.pdf.
[244] Link to source: https://www.5gradar.com/features/ways-5g-can-boost-finance.

make these processes more automated, time-efficient and hyper-personalized. 5G enabled robo-advisors will reduce the cost of providing financial advisory services by performing select tasks (e.g., reply to phone calls and emails in real-time while operating 24/7/365, respond immediately to basic requests such as selling or purchasing stocks, or providing balance information) thereby creating more time for human financial advisors to focus on complex value-added tasks.[245]

- **ESGB** - Improved financial and insurance product penetration in rural and remote regions will enable financial inclusion for rural and remote populations across the world. While these individuals may not have access to a physical bank, they will likely have access to a 5G-enabled smart device in the coming years.[246]
- **ESGB** - Promotion of new skills and access to better professional jobs.

2. **Enhanced security measures**
   - **OB** - Fewer fraud events as banks leverage AI-enabled analytics at the edge to detect fraudulent patterns; edge computing can deliver low-latency analytics while also maintaining data sovereignty and security.[247] Real-time analysis of biometric tests, such as fingerprint or iris matching, with increased processing power will improve security measures. Behavioural tests, such as looking at the way a person signs or walks, might also be used to confirm an account holder's identity in real-time.[248]
3. **Mobile as a digital wallet**
   - **OB** - Better mobile payments, online acquisitions and banking processes. Due to its improved throughput and speeds, 5G connectivity is a crucial enabler of the migration towards mobile wallets and digital transactions.[249] Also, enhanced mobile execution of time sensitive financial transactions, such as high-frequency mobile trading, with near zero latency will increase efficiency of stock market transactions.[250]
4. **Wearable technology**
   - **OB** - 5G technologies will provide a more granular view of a customer's behaviour and health, which may inform insurance pricing and purchase decisions. Also, wearables are likely to be used to manage money; 5G-enabled AR glasses will help financial institutions present information more simply and improve the overall customer service experience. From an identification standpoint, wearable technology can evaluate biometrics to verify customers.[251]
5. **Seamless credit processing**
   - **OB** - Streamlined loan processing with faster end-to-end cycle time for application review and credit checks that expedites access to funds. "The ability to integrate AI, data and real-time parallel processing into mobile applications will improve the speed and accuracy behind lending decisions and optimize lending rates for match each applicant. Mortgage and loan approvals, for example, can use a combination of technologies to securely record property details (geo-mapping location, 360-degree view of the property in real-time), scan documents and calculate risk-profit ratios within seconds from mobile devices."[252]
6. **Blockchain and trade finance**
   - **OB** - Reduced cost of trade finance used for acquisition of commodities and goods with the use of blockchain (often described as distributed ledger technology). The blockchain could use smart contracts

[245] Link to source: https://www.eescorporation.com/do-robo-advisors-use-artificial-intelligence/.
[246] Link to source: https://www.stl.tech/blog/thanks-to-5g-everything-you-know-about-banking-will-change/.
[247] Link to source: https://stlpartners.com/articles/edge-computing/edge-use-cases-for-financial-services/.
[248] Link to source: https://www.5gradar.com/features/ways-5g-can-boost-finance.
[249] Link to source: https://www.paymentsjournal.com/5-ways-5g-is-changing-the-way-we-use-digital-banking-epayments/.
[250] Link to source: https://www.deltecbank.com/2021/03/31/the-impact-of-5g-in-financial-services/.
[251] Link to source: https://www.5gradar.com/features/ways-5g-can-boost-finance.
[252] Link to source: https://blogs.perficient.com/2020/04/30/why-should-banks-care-about-5g/.

managed via the 5G network to save millions in costs that would otherwise be spent on intermediaries and operations.[253]

7. **Faster insurance analysis**

   - **OB** - An enhanced digital experience for insurance customers ranging from admirative queries and policy selection to claim submission; 5G enabled digital solutions will transform customer engagement by allowing customers to obtain insurance quotes through digital assistants or chatbots powered by AI and submit claims with the help of augmented reality while insurers can assess the claims and reduce the time for approval using AI software. Furthermore, the 5G network will be able to support interconnected sensors and devices that can play a crucial role in mitigating and assessing risk.

8. **Loan monitoring and collateral management**

   - **OB** - Improved accuracy of loan monitoring and collateral assessment using IoT technology. IoT technology will allow banks to have better control over a customer's mortgaged assets while monitoring the condition of those assets. The lending institution would also be able to remotely disable or enable the productive assets anytime based on defined business rules. The use and maintenance of the collateral could also be monitored in real-time. The request for financing, as well as the transfer of ownership, could be automatic, completely digital and achieved within seconds, with loan issuance occurring immediately thereafter.[254]

9. **Regulatory technology and applications**

   - **ESGB** - Real-time monitoring and use of data for predictive analytics, driving better regulatory outcomes and potentially fewer compliance burdens for businesses. The aim of 5G-enabled regulatory software and digital applications (referred to as "RegTechs"[255]) will be to improve accuracy, efficiency, productivity and safety, and reduce operational risks and costs associated with meeting compliance and reporting obligations. "Many emerging RegTechs are using cloud technology to deliver solutions involving machine learning, big data analytics, and natural language processors to aggregate and analyze bank data and to detect, predict, and mitigate risks to the organization."[256]

Estimated Economic Benefits	Example Metrics Potentially Impacted by 5G[257,258]
1. 5G applications in finance sector could add US$86 billion to global GDP and US$44 billion to U.S. GDP by 2030.[259]	1. Access to the 5G network 2. Number of 5G enabled solutions implemented 3. Percentage of public facilities incorporating energy and water efficient upgrades 4. Estimated total value realized from 5G enabled digital solutions that are implemented. 5. Increase in number of mobile apps and mobile app users 6. Increase in the number of rural remote services offered and new customers onboarded 7. Increase in revenue attributable to 5G enabled technologies and applications

[253] Link to source: https://www.5gradar.com/features/ways-5g-can-boost-finance.

[254] Link to source: https://www.iotone.com/usecase/smart-collateral-management/u160.

[255] Regulatory Technology (RegTech) is the management of regulatory processes within the financial industry through technology. The main functions of RegTech include regulatory monitoring, reporting, and compliance.

[256] Link to source: https://www.pwc.com/us/en/industries/financial-services/regulatory-services/regtech.html.

[257] Link to source: https://www.clearpointstrategy.com/bank-kpis/.

[258] Link to source: https://insightsoftware.com/blog/best-insurance-kpis-and-metrics/.

[259] Link to source: https://www.pwc.com/gx/en/industries/technology/publications/economic-impact-5g.html#explorer.

	8. Increase in customer satisfaction 9. Increase in number of new jobs created 10. Decrease in operating expenses attributable to 5G enabled technologies and applications 11. Decrease in average time to close issues 12. Decrease in new account setup time and error rate 13. Decrease in average processing time, cost and errors per claim 14. Increase in policy renewal and retention rate 15. Increase in quote rate 16. Increase in underwriting speed 17. Increase in the referral and contact rates

3.2.4 Real Estate

Industry Overview: The real estate sector (including buildings and construction) accounts for approximately 21% of Canada's total GDP.[260] Capabilities like enhanced connectivity quality, speed, latency, and bandwidth enabled by 5G will be critical to the industry's use cases.

The real estate and construction sectors face numerous challenges, including a large carbon footprint, which accounts for approximately 40% of global greenhouse gas (GHG) emissions[261]; shortening space utilization cycles; rising construction costs; a skilled labour shortage; increased project complexity with new regulatory and environmental policies; development cycle volatility; supply chain vulnerabilities; complex and time consuming documentation processes; an aging property inventory with elevated property and liability risks; inefficient tenant search capabilities and due diligence costs; and changing customer needs and behaviors.

5G networks offer building owners and developers the ability to build new or convert existing buildings into smart commercial and residential buildings and take advantage of innovative digital solutions and complementary technologies such as automation, artificial intelligence, augmented reality and the Internet of Everything (IoE) to reduce costs. Many of the use cases will reduce GHG emissions by improving the efficiency and effectiveness of current infrastructure, equipment, processes and systems.

Potential Digital Solutions Supported by 5G & Their Operational Benefits (OB) and ESG Benefits (ESGB) [262, 263]
1. **Smart heating, ventilation, and air conditioning (HVAC)**

[260] Link to source: Statistics Canada. Table 36-10-0434-03 Gross domestic product (GDP) at basic prices, by industry, annual average (x 1,000,000); ((Real estate and rental and leasing [53] + Construction [23]) / All industries [T001]).
[261] Link to source: https://www2.deloitte.com/ce/en/pages/real-estate/articles/putting-the-construction-sector-at-the-core-of-the-climate-change-debate.html.
[262] Link to source: https://www.aceee.org/sites/default/files/publications/researchreports/a1701.pdf.
[263] Link to source: https://www.mdpi.com/2079-9292/10/14/1713.

- **OB** - Improved temperature control by allowing users to set different temperatures for different parts of the commercial, industrial or residential building; the system gathers real-time data from multiple monitoring and control sensors in and around the building exterior. In conjunction with software and applications, the system analyzes and interprets the data generated by these sensors to optimize the HVAC system's operation. Temperature settings can be based on predicted external temperature provided in real-time via a 5G connection. The enhanced HVAC system can also detect and diagnose anomalies, such as open windows, shut vents, unclean filters, air pollutants and system malfunctions.
- **ESGB** - Reduced energy consumption and GHG emissions.

2. **Smart lighting**
   - **OB** - Advanced controls that monitor and optimize natural lighting via windows while observing changes in lighting and its temperature impacts; Smart lighting systems can be accessed wirelessly and are usually integrated with building management platforms.
   - **ESGB** - Increased energy conservation through lower usage; further energy reduction is also possible with complementary technologies such as the use of compact fluorescent lamps (CFL) or light-emitting diode (LED) lights instead of incandescent lights. When integrated with motion-detection features, this digital solution also increases security.
3. **Smart windows**
   - **OB** - Increased privacy and security by using real-time sensor data to lighten or darken windows; improved employee productivity as smart windows allow natural light without excessive heat or glare.
   - **ESGB** - Reduced energy use driven by enhanced heat management from windows.
4. **Automated system optimization (ASO)**
   - **OB** - Enhanced building automation systems (BAS) and energy management and information systems (EMIS) that "have the data infrastructure and can be made aware of external influences coming from utility providers, current and forecasted weather, and building usage and occupancy, providing the visibility needed to perform more advanced system optimization strategies"[264]; uses 5G networks to collect and analyze real-time data versus conventional BAS which rely on static programming for building operations and maintenance.
   - **ESGB** - Optimized energy utilization, reduced emissions and increased occupant comfort.
5. **Smart maintenance management**
   - **OB** - Increased asset efficiency, uptime and service life through predictive and demand-based maintenance management.
   - **ESGB** - Delayed asset obsolescence and increased energy conservation.
6. **Smart traffic management**
   - **OB** - Increased parking efficiency for occupants and visitors in large facilities.
   - **ESGB** - Increased comfort and reduced energy use.
7. **Smart security management**
   - **OB** - Enhanced real-time identification and elimination of security threats.
8. **Remotely controlled autonomous machinery**
   - **OB** - Avoidance of human errors and increased productivity through the coordination of different processes in real-time using technologies such as video images and sensors.

[264] Link to source: https://www.coppertreeanalytics.com/application-series-on-building-analytics-the-role-of-analytics-software-in-automated-system-optimization/.

- **ESGB** - Increased worker health and safety.

9. **3D building models**
   - **OB** - Streamlined sequencing and organization of construction phases with decreased probability of implementation mistakes. Additional information such as task planning, material sourcing, and construction details could be provided with the use of augmented reality (AR), virtual reality (VR) and digital twin technologies; these technologies could also play a key role in real estate sales with virtual tours.
10. **Construction processes management**
    - **OB** - Improved efficiency of critical construction processes that have a significant impact on the final quality of the building and/or project timeline; these require the use of technologies such as "sensor networks that allow knowing in real-time data such as the maturity of the concrete, the location of equipment and machinery, or the weather conditions."[265]
11. **Automated advertising, lead generation and engagement**
    - **OB** - Decreased time and effort for real estate agents with automated software generated advertising and real-time data on clicks, views and demographics; chatbots can then be leveraged in conjunction with artificial intelligence to qualify and engage leads.
12. **Smart blockchain contracts**
    - **OB** - Reduced fraud or data breaches and increased efficiency through the elimination of verifications of contracts; this technology creates "smart contracts" into transactions with clients.

Estimated Economic Benefits	Example Metrics Potentially Impacted by 5G
1. No estimates found.	1. Access to the 5G network 2. Number of 5G enabled solutions implemented 3. Estimated total value realized from 5G enabled digital solutions that are implemented 4. Decrease in energy usage and GHG emissions 5. Decrease in gross facilities management costs per square meter or square foot 6. Decrease in maintenance backlog 7. Decrease in mean time to repair (MTTR) 8. Decrease in mean time between failures (MTBF) 9. Decrease in the number of accidents per contractor 10. Decrease in the amount of waste (and recycling) generated per construction site 11. Decrease in employee downtime 12. Decrease in equipment downtime 13. Decrease in the number of total project defects 14. Increase in overall equipment effectiveness (OEE) 15. Increase in planned maintenance percentage 16. Increase in tenant satisfaction 17. Increase in the number of calls or contacts made 18. Increase in the appointments generated

[265] https://www.mdpi.com/2079-9292/10/14/1713.

	19. Increase in sold homes per available inventory

3.2.5 Education

Industry Overview: The global education sector accounts for approximately 4% of global GDP.[266] In Canada, the education sector accounts for approximately 6% of total Canadian GDP.[267]

The education sector needs to transform its current approach, systems, skillsets, instruction and testing models to support the workforce of the future. Additional challenges include inaccessible environments; a shortage of teachers and poor quality of instruction; funding constraints; and safety risks.[268] 5G enabled real-time digital solutions and complementary technologies like video conferencing, virtual reality (VR) and augmented reality (AR), artificial intelligence (AI), autonomous passenger vehicles, drone and robot delivery services, and integrated security and building resource management systems can help the education sector become more responsive to the needs of today's learners.

Potential Digital Solutions Supported by 5G & Their Operational Benefits (OB) and ESG Benefits (ESGB)

1. **Augmented reality, virtual reality and extended reality (XR) teaching and training**
   - **ESGB** - Deeper understandings of the subject matter fostered by more immersive learning/training experiences that utilize devices such as headsets, visors and sensors. Teachers and trainers can illustrate more complex and abstract concepts to students in a manner that engages the senses and makes the learning more practical. Also, virtual classrooms and training workshops eliminate the limitations of physical facilities and security risks of challenging work conditions.[269]
2. **Artificial Intelligence**
   - **ESGB** - Improved retention and course success rates by leveraging AI that provides targeted support for students by analyzing data from student databases and suggesting actions to assist. AI applications could even recommend classes and projects for students based on their schedules and interests.[270]
3. **5G fixed wireless access (FWA)**
   - **ESGB** - Better access to quality education for rural or under-resourced communities.[271]
4. **Intelligent campus management**
   - **OB -** Reduced security and energy costs as fewer security personnel and less energy will be required with the implementation of these applications. Video surveillance in conjunction with facial recognition technology, AI and sensors across campuses will reduce the need for field security personnel as all data will be collected and analyzed at the center, and targeted instructions provided to field security staff. 5G,

[266] Link to source: http://gem-report-2019.unesco.org/chapter/finance/.
[267] Link to source: https://gpseducation.oecd.org/CountryProfile?primaryCountry=CAN&treshold=5&topic=EO.
[268] Link to source: https://www.datatobiz.com/blog/challenges-in-education-industry/.
[269] Link to source: https://telecoms.com/opinion/how-5g-will-transform-the-learning-experience-from-early-years-to-in-work-training.
[270] Link to source: https://www.t-mobile.com/business/resources/articles/5-ways-to-use-5g-technology-in-education?icid=TFB_TMO_P_TFB5GHQ_5CQGUGE85REHUI7529183.
[271] Link to source: https://blogs.worldbank.org/digital-development/how-can-5g-make-difference-education.

AI, and sensor-enabled building management systems will optimize facilities maintenance and management.

- **ESGB** - Increased staff and student safety and security with an integrated security system acting as an early warning system. Integrated building management applications will also reduce energy consumption.

Estimated Economic Benefits	Example Metrics Potentially Impacted by 5G
1. Estimates not found.	1. Access to the 5G network 2. Number of 5G enabled solutions implemented 3. Increase in percentage of facilities incorporating energy and water efficient upgrades 4. Estimated total value realized from 5G enabled digital solutions implemented. 5. Increase in student attendance rate 6. Increase in graduation (completion) rate 7. Increase in proficiency rates for each subject 8. Increase in average daily attendance percentages 9. Increase in distance learning enrollment 10. Increase in percentage of school-age students with disabilities participating in occupational education programs 11. Increase in percentage of school-age students with disabilities receiving special education services in general class placements 12. Increase in student engagement 13. Increase in hours of instructions per faculty 14. Increase in classroom utilization 15. Decrease in instruction costs 16. Decrease in faculty workload

3.2.6 Retail

Industry Overview: For Canada, retail sector GDP accounts for approximately 5% of total GDP.[272] Even before the start of COVID-19 lockdowns, the retail industry was undergoing fundamental changes in customer shopping habits, including a shift from physical retail shopping to online shopping. According to data from Adobe Digital Insights, COVID-19 lockdowns expedited the shift from brick-and-mortar stores to the online virtual realm by approximately four to six years.[273] While customers have returned to brick-and-mortar stores since lockdowns were lifted,[274] the underlying trend towards online shopping continues and is pushing retailers to develop strong omnichannel strategies. There has also been a significant change over the past

[272] Link to source: Statistics Canada. Table 36-10-0434-03 Gross domestic product (GDP) at basic prices, by industry, annual average (x 1,000,000) (Retail trade [44-45] / All industries [T001]).
[273] Link to source: https://www.forbes.com/sites/johnkoetsier/2020/06/12/covid-19-accelerated-e-commerce-growth-4-to-6-years/?sh=1ab1e89f600f.
[274] Link to source: https://www150.statcan.gc.ca/n1/daily-quotidien/220526/t004b-eng.htm.

few years in terms of customer service expectations. Today, customers are demanding a seamless purchasing experience – what I want, where I want it, and how I want it – with expert product/service instructions, no mistakes or delays, and consistency of branding, messaging and service commitment across all channels.

Other critical challenges faced by the retail sector include intensifying competition, increasing costs, supply chain disruptions, shortage of retail talent, a growing culture of immediacy and personalization of customer service, and convenience of the end-to-end purchase process, including the increasing use of the digital mobile wallet.

To address these challenges, retailers are developing integrated strategies that align talent, physical space, processes, marketing and merchandising to meet ever increasing consumer demands. Many of these strategies require 5G networks and applications as well as complementary technologies to continually adapt to the dynamic retail environment and remain relevant to the customer of tomorrow. According to Jean-Emmanuel Biondi, Principal Retail, Wholesale & Distribution at Deloitte Consulting, "We're on the verge of disruption where the in-store customer experience and retail operations will be vastly different. 5G in retail will serve as an accelerator for numerous technologies, such as the Internet of Things (IoT) and augmented reality (AR), that will improve the in-store customer experience in terms of personalization and engagement with products. It will also serve as a catalyst for operational efficiency improvement, including inventory, store operations, and labor productivity."[275]

Potential Digital Solutions Supported by 5G & Their Operational Benefits (OB) and ESG Benefits (ESGB)

1. **Consumer 3D calls and holograms**
   - **OB** - Enhanced, more engaging shopping experience supported by hologram-enabled brand storytelling. In addition, holograms attract attention immediately and make the shopping experience more real and personal.[276]
2. **Consumer augmented, virtual and extended reality**
   - **OB** - More immersive buying experience that enables experimenting with different product styles, sizes, colors, and opinions from friends and family; increased brand awareness, conversion rates and upselling prospects; enhanced product/service knowledge resulting in lowered returns and higher overall satisfaction; and the ability to generate real-time product interaction insights with AR-based magic mirrors. According to a report by Accenture, "5G can enable rich video streaming experiences in the store, enabling up to 50% increase in sales growth when combined with human-focused processes and extended reality visualizations."[277]
3. **Automated digital and contactless checkout**
   - **OB** - Increased customer hygiene as customers do not have to interact with payment devices; enhanced customer information security as contactless payments provide a higher level of protection than traditional magnetic stripe cards; near-field communication makes it difficult to steal a customer's card information.

[275] Link to source: https://www2.deloitte.com/us/en/pages/consulting/articles/5g-in-retail.html.
[276] Link to source: https://www.netscribes.com/retail-technologies-advancing-the-store-of-the-future/.
[277] Link to source: https://www.accenture.com/_acnmedia/PDF-146/Accenture-5G-WP-US.pdf.

Contactless checkout also reduces checkout times and allows transactions to be completed within seconds, allowing customers to get through the checkout line faster.[278]

4. **Indoor position systems (IPS)**
   - **OB** - Increased sales and customer convenience with in-store layout optimization. "IPS can help retailers in developing real-time personalized offers and allocating in-store staff members more efficiently. From a consumer's perspective, an IPS can inform them about the shortest routes needed to fulfill their shopping lists and can help them discover products in addition to shops and facilities in a mall."[279]
5. **Artificial intelligence (AI) and big data analytics (BDA)**
   - **OB** - Improved identification of customer behaviours and a more personalized customer experience, which allow for more customer data to be collected and processed. An example of personalized and real-time customer experience is the ability for customers to easily access product information, recipes and promotions based on their preferences.
6. **Radio-frequency identification (RFID) Asset Tracking, Video Surveillance Powered by ML and Shelf Sensors and Point-of-Sale (POS) technologies; shelf sensors and cameras monitor inventory and alert staff for re-stocking**
   - **OB** - Reduced inventory shrinkage and automation of inventory management and restocking processes.[280] If tied to a smart POS and surveillance solution, the asset tracking solution could flag items that leave the geofenced area unexpectedly and mark video records with the exact time and location the item left the area.
8. **Smart heating, ventilation and air conditioning (HVAC)**
   - **ESGB** - Reduced energy consumption and GHG emissions.

Estimated Economic Benefits	Example Metrics Potentially Impacted by 5G
1. No estimates found.	1. Access to the 5G network 2. Number of 5G enabled solutions implemented 3. Increase in percentage of stores incorporating energy and water efficient upgrades 4. Estimated total value realized from 5G enabled digital solutions rolled out 5. Decrease in stock-outs 6. Decrease in shrinkage 7. Increase in inventory turnover ratio 8. Increase in revenue growth 9. Increase in sales per square foot 10. Increase in sales per employee 11. Increase in foot traffic 12. Increase in conversion rate 13. Increase in customer satisfaction 14. Increase in customer lifetime value

[278] Link to source: https://appfrontier.com/blog/what-every-business-needs-to-know-about-contactless-payments.

[279] Link to source: https://journals.sagepub.com/doi/10.1177/1550147717692585.

[280] Link to source: https://acsicorp.com/wp-content/uploads/2021/02/Whitepaper-Prototype-5G-Retail-Case-Study.pdf.

3.2.7 Logistics

Industry Overview: The global logistics sector accounts for 10% to 15% of global GDP.[281]

The sector is facing strong headwinds in the form of intensifying competition, high fuel costs, economic uncertainties, low supply chain visibility, inadequate vendor and supplier collaboration, higher customer expectations and lower willingness to pay, a labour shortage and increasing environmental regulation.[282]

5G enabled real-time digital solutions and complementary technologies like smart sensors; Radio Frequency Identification Devices (RFIDs); warehouse management technologies, including automated storage and retrieval systems (AS/RS); Global Positioning System (GPS)-enabled tracking, virtual, augmented and mixed reality technologies; artificial intelligence and machine learning systems; image processing; blockchain; autonomous and electric vehicles; drones; and robots will help the sector address these challenges. They will also allow the logistics industry to enhance its current services and create new innovative services, which include security, privacy and customer experience by design.

Potential Digital Solutions Supported by 5G & Their Operational Benefits (OB) and ESG Benefits (ESGB)

1. **Smart logistics transportation**
   - **OB** - Increased transportation efficiency; reduced costs; reduced cargo loss; a decreased risk of accidents and damage via real-time vehicle, cargo and driver monitoring; autonomous and electric vehicles; and unmanned drone-based delivery.[283]
   - **ESGB** - Decreased energy consumption and reduced GHG emissions.
2. **Smart warehousing**
   - **OB** - Optimized space, environment and product management processes with real-time monitoring and recalibration using applications like automated storage and retrieval systems (AS/RS) and the ZigBee[284] technology, along with warehouse control and environmental management systems, to monitor and adjust temperature and humidity; better inventory control and improved operational efficiency with RFID-based intelligent warehouse management systems.[285] Artificial intelligence (AI) and machine learning (ML) technologies can also be leveraged to increase predictive capabilities in loading and unloading of goods, intelligent routing and human scheduling to achieve better operational and capacity performance.[286] AI will also play a critical role in product sorting and packaging, warehouse site selection and customer satisfaction with the help of complementary technologies like smart sensors, big data analytics and speech recognition.[287]
   - **ESGB** - Decreased energy consumption and GHG emissions.

[281] Link to source: https://transportgeography.org/contents/chapter7/logistics-freight-distribution/global-logistics-costs-function/.
[282] Link to source: https://www.logisticsmgmt.com/article/top_8_logistics_challenges_facing_the_industry.
[283] Link to source: https://www.csit.carleton.ca/~fyu/Papers/09241736.pdf.
[284] Zigbee is a standards-based wireless technology developed to enable low-cost, low-power wireless machine-to-machine (M2M) and internet of things (IoT) networks.
[285] Link to source: https://www.csit.carleton.ca/~fyu/Papers/09241736.pdf.
[286] Link to source: https://piernext.portdebarcelona.cat/en/technology/5g-logistics-and-ports/.
[287] Link to source: https://www.csit.carleton.ca/~fyu/Papers/09241736.pdf.

3. **Smart loading/unloading**
   - **OB** - Reduced costs and increased efficiency and accuracy of loading and unloading processes with technologies such as robotics, automated guided vehicles, equipment positioning, equipment status monitoring and equipment dispatching.[288]
   - **ESGB** - Decreased energy consumption and GHG emissions and increased worker health and safety.
4. **Smart packaging**
   - **OB** - Increased product traceability, quality and safety with QR codes, RFID or NFC, and smart sensors to load product data and environmental requirements for product freshness and origin.[289]
   - **ESGB** - Reduced product wastage from environmental factors.
5. **Smart distribution**
   - **OB** - Improved management of distribution centers and enhanced delivery approaches with technologies such as automatic sorting and labeling, IoT-based route planning system (IRPS) and intelligent containers.[290]
   - **ESGB** - Reduced product wastage, energy consumption and GHG emissions.

Estimated Economic Benefits	Example Metrics Potentially Impacted by 5G
1. Estimates not found.	1. Access to the 5G network 2. Number of 5G enabled solutions implemented 3. Growth in percentage of facilities incorporating energy and water efficient upgrades 4. Estimated total value realized from 5G enabled digital solutions rolled out 5. Decrease in warehousing costs 6. Decrease in supply chain costs 7. Decrease in delivery time 8. Decrease in inventory days of supply 9. Decrease in pick & pack cycle time 10. Increase in inventory velocity 11. Increase in on-time shipping 12. Increase in freight bill accuracy 13. Increase in perfect order rate 14. Increase in fill rate

[288] Ibid.
[289] Ibid.
[290] Ibid.

3.2.8 Communications

Industry Overview: The global communication service provider (CSP) sector accounts for approximately 2% of global GDP.[291] In Canada, the CSP sector accounts for approximately 3% of total Canadian GDP.[292]

The CSP sector is facing strong headwinds in the form of intensifying competition, slowing growth in core offerings, rising cybersecurity and privacy threats, mounting operational and technological complexity, ever expanding customer demand for data, necessitating escalating capital requirements and heightened investment risk, a skilled labour shortage, and increasing government regulation and environmental issues.[293]

The CSP sector needs to transform its current networks, processes, systems, skillsets, business models and regulatory environment to survive and thrive in the future. 5G enabled real-time digital solutions and complementary technologies like smart sensors; artificial intelligence (AI); machine learning (ML); big data analytics (BDA); Chatbots; GPS-enabled tracking; virtual, augmented and mixed reality; blockchain; autonomous and electric vehicles; drones; and robots will drive the transformation of this sector and allow it to enhance current services and create new innovative services, such as security, privacy and customer experience (CX) by design.[294]

Potential Digital Solutions Supported by 5G & Their Operational Benefits (OB) and ESG Benefits (ESGB)

1. **Big data analytics**
   - **OB** - More timely marketing insights using real-time analytics on data generated by a massive number of transactions undertaken by CSP customers; improved support for real-time scenario analysis and campaign stimulations; also helps with effective use of social media data. Other uses of BDA include fraud detection, predictive analysis, customer churn prevention, lifetime value prediction, customer segmentation, product development, customer sentiment analysis, price optimization, network management and optimization.[295]
2. **Chatbots**
   - **OB** - Enhanced customer service at minimal expense and also reduced service, sales and support costs; can be integrated as part of an omnichannel business model.
3. **Smart heating, ventilation, and air conditioning (HVAC)**
   - **OB** - Improved temperature control in data centers and network equipment facilities; reduced energy costs.

[291] Link to source: https://www.grandviewresearch.com/industry-analysis/global-telecom-services-market. Global telecom services market size was valued at US$1.66T in 2020, with Global GDP estimated at US$84.91T (https://data.worldbank.org/indicator/NY.GDP.MKTP.CD). Global telecom services sector accounts for approximately 2% of global GDP (US$1.66T / US$84.91T).

[292] Link to source: https://www.cwta.ca/wp-content/uploads/2021/11/CWTA-Economic-Report-2020-EN.pdf.

[293] Link to source: https://home.kpmg/au/en/home/insights/2021/06/risk-spotlight-telecommunications-sector.html.

[294] The concept of - "by design" - requires engineering a product, service, system or process so that it incorporates a specific attribute(s) right from the start of designing that product, service, system or process. For example, security and privacy by design, would require investigating alternate security and privacy strategies, tactics and patterns at the beginning of a software design, and selecting the best security and privacy approach and enforcing it by the architecture.

[295] Link to source: https://techvidvan.com/tutorials/big-data-in-telecommunication/.

- **ESGB** - Decreased energy consumption and reduced GHG emissions.

4. **Camera-equipped drones**
   - **OB** - Improved maintenance of hard-to-reach equipment such as mobile equipment mounted on cell towers.
   - **ESGB** - Increased worker health and safety.
5. **Smart logistics and warehousing**
   - **OB** - As in the logistics sector, CSPs purchase a lot of equipment and could leverage 5G enabled logistics and warehousing applications to increase operational efficiencies, reduce inventory outages, increase customer satisfaction and reduce costs.
   - **ESGB** - Reduced energy consumption and GHG emissions.

Estimated Economic Benefits	Example Metrics Potentially Impacted by 5G
1. Estimates not found.	1. Access to the 5G network 2. Number of 5G enabled solutions implemented. 3. Growth in the percentage of facilities incorporating energy and water efficient upgrades 4. Estimated total value realized from 5G enabled digital solutions rolled out

4 Estimated Economic Impacts of 5G

Key Takeaways

- 5G will create economic growth and high paying jobs through increases in productivity, i.e., the efficiency with which labour, capital and other inputs are used to generate output. 5G drives productivity growth by making it easier and cheaper to use technologies that run on mobile and fixed networks to create value. For example, 5G is a necessary factor to make it economical to build self-driving vehicle systems or deploy remote-operated robots for mineral extraction.

- Productivity matters because it is by far the most significant driver of Canada's standard of living as measured by growth in GDP per capita, which itself is strongly correlated over the run with wage growth over the long run. In a 2021 forecast, the OECD places Canada last among advanced economies in GDP per capita growth between 2020 and 2030. Therefore, finding ways to increase productivity is critical to correcting this course.

- 5G is a central solution to Canada's long standing productivity challenge. Based on a review of numerous studies that estimate the potential economic benefits of 5G for Canada, as well as independent modeling undertaken for this report, 5G and related technologies could add between $100 billion and $120 billion in GDP in Canada by 2036, and account for approximately 4% of Canada's total GDP by 2036.

- 5G is also associated with high paying jobs. Average earnings in the wireless sector are almost 25% higher than in the wider business sector. 5G also plays a fundamental role in the wider digital economy. Employment in the digital economy is forecast to grow faster than in the overall business sector over the 2022-2025 period and account for 11% of total employment in the business sector by 2025.

Several studies reviewed for this report attempt to estimate the economic benefits of 5G and the technology advancements it enables. The estimates are necessarily speculative given the infancy of 5G-enabled use cases and, thus, vary considerably. The clarity of the methodologies used to generate the estimates also varies, making it difficult to assess the reasonableness of the estimates. **For this reason, a framework was prepared to evaluate these estimates and provide an independent and transparent viewpoint with which to consider the economic impact of 5G**. The design of the framework, its key assumptions and the results are described in this section of the report.

The framework incorporates a growth accounting approach consistent with Statistics Canada's published productivity data. Growth accounting is a method that separates economic growth into its contributing factors. Those factors are capital, labour and productivity – the efficiency with which capital and labour are used to generate output. The framework built for the report focuses on the potential economic gains enabled by 5G from increases in productivity. The most common

measure of productivity is labour productivity. In the framework, labour productivity is defined as GDP generated per hour worked. Growth in labour productivity can be separated into growth in capital intensity (more equipment such as machinery or tools per hour of labour), labour composition (an overall increase in the skill and/or experience of the labour force), and the unexplained residual component called multifactor productivity (MFP). Technological improvement is generally understood to be a key driver of MFP growth. Consider, for example, that personal computers in the workplace have improved in their performance over time while their real dollar value has stayed relatively constant: a worker gets more work done with a modern computer compared to an older computer and, hence, their productivity is higher. There are many other factors that can increase MFP such as business model, process and management practices improvements. Governments can also improve MFP by making regulatory and tax system changes that result in more efficient allocation and/or utilization of inputs.

Within this context, 5G can enable growth in both capital intensity and MFP. For example, with respect to capital intensity, 5G enables new forms of machinery and robotics that depend on next-generation network performance to operate effectively and safely. With respect to MFP, 5G helps put labour and capital to more efficient use. However, there are significant lags between the introduction of so-called "general purpose technologies" and observed increases in output attributable to these technologies. Complementary intangible investments to transform strategy, organization, and processes are also required to attain the value available from adopting these new technologies. The lag between the introduction of 5G technology and the attainment of value enabled by it is estimated as described further below.

The framework considers historical and forecasted figures published by trusted statistical agencies, including Statistics Canada and OECD, to establish key assumptions for estimating the potential economic growth that will be enabled by 5G. A description of these data and the corresponding assumptions built into the framework are as follows:

TABLE 4.1: ECONOMIC MODEL FRAMEWORK PARAMETERS

Framework Parameters	Description
Real GDP per capita	This is the size of the economy as measured by GDP in constant dollars divided by the population. Economic growth on a per-person basis supports a continuously rising standard of living for all Canadians and a strong foundation for the government to invest in evolving priorities (e.g., climate change, aging population). A recent OECD report forecasts real GDP per capita annual growth for Canada at 0.7% to 2030 and 0.8% from 2030 to 2060. These compare poorly to forecasts for the U.S. and Euro area: 1.2% and 1.0% to 2030 and 1.0% and 1.1% from 2030 to 2060 for the U.S. and Euro area, respectively.[296] Recent real GDP per capita growth in Canada, based on data published by Statistics Canada, is somewhat higher: the average annual growth was 1.1%, as was the compound annual growth rate.[297]

[296] Link to source: https://www.oecd-ilibrary.org/economics/the-long-game-fiscal-outlooks-to-2060-underline-need-for-structural-reform_a112307e-en.

[297] Links to sources: Statistics Canada. Table 17-10-0005-01 Population estimates on July 1st, by age and sex; Statistics Canada. Table 36-10-0222-01 Gross domestic product, expenditure-based, provincial and territorial, annual (x 1,000,000). The growth rate is based on annual data for years 2010 to 2019.

Framework Parameters	Description
	Real GDP per capita is not used as an input, but rather is used as a reasonableness check on the outputs.
Population	A forecast from the OECD is used for the population of Canada.[298]
Labour force	A study by Statistics Canada from 2018 provides labour force projections to 2036 that are used in the framework. Several scenarios are presented in that study based on different participation rates by age cohort. The framework uses the average of two of those scenarios: 1) the "reference" case, which assumes labour force participation rates of older Canadians continues to increase according to prevailing trends in 2018; and 2) the "constant" scenario, which assumes the participation rates in 2018 remain constant.[299] The size of the labour force has implications for the labour productivity growth required to achieve a given GDP per capita growth rate.
Hours worked	The number of hours worked by the labour force also has implications for the labour productivity growth required to achieve a given GDP per capita growth rate. Total hours worked per worker were compared to historical labour force figures from Statistics Canada and were found to have remained fairly constant over the 2010 to 2019 period. Therefore, the framework assumes that the total hours worked divided by the labour force remains constant.
Productivity	Labour composition growth (i.e., the degree to which the overall skill and experience of the workforce changes over time) has been relatively constant at 0.2%. The framework assumes this growth rate going forward and, to be conservative, none of this growth is attributable to the deployment of 5G technology; instead, this growth results from a gradually aging workforce and increase in the skill level of the workforce through attainment of higher levels of education. Meanwhile, capital intensity plus MFP in Canada grew at an average annual rate of 1.1% from 2010 to 2019, while the average 5-year growth rate over the 1997-2019 period was 0.8%. The framework assumes that capital intensity plus MFP will gradually increase to 1.3% as adoption of artificial intelligence and other digital technologies enabled by 5G grows. An increase in labour productivity from current levels has support from some academic research that foresees a rapid increase in output as investments in digital-related technologies begin to bear fruit.[300]
Adoption	To model the ramp-up of capital intensity plus MFP growth, assumptions were made about 1) the timing of the sales of different 5G spectrum classes; 2) the proportion of economic value that each of these classes represents in terms of the innovation they enable; 3) the relative size and timing of adoption cohorts (early, medium, and lagging adopters); and 4) the number of years that 5G adopters achieve productivity gains from 5G.
5G-enabled growth	The framework assumes annual combined MFP and capital intensity growth of 0.8% enabled by factors unrelated to 5G. There are many such potential factors. For example, the 2022 federal budget refers to a recent study by the International Monetary Fund which found that Canada could increase its GDP per capita by 4% through a complete liberalization of interprovincial trade in goods and goes to

[298] Link to source: https://stats.oecd.org/Index.aspx?DataSetCode=POPPROJ. Retrieved April 8, 2022.

[299] Link to source: https://www150.statcan.gc.ca/n1/pub/75-006-x/2019001/article/00004-eng.htm.

[300] Links to sources: https://www.technologyreview.com/2021/06/10/1026008/the-coming-productivity-boom/; http://www.csls.ca/ipm/37/OECD.pdf.

Framework Parameters	Description
	highlight its continued commitment to remove interprovincial trade barriers.[301] Adopters of 5G are assumed to achieve an addition 0.5% in annual combined MFP and capital intensity growth. The assumption that 5G can enable 0.5% in annual labour productivity growth is a rough estimate based on literature from proponents of the viewpoint that intangible digital-related investment will drive an upswing in output. For example, Erik Brynjolfsson and Georgios Petropoulos wrote in the *MIT Technology Review* in June 2021 that U.S. productivity growth, which averaged 1.1% from 2010 to 2020, could reach or exceed levels observed in the 1990s, which averaged 2.3% from 1990 to 2000, due to digital technologies.[302] However, a growth rate of 0.5% is on the high end compared to, for example, "general purpose technology" use cases included in a 2018 report by the Australian government about the potential economic benefits from 5G.[303]

The results of the analysis are summarized in Figure 4.1 and Table 4.2 below. Based on the assumptions, the analysis suggests that 5G-enabled growth could add an estimated $51 billion in real GDP by 2030 (14% of total GDP growth) and $109 billion by 2036 (16% of total growth) relative to a 2021 baseline of $2,152 billion. Increases in labour composition, productivity growth from sources other than 5G-related innovation, and growth in the labour force account for the remainder of GDP growth. Compound annual growth rates are also included in the table. Real GDP grows at an annual rate of 2.0% to 2030 and 2.0% to 2036, while real GDP per capita grows at an annual rate of 0.9% to 2030 and 0.9% to 2036. The growth rates converge slightly because of a gradually aging population and a corresponding decline in labour force participation among those 15 years of age and older.

While the results seem optimistic given the OECD's projections about Canada's real GDP per capita (i.e., annual rates of between 0.7% and 0.8% during the 2022-2036 timeframe) and the average annual labour productivity growth from 2010 to 2019 was just 1.3%, they are reasonable because of the expected increase in output that will be unlocked by adoption of digital services, including those enabled by 5G.

[301] Link to source: https://budget.gc.ca/2022/pdf/budget-2022-en.pdf.

[302] Link to source: https://www.technologyreview.com/2021/06/10/1026008/the-coming-productivity-boom.

[303] Australian Government, Impacts of 5G on productivity and economic growth, April 2018. Figure 5 page 16. Link to source: https://www.infrastructure.gov.au/sites/default/files/impacts-5g-productivity-economic-growth.pdf.

FIGURE 4.1: REAL GDP AT MARKET PRICES, CHAINED (2012) DOLLARS, GROWTH BY SOURCE FROM 2021 BASELINE

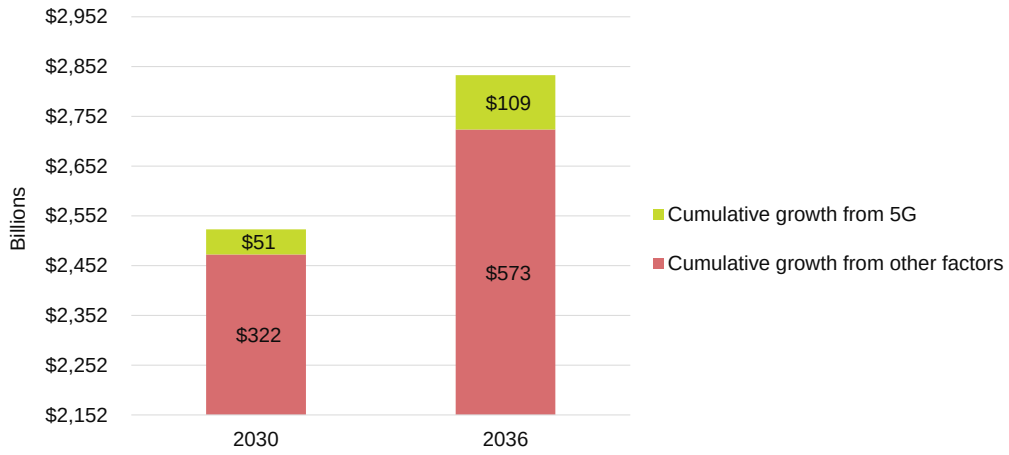

TABLE 4.2: ECONOMIC MODEL FRAMEWORK RESULTS

Real GDP at Market Prices, Chained (2012) dollars, billions	2030		2036	
	Value	*% of Total*	*Value*	*% of Total*
2021 baseline	$ 2,152	85%	$ 2,152	76%
5G-enabled	**$ 51**	**2%**	**$ 109**	**4%**
Labour composition	$ 40	2%	$ 69	2%
Other productivity improvement	$ 165	7%	$ 287	10%
Labour force	$ 118	5%	$ 218	8%
Total	$ 2,525	100%	$ 2,835	100%

Compound Annual Growth Rates compared to 2021 baseline	2030	2036
Real GDP	2.0%	2.0%
Real GDP per capita	0.9%	0.9%

A key limitation of the framework is endogeneity with respect to how 5G-enabled innovation is considered. Specifically, the impact of 5G is presented as both an output and an input. A more robust "bottom-up" approach would consider individual use cases and their impact at the sector level and aggregate these results. However, the **purpose of the framework is to establish a test for reasonableness when evaluating the estimates observed in other research**, which is discussed below. The reasonableness of the framework itself is, again, established by the assumptions described above.

Five reports on 5G's impact on Canadian economic growth were evaluated. All five describe the nature of growth similarly: growth driven by an accelerated transition towards the digital economy enabled by the deployment of 5G connectivity.

TABLE 4.3: ESTIMATES OF 5G IMPACTS ON CANADA GDP FROM REVIEWED REPORTS

Author, Year Published	Estimates
PwC, 2021	A 2021 report by PricewaterhouseCoopers (PwC) estimates that 5G-enabled GDP will increase to $78 billion by 2030 and grow more slowly to $94 billion in 2035.[304] The methodology is not described.
GSMA Intelligence, 2020	A 2020 report by GSMA Intelligence estimates that 5G-enabled GDP will reach US$150 billion (CA$201 billion) by 2040.[305] The estimates are across all sectors and are based on historical and forecasted correlations between GDP growth and the number of mobile connections.
BCG, 2019	A 2019 report by Boston Consulting Group (BCG) similarly estimates 5G-enabled GDP to grow to $200 billion by 2040.[306]
ICTC, 2018	A 2018 report by Information and Communications Technology Council (ICTC) estimates the GDP impact by 2030 to be $26.1 billion.[307] The estimates are based on historical and forecasted correlations between GDP growth and mobile subscriptions per capita.
Accenture, 2018	A 2018 report by Accenture estimates the GDP impact by 2026 to be $40 billion.[308] This report's estimates also appear to be based on historical and forecasted correlations between GDP growth and service penetration.

Based on the analysis framework prepared for this report, the following are key observations about the economic growth potential enabled by 5G:

- **It is reasonable to expect 5G-enabled real GDP in Canada to grow to approximately $40 billion to $60 billion by 2030 and $100 billion to $120 billion by 2036.** This growth is optimistic, though reasonable, given guardrail assumptions and considerations with respect to real GDP per capita, population, labour force, hours worked, etc., as described above.
- This growth depends on a host of factors, including the expedient deployment of 5G infrastructure and the preceding release of 5G spectrum.

[304] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.
[305] Link to source: https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165916&file=051120-5G-in-Canada.pdf. US-CAN average annual exchange rate for 2020 (1.3415) sourced from Bank of Canada, accessed on April 18, from webpage https://www.bankofcanada.ca/rates/exchange/annual-average-exchange-rates/.
[306] Link to source: https://media-publications.bcg.com/flash/dotbcg_other/CCF%20Digital%20Infrastructure-%20In%20the%20Balance.pdf.
[307] Link to source: https://www.ictc-ctic.ca/wp-content/uploads/2019/03/ICTC_5G-Jumpstart_2018_EN_Mar14.pdf.
[308] Link to source: https://www.5gcc.ca/wp-content/uploads/2018/06/CWTA-Accenture-Whitepaper-5G-Economic-Impact_Updates_WEB_06-19-2018.pdf.

- If productivity enabled by 5G grows at the same rate as the OECD aggregate level as is assumed for Canada, 5G-enabled real GDP across the OECD is estimated at CA$2 trillion by 2030 and CA$4 trillion by 2036.[309]

Additional research reviewed for this report found significant economic gains from upgrading to previous next-generation mobile technologies. For example, a study by GSMA Intelligence, which considers data from 160 countries from 2000 to 2017, estimates up to 0.07% and 0.05% increases in GDP from a 10% increase in adoption of 3G (over 2G) and 4G (over 3G), respectively, controlling for factors such as the number of mobile connections and labour and capital endowments.[310] Another GSMA report observes that 4G accounted for nearly 80% of mobile connections in Canada by the end of 2019 which "compares favourably with other developed markets," [311] suggesting Canada has done a good job in building the infrastructure and harvesting the benefits available from 4G adoption.

There is good reason to expect higher economic gains from 5G adoption given it enables productivity-enhancing digital capabilities, such as AI and automation, that promise potential benefits **across all sectors** in the economy. While 3G enabled integrated voice, video, and data and led to the mass adoption of cell phones, and 4G, coupled with cloud-based computing, enabled new business models such as ride-sharing services, live-streaming media, and other rich-feature software-as-a-service applications, the use cases enabled by 5G, as described in this report, demonstrate the next-level transformative potential of 5G networks. An indicator of 5G's nature as an "industry play" is the number of IoT connections. In a 2022 report, Ericsson predicts that IoT connections will more than double from 14.6 billion in 2022 to 30.2 billion in 2027. Meanwhile, 5G subscriptions will increase from under 1 billion in 2021 to 4.4 billion in 2027 and will account for 48% of total mobile subscriptions by 2027.[312]

As this report shows, there are numerous use cases across industries and the public sector to enhance quality and efficiency through 5G-enabled digitalization. 5G and digitalization are critically important to enhancing Canada's productivity and standard of living and to counteracting its aging population and resultant drag on labour market growth.

5G is also an enabler of job growth. According to the Information and Communications Technology Council (ICTC), employment growth in the digital economy will continue to outpace employment growth in the general economy and will account for roughly 11% of total employment in Canada by 2025.[313] Tech workers in its report include 30 National Occupational Classification (NOC) codes, while the tech sector is defined by 18 North American Industry Classification System (NAICS) codes. Although these are detailed in the report, they almost certainly include

[309] Based on comparing real GDP for OECD total to Canada in 2019 in Million US$. OECD total was 34 times that of Canada. Data sourced from OECD on April 18, from webpage https://data.oecd.org/gdp/gross-domestic-product-gdp.htm#indicator-chart.
[310] Link to source: https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165922&file=121120-working-paper.pdf.
[311] Link to source: https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165916&file=051120-5G-in-Canada.pdf.
[312] Link to source: https://www.ericsson.com/49d3a0/assets/local/reports-papers/mobility-report/documents/2022/ericsson-mobility-report-june-2022.pdf.
[313] Link to source: https://www.ictc-ctic.ca/wp-content/uploads/2021/08/digital-talent-outlook-for-2025.pdf.

individuals working in the wireless sector. According to Statistics Canada, the wireless sector accounted for 55,192 direct jobs plus an additional 57,344 indirect and 33,164 induced jobs in 2020.[314] Meanwhile, average weekly earnings in the wider wired and wireless telecommunications carriers sector were 24% higher than in the service industry in 2020.[315]

It is important to highlight, however, that 5G drives economic growth primarily through productivity gains rather than job creation; that is, 5G and the applications that run on it have the potential to make labour more productive (which, recall, tends to increase wages). More so than creating new jobs, 5G and its related technologies place demands on workers to adapt to new ways of work that are more digitally intensive and require digitally aware skills. In more extreme cases where 5G-enabled technologies such as automation eliminate jobs, impacted workers will need to get re-skilled for a different occupation. On aggregate, however, technologies such as automation and robots may be associated with higher levels of employment. For instance, a 2022 study by the Centre for Future Work finds that business machinery & equipment investment as a percent of GDP is positively correlated with annual changes in employment when looking at years 1976 to 2020 in Canada.[316]

5 Impact of 5G on Environment, Social, and Governance (ESG) Issues

Key Takeaways

- From an environmental perspective, many of the use cases of 5G reviewed for this report that promise commercial viability also reduce greenhouse gas emissions. 5G and the services it enables should be regarded as an important component in the portfolio of options available to reduce global warming. 5G and the services it enables could reduce Canada's GHG emissions by 20%. 5G-enabled technologies will also help feed a growing global population, advance sustainable agriculture, and improve waste management practices.
- From a social perspective, there are numerous use cases in the healthcare arena that stand to improve the effectiveness and efficiency of healthcare delivery. 5G technologies also support sustainable urbanization and offer possibilities to improve accessibility for traditionally disadvantaged populations, including those living in remote regions, older citizens, and those with disabilities.
- Reskilling the workforce to meet the demands of the digital economy will require a fundamental rethinking of current training and learning methodologies and support for

[314] Link to source: Statistics Canada. Table 36-10-0669-01 Wireless telecommunications carriers industry economic impact. Direct jobs reflect those working in the sector. Indirect jobs reflect demand for inputs from other Canadian businesses. Induced jobs reflect the economic activity that arises because of workers involved in the direct or indirect activity spending part of their earnings on other goods and services provided by Canadian businesses.

[315] Link to source: Statistics Canada. Table 14-10-0204-01 Survey of Employment, Payrolls and Hours (SEPH) Average Weekly Earnings by Industry, annual.

[316] Link to source: https://centreforfuturework.ca/wp-content/uploads/2022/04/Where-Are-The-Robots.pdf.

impacted workers through this transition. Government in collaboration with industry has an important role to play to ensure that the right market structures and supports are in place to ensure that all demographics and regions benefit equitably from the opportunities enabled by 5G.

- 5G adoption may introduce new risks around cyber security and privacy protection. However, it also enables new capabilities that may mitigate these concerns such as network slicing and new, more secure encryption algorithms. Energy consumption has tended to increase with the introduction of previous network standards, such as from 3G to 4G. However, 5G itself is expected to reduce energy use on a per bit of data consumed basis by 85% to 90% from what 4G required. Building 5G with precision will facilitate the optimization of network performance on the new 5G frequencies while keeping capital and operating expenditures within reasonable levels. This means service providers will be able to limit energy consumption growth when introducing 5G.
- A further challenge is the increase in electronic waste that could occur as devices and sensors that utilize 5G networks become obsolete or non-functioning. Supporting the growth of e-waste recycling markets, finding new ways to divert e-waste from landfills, and reducing the toxicity of substances used in these devices are important steps for government, industry and stakeholders to undertake in partnership..

This section of the report considers the non-economic impacts of 5G adoption. It is organized around the three ESG pillars (Environment, Social Governance) and outlines both the positive benefits that arise with 5G adoption as well as new challenges that will need to be monitored and managed. The pillars can be summarized[317] as:

- Environment – conservation of the natural world
- Social – consideration of people and relationships
- Governance – standards of running a company

The ESG pillars provide the basis for establishing metrics for investors and analysts to assess companies on their environmental, social and governance practices while also considering financial returns. As a result of external pressure from governments, regulatory bodies and ESG agencies, as well as widespread realization of the benefits of ESG practices, ESG has advanced to the forefront of public and private organizations' agendas and is playing a crucial role in their strategic planning and risk management. Given the non-economic impacts of 5G adoption discussed in this section, 5G is a relevant factor that organizations should consider in their ESG programs.

A second, related organizing framework considered in this section is the United Nations Sustainable Development Goals (SDG). The SDGs are at the core of the U.N. 2030 Agenda for Sustainable Development, which provides a "shared blueprint for peace and prosperity for people

[317] Definitions sourced from https://www.cfainstitute.org/research/esg-investing.

and the planet, now and into the future."[318] The SDGs comprise 17 goals with associated indicators and related targets. These are particularly relevant to governments and multilateral institutions in providing guidance about efforts to prioritize, monitor and manage their efforts to advance sustainable development. They are also relevant to businesses because they serve as a quasi-standard for defining ESG goals and metrics. A report by KPMG found that in 2018, 40% of the G250, the world's 250 largest firms, acknowledged the SDGs in their corporate reporting. Of those companies who acknowledged the SDGs, 39% also referenced them in their CEO and/or Chair's statement.[319]

Below is a summary of key non-economic impacts of 5G organized by ESG pillar. Related SDGs are also noted. This information draws on the findings in Section 5 and from other research. Refer to Section 5 for more detail about ESG impacts related to the 11 evaluated industry verticals.

5.1 Environment

Many of the use cases for 5G have a corollary benefit in the form of GHG emissions reductions.

According to the Intergovernmental Panel on Climate Change (IPCC), limiting global warming to the Paris Agreement target of 1.5°C by 2100 requires global net emissions to be reduced by approximately 43% (to 31 $GtCO_2$) by 2030 (compared to 2019 emissions) and by approximately 84% (to 9 $GtCO_2$) by 2050.[320] The mitigation pathways analyzed by the IPCC to achieve this target focus on institutional design, policy, finance, technological innovation and governance arrangements. In Canada, the Canadian Net-Zero Emissions Accountability Act preserves Canada's commitment to achieve net-zero emissions by 2050. The 2030 Emissions Reduction Plan, published by the Government of Canada in March 2022, maps out Canada's path to achieve its improved Paris Agreement target to cut emissions by 40% to 45% from 2005 levels by 2030. The plan includes contributions from various groups within Canada, including provinces, territories, First Nations, Canadian citizens, and the Net-Zero Advisory Body, on what is required to attain Canada's more ambitious climate target.[321]

According to the 2030 Emissions Reduction Plan, "economy-wide strategies to reduce emissions, like carbon pricing, clean fuels and reducing methane emissions, will enable Canada to reduce emissions in the most flexible and cost-effective way. They will also provide policy certainty to businesses and Canadians, allowing everyone to make more informed decisions as Canada's economy decarbonizes."[322] In addition, the Government of Canada is funding several programs

[318] Link to source: https://sdgs.un.org/goals.

[319] Link to source: https://assets.kpmg/content/dam/kpmg/xx/pdf/2018/02/how-to-report-on-sdgs.pdf.

[320] Link to source: https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf.

[321] https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html.

[322] https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/sector-overview.html#sector1.

across various sectors (buildings, electricity, heavy industry, oil and gas, transportation, agriculture and waste) to support their emissions reductions.[323]

Digital technologies can and will play a role in these objectives. Many 5G use cases have commercial viability because they reduce energy requirements; a corollary benefit is that GHG emissions are reduced to the extent the energy requirements are met by fossil fuels. According to a report by Ericsson, the adoption of digital solutions in energy, buildings, transport, travel, work, services and agriculture industries could reduce global GHG emissions by 7% to 15% by 2030.[324] Meanwhile, a study by Accenture finds that 5G-enabled mobile technologies in Canada will enable the abatement of up to 54 metric tonnes of carbon dioxide equivalent ($MtCO_2e$). Smart working, living and health mobile technologies will drive approximately 29% of the abated carbon emissions, smart transport and cities will drive 24%, smart manufacturing 18%, smart buildings 16%, smart agriculture 7%, and smart energy 5%. Overall, research suggests 5G and the digital solutions they enable could reduce Canada's GHG emission by up to 20%.[325] Potential impacts of 5G solutions include:

1. **Traffic Congestion Management** – Vehicle platooning (i.e., groups of vehicles moving together), enabled by vehicle-to-vehicle (V2V) communication, can reduce air drag by 20% to 60%. It is estimated that this could reduce CO_2 emissions by 10% to 30%, depending on the platoon's composition and space between vehicle, among other factors.[326]

2. **Smart Public Transportation & Ride-Sharing** – Per person emissions for public transit are roughly 53% lower when compared to driving or ride hailing solo.[327] 5G will support the use of public transit by enabling minute-by-minute updates on the location of buses and trains and the number of available seats, thereby increasing passenger trust and utilization. Real-time schedules and updated timetables will help commuters plan their travel in advance, leading to more reliance on public transport. Transit operators will optimize bus inventory and enable dynamic bus routing, reducing idling. The more consistent driving patterns of automated trains could reduce energy consumption by 20%.[328]

3. **Building Energy Management Systems and Smart Meters** – According to a 2022 report by Accenture, "heating, ventilation, and air conditioning (HVAC) account for one-

[323] Ibid.

[324] Link to source: https://www.ericsson.com/en/reports-and-papers/research-papers/exploring-the-effects-of-ict-solutions-on-ghg-emissions-in-2030.

[325] Link to sources: https://www.farrpoint.com/uploads/store/mediaupload/492/file/Digital_Policy_and_Climate_Change_Report_FarrPoint_2022.pdf; https://www.cwta.ca/wp-content/uploads/2020/10/5G_Role_In_Fight_Against_Climate_Change.pdf.

[326] Link to source: https://www.researchgate.net/profile/Imran-Reza/publication/351785569_Impacts_of_Autonomous_Vehicles_on_Greenhouse_Gas_Emissions-Positive_or_Negative/links/60aa8c12299bf1031fc4023e/Impacts-of-Autonomous-Vehicles-on-Greenhouse-Gas-Emissions-Positive-or-Negative.pdf.

[327] Link to source: https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/PublicTransportationsRoleInRespondingToClimateChange2010.pdf.

[328] Link to source: https://www.railjournal.com/in_depth/automatic-for-the-people-unlocking-the-benefits-of-automated-operation-on-the-main-line/.

third of a building's energy use on average. … 5G-enabled temperature and motion sensors can detect the temperature, air quality, and number of people using different spaces in a building to automatically adjust these factors in real-time to conserve energy. Similarly, Energy as a Service (EaaS) solutions are made possible with the enhanced network connectivity of 5G [and] can reduce electricity costs and thus emissions by up to 20% to 50%."[329]

4. **Asset Monitoring and Predictive Maintenance** – According to the same Accenture report, "real-time data about machines, or assets, and analytics of that data can improve productivity and thereby energy efficiency. For example, digital twins make it easier to monitor and operate assets remotely and avoid travel. … Predictive maintenance enabled by 5G can also abate emissions by helping companies reduce unplanned downtime, which is costly and leads to more on-site visits from technicians".[330] These combined benefits will drive a 2% to 5% product throughput increase, 2% to 3% asset utilization increase, 25% workforce productivity increase, 10% to 15% asset downtime reduction, and 10% to 15% maintenance, repair and operation (MRO) inventory reduction.[331]

More intensive use of digital services will increase the GHG emissions from the Information and Communication Technology (ICT) sector. However, 5G itself is expected to reduce energy use on a per bit of data consumed basis by 85 to 90% from what 4G required.[332] Building 5G with precision will facilitate the optimization of network performance on the new 5G frequencies while keeping capital and operating expenditures within certain limits and allowing a swift 5G rollout. This means service providers will be able to limit energy consumption growth when introducing 5G. By using artificial intelligence (AI), service providers will be able to operate site infrastructure more proactively through such things as predictive maintenance and no-touch problem-solving to reduce costs, site energy usage and site visits. Pilot studies of 5G deployment reveal that, when equipped with energy efficient tools (e.g., energy-saving software, machine learning (ML), smart sleep modes, etc.), 5G technology will be up to 90% more efficient than 4G in terms of energy consumption per unit of traffic (W/Mbps).[333]

5G-enabled technology will help feed a growing global population and advance sustainable agriculture and natural resources management practices.

Today's global population of 7.7 billion people is expected to increase to 8.5 billion by 2030 and 9.7 billion by 2050.[334] By 2050, the world will need to produce 70% more food (based on the farming practices, techniques and technology of 2009), thereby further straining our natural

[329] Link to source: https://api.ctia.org/wp-content/uploads/2022/01/5G-Connectivity-A-Key-Enabling-Technology-to-meet-Americas-Climate-Change-Goals-2022-01-25.pdf.
[330] Ibid.
[331] Link to source: https://www.accenture.com/us-en/services/industry-x/intelligent-asset-management.
[332] Link to source: https://www.cwta.ca/wp-content/uploads/2020/10/5G_Role_In_Fight_Against_Climate_Change.pdf.
[333] Link to source: https://www.ericsson.com/en/blog/3/2021/1/achieving-sustainability-with-energy-efficiency-in-5g-networks.
[334] Link to source: https://www.un.org/en/global-issues/population.

resources.[335] Meanwhile, 33% of the land is currently degraded due to the erosion, salinization, compaction, acidification and chemical pollution of soils.[336] Water resources are also highly stressed; roughly 1.2 billion people are living in severely water-constrained agricultural areas.[337] In Canada, farmers are also under pressure to produce more food, enhance crop protection and soil conservation, manage labour shortages and skill mismatch, mitigate the effects of climate change and deal with new regulations and policies. 5G networks and complimentary technologies and applications will be able to help the farmers improve input costs of seeds, fuel, pesticides, herbicides and fertilizers; better weather forecasting; reduced water consumption and better soil conservation. Potential impacts of 5G solutions include:

1. **Controlled Traffic Farming** – This refers to guidance technologies (e.g., controlled traffic farming, driver assistance and machine guidance) that optimize machinery driving patterns and confine them to the least possible area of permanent traffic lanes. Trials of controlled traffic farming have shown a tractor fuel reduction of 40% and 70%; herbicide use reduction of 25%; increased nitrogen efficiency of 40% to 80% due to reduced soil compaction and improved soil biological activity; and a 15% increase in crop yield (compared to randomly trafficked soils) as a result of improved root growth that uses water and fertiliser more efficiently.[338]

2. **Variable rate applications** – Fertiliser production is responsible for approximately 1.2% of total global GHG emissions.[339] According to one study, only 45% to 50% of the applied nitrogen for crop growth is being incorporated into the agricultural products – the remainder leads to runoff and can cause damage to marine ecosystems.[340] Variable rate nutrient application (VRNA) technologies can reduce fertilizer use. VRNA prescription maps in two studies resulted in a 50% to 63% reduction of nitrogen fertilizer use (compared to uniform application). One study also reported that crop yield differed by 4% and costs fell up to 7%.[341] In addition, this technology can also be applied to reduce pesticide and water use. A study conducted by the European Parliamentary Research Service suggests that early, accurate detection and localized pest and disease treatment has the potential to reduce pesticide costs by up to 85%.[342] Agriculture currently accounts for 70% of all freshwater withdrawals,[343] and variable rate irrigation systems could reduce irrigation water use by 8% to 20%.[344]

3. **Health sensors** – In cattle, sensors such as smart ear tags are used to gauge the health of animals, and IoT feeders have been shown to increase milk yields in herds by 1% and

[335] Link to source: https://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf.
[336] Link to source: https://www.fao.org/3/i5199e/I5199E.pdf.
[337] Link to source: https://www.fao.org/3/cb1447en/cb1447en.pdf.
[338] Link to source: https://elk.adalidda.com/2017/08/sustainability-09-01339.pdf.
[339] Ibid.
[340] Link to source: https://www.mdpi.com/2071-1050/13/4/2400/htm.
[341] Link to source: https://www.mdpi.com/2071-1050/12/17/6893/htm.
[342] Link to source: http://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf.
[343] Link to source: https://www.worldbank.org/en/topic/water-in-agriculture#1.
[344] Link to source: https://elk.adalidda.com/2017/08/sustainability-09-01339.pdf.

improve milk quality by 20%. Moreover, this technology decreases the number of diseased cattle by 6% and the number of cows lost due to health problems by 24% (compared to a herd without sensor tags).[345]

4. **Smart water infrastructure** – Sensor-based leak detection technologies can allow utilities to monitor their networks in near real-time, thereby enabling proactive incident or maintenance responses. This technology has helped the Las Vegas Valley lower the average amount of water lost to leaks from roughly 30% to just 5%.[346] One report claims that "the expected deployment of smart water infrastructure could mitigate around 22% of the estimated increase in global municipal water withdrawals against a business-as-usual scenario."[347]

5G presents opportunities to improvement waste management while introducing new challenges.

According to the World Bank, "the world generates approximately 2.01 billion tonnes of municipal solid waste annually, with at least 33% of that – extremely conservatively – not managed in an environmentally safe manner. Worldwide, waste generated per person per day averages 0.74 kilogram. … Global waste is expected to grow to 3.40 billion tonnes by 2050."[348] They estimate that solid waste management accounts for roughly 5% of global emissions, with food waste and improper management being major drivers of these emissions.[349] Potential impacts of 5G solutions include:

1. **Smart recycling technologies** – Currently, the global economy is only 8.6% circular.[350] In other words, less than 10% of the material used in a year is recycled or reused in some way. 5G enabled technologies such as radio-frequency identification (RFID), big data analytics (BDA), blockchain, AI and cyber-physical systems (CPS) should help increase the reuse and recycling of natural resources, thereby decreasing energy usage. According to one research study, "by knowing the waste levels and the locations of the corresponding bins, the routing and scheduling of the garbage picking procedures can be optimized, [allowing] service costs [to] be cut by 50%."[351] Technologies such as Convolutional Neural Networks (CNN) can be leveraged to classify trash (glass, paper, metal, and plastic) with more than 90% accuracy.[352] This technology can be built into smart bins to accurately classify and segregate trash while requiring minimal effort to the users.

[345] Link to source: https://phys.org/news/2020-05-crop-animal-sensors-farming-smarter.html.
[346] Link to source: https://www.verizon.com/about/news/technology-water-how-5g-and-iot-can-update-our-water-infrastructure
[347] Link to source: https://gesi.org/research/download/36.
[348] Link to source: https://datatopics.worldbank.org/what-a-waste/.
[349] Ibid.
[350] Link to source: https://www.circularity-gap.world/2022#Download-the-report.
[351] Link to source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8709486/.
[352] Ibid.

2. **Food waste-reduction technologies** – From 2010 to 2016, food production that ends up as food loss or waste generated 8% to 10% of total anthropogenic greenhouse gas emissions.[353] Moreover, one study finds that "an estimated 70% of biodiversity loss stems from agriculture and the cultivation of food, fuel and fibre, suggesting that food loss and waste contribute significantly to the decline in plant and animal species."[354] Food waste-reduction technologies such as smart labelling, smart packaging, smart fridge, smart bin, applications for food planning, shopping, cooking, storage, sharing and redistribution, and recycling into animal feed and compost will drastically reduce food waste. The management of unavoidable food waste can be improved through recycling, energy recovery and engineered landfills.[355] Gartner predicts that by 2025, "20 percent of the top 10 global grocers by revenue will be using blockchain for food safety and traceability to create visibility to production, quality and freshness."[356]

A challenge that is exacerbated by 5G adoption is the increase in electronic waste that will occur as devices and sensors become obsolete or non-functioning. Market Research Future estimates the global e-waste recycling market to grow at a compound annual rate of 16.2% by 2030.[357] It is reasonable that a similar growth rate in e-waste that does not get recycled is likely. Supporting the growth of e-waste recycling markets, finding other ways to divert e-waste from landfills, and reducing the toxicity of substances used in these devices are important steps for government, industry and stakeholders to undertake in partnership.

The U.N. Sustainability Development Goals (SDG) that are related to the use cases discussed under the Environmental pillar include:

(1) No Poverty
(2) Zero Hunger
(7) Affordable and Clean Energy
(11) Sustainable Cities and Communities
(12) Responsible Consumption and Production
(13) Climate Action
(14) Life Below Water
(15) Life On Land

[353] Link to source: https://www.ipcc.ch/srccl/chapter/chapter-5/.
[354] Link to source: https://unepdtu.org/wp-content/uploads/2022/03/reducing-consumer-food-waste-using-green-and-digital-technologies.pdf.
[355] Ibid.
[356] Link to source: https://www.gartner.com/en/newsroom/press-releases/2019-04-30-gartner-predicts-20-percent-of-top-global-grocers-wil.
[357] Link to source: https://www.globenewswire.com/news-release/2022/04/21/2426699/0/en/E-Waste-Recycling-Market-will-Touch-USD-99-67-Billion-at-a-Whopping-16-2-CAGR-by-2030-Report-by-Market-Research-Future-MRFR.html.

5.2 Social

There are numerous 5G use cases in the healthcare arena that stand to improve the effectiveness and efficiency of healthcare delivery.

As described in Section 3, healthcare systems face a range of pressures, such as adapting to an aging population, providing equitable access to services across population groups and regions, and responding to new public health challenges such as aggravations caused by climate change. Canada is also facing significant healthcare challenges: a culturally diverse population with unique healthcare needs; an aging baby boomer generation; escalating healthcare spending as a percent of GDP; extended waits in emergency departments for unavailable hospital beds; delays in various surgery procedures; unavailability of necessary home care services; and asymmetrical supply and distribution of nurses, doctors and other healthcare providers. In particular, rural Canadians have difficulty accessing primary healthcare, diagnostic services, and advanced treatments and struggle to keep healthcare providers in their communities.[358] 5G networks and complementary technologies and applications will be able to materially improve both the patient outcomes and healthcare service quality, while cutting the total healthcare system costs. Potential impacts of 5G solutions include:

1. **Improved connectivity** – Specifically in rural areas, technologies such as 5G FWA and 5G-enabled digital solutions such as remote patient monitoring, connected ambulance, HD virtual consultations, video-enabled prescription management and others, will allow governments, healthcare providers and healthcare recipients to experience a more efficient, effective and responsive health ecosystem. One report estimates that 5G-enabled access and digital solutions will reduce spending in the U.S. healthcare system by up to 30% through increased efficiencies.[359]

2. **Predictive analytics and AI** – The processing of comprehensive data generated by continuous patient monitoring will power predictive analytics and distributed AI-driven intelligent care and enable personalized medicine and treatment. Thus, patients can avoid potential stays in the hospital and hospital resources can be allocated more efficiently.[360, 361]

3. **Interactive smart pharmaceuticals** – "Smart inhalers or insulin pens, and similar devices equipped with embedded subscriber identity modules (eSIM) can record their application. Additionally, these devices might incorporate sensors and algorithmic functions to estimate the medication effect on the patient and consequently predict critical situations. These devices may also support personalized medication dose management and precision medication."[362]

[358] Link to source: https://nursinganswers.net/essays/challenges-of-canadian-health-care-health-and-social-care-essay.php.
[359] Link to source: https://cip2.gmu.edu/2021/03/08/accenture-report-outlines-how-5g-technology-accelerates-economic-growth/.
[360] Link to source: https://haas.berkeley.edu/wp-content/uploads/5g-mobile-impact-on-the-health-care-sector.pdf.
[361] Link to source: https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf.
[362] Ibid.

4. **Privacy-preserving contact tracing** – An example technology is PTBM: **P**rivacy-preserving contact **T**racing schemes in 5G-integrated and **B**lockchain-based **M**edical applications. According to one study about PTBM, "the 5G-integrated network is leveraged as the underlying infrastructure where everyone can perform location checking with mobile phones or even wearable devices connected to [the] 5G network to find whether they have been in possible contact with a diagnosed patient without violating their privacy. A trusted medical center can effectively trace the patients and their corresponding close contacts. Thorough security and performance analysis show that the proposed PTBM scheme achieves privacy protection, traceability, reliability and authentication, with high computation and communication efficiency and low latency."[363]

5. **Smart disinfection** – Contact between patients and hospital staff, as well as exposure to infectious environments, can be further reduced by employing AI-driven robots and/or equipment. One pilot project has experimented with deploying a "disinfection robot" – equipped with ultraviolet disinfection, ultra-dry fog hydrogen peroxide sterilization, and air filtration – into high-risk areas, such as those containing patients infected with COVID-19. "Using the 5G network and laser navigation technology, the robot moves autonomously according to the set route, and automatically carries out regular disinfection in complex environments, ensuring all areas are appropriately disinfected."[364]

5G technologies support sustainable urbanization.

According to the U.N., 68% of the world's population will live in cities by 2050[365], potentially leading to lower public safety, higher pollution, inadequate and overburdened services, inefficient public transport and traffic congestion. Potential impacts of 5G solutions include:

1. **Energy use optimization** – A study by McKinsey finds that "water-consumption tracking, which pairs advanced metering with digital feedback messages, can nudge people towards conservation and reduce consumption by 15% in cities where residential water usage is high."[366] Technologies like smart street lighting and smart meter parking conserve energy and reduce traffic congestion. Experiments of smart street lighting demonstrate potential energy savings of up to 48% when compared to conventional street lighting.[367] Smart cities can also leverage 5G networks to enable building automation, which will reduce energy consumption and greenhouse gas emissions. Currently, buildings are responsible for over 30% of global energy consumption.[368] Smart buildings help reduce energy usage by utilizing reactive, automated system controls that ensure consistent optimization. Incorporating multiple smart building technologies results

[363] Link to source: https://www.sciencedirect.com/science/article/pii/S0920548921000155.
[364] Link to source: https://www.nature.com/articles/s43856-022-00118-3.
[365] Link to source: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.
[366] Link to source: https://www.mckinsey.com/business-functions/operations/our-insights/smart-cities-digital-solutions-for-a-more-livable-future.
[367] Link to source: https://www.researchgate.net/publication/339309759_An_Energy-efficient_Smart_Street_Lighting_System_with_Adaptive_Control_based_on_Environment.
[368] Link to source: https://www.energyefficiencymovement.com/wp-content/uploads/2021/05/ABB_EE_WhitePaper_Smart-buildings_final-1.pdf.

in compounded efficiencies: "whereas an upgrade to a single component or isolated system can result in energy savings of 5% to 15%, a smart building with integrated systems can realize 30% to 50% savings in existing buildings that are otherwise inefficient." [369]

2. **Public safety and health** – A study by McKinsey finds that "deploying a range of [smart] applications to their maximum effect could potentially reduce fatalities from homicide, road traffic and fires by 8% to 10%. … Incidents of assault, robbery, burglary, and auto theft could be lowered by 30% to 40%. … Smart systems can optimize call centers and field operations, while traffic-signal pre-emption gives emergency vehicles a clear driving path. These types of applications could cut emergency response times by 20% to 35%."[370]

3. **City operations** – A study by Deloitte includes a case study of a city that implemented a cloud-based command center to analyze data and insights on their operations pertaining to waste management, transportation, and others. In waste management, these efforts reduced energy costs by 20% and operational costs by 40%. Transportation costs fell by 10% to 27% across their electric vehicle charging network, bus lines, shared bicycle fleet, and parking infrastructure.[371]

4. **Environmental health** – Collaborative driving of connected and automated vehicles (CAVs) can lead to 3% to 20% in energy saving.[372] By implementing smart traffic signals, one U.S. city was able to reduce commuter travel time by 26% and reduce vehicle idle time by 40%.[373]

5. **Quality of life** – A study by McKinsey claims that if cities were to deploy all the smart applications in their analysis to their fullest extent, disability-adjusted life years (DALYs[374]) would fall by 8% to 15%.[375]

5G offers possibilities to improve accessibility for traditionally disadvantaged populations.

5G-enabled digital technologies offer new capabilities that enhance the quality of life, economic opportunities and health outcomes of traditionally disadvantaged populations. While advancing equity through digital services is within reach, it will depend on establishing and supporting a common purpose between government, industry and other stakeholders to reduce rather than exacerbate so-called digital divides. The term "digital divide" refers to the gap between demographics and regions that have access to modern information and communications technology (ICT) and those that do not or have restricted access. The term can be extended to

[369] Link to source: https://www.aceee.org/research-report/a1701.

[370] Link to source: https://www.mckinsey.com/business-functions/operations/our-insights/smart-cities-digital-solutions-for-a-more-livable-future.

[371] Link to source: https://www2.deloitte.com/us/en/pages/consulting/articles/smart-city-project-case-study.html.

[372] Link to source: https://www.sciencedirect.com/science/article/abs/pii/S0968090X18305199.

[373] Link to source: https://www.cmu.edu/homepage/computing/2012/fall/smart-traffic-signals.shtml.

[374] Disability-adjusted life years, or DALYs, is a time-based metric that combines the years of life lost to premature death and the productive and healthy years of life lost to disability or incapacitation (https://www.who.int/data/gho/indicator-metadata-registry/imr-details/158).

[375] Link to source: https://www.mckinsey.com/business-functions/operations/our-insights/smart-cities-digital-solutions-for-a-more-livable-future.

consider not only access, but also usability; that is to say digital services should be both broadly available to and usable by different demographic groups. In Canada, rural communities confront disproportionate connectivity challenges, and those with a connection frequently suffer from speeds below the CRTC's minimum recommendation of 50/10 Mbps. This challenge of the digital divide in Canada in part causes complex socio-economic issues like opportunity, income and health education disparities, to name a few. Closing the digital divide with 5G technology like FWA will enhance the access of these disadvantaged communities into the digital economy and provide them the digital resources to actively participate in the new digital economy. Examples of how 5G-services can advance the needs of select demographic groups are provided below:

1. **Remote communities** – 5G connectivity brings new capabilities and benefits to rural communities such as high-performance telehealth services, improved remote/rural work opportunities and fully immersive workforce training using AR/VR technologies.

2. **Learners with diverse abilities** – 5G-enabled technologies and solutions will support easy access to online resources, be environmentally friendly, save time, increase productivity and make learning a collaborative and lifelong experience by, for example, allowing immersive learning environments that facilitate collaboration between dispersed learners. Teachers who provide physical, skills-based classes or want to provide a gamified learning experience could leverage VR and AR capabilities, which will be accessible with 5G. A study conducted by Nicklaus Children's Hospital finds that medical personnel trained with VR retain as much as 80% of the course material after one year, while those trained with traditional methods retain only 20% of information after one week.[376]

3. **Seniors and persons with disabilities** – 5G FWA will increase accessibility for older adults and will provide technological solutions for age-related disabilities, such as reduced vision and hearing loss. Digital technologies are also being developed to help address loneliness and isolation among older people who are physically distanced from family and friends. Recent studies have shown that VR-based therapy can reduce chronic pain – a prevalent ailment in older adults – by 25%.[377] Other technologies such as voice-activated smart appliances, lighting, heating, emergency notification devices and home security can all enhance the comfort and quality of life for older adults.

A further consideration is the impact of digital services adoption on workforce dynamics. Reskilling the workforce to meet the demands of the digital economy will require a fundamental rethinking of current training and learning methodologies and support for impacted workers through this transition. Impacted workers include both those that are displaced by technology and those who need to use or understand these technologies to do their jobs. For example, a recent study by the Centre for Work highlights the need for greater investment in technology and innovation to increase output per worker, leading to better paying jobs that are also more safe.[378] As with

[376] Link to source: https://learningsolutionsmag.com/articles/2427/healthcare-training-on-the-verge-of-vr-revolution.

[377] Link to source: https://www.frost.com/frost-perspectives/5g-set-to-disrupt-the-healthcare-industry-and-address-rising-aging-population-in-japan/.

[378] Link to source: https://centreforfuturework.ca/wp-content/uploads/2022/04/Where-Are-The-Robots.pdf.

reducing rather than exacerbating digital divides, collaborative models between government, industry and stakeholders are needed to ensure the labour market evolves in sync with digital services adoption – that workers have the skills they need to participate in an increasingly digitally oriented labour market.

The U.N. Sustainability Development Goals (SDG) that are related to the use cases discussed under the Social pillar include:

(3) Good Health and Well-being

(4) Quality Education

(7) Affordable and Clean Energy

(8) Decent Work and Economic Growth

(10) Reduced Inequality

(11) Sustainable Cities and Communities

5.3 Governance

An increasingly connected fabric of technologies further complicates cyber security and privacy protection.

Privacy, physical security and cybersecurity are at the forefront of both governments' and business organizations' agendas. These concerns transcend borders in the evolving digital age as organizations collect and process large amounts of sensitive personal data and have physical assets in numerous jurisdictions. With its ability to introduce a vast array of new connections, capabilities, and services, 5G also introduces potential new vulnerabilities for threat actors to exploit. A report commissioned by the U.S. National Security Agency and Cybersecurity and Infrastructure Security Agency outlines the "threat vectors" of 5G, which include undue influence from nation-states in defining 5G security standards; organizations and communications providers choosing not to implement optional security controls; use of counterfeit components in the ICT supply chain; and inherited vulnerabilities from 4G networks; among others.[379] In Canada, the Government is continuously enhancing its Security Review Program, led by the Communications Security Establishment in collaboration with Canadian telecommunications service providers. This program is expanding its scope to access risks from all key telecommunications equipment, software and application suppliers to support the MNOs further fortify their cyber security processes and network resiliency. To this effect, "the Canadian Government [has announced] its intention to implement the following actions:

1. The use of new 5G equipment and managed services from Huawei and ZTE will be prohibited and existing 5G equipment and managed services must be removed or terminated by June 28, 2024.
2. Any use of new 4G equipment and managed services from Huawei and ZTE will be prohibited and any existing 4G equipment and managed services must be removed or terminated by December 31, 2027.

[379] Link to source: https://media.defense.gov/2021/May/10/2002637751/-1/-1/1/POTENTIAL%20THREAT%20VECTORS%20TO%205G%20INFRASTRUCTURE.PDF.

3. The Government expects that telecommunications service providers will cease procurement of new 4G or 5G equipment and associated services by September 1, 2022.
4. The Government further intends to impose restrictions on Gigabit Passive Optical Network (GPON) equipment used in fibre-optic networks.
5. During these transition periods, telecommunications service providers that use this equipment and managed services would be required to comply with any assurance requirements prescribed by the Government, building from the Communications Security Establishment's Security Review Program."[380]

5G networks will enable new capabilities that will help mitigate cybersecurity, privacy and resilience risks to a significant extent. These capabilities include stronger air interface security with user data integrity protection to prevent user data from being tampered with; transmission of users' permanent IDs in ciphertext to defend against privacy attacks; better roaming security through implementation of security protection for inter-operator signaling at the transport and application strata which prevents third-party operators' devices from tampering with sensitive data exchanged between core networks; and enhanced user privacy protection providing reliability and robustness against non-malicious unavailability situations (e.g., errors that appear due to unusual but expected bad radio conditions and broken links). Furthermore, 5G's compartmentalization functionality will aim to isolate potential security breaches from spreading to different parts of the network, and its increased bandwidth enables more frequent updates of temporary user identifiers.[381] "The use of technologies such as artificial intelligence (AI), cloud computing and the deployment of Internet of Things (IoT), all enabled by the strong backbone network provided by 5G, will help IT teams prevent new cybersecurity threats to operate entire business networks more securely."[382] Other security, privacy and resilience benefits of 5G networks are as follows:

1. **Network slicing** – "allows different networks and services to share the same infrastructure but are isolated and segregated from each other. Network slicing carves out (or slices, as it were) specific types of network traffic to match various use cases – be it enterprise, consumer, IoT or public safety."[383]
2. **New Radio Encryption Algorithm (NEA) and New Radio Integrity Algorithm (NIA)** – Both algorithms support the highly secure Advanced Encryption Standard (AES), which is the most robust security protocol. AES uses higher length key sizes such as 128, 192 and 256 bits for encryption, making it more robust against hacking. The robust encryption algorithm scrambles voice and data traffic between devices and cell towers, making it more difficult for hackers to decrypt information.
3. **Virtualization** – This implies the use of more intelligent software and "virtual" hardware solutions that can be deployed quickly to any network location to automatically respond to threats. "Instead of specialized hardware that could be compromised, … data can be

[380] Link to source: https://www.canada.ca/en/innovation-science-economic-development/news/2022/05/policy-statement--securing-canadas-telecommunications-system.html.
[381] Link to source: https://www.ericsson.com/4a66f8/assets/local/news/2021/09172021-a-guide-to-5g-network-security-2.0.pdf.
[382] Link to source: https://www.infosecurity-magazine.com/opinions/5g-driving-cybersecurity-evolution/.
[383] Link to source: https://cybersecurity.att.com/blogs/security-essentials/what-is-5g-security.

routed through virtual hubs and switches that can be moved or changed quickly if required."[384]

4. **Edge computing** – With traditional or cloud computing, data usually travels to a server to be processed. With edge, data is processed closer to the source, improving threat detection.[385]

Common, robust standards are also important. Canadian stakeholders have a role to play in establishing security standards for 5G to safeguard sensitive and personal information. Collaboration between all participants of the 5G ecosystem, including governments and regulatory bodies who will establish and enforce the final security and privacy policies for 5G at the national level, is critical to ensure that the end-to-end 5G architecture encapsulates privacy-by-design approaches that are service-oriented and privacy-preserving. See Section 6 for further discussion about key actions to ensure the security of 5G and 5G-related technologies.

Stakeholders should be mindful of the potential for negative consequences that could arise with the transition to an increasingly digitally oriented economy and society.

Already discussed above are challenges with respect to: ensuring workers are not left behind and have the skills needed to participate meaningfully in the digital economy; ensuring 5G services reduce rather than exacerbate "digital divides"; and ensuring the responsible management of e-waste generated for reasons related to 5G. Additionally, there are some concerns about the public health risks posed by 5G, specifically with respect to radiofrequency (RF) energy transmitted by 5G base stations. The U.S.-based National Institute of Environmental Health Sciences has stated that "at this point, it is unclear exactly whether, or to what degree, human exposure to [RF energy] will change. What is known regarding 5G, however, is that while continuing to be exposed to the current frequencies, wireless consumers will be exposed to higher frequencies as well."[386]

The U.N. Sustainability Development Goals (SDG) that are related to the use cases discussed under the Governance pillar include:

(16) Peace, Justice, and Strong Institutions

(17) Partnerships for the Goals

[384] Ibid.

[385] Ibid.

[386] Link to source: https://ntp.niehs.nih.gov/whatwestudy/topics/cellphones/index.html.

6 Policy Implications

Key Takeaways

5G connectivity will be a core enabler of digitalization as well as next-generation technologies, applications, and tools. Canada's current regulatory policies are causing significant delays in 5G deployment and hindering the realization of the socio-economic benefits of critical new technology. Canadian policymakers should collaborate across all levels of government and with 5G ecosystem participants to make current regulatory frameworks and policies more flexible, aligned with industry needs, and optimized for digitalization, harmonization, privacy and security.

This section provides detail as far as what actions each stakeholder group should ideally undertake to achieve a set of seven key **outcomes**. Additionally, a high-level framework is described for developing a 3-year **roadmap** to achieve these outcomes. Finally, a set of example metrics are provided as a foundation of a **performance measurement framework** to track and monitor deployment and adoption success. The federal government should play a leadership role in moving these steps forward. Involvement from Canadian Radio-television and Telecommunications Commission (CRTC) and Innovation, Science and Economic Development Canada (ISED), and Statistics Canada is critical, and so too will be involvement from other departments in the federal government as well as other levels of government.

Below are the proposed key actions that need to be taken by each stakeholder group to address the current policy shortcomings and other implementation gaps. The stakeholders are categorized as:[387]

1. Government, regulators, and policy makers; referred to as "**Regulators**"
2. Enterprises, organizations, and associations; referred to as "**Industry Participants**"
3. Service Providers; referred to as "**MNOs**" and
4. Hardware, software and application providers; referred to as "**Technology Providers**":

Regulators:

i. Develop a comprehensive digital three-year roadmap including a 5G implementation plan that includes clear directions and performance management metrics for the entire 5G ecosystem.

ii. Establish 12-24-36-month national key performance indicators (KPIs) for the deployment, operational performance, customer uptake, application development and socio-economic benefits for 5G.

[387] The stakeholder groups are similar to those described in PwC work with the World Economic Forum and used in a Canada telecommunications industry report in 2020. Link to source: https://www.pwc.com/ca/en/communications/publications/761378-the-importance-of-a-healthy-telecommunications-industry-to-canadas-high-tech-success.pdf.

iii. Accelerate auctions of low and high band spectrum, ensure availability of sufficient contiguous spectrum, reduce spectrum auction reserve prices and annual fees, and avoid spectrum set-asides.

iv. Adopt a “bottom up” approach to the creation of unified national standards by promoting and supporting industry collaboration on standards, because this is the best way to ensure that technologically superior approaches prevail.

v. Provide additional government incentives in the form of: (i) accelerated capital depreciation tax policies; (ii), funding for labour reskilling support; (iii) funding for early-stage wireless research and development (R&D) programs; and (iv) target subsidies for pilot 5G-enabled use cases.

Industry Participants:

i. Ensure 5G networks are able to support cutting-edge technologies like artificial intelligence (AI), machine learning (ML), big data analytics, cloud computing and blockchain to fully realize the socio-economic benefits of these complementary technologies.

ii. Create relevant and actionable KPIs for key industry sectors to measure the operational and socio-economic impacts of 5G.

iii. Collaborate to implement proactive changes to data governance policies and support the creation of universal encryption.

MNOs:

i. Invest extensively in capacity, availability and reach of fibre backhaul and commit to resilient 5G operations.

ii. Explore new tiered service propositions for consumers and businesses and invest in and pilot viable sector-specific use cases.

iii. Establish a zero-trust security and privacy-by-design approach in 5G deployment and operations.

iv. Support government in the creation, collection and benchmarking of 5G deployment and operational metrics.

Technology Providers:

i. Orchestrate evolving technologies like AI, ML, big data analytics, anonymity-based techniques and temporary mobile subscriber identity (TMSI) to identify and mitigate cyber risks.

ii. Develop latest connected devices, software and applications in multiple forms meeting users' high-performance needs.

Globally, the deployment of 5G networks and related technologies are surfacing novel policy and regulatory opportunities and challenges around individual privacy, technological leadership, national security and economic competitiveness. Given the focus of this report on 5G networks, Deetken has targeted the policy implications discussion on this topic. The policy implications and required actions identified below have been synthesized from a rigorous systematic review of currently available literature. The literature review scope was global in nature including (as and where available) related to OECD and G7 countries. However, the policy implications are tailored for applicability within the Canadian context.

The section presents:

- **Recommended Actions** – areas of attention to address a set of recommended outcomes to support wide-scale successful and responsible adoption of 5G and related services
- **Roadmap** – a proposed framework for a 3-year integrated roadmap to achieve the outcomes
- **Performance measurement framework** – an example set of metrics to serve as a foundation for monitoring 5G deployment and adoption progress

6.1 Recommended Actions

While progress to date on 5G networks is encouraging and offers significant lessons learned, more collaboration and concrete actions are required on the part of all stakeholders to accelerate development of a healthy and strongly interlocked 5G ecosystem. The private sector will lead the 5G rollout, but governments must help. As regulators and policymakers seek to promote 5G deployment, this section outlines seven key recommended outcomes to orient policy approaches and government action. Using these key outcomes, we have identified actions to be taken by each stakeholder group. The stakeholders are categorized as:[388]

- Government, regulators, and policy makers; referred to as "**Regulators**"
- Enterprises, organizations, and associations; referred to as "**Industry Participants**"
- Service Providers; referred to as "**MNOs**" and
- Hardware, software and application providers; referred to as "**Technology Providers**":

1. **Supportive spectrum policy and timely access to spectrum across all bands:**

   Regulators should adopt national spectrum policy measures to encourage long-term heavy investment in 5G networks (e.g., long-term licenses, simple renewal process, spectrum roadmap, etc.).

[388] The stakeholder groups are similar to those described in PwC work with the World Economic Forum and used in a Canada telecommunications industry report in 2020. Link to source: https://www.pwc.com/ca/en/communications/publications/761378-the-importance-of-a-healthy-telecommunications-industry-to-canadas-high-tech-success.pdf.

Regulators should accelerate auctions of low and high band spectrum. South Korea was the first country to commercialize 5G by auctioning mid- and high-band 5G spectrum in June 2018[389], suggesting a willingness to expedite 5G rollout and desire to be a leader in 5G networks. In contrast, Canada is the last country among the G7, Australia and South Korea to issue mid-band spectrum and one of the last in the group to issue high-band spectrum. Canada's first mid-band 3500MHz spectrum auction was held in July 2021, more than four years behind leading jurisdictions.[390] The 3800MHz will be held in October 2023, while further low-band auctions are indicated to take place in 2027 after band clearing.[391] Expediting the clearing/repurposing of spectrum is critical for faster deployment of 5G.

Regulators should ensure availability of sufficient contiguous spectrum, as this is an important factor contributing to telecommunications MNOs' ability to roll out 5G networks effectively. The International Telecommunication Union (ITU) recommends that 80-100MHz of spectrum in 5G mid-band should be allocated per carrier to ensure support for high speeds and large amounts of traffic. Contrary to this guideline, the amount of spectrum made available for large MNOs in Canada thus far has been below global industry standards. "The auctions held in Canada in July 2021 assigned 200MHz of spectrum between 3.45GHz and 3.65GHz. Moreover, of this 200MHz, only 111MHz (average weighted by population) was actually up for auction, with the remaining 89MHz retained by incumbents (principally Bell Canada, Rogers and Xplornet)."[392] "In Canada, there was a more limited supply of spectrum available to national operators at the principal auction than in any of the benchmarked countries. Depending on the size of population centres, and depending on the amount of unencumbered spectrum available, 47MHz of the 3.45MHz to 3.65MHz block was set aside for facilities-based providers other than the national mobile service providers (NMSPs), defined as those mobile network operators (MNOs) with >10% national market-share."[393]

Regulators should create a timely success-based schedule for significant additional spectrum allocations and subsequent awards in both mid- and high-spectrum ranges to help 5G scale deliver widespread coverage and support a wide range of use cases. **"**Governments and regulators should support new harmonised bands on the international stage to help 5G services grow over the longer term (e.g., UHF, 3.3-4.2 GHz, 4.8 GHz and 6 GHz). This includes engaging in the WRC-23 process to ensure sufficient mid- and low-band spectrum is available."[394]

Regulators should support spectrum sharing and unlicensed spectrum that can play a complementary role. Policymakers should promote R&D of spectrum-sharing technologies to allow for more efficient use of limited spectrum available for 5G and for future

[389] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.
[390] Ibid.
[391] TELUS.
[392] Link to source: https://www.analysysmason.com/contentassets/3142cca88f924253be79605a6703503a/analysys_mason_5g_spectrum_canada_nov2021_rdnt0.pdf.
[393] Ibid.
[394] Link to source: https://www.gsma.com/spectrum/wp-content/uploads/2021/04/5G-Spectrum-Positions.pdf.

generations of wireless networks. Development of sharing technologies will also be important for use in unlicensed spectrum, where multiple users are allowed to operate simultaneously. "[The] Defense Advanced Research Projects Agency's Spectrum Collaboration Challenge has presented successful examples of new approaches to improve spectrum sharing, leveraging automation and artificial intelligence to improve adaptability. Future initiatives should continue to build upon its initial successes."[395]

Regulators should avoid setting spectrum aside since it could jeopardise the success of public 5G services and may waste spectrum. "Canada is the only country among the 24 [reviewed] to use set-asides regularly in spectrum auctions, and it does so in a way that makes the set-aside available for companies that are already well-established."[396]

Regulators should structure reserve prices, annual fees, spectrum supply and auction design in a manner to avoid inflating 5G spectrum prices. "The average price paid at the Canada July 2021 [3500 MHz] auction, US$1.833 per MHz/pop, was the highest price paid. It was 164% of the average price paid in the U.S., the next highest average price paid in any country. It was around 10 times higher than in France and 11 times higher than in the U.K. NMSPs paid an even higher average price, US$2.62 per MHz/pop."[397] The reserve prices, annual spectrum fees, spectrum supply and auction design are primarily the responsibility of government and regulators who should also carefully consider 5G backhaul needs, including making additional bands available and supporting wider bandwidths in existing bands. Measures should also be taken to ensure licenses are affordable and designed effectively in consultation with ecosystem participants to maximise benefits of 5G. An example of best practice is Spain, which has cut reserve prices by 12.5% to 20% for its 700 MHz band while also doubling the length of the spectrum license lease from 20 to 40 years.[398]

2. **Reinforcement of resilient network infrastructure with appropriate coverage, bandwidth, latency and reliability:**

Regulators should facilitate fewer restrictions on infrastructure planning and restrictions on permits as 5G and other wireless services have significantly higher infrastructure needs, including fibre networks and small cell deployment. New legislation should be implemented to provide a single regulatory body, such as the Canadian Radio-television and Telecommunications Commission (CRTC), with direct authority to resolve disputes, order access and establish guidelines (as appropriate) with respect to all passive infrastructure owned by utilities such as power, gas, water and local authorities. This additional authority should also be applicable to non-traditional structures for which access will be key for efficient deployment of many future technologies. This would include light

395 Link to source: https://www.cnas.org/publications/reports/securing-our-5g-future.

396 Link to source: https://www.analysysmason.com/contentassets/3142cca88f924253be79605a6703503a/analysys_mason_5g_spectrum_canada_nov2021_rdnt0.pdf.

397 Ibid.

398 Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

poles, bridges, water towers, street furniture, and privately owned buildings such as high-rises and office towers. “5G implementation requires access to poles, buildings and trenches – passive infrastructure – since large numbers of installed antennas are required to compensate for short range of signal when communicating at very high speed.”[399] Proactive amendments to the Telecommunications Act are required to ensure that public access rights for MNOs apply to the construction of “transmission facilities” instead of “transmission lines” to enable faster deployment of network infrastructure. Changes are also required to the Radiocommunication Act to accelerate the deployment of wireless network facilities by eliminating some site approval requirements and providing for access (as well as procedures that govern said access) to supporting structures owned and operated by third parties. Infocomm Media Development Authority in Singapore has required that “mobile installation spaces” – typically rooftop spaces reserved for telecommunication equipment – be provided to MNOs by building developers and owners free of charge.[400] In Japan, MNOs can install 5G base stations on roughly 200,000 traffic lights across the country. Moreover, the Japanese government has proposed that costs of using traffic lights for 5G deployments be shared between MNOs and local governments.[401] In 2018, the U.S. Federal Communications Commission issued infrastructure rules aimed at streamlining and removing barriers at federal, state and city levels. These include establishment of two new “shot clocks” to review small wireless facilities deployments: 60 days for collocation on pre-existing structures and 90 days for new construction.[402] Similarly, the EU has launched a consultation on light deployment regime for small cells, which will likely lead to regulation updates in the intermediate term.[403] The Danish Energy Agency is exploring guidelines (including best practice examples) for public authorities on how to deal with applications for permission to set up telecommunications infrastructure.[404]

Regulators and MNOs should promote extensive capacity, availability and reach of fibre backhaul. The Canadian government launched the CA$2.75 billion Universal Broadband Fund to support high-speed internet projects across the country. These projects will bring the internet at speeds of 50/10 Megabits per second (Mbps) to rural and remote communities by 2030.[405] Some of the currently allocated broadband funds may be used to expand 4G wireless coverage on roads. This is a good start, but it should also be expanded to encourage 5G access, including selective funding of fibre backhaul, cell towers or other

[399] Link to source: https://ppforum.ca/wp-content/uploads/2021/09/FutureProof-ConnectingPost-PandemicCanada-OCT2021-PPF-EN.pdf

[400] Link to source: https://www.imda.gov.sg/-/media/Imda/Files/Regulation-Licensing-and-Consultations/Consultations/completed-consultations/consultation-papers/12/COPIF-2018-Industry-briefing-on-7Dec2018-cleanpptx.pdf?la=en.

[401] Link to source: https://resources.realestate.co.jp/living/5g-in-japan-govt-to-allow-5g-base-stations-to-be-installed-on-200000-traffic-lights-nationwide/.

[402] Link to source: https://docs.fcc.gov/public/attachments/FCC-18-133A1_Rcd.pdf.

[403] Link to source: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/1981-Light-deployment-regime-for-small-area-wireless-access-points_en.

[404] Link to source: https://ens.dk/sites/ens.dk/files/Tele/5g_action_plan_for_denmark.pdf.

[405] Link to source: https://ised-isde.canada.ca/site/high-speed-internet-canada/en/universal-broadband-fund.

network investments needed to expedite rural/remote 5G rollout, in rural and remote communities where market-based service economics are insufficient.

5G coverage and service obligations should be imposed by Regulators, but they should be reasonable, with financial incentives if considered. Coverage and service obligations directly impact the cost of network deployment. MNOs will deploy and create service levels for networks based on the marginal return of building and servicing a new site. If regulators impose onerous coverage and service obligations that are not commercially feasible, this will negatively impact return on investment for MNOs and delay deployment and innovation.[406] However, reasonable time limits should be placed on the deployment of the spectrum so that MNOs are incentivized to deploy the acquired spectrum in a cost effective and timely manner, thereby avoiding having to surrender the spectrum back to the government for auction to other players.

MNOs should commit to sustainable operations including softwarization and virtualization, flexibility and adaptation to diverse (and changing) requirements of applications with maximum reusability of common network infrastructure capabilities. Efficiency and open integration between application and 5G ecosystem will be critical, as will scalability, energy efficiency and customisation (i.e., modularization of functions, separation between control plane and user plane, network slicing, flexible user plane and fixed mobile convergence).

3. **Investment in latest connected devices, software and applications in multiple forms meeting users' high-performance needs:**

Regulators, MNOs, Technology Providers and Industry Participants should develop a comprehensive digital three-year roadmap, including a 5G implementation plan that includes clear directions and performance management metrics for infrastructure and device vendors, software and applications providers, service providers and other industry sector associations. This will ensure the availability of devices, software and applications that are compatible with local spectrum allocation and in line with harmonized global standards.

Regulators and MNOs should ensure supply chain trust. According to a U.S. April 2019 Defense Innovation Board report, "the compromised supply chain issue poses a serious threat to national security by introducing vulnerabilities into networks and systems."[407] Moreover, supply chains for 5G wireless telecommunications will expand on existing global supply chains for wireless technology and be highly complex. Another report states that "the two keys to supply chain trust are promoting supplier diversity and creating risk management strategies for technology acquirers."[408]

MNOs, Technology Providers and Industry Participants should integrate 5G networks with cutting-edge technologies like AI, big data, cloud computing and block chain to fully realize the socio-economic benefits of 5G.

[406] Link to source: http://www.coleago.com/app/uploads/2020/10/Regulatory-Policy-and-Assignment-to-Support-5G1.pdf.
[407] Link to source: https://media.defense.gov/2019/Apr/03/2002109302/-1/-1/0/DIB_5G_STUDY_04.03.19.PDF.
[408] Link to source: https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/210301_Lewis_Accelerating_5G_0.pdf.

Regulators should engage and collaborate with all ecosystem participants to crystalize priorities, cut red tape and cultivate a spirit of innovation. This will help businesses tap into 5G in scalable ways. The right regulatory environment will cultivate the right innovation environment. Federal, provincial, and municipal governments need to align on the 5G services and outcomes they expect to deliver to their citizens and businesses.

4. **Development of competitive and targeted services provided by MNOs for different market segments and key sectors through right partnership models:**

Regulators should provide additional government incentives in the form of targeted subsidies and accelerated capital depreciation tax policies to incent investment from various ecosystem participants. Many nations already offer a range of tax grants, holidays and related benefits. To unlock the full value of 5G for the entire country, governments should consider providing financial support to achieve the widest coverage. Several financial incentive models are taking shape. In the U.K., for example, MNOs agreed with the government to build a shared rural network with financial contributions from both industry and government.[409] Not all subsidies are for rural deployment. Another example is Japan, which has introduced tax measures that allow MNOs to use either a 30% special depreciation rate or a 15% tax credit for their 5G network investments.[410]

Regulators should increase funding for early-stage wireless research and development (R&D) and pilot programs to identify and overcome challenges with the ongoing transition to virtualized network functions, enable more software running on generic hardware infrastructure in wireless networks and protect innovators' intellectual property rights.[411]

MNOs and Regulators should generate and align incentives for cross-sector collaboration by ensuring that entities that bear the cost and risk of investment participate proportionately in the resulting value. There are many reasons to believe that much of the new 5G value will be generated in business-to-business applications. In Japan, NTT DOCOMO and an international group of other leading firms jointly announced in early 2021 that they "have signed a basic agreement to establish a consortium to provide 5G solutions, first in Thailand and later in other Asia Pacific countries with possible inclusion of additional partners."[412]

Regulators and MNOs should invest in and pilot viable sector-specific use cases that help unleash the power of evolving technologies (e.g., Internet of Everything, AI, big data analytics, etc.). Currently, value potential is fragmented across hundreds of use cases and different domains without a single source of significant demand. Direct investments and incentives related to specific 5G implementations are required across industry verticals to

[409] Link to source: https://www.ofcom.org.uk/__data/assets/pdf_file/0035/229688/connected-nations-2021-uk.pdf.

[410] Link to source: https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf.

[411] Link to source: https://itif.org/publications/2020/04/27/us-national-strategy-5g-and-future-wireless-innovation.

[412] Link to source: https://www.ntt.com/en/about-us/press-releases/news/article/2021/0203.html.

accelerate nationwide 5G deployment and to support Canadian manufacturing, agriculture, community anchor institutions, remote education, remote work and telemedicine. The supply-side dimension must be complemented with initiatives to strengthen demand for innovative applications of 5G from industry, institutional and public sectors. One laudable step was the $400 million investment by the governments of Canada, Ontario and Quebec to create a 5G test bed, ENCQOR, which has enabled hundreds of smaller developers of 5G technology and applications to build and test their 5G-enabled technology. To finance the cost of extending the ENCQOR model and the Centre of Excellence for Next Generation Networks (CENGN), at least 5% of the recent 5G spectrum auction windfall of CDN$8.9 billion should be earmarked to support demand-side experimentation and testing of new 5G-enabled technologies. This would require an investment of $450 million by the federal government.[413] This, and similar cooperative models, need to be well-funded and replicated across Canada.

MNOs should explore new tiered service propositions for consumers and businesses, while Regulators should consider some form of compromise to aspects of Net Neutrality to promote investment. Regulatory authorities should acknowledge the dynamic nature of 5G networks and services and that optimised connectivity built on network slicing is compatible with the open internet principle. Network slicing will enable MNOs to create products for different verticals that can be customized for enterprises. Customizable network capabilities include data throughput, latency, reliability, security and service optimization. Currently, the CRTC defines net neutrality as "the concept that all traffic on the Internet should be given equal treatment by Internet providers with little to no manipulation, interference, prioritization, discrimination or preference given."[414] However, 5G will use advanced structures, devices, systems, and processes to manage various types of traffic thereby allowing 5G to provide a broader array of use cases than previous mobile technologies, such as 3G and 4G. Several of the applications envisaged for 5G will be of a control nature, requiring infinitesimal delay and high consistency and dependability. These applications will necessitate traffic prioritization – a capability currently restricted by current CRTC net neutrality rules. 5G networks face the obstacle of being built in an environment of high ambiguity, where most of the services that support 5G business models seem to be in direct contravention of the current CRTC rules pertaining to net neutrality. It is critical to immediately begin collaborative discussions among the 5G ecosystem participants to address this challenge and promote 5G functionality and modernization. While controversial, regulators should collaborate with MNOs to formulate some form of compromise where "a minimum level of performance is guaranteed for all Internet users, but operators can provide a differentiated service for speeds above the minimum."[415]

Regulators, MNOs, Technology Providers and Industry Participants should work to mitigate the current shortage of technical skills across the ecosystem by launching upskilling or reskilling initiatives among current workers, reimagining training for tech talent

[413] Link to source: https://ppforum.ca/wp-content/uploads/2021/09/FutureProof-ConnectingPost-PandemicCanada-OCT2021-PPF-EN.pdf.
[414] Link to source: https://crtc.gc.ca/eng/internet/diff.htm.
[415] Link to source: http://www.coleago.com/app/uploads/2020/10/Regulatory-Policy-and-Assignment-to-Support-5G1.pdf.

by promoting apprenticeship programs, turning to the global freelance economy, and reshaping national immigration policy. According to a 2021 survey by Gartner, businesses think that talent shortage is the biggest barrier to adoption of 64% of new technologies, compared to just 4% in 2020. This means that in most cases, IT leaders who want to deploy a new tool to boost business outcomes anticipate that a lack of suitable workers to implement the technology will be problematic at some point. Talent availability even overtook implementation costs (29%) or security risks (7%) as a top barrier to deploying a new technology. This issue is particularly prevalent when it comes to adopting IT automation technologies: in 75% of cases, leaders cited talent availability as the main adoption risk factor. There is a similar talent shortage for computer infrastructure, platform services, network security, digital workplace, and storage and database.[416] Canada faces these challenges as well. According to a report by the Business Development Bank of Canada, at least 55% of Canadian tech entrepreneurs are having difficulty hiring the employees they need.[417]

5. **Creation of unified national standards that are strongly interlocked with global standards to support the timely and responsible deployment and adoption of 5G:**

Regulators, MNOs, Technology Providers and Industry Participants should participate nationally in international standards-setting bodies, specifically the International Telecommunication Union (ITU), 3rd Generation Partnership Project (3GPP), Global System for Mobile Communications (GSMA), O-RAN Alliance, Internet Engineering Task Force (IET), Institute for Electrical and Electronics Engineers (IEEE), International Standards Organization (ISO), and International Electrotechnical Commission (IEC) that are defining the building blocks for 5G. "Standards bodies are not all the same. In order to assess the proper role of government in global standards setting organizations, and to avoid unintended consequences, policymakers need to account for the different goals and roles of standards bodies, their historical roles and responsibilities, and the positive benefits they have achieved."[418]

Regulators, MNOs, Technology Providers and Industry Participants should conduct research and develop national technical standards based on consensus global technical direction while maximizing technology compatibility, configurability, interoperability, portability, security, repeatability, energy efficiency, and quality, thereby avoiding unnecessary duplication of effort in terms of network and device upgrades. These stakeholders should also demonstrate leadership in the ongoing modernization and streamlining of regulation that is supportive of standards for network infrastructure, spectrum, devices and applications.

Regulators, MNOs, Technology Providers and Industry Participants should adopt a "bottom up" approach to global standards by promoting and supporting industry collaboration on standards, because this is the best way to ensure that technologically

[416] Link to source: https://www.marketscreener.com/quote/stock/GARTNER-INC-40311131/news/Gartner-Survey-Reveals-Talent-Shortages-as-Biggest-Barrier-to-Emerging-Technologies-Adoption-36410808/.
[417] Link to source: https://www.bdc.ca/en/about/analysis-research/tech-industry-outlook.
[418] Link to source: https://www.wiley.law/assets/htmldocuments/Tech-Standards.pdf.

superior approaches prevail. “Rather than taking a direct role in standards setting organizations where the private sector has typically led, the government should instead prioritize support for private efforts in standards bodies, encouraging and facilitating broader private participation.”[419]

Regulators, MNOs, Technology Providers and Industry Participants should support research and other initiatives to ensure the responsible adoption of 5G and related services. Stakeholders should monitor for and address unintended consequences of 5G such as the potential proliferation of e-waste related to expired or faulty devices and sensors.

6. **A uniform approach or minimum requirements to data governance and security at the underlying network level:**

Regulators, MNOs and Technology Providers should establish a zero-trust security-by-design approach from end to end for all devices and software on the 5G network. “Each device and application must be assessed for cyber risk and allowed access to network resources only if they meet high security standards. Also, all software must be constantly checked for vulnerabilities and malware.”[420]

Regulators, MNOs and Technology Providers should adopt uniform privacy-by-design practices that help enhance protection of consumers’ personal information. “These practices would address (1) the collection, storage, and use of 5G user data and (2) uniform practices for informing users and obtaining their consent for collection, storage and use of such data. Policymakers could also choose to apply practices to ensure the policy framework addresses other new technologies, such as biometric data collection. Uniform practices could help consumers better understand the privacy of their data and inform their decisions on what information to provide. Such practices could help overcome the privacy concerns exacerbated by 5G networks and applications because they could reduce consumer uncertainty about data collection, use and storage.”[421]

Regulators, MNOs, Technology Providers and Industry Participants should create universal encryption to minimize the risk of data being compromised or corrupted. MNOs and other 5G participants will need to adopt strong encryption methods for traffic between end points and services. These methods will need to be flexible and scalable enough to be strengthened progressively over time as standards and risks evolve. They should also be sufficiently agile to thwart middleware attacks, in which hackers eavesdrop on communications between two network participants.

MNOs and Technology Providers should orchestrate evolving technologies like artificial intelligence (AI), machine learning (ML), big data analytics (BDA), anonymity-based techniques and temporary mobile subscriber identity (TMSI) to identify and mitigate mutable cyber risks, provide high levels of automated intelligence to manage and

[419] Ibid.

[420] Link to source: https://www.pwc.com/gx/en/industries/tmt/5g/pwc-5g-in-healthcare.pdf.

[421] Link to source: https://www.gao.gov/assets/gao-21-26sp.pdf.

eliminate security intrusions across hyper-dense communications and ultra-low latency applications, and increase the difficulty of identifying mobile devices and subscribers. These technologies will be used for traffic analysis, network packet inspections, threat identification, infection isolation and location, and identity tagging.

Regulators, MNOs, Technology Providers and Industry Participants should collaborate to implement proactive changes to data governance policies that could abate the strain of increased mobile capacities, such as ensuring data singularity, reducing existing data "Redundancy, Obsolescence, Triviality" (ROT), prioritizing important data in ingestion, virtually merging “silo-ed” information, and ensuring all data management policies are uniform across platforms.

7. **Need for a comprehensive set of operational and sector specific Key Performance Indicators (KPIs) to track the performance and socio-economic contributions of 5G:**

Regulators, MNOs and Industry Participants should work together to set 12-24-36-month national KPIs for the deployment, customer uptake and application development for 5G. China’s Ministry of Industry and Information Technology recently released a draft of the 2021-2023 Action Plan for 5G Applications, putting forward seven key performance indicators (KPIs) and three initiatives on the application and development of 5G. The action plan sets a goal to greatly improve the application and development of 5G and the overall strengths in 5G by 2023. Specifically, a new ecosystem featuring deep integration of IT (information technology), CT (communication technology) and OT (operational technology) will be developed; breakthroughs in 5G applications in key fields will be achieved; the dual pillars of the technology industry and standard system will be built; fundamental capabilities in terms of network, platform, security and other fields will be further improved; and a pattern of a wide range of 5G applications will basically take shape. Seven key performance indicators are set for the application and development of 5G, namely a 5G penetration rate of 40% among individual users; 50% of access traffic with 5G networks; a 5G penetration rate of 35% in large industrial enterprises; a 200% average annual growth rate of 5G-powered IoT end users; 18 5G base stations per 10,000 people; 3,000 5G-empowered industry-specific virtual private networks; and 100 5G applications in each key industry.[422]

Regulators, MNOs and Industry Participants should create relevant and actionable KPIs for both MNOs and key industry sectors to measure the operational performance and socio-economic impacts of 5G. 3rd Generation Partnership Project **(**3GPP) is still in the process of completing 5G KPIs. These KPIs are driven from ITM-2020 and mainly consider three broad categories: (1) Enhanced Mobile Broadband (eMBB), (2) Mission Critical Control (MCC) and (3) Massive Internet of Things (mIoT). These KPIs should be tracked and reported to Canadian Radio-television and Telecommunications Commission (CRTC) and Statistics Canada by each MNO across province/territory, and population centers. The key operational and customer centric KPIs are discussed further below in this

[422] Link to source: https://cset.georgetown.edu/wp-content/uploads/t0339_5G_action_plan_draft_EN.pdf.

section and in Section 3. Metrics should dovetail with sector strategies, for example, creating a national virtual care strategy to ensure universal access to virtual care, especially for patients in underserved communities that cannot access physical clinics.

Regulators, MNOs and Industry Participants should collect, audit and publish the socio-economic benefits that are being driven by the deployment and adoption of 5G services and applications by province/territory, population centers and nationally. These metrics should be defined jointly by CRTC and Statistics Canada and measured and gathered by the various industry associations and provided to both CRTC and Statistics Canada for the purposes of reporting and publishing. The CRTC and Statistics Canada should also ensure the integrity and accuracy of the data submitted via random audits. The data should be made available to the public via open government concept so that it may be leveraged by MNOs, researchers and other consultancy firms for big data analytics to provide key insights on future policy decisions.

6.2 Roadmap

As demonstrated above, 5G will present a high degree of complexity for policymakers and regulators as these new technologies and business models replace the current system. For Canada to capitalize on the extensive environmental, social and economic benefits of 5G technology, policy and regulatory modernization will be required for infrastructure and spectrum, public safety, cybersecurity, privacy, healthcare and training standards. Regulators and policymakers are under increasing pressure to connect with peers across all economic sectors to leverage digital transformation as an engine for the achievement of the United Nations Sustainable Development Goals (SDGs). They will need to engage with all their 5G ecosystem partners to define initiatives that help clear the path for 5G by future-proofing access to connectivity and encouraging early adoption of 5G and digitalization. Regulatory reform is critical for the future success of 5G. Finding the right balance that serves the interests of diverse stakeholders is key to that success.

The current Canadian government regulatory frameworks and policies do not fully embrace the new shift in regulatory perspectives mentioned above. By focusing on the affordability of mobility services, the government risks overlooking other factors that play an important role in the promotion of a healthy telecommunications ecosystem. The marginalization of these other key factors will have severe negative long-term impacts not only on the Canadian telecommunications industry, but on the national socio-economic objectives and global competitiveness goals of the current administration, such as addressing regional inequalities, achieving GHG emissions targets and climate change objectives and other ESG goals.

The creation of a three-year digital roadmap is recommended to achieve these outcomes. The creation of this roadmap should be led by the federal government, as seen in the case of China,[423]

[423] Link to source: https://english.www.gov.cn/policies/latestreleases/202201/12/content_WS61de9a35c6d09c94e48a385f.html.

United Kingdom,[424] and Finland,[425] in active collaboration with the provincial and municipal governments, regulatory bodies and agencies such as Canadian Radio-television and Telecommunications Commission (CRTC) and Innovation, Science and Economic Development Canada (ISED), MNOs and other 5G ecosystem participants. Below is a proposed framework for the creation of a well articulated evergreen national Digital Roadmap including 5G enablement.

TABLE 6.1: 5G ROADMAP FRAMEWORK

Phases	Roadmap Components
1. Identify strategic context and foundational elements	1. Identify Canadian long-term digital objectives including 5G enablement. 2. Ascertain roles and responsibilities of the key players (e.g., government, regulatory bodies and other agencies, enterprises, organizations, and associations of industry verticals; MNOs; and hardware, software, and application providers) in the development of the digital roadmap including the deployment, implementation and operations of 5G networks and complementary technologies. 3. Conduct an environmental scan on digital frameworks, 5G networks and complementary technologies with targeted and coordinated research and analysis of (e.g., spectrum and technology; competitors; customer and industry vertical needs assessment; regulatory environment; and core competencies) to assess Canadian strengths/weaknesses versus other countries.
2. Define policy and ecosystem development guidelines to facilitate 5G build out	1. Shortlist suppliers/partners and evaluate their global competitiveness and risk (e.g., threats, vulnerabilities, and risks to 5G infrastructure). 2. Develop an on-going partner engagement and collaboration model. 3. Create a list of different capabilities and business models by industry vertical that 5G digital solutions and complementary technologies could potentially enable as well as corresponding governance models. 4. Establish a spectrum allocation, sharing, pricing, and licensing framework as well as a standards policy framework. 5. Identify and establish additional legal and policy frameworks pertaining to infrastructure support, development of 5G sites, cross border issues, industry verticals applications, coordination, and harmonization of 5G across different levels of government and different regions. 6. Define security principles for 5G infrastructure, software, applications, and complementary technologies and devices. Establish potential policies and incentives to address any challenges. 7. Identify other potential incentives and options for ecosystem partners to ensure Canada's telecommunication, technology and industrial base are economically viable in the long-term including tax system

[424] Link to source: https://www.gov.uk/government/publications/roadmap-for-digital-and-data-2022-to-2025/transforming-for-a-digital-future-2022-to-2025-roadmap-for-digital-and-data.
[425] Link to source: https://valtioneuvosto.fi/en/-//10623/ministerial-working-group-sets-finland-s-digital-vision-and-targets-for-2030.

	revisions, R&D and use case subsidization, and dedicated funds for remote/rural buildout. 8. Create a list of potential "workforce of the future" skill gaps and develop potential incentives and options for "workforce of the future" training and development programs. 9. Determine 5G awareness and education plan and roles of different partners.
3. Monitor and report 5G deployment, new service and device introductions and realization of economic and ESG benefits	1. Construct detailed deployment, operational and customer satisfaction KPIs/metrics along with descriptions and calculation methodology, scope, limitations, and frequency of reporting. 2. Ascertain roles and responsibilities of ecosystem partners and government agencies such as ISED, CRTC and Statistics Canada in gathering, verifying, benchmarking and publishing these metrics to ensure a "Single Version of the Truth".

6.3 Performance Measurement Framework

While a strong metric-based deployment and operations framework is critical to measuring the performance of 5G rollout, it is only a component of a holistic 5G value creation framework. To realize the full spectrum of 5G benefits, the 5G ecosystem partners need to develop a performance measurement framework which includes other facets such as consumer and business adoption; cybersecurity, privacy and resilience of the network and applications; proliferation of uses cases; improved productivity, cost and quality competitiveness for Canadian industries; improved health and safety for Canadian citizens; and the closing of the digital divide in Canada. The ultimate measure of success will be in how efficiently and effectively 5G is deployed, operated, and used to create revenue and growth and/or reduce costs and/or deliver environmental and social value. The next few years are crucial for the expansion of a 5G ecosystem in Canada. If this expansion is executed well, it will help sustain and potentially grow Canada's competitive advantage in key industries while simultaneously facilitating the achievement of key government policy objectives in the areas of environmental and social sustainability.

The creation of simple, measurable, and actionable metrics will be important to measure the operational performance and subsequent socio-economic impacts of 5G. Additional consumer metrics that measure the uptake and "experience" of 5G services and applications for end-users will be equally important. Operational KPIs are driven from ITM-2020 and mainly consider three broad categories: (1) Enhanced Mobile Broadband (eMBB), (2) Ultra Reliable Low Latency Communication (URLLC), and (3) Massive Internet of Things (mIoT). These KPIs should be tracked and reported to Canadian Radio-television and Telecommunications Commission (CRTC) and Statistics Canada by each MNO across province/territory, and population centers.

In addition to the operational metrics described above, regulators, service providers, and industry participants should collect, audit, and publish the socio-economic benefits that are being driven

by deployment and adoption of 5G services and applications by province/territory, population centers, and nationally. These "consumer metrics" should be completed by the various industry associations and provided to both CRTC and Statistics Canada. The data should be leveraged for big data analytics to provide key insights on future policy decisions.

An example set of operational and consumer related metrics are listed below.

TABLE 6.2: EXAMPLE PERFORMANCE MANAGEMENT FRAMEWORK METRICS[426]

Metric	Definition	Example 5G Performance Requirements	Category
Operational Metrics			
Peak data rate	The highest theoretical data rate, which is the received data bits assuming error-free conditions, assignable to a single mobile station when all assignable radio resources for the corresponding link direction are utilised (i.e., excluding radio resources that are used for physical layer synchronisation, reference signals or pilots, guard bands and guard times).	The target for peak data rates should be 20Gbps for downlink and 10Gbps for uplink.	eMBB
Peak spectral efficiency	The maximum achievable data rate under ideal conditions, usually measured in gigabits per second (Gbps), that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the medium access control (the channel access protocol).	The target for peak spectral efficiency should be 30bps/Hz for downlink and 15bps/Hz for uplink.	eMBB
User experienced data rate	The 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e., the number of bits contained in the service data units delivered to Layer 3, over a certain period of time.	The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment: (1) Downlink user experienced data rate is 100Mbps; (2) Uplink user experienced data rate is 50Mbps.	eMBB
System bandwidth	The maximum aggregated system bandwidth. The bandwidth may be supported by single or multiple radio frequency carriers.	The requirement for bandwidth is at least 100 MHz, up to 1 GHz for operation in high-frequency bands above 6 GHz.	eMBB URLLC mIoT

[426] The following sources were used to inform the contents of this table: 1) https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf; 2) https://www.opensignal.com/reports/2021/04/canada/mobile-network-experience-5g; and 3) https://telcomatraining.com/5g-kpis-key-performance-indicators-2/.

Metric	Definition	Example 5G Performance Requirements	Category
Control plane latency	Refers to the transition time from a most "battery efficient" state (e.g., Idle state) to the start of continuous data transfer (e.g., Active state).	The target for control plane latency should be 10ms.	eMBB
User plane latency	Also known as the radio segment latency. It is the one-way latency for successful reception of a packet and includes the time for one or more retransmissions if packet reception fails. Furthermore, if possible, the latency should also be low enough to support the use of the next generation access technologies as a wireless transport technology that can be used within the next generation access architecture.	The target for user plane latency should be 0.5ms for downlink and uplink. For eMBB specifically, the target for user plane latency should be 4ms for downlink and uplink.	eMBB URLLC
Area traffic capacity	Refers to the total traffic throughput served per geographic area, measured as data rate per unit area. Area traffic capacity increases will enable better network performance in densely populated areas.	The target for area traffic capacity should be 10Mbps/m^2.	mIoT
Connection density	The total number of connected and/or accessible devices that can be accommodated, measured in devices per unit area. Increased connection density will support customer use where there are a tremendous number of devices, such as in stadiums and warehouses.	The target for connection density should be 1,000,000 devices/km^2.	mIoT
Energy efficiency	On the device side, the number of bits transmitted or received per unit of energy consumption. On the network side, energy efficiency refers to the quantity of information bits transmitted to or received from users, per unit of energy consumption of the radio access network, measured in bits per joule. Energy efficiency improvements are critical due to the expected massive increase in data use over time.	Targeted energy efficiency should be 90% reduction in energy usage.	mIoT
Mobility	The maximum speed a device can be traveling and still experience a defined quality of service. Mobility is important for applications that require reliable connection when moving, such as in transportation safety.	The target for mobility should be up to 500km/h.	eMBB
Mobility interruption	The shortest time duration supported by the system during which a user terminal cannot exchange user plane packets with any base station during transitions. This KPI is for both	The target for mobility interruption time should be 0ms.	URLLC

Metric	Definition	Example 5G Performance Requirements	Category
	intra-frequency and inter-frequency mobility for intra-New Radio mobility.		
Coverage	The uplink and downlink between device and Base Station site (antenna connector(s)) for a data rate of 160bps, where the data rate is observed at the egress/ingress point of the radio protocol stack in uplink and downlink. Link budget and/or link level analysis are used as the evaluation methodology.	The target for coverage should be 164dB.	mIoT
User equipment (UE) battery life	The battery life of the UE without recharge. For mIoT, UE battery life in extreme coverage shall be based on the activity of mobile originated data transfer consisting of 200bytes uplink per day followed by 20bytes downlink from MaxCL of 164dB, assuming a stored energy capacity of 5Wh.	The target for mIoT device battery life should be 15 years.	mIoT
UE energy efficiency	The capability of a UE to sustain much better mobile broadband data rate while minimizing the UE modem energy consumption.	Example not found. Target to be determined by stakeholders.	mIoT
Network energy efficiency	The capability of a network to minimize the RAN energy consumption while providing a much better area traffic capacity. Both qualitative and quantitative KPIs are proposed. Network energy efficiency shall be considered as a basic principle in the New Radio design. The target is a design with: (1) the ability to efficiently deliver data; (2) the ability to provide sufficiently granular network discontinuous transmission when there is no data to transmit and network availability is maintained; (3) the ability to provide operator flexibility to adapt sleep durations of base stations depending on load, services, and area.	Example not found. Target to be determined by stakeholders.	eMBB URLLC mIoT
Spectrum and bandwidth flexibility	The flexibility of the network design to handle 5G Wireless different scenarios, such as the capability to operate at different frequency ranges.	Example not found. Target to be determined by stakeholders.	eMBB URLLC mIoT
Reliability	The capability to provide a given service with a very high level of availability. Reliability is compromised if too much data is lost, late, or has errors. Improving the reliability of the network is critical for time-sensitive, mission-critical applications like automation and healthcare.	The target for reliability should be 1 x 10^{-5} probability of transmitting layer-2 PDU of 32 bytes in size within 1ms, in channel quality of coverage edge for Urban Macro-URLLC test environment.	URLLC

Metric	Definition	Example 5G Performance Requirements	Category
Resilience	The ability of the network to continue operating correctly during and after a natural or man-made disturbance, such as the loss of power.	Example not found. Target to be determined by stakeholders.	eMBB URLLC mIoT
Security and privacy	The ability to encrypt and protect user data and signaling, and enhance network security against cyberattacks, such as unauthorized user tracking, hacking, fraud, sabotaging, and denial of service, which can be detrimental to national security and the safeguarding and privacy of users' data.	Example not found. Target to be determined by stakeholders.	eMBB URLLC mIoT
Operational lifetime	Operation time per stored energy capacity, which is particularly important for IoT devices requiring a very long battery life whose regular maintenance is difficult for physical or economic reasons.	Example not found. Target to be determined by stakeholders.	eMBB URLLC mIoT
Consumer Metrics			
5G spectrum owned	The type and quantity of spectrum held by an MNO.	Example not found. Target to be determined by stakeholders.	eMBB URLLC mIoT
5G spectrum deployed	The type and quantity of spectrum put in use by the MNO.	Example not found. Target to be determined by stakeholders.	eMBB URLLC mIoT
5G coverage	The geographic extent of an MNO's network	Example not found. Target to be determined by stakeholders.	eMBB URLLC mIoT
5G availability	The proportion of time users with a 5G device have a 5G connection. It is not a measure of coverage or the geographic extent of a network.	Example not found. Target to be determined by stakeholders.	eMBB
5G reach	Measures how users experience the geographical extent of an MNO's 5G network. It analyzes the average proportion of locations where users were connected to a 5G network out of all locations those users have visited. In simple terms, 5G reach measures the 5G mobile experience in all locations that matter most to everyday users	Example not found. Target to be determined by stakeholders.	eMBB

Metric	Definition	Example 5G Performance Requirements	Category
	- i.e., all places where they live, work and travel.		
5G video experience	Quantifies the quality of mobile video experienced by users on real-world video streams. It is calculated by measuring video streams from end-user devices using an ITU-based approach to quantify factors such as load times, stalling and video resolution over an MNO's 5G networks.	Example not found. Target to be determined by stakeholders.	eMBB
5G games experience	A measure of how mobile users experience real-time multiplayer mobile gaming on an MNO's 5G network. It analyzes how the multiplayer mobile games experience is affected by mobile network conditions including latency, packet loss, and jitter to determine impact on gameplay and overall multiplayer 5G Games Experience.	Example not found. Target to be determined by stakeholders.	eMBB
5G voice app experience	Quantifies the quality of experience over mobile voice services for each operator on 5G connections.	Example not found. Target to be determined by stakeholders.	eMBB
5G download and upload speed	The average download and upload speed experienced by users across an MNO's 5G network.	Example not found. Target to be determined by stakeholders.	eMBB

Appendices

A. List of Tables

B. Glossary of Key Terms

Terms	Definitions
3GPP	The focal point of development for 5G specifications and standards is the Third Generation Partnership Project (3GPP), a consortium made up of seven of the regional telecommunications standards development bodies. 3GPP has hundreds of technical specifications under development for mobile wireless communications, including the air interface/radio access (5G New Radio), the 5G core, and the IoT, among others. 3GPP is also developing standards for networks to interconnect and collaborate with one another. For example, 3GPP's non-public network support is intended to allow private networks optimized for a specific purpose (e.g., an automated manufacturing facility) to co-exist with public carrier networks.
Area traffic capacity	Total traffic throughput served per geographic area, measured as data rate per unit area. Area traffic capacity increases will enable better network performance in densely populated areas. *Category - Massive Internet of Things (Massive IoT).*
Artificial Intelligence	The ability of a computer or a robot controlled by a computer to do tasks that are usually done by humans because they require human intelligence and discernment.
Augmented Reality (AR)	An enhanced version of the real physical world that is achieved through the use of digital visual elements, sound, or other sensory stimuli delivered via technology.
Automation	Describes a wide range of technologies that reduce human intervention in processes. Human intervention is reduced by predetermining decision criteria, sub process relationships, and related actions — and embodying those predeterminations in machines. Automation includes the use of various equipment and control systems such as machinery, processes in factories, boilers, and heat-treating ovens, switching on telephone networks, steering, and stabilization of ships, aircraft, and other applications and vehicles with reduced human intervention. Automation has been achieved by various means including mechanical, hydraulic, pneumatic, electrical, electronic devices, and computers, usually in combination. Complicated systems, such as modern factories, airplanes, and ships typically use all these combined techniques. The benefit of automation includes labor savings, reducing waste, savings in electricity costs, savings in material costs, and improvements to quality, accuracy, and precision.
Backhaul	The portion of the network that comprises the intermediate links between the core network and the small subnetworks at the edge of the network. In the context of a mobile network, the backhaul connects a cell site toward the core network. The two main methods of mobile backhaul implementations are fibre-based backhaul and wireless point-to-point backhaul.
Bandwidth	Is the maximum aggregated system bandwidth. The bandwidth may be supported by single or multiple radio frequency (RF) carriers. The requirement for bandwidth is at least 100 MHz. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
Big Data Analytics	The use of advanced analytic techniques against very large, diverse data sets that include structured, semi-structured and unstructured data, from different sources, and in different sizes from terabytes to zettabytes.
Connection density	Total number of connected and/or accessible devices that can be accommodated, measured in devices per unit area. Increased connection density will support customer use where there are a tremendous number of devices, such as in stadiums and warehouses. *Category - Massive Internet of Things (Massive IoT).*
Control plane latency	Control-plane latency refers to the transition time from a most "battery efficient" state (e.g., Idle state) to the start of continuous data transfer (e.g., Active state). The target for control plane latency should be 10ms. *Category - Enhanced Mobile Broadband (eMBB).*
Coverage	Is the uplink and downlink between device and Base Station site (antenna connector(s)) for a data rate of 160bps, where the data rate is observed at the egress/ingress point of the radio protocol stack in uplink and downlink. The target for coverage should be 164dB (decibel). Link budget and/or link level analysis are used as the evaluation methodology. *Category - Massive Internet of Things (Massive IoT).*

Terms	Definitions
Cyber-physical system (CPS)	A computer system in which a mechanism is controlled or monitored by computer-based algorithms. In cyber-physical systems, physical and software components are deeply intertwined and are able to operate on different spatial and temporal scales, exhibit multiple and distinct behavioral modalities, and interact with each other in ways that change with context. CPS involves transdisciplinary approaches, merging theory of cybernetics, mechatronics, design and process science. CPS is also similar to the Internet of Things (IoT), sharing the same basic architecture; nevertheless, CPS presents a higher combination and coordination between physical and computational elements. Examples of CPS include smart grid, autonomous automobile systems, medical monitoring, industrial control systems, robotics systems, and automatic pilot avionics.
Digital Twin	A virtual representation that serves as the real-time digital counterpart of a physical object or process. Data collected from sensors connected to a physical device can be used to update the digital twin copy to reflect any changes to the device's current state.
Digitalization	The use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business.
Digitization	the process of converting information into a digital (i.e., computer-readable) format. The result is the representation of an object, image, sound, document, or signal (usually an analog signal) obtained by generating a series of numbers that describe a discrete set of points or samples. The result is called digital representation or, more specifically, a digital image, for the object, and digital form, for the signal. Digitization is of crucial importance to data processing, storage, and transmission, because it "allows information of all kinds in all formats to be carried with the same efficiency and also intermingled".
Energy efficiency	On the device side, the number of bits transmitted or received per unit of energy consumption. On the network side, energy efficiency refers to the quantity of information bits transmitted to or received from users, per unit of energy consumption of the radio access network (RAN), measured in bits per joule. Energy efficiency improvements are critical due to the expected massive increase in data use over time. Category - Massive Internet of Things (Massive IoT).
GSMA	Global System for Mobile Communications, originally Groupe Spécial Mobile, is an industry association representing the interests of mobile operators worldwide, including more than 750 operators and almost 400 companies in the broader mobile ecosystem. GSMA has published hundreds of security guidelines, recommendations, and requirements over the years regarding best practices in mobile security that support real world deployments related to security of devices, networks, interconnect protocols, and services. GSMA's Fraud and Security Group is particularly active, working on 5G security in the context of other interdependent topics such as IoT and roaming.
IEC	International Electrotechnical Commission is an international standards organization that prepares and publishes international standards for all electrical, electronic, and related technologies – collectively known as "electrotechnology". IEC standards cover a vast range of technologies from power generation, transmission and distribution to home appliances and office equipment, semiconductors, fibre optics, batteries, solar energy, nanotechnology, and marine energy as well as many others. The IEC also manages four global conformity assessment systems that certify whether equipment, systems, or components conform to its international standards. All electro-technologies are covered by IEC Standards, including energy production and distribution, electronics, magnetics and electromagnetics, electroacoustics, multimedia, telecommunication, and medical technology, as well as associated general disciplines such as terminology and symbols, electromagnetic compatibility, measurement and performance, dependability, design and development, safety, and the environment.
IEEE	Institute for Electrical and Electronics Engineers is involved in the creation of many standards, including WiFi and WiMAX standards, as well as other machine communications standards that will change with 5G.
IETF	Internet Engineering Task Force covers specifications related to 5G non-radio network segments.

Terms	Definitions
Industry 4.0	The Fourth Industrial Revolution, 4IR, or Industry 4.0, conceptualizes the current rapid change to technology, industries, and societal patterns and processes due to increasing interconnectivity and smart automation. The term has been used widely in scientific literature, and was popularized by KIaus Schwab in 2015, the World Economic Forum Founder and Executive Chairman. Schwab asserts that the changes seen are more than just improvements to efficiency, but express a significant shift in industrial capitalism. A part of this phase of industrial change is the joining of technologies like artificial intelligence, gene editing, to advanced robotics that blur the lines between the physical, digital, and biological worlds. Throughout this, fundamental shifts are taking place in how the global production and supply network operates through ongoing automation of traditional manufacturing and industrial practices, using modern smart technology, large-scale machine-to-machine communication (M2M), and the internet of things (IoT). This integration results in increasing automation, improving communication and self-monitoring, and the use of smart machines that can analyze and diagnose issues without the need for human intervention. It also represents a social, political, and economic shift from the digital age of the late 1990s and early 2000s to an era of embedded connectivity distinguished by the omni-use and commonness of technological use throughout society (e.g., a metaverse) that changes the ways we experience and know the world around us. It posits that we have created and are entering an augmented social reality compared to just the natural senses and industrial ability of humans alone.
Internet of Everything (IoE)	The networked connection of people, process, data, and things. The benefit of IoE is derived from the compound impact of connecting people, process, data, and things, and the value this increased connectedness creates as “everything” comes online.
ISO	International Standards Organization is an international non-governmental organization made up of national standards bodies that develops and publishes a wide range of proprietary, industrial, and commercial standards. In addition to producing standards, ISO also publishes technical reports, technical specifications, publicly available specifications, technical corrigenda, and guides. The ISO plays an important role in facilitating world trade by providing common standards among different countries. ISO standards cover all fields, from healthcare to technology to manufacturing to security to the environment.
ITU	The International Telecommunications Union is in the process of developing ITU-R Recommendations for the terrestrial components of the IMT-2020 radio interface(s) based upon specifications from external, industry-led standards development organizations.
Latency	Time it takes from when the source sends a packet of data to when the destination receives it, usually measured in milliseconds. More precisely, latency for 5G is the contribution by the radio network to this time. Low latency is especially important for applications, such as industrial automation or remote medicine, where delays in data transfers could be disastrous. *Category - Mission Critical Control (MCC).*
Machine Learning	The use and development of computer systems that are able to learn and adapt without following explicit instructions, by using algorithms and statistical models to analyze and draw inferences from patterns in data.
Mobility	Maximum speed a device can be traveling and still experience a defined quality of service. Mobility is important for applications that require reliable connection when moving, such as in transportation safety. The target for mobility should be 500km/h. *Category - Enhanced Mobile Broadband (eMBB).*
Mobility interruption	Mobility interruption time means the shortest time duration supported by the system during which a user terminal cannot exchange user plane packets with any base station during transitions. The target for mobility interruption time should be 0ms. This KPI is for both intra-frequency and inter-frequency mobility for intra-New Radio (NR) mobility. *Category - Mission Critical Control (MCC).*
Network energy efficiency	The capability is to minimize the RAN energy consumption while providing a much better area traffic capacity. Both qualitative and quantitative KPIs are proposed. Network energy efficiency shall be considered as a basic principle in the New Radio (NR) design. The target is a design with: (1) the ability to efficiently deliver data; (2) the ability to provide sufficiently granular network discontinuous transmission when there is no data to transmit and network availability is maintained; (3) the ability to provide operator flexibility to adapt sleep durations of base stations depending on load, services, and area. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*

Terms	Definitions
Operational lifetime	Operation time per stored energy capacity, which is particularly important for Internet of Things (IoT) devices requiring a very long battery life whose regular maintenance is difficult for physical or economic reasons. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
O-RAN Alliance	Is working to build specifications and standards for 5G networks, focused on open and interoperable interfaces for radio access networks.
Peak data rate	Peak data rate is the highest theoretical data rate, which is the received data bits assuming error-free conditions, assignable to a single mobile station when all assignable radio resources for the corresponding link direction are utilised (i.e., excluding radio resources that are used for physical layer synchronisation, reference signals or pilots, guard bands and guard times). The target for peak data rate should be 20Gbps for downlink (DL) and 10Gbps for uplink (UL). *Category - Enhanced Mobile Broadband (eMBB).*
Peak spectral efficiency	Maximum achievable data rate under ideal conditions, usually measured in gigabits per second (Gbps), that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the medium access control (the channel access protocol). The target for peak spectral efficiency should be 30bps/Hz for downlink (DL) and 15bps/Hz for uplink (UL). Higher frequency bands could have higher bandwidth, but lower spectral efficiency and lower frequency bands could have lower bandwidth but higher spectral efficiency. Thus, peak data rate cannot be directly derived from peak spectral efficiency and bandwidth multiplication. *Category - Enhanced Mobile Broadband (eMBB).*
Price per MHz per unit population	A commonly used metric for expressing prices paid for spectrum during government auctions. Price per MHz per unit population first takes the total price paid by a network provider for a range of spectrum and divides it by the number of MHz purchased. This price per MHz is then divided again by the provider's number of people covered to obtain the final price per MHz per unit population. This metric allows for more accurate comparisons of spectrum prices across different auctions to be made since it accounts for market size.
Reliability	Capability to provide a given service with a very high level of availability. Reliability is compromised if too much data is lost, late, or has errors. Improving the reliability of the network is critical for time-sensitive, mission-critical applications like automation and healthcare. Category - Mission Critical Control (MCC).
Resilience	Ability of the network to continue operating correctly during and after a natural or man-made disturbance, such as the loss of power. Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).
Robotics	An interdisciplinary branch of computer science and engineering. Robotics involves design, construction, operation, and use of robots. The goal of robotics is to design machines that can help and assist humans. Robotics integrates fields of mechanical engineering, electrical engineering, information engineering, mechatronics, electronics, bioengineering, computer engineering, control engineering, software engineering, mathematics, etc. Robotics develops machines that can substitute for humans and replicate human actions. Robots can be used in many situations for many purposes, but today many are used in dangerous environments (including inspection of radioactive materials, bomb detection and deactivation), manufacturing processes, or where humans cannot survive (e.g., in space, underwater, in high heat, and clean up and containment of hazardous materials and radiation).
Security and privacy	Ability to encrypt and protect user data and signaling, and enhance network security against cyberattacks, such as unauthorized user tracking, hacking, fraud, sabotaging, and denial of service, which can be detrimental to national security and the safeguarding and privacy of users' data. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*

Terms	Definitions
Sensor	A device that produces an output signal for the purpose of sensing of a physical phenomenon. In the broadest definition, a sensor is a device, module, machine, or subsystem that detects events or changes in its environment and sends the information to other electronics, frequently a computer processor. Sensors are always used with other electronics. Sensors are used in everyday objects such as touch-sensitive elevator buttons (tactile sensor) and lamps which dim or brighten by touching the base, and in innumerable applications of which most people are never aware. With advances in micromachinery and easy-to-use microcontroller platforms, the uses of sensors have expanded beyond the traditional fields of temperature, pressure, and flow measurement, for example into MARG sensors. Analog sensors such as potentiometers and force-sensing resistors are still widely used. Their applications include manufacturing and machinery, airplanes and aerospace, cars, medicine, robotics, and many other aspects of our day-to-day life. There is a wide range of other sensors that measure chemical and physical properties of materials, including optical sensors for refractive index measurement, vibrational sensors for fluid viscosity measurement, and electro-chemical sensors for monitoring pH of fluids.
Spectrum	The ranges of frequencies (or airwaves) on the electromagnetic spectrum that are allocated to the mobile industry and other sectors for wireless communication. Spectrum is a sovereign asset, which implies that the use of such airwaves is overseen by the government or national regulator, who manages and issues licenses to permit usage.
Spectrum and bandwidth flexibility	Flexibility of the network design to handle 5G Wireless different scenarios, such as the capability to operate at different frequency ranges. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
UE energy efficiency	Is the capability of a UE to sustain much better mobile broadband data rate while minimizing the UE modem energy consumption. *Category - Massive Internet of Things (Massive IoT).*
User Equipment (UE) battery life	Is the battery life of the UE without recharge. For mMTC, UE battery life in extreme coverage shall be based on the activity of mobile originated data transfer consisting of 200bytes UL per day followed by 20bytes DL from MaxCL of 164dB, assuming a stored energy capacity of 5Wh. *Category - Massive Internet of Things (Massive IoT).*
User plane latency	Is also known as the radio segment latency. It is the one-way latency for successful reception of a packet and includes the time for one or more retransmissions if packet reception fails. The target for user plane latency should be 0.5ms for upload (UL), and 0.5ms for download (DL). Furthermore, if possible, the latency should also be low enough to support the use of the next generation access technologies as a wireless transport technology that can be used within the next generation access architecture. For eMBB, the target for user plane latency should be 4ms for UL, and 4ms for DL. *Category - Enhanced Mobile Broadband (eMBB).*
User-experienced data rate	User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e., the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time. The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment: (1) Downlink user experienced data rate is 100 Mbit/s; (2) Uplink user experienced data rate is 50 Mbit/s. *Category - Enhanced Mobile Broadband (eMBB)*
Virtual Reality	The use of computer technology to create a simulated environment which can be explored in 360 degrees. Unlike traditional interfaces, VR places the user inside the virtual environment to give an immersive experience.

Bibliography

5G Americas. *Cellular Communications in a 5G Era.* 2022. Retrieved from https://www.5gamericas.org/wp-content/uploads/2022/01/Cellular-Communications-in-a-5G-Era-InDesign.pdf

ABB Motion. *Energy Efficiency of Smart Buildings: Towards Zero Consumption and Beyond.* 2021. Retrieved from https://www.energyefficiencymovement.com/wp-content/uploads/2021/05/ABB_EE_WhitePaper_Smart-buildings_final-1.pdf

Accenture. *Accelerating the 5G Future of Business.* 2020. Retrieved from https://www.accenture.com/_acnmedia/Accenture/Redesign-Assets/DotCom/Documents/Global/2/Accenture-Accelerating-5G-Future.pdf

Akhtar, M.W. et al. *The Shift to 6G Communications: Vision and Requirements.* Human-centric Computing Information Sciences 10: 53, 2020. Retrieved from https://doi.org/10.1186/s13673-020-00258-2

Alexa, A. et al. *5G Connectivity: A Key Enabling Technology to Meet America's Climate Change Goals.* Accenture, 2022. Retrieved from https://api.ctia.org/wp-content/uploads/2022/01/5G-Connectivity-A-Key-Enabling-Technology-to-meet-Americas-Climate-Change-Goals-2022-01-25.pdf

Alexa, A.; Mulcahy, S.; Chiang, E. K. *Connecting Canadians during COVID-19: The Impact of the Wireless and Wireline Industry in 2020 and Beyond.* Accenture, 2021. Retrieved from https://www.cwta.ca/wp-content/uploads/2021/11/CWTA-Economic-Report-2020-EN.pdf

Arata, H. J.; Hale, B. L. *Smart Bases, Smart Decisions.* The Cyber Defense Review, Spring 2018, 69-78. Retrieved from https://cyberdefensereview.army.mil/Portals/6/Documents/CDR%20Journal%20Articles/Smart%20Bases%20Smart%20Decisions_Arata_Hale.pdf?ver=2018-07-31-093711-343

Arias, R. et al. *The Impact of 5G: Creating New Value across Industries and Society.* World Economic Forum and PWC, 2020. Retrieved from https://www3.weforum.org/docs/WEF_The_Impact_of_5G_Report.pdf

Association of Equipment Manufacturers et al. *The Environmental Benefits of Precision Agriculture in the United States.* 2021. Retrieved from https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf

Astarloa, B. et al. *The Future of Electricity: New Technologies Transforming the Grid Edge.* World Economic Forum, 2017. Retrieved from https://www3.weforum.org/docs/WEF_Future_of_Electricity_2017.pdf

Attaran, M. *The Impact of 5G on the Evolution of Intelligent Automation and Industry Digitalization.* Journal of Ambient Intelligence and Humanized Computing, 2021. Retrieved from https://link.springer.com/content/pdf/10.1007/s12652-020-02521-x.pdf

Bahia, K.; Castells, P.; Pedros, X. *Mobile Technology: Two Decades Driving Economic Growth.* GSMA Intelligence, 2020. Retrieved from https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165922&file=121120-working-paper.pdf

Balafoutis, A. et al. *Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation, Farm Productivity and Economics.* Sustainability 9, 2017, 1339-1366. Retrieved from https://elk.adalidda.com/2017/08/sustainability-09-01339.pdf

Barua, B.; Moir, M. *Comparing Performance of Universal Health Care Countries, 2019.* Fraser Institute, 2019. Retrieved from https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf

Barua, B.; Moir, M. *Waiting Your Turn: Wait Times for Health Care in Canada, 2020 Report.* Fraser Institute, 2020. Retrieved from https://www.fraserinstitute.org/sites/default/files/waiting-your-turn-2020-execsum-national.pdf

BCG Centre for Canada's Future. *In the Balance: Future-Proofing Canada's Digital Infrastructure to Unlock Benefits for All.* 2019. Retrieved from https://media-publications.bcg.com/flash/dotbcg_other/CCF%20Digital%20Infrastructure-%20In%20the%20Balance.pdf

Blasco, J.; King, A.; Jayaram, S. *How to Report on the SDGs: What Good Looks Like and Why it Matters.* KPMG International, 2018. Retrieved from https://assets.kpmg/content/dam/kpmg/xx/pdf/2018/02/how-to-report-on-sdgs.pdf

Bonte, D. *Role of Smart Cities for Economic Development.* ABI Research, 2018. Retrieved from https://www.caba.org/wp-content/uploads/2020/04/IS-2018-215.pdf

Bosco, C.; Oandasan, I. *Review of Family Medicine Within Rural and Remote Canada: Education, Practice, and Policy.* College of Family Physicians of Canada, 2016. Retrieved from https://www.cfpc.ca/CFPC/media/Resources/Rural-Practice/ARFM_BackgroundPaper_Eng_WEB_FINAL.pdf

Brake, D. *A U.S. National Strategy for 5G and Future Wireless Innovation.* Information Technology & Innovation Foundation, 2020. Retrieved from https://itif.org/publications/2020/04/27/us-national-strategy-5g-and-future-wireless-innovation/

Brown, M. *Promoting 5G and Future Technology Development by Supporting Global Standards.* The National Security Institute, 2020. Retrieved from https://www.wiley.law/assets/htmldocuments/Tech-Standards.pdf

Brynjolfsson, E.; Petropoulos, G. *The Coming Productivity Boom.* MIT Technology Review, 2021. Retrieved from https://www.technologyreview.com/2021/06/10/1026008/the-coming-productivity-boom

Bulitta, C. et al. *5G Health: The Need for 5G Technologies in the Healthcare Domain.* 5G Health Association, 2020. Retrieved from https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf

Canadian Institute for Health Information. *National Health Expenditure Trends, 1975 to 2019.* 2019. Retrieved from https://www.cihi.ca/sites/default/files/document/nhex-trends-narrative-report-2019-en-web.pdf

Castells, P. et al. *5G and Economic Growth: An Assessment of GDP Impacts in Canada.* GSMA Intelligence, 2020. Retrieved from https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165916&file=051120-5G-in-Canada.pdf

Center for Strategic & International Studies. *Accelerating 5G in the United States.* 2021. Retrieved from https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/210301_Lewis_Accelerating_5G_0.pdf

Chang, J.; Guan, J.; Guan, H. *5G Use Cases for Vertical China 2021.* GSMA, 2021. Retrieved from https://www.gsma.com/greater-china/wp-content/uploads/2021/02/5G-Use-Cases-for-Vertical-China-2021-EN.pdf

Cybersecurity & Infrastructure Security Agency; National Security Agency; Office of the Director of National Intelligence. *Potential Threat Vectors to 5G Infrastructure.* 2021. Retrieved from https://media.defense.gov/2021/May/10/2002637751/-1/-1/1/POTENTIAL%20THREAT%20VECTORS%20TO%205G%20INFRASTRUCTURE.PDF

Danish Energy Agency. *5G Action Plan for Denmark.* 2019. Retrieved from https://ens.dk/sites/ens.dk/files/Tele/5g_action_plan_for_denmark.pdf

Davidson, R.; McLaughlin, R. *5G: Jumpstarting Our Digital Future.* Information and Communications Technology Council, 2018. Retrieved from https://www.ictc-ctic.ca/wp-content/uploads/2019/03/ICTC_5G-Jumpstart_2018_EN_Mar14.pdf

de Wit, M. et al. *The Circularity Gap Report.* Circle Economy, 2022. Retrieved from https://www.circularity-gap.world/2022#Download-the-report

Economic Forensics and Analytics, Inc. *Canada's Wine Economy – Growth and Innovation Through Global Challenges*. Wine Growers Canada. 2022. Retrieved from https://www.winegrowerscanada.ca/wp-content/uploads/2022/08/RPT-Canadian-Wine-Economic-Impact-2019-1.pdf

Elhuni, R. M.; Ahmad, M. M. *Key Performance Indicators for Sustainable Production Evaluation in Oil and Gas Sector.* Procedia Manufacturing 11, 2017, 718-724. Retrieved from https://www.sciencedirect.com/science/article/pii/S2351978917303785

Ericsson. *Ericsson Mobility Report.* 2022. Retrieved from https://www.ericsson.com/49d3a0/assets/local/reports-papers/mobility-report/documents/2022/ericsson-mobility-report-june-2022.pdf

Ericsson. *What Industry 4.0 Means for Manufacturing.* 2019. Retrieved from https://www.ericsson.com/497d92/assets/local/internet-of-things/industry-4.0/docs/ericsson-tallinn-factory_case_study.pdf

FarrPoint. *Digital Policy and Climate Change Canada Study Report.* 2022. Retrieved from https://www.farrpoint.com/uploads/store/mediaupload/492/file/Digital_Policy_and_Climate_Change_Report_FarrPoint_2022.pdf

Federal Transit Administration. *Public Transportation's Role in Responding to Climate Change.* United States Department of Transportation, 2010. Retrieved from https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/PublicTransportationsRoleInRespondingToClimateChange2010.pdf

Food and Agriculture Organization of the United Nations. *How to Feed the World in 2050.* 2009. Retrieved from

https://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

Food and Agriculture Organization of the United Nations. *The State of Food and Agriculture: Overcoming Water Challenges in Agriculture.* 2020. Retrieved from https://www.fao.org/3/cb1447en/cb1447en.pdf

Food and Agriculture Organization of the United Nations; Intergovernmental Technical Panel on Soils. *Status of the World's Soil Resources.* 2015. Retrieved from https://www.fao.org/3/i5199e/I5199E.pdf

Friend, G.; Hobbs, S. *5G Regulatory Policy and Assignment Strategies.* Coleago Consulting, 2018. Retrieved from http://www.coleago.com/app/uploads/2020/10/Regulatory-Policy-and-Assignment-to-Support-5G1.pdf

Fu, H.; Shi, Y.; Zeng, Y. *Estimating Smart Grid's Carbon Emission Reduction Potential in China's Manufacturing Industry Based on Decomposition Analysis.* Frontiers in Energy Research 30, 2021. Retrieved from https://www.frontiersin.org/articles/10.3389/fenrg.2021.681244/full

Gal, P. et al. *Digitalization and Productivity: In Search of the Holy Grail - Firm-level Empirical Evidence from European Countries.* International Productivity Monitor 39, 2019, 39-71. Retrieved from http://www.csls.ca/ipm/37/OECD.pdf

García, L. et al. *Deployment Strategies of Soil Monitoring WSN for Precision Agriculture Irrigation Scheduling in Rural Areas.* Sensors 21:5, 2021, 1693. Retrieved from https://doi.org/10.3390/s21051693

Georgiou, K. E.; Georgiou, E.; Satava, R. M. *5G Use in Healthcare: The Future is Present.* Journal of the Society of Laparoscopic & Robotic Surgeons 25:4, 2021. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8764898/

Gilbert, T. *$1.4T of Benefits in 2030: 5G's Impact on Industry Verticals.* STL Partners, 2019. Retrieved from https://carrier.huawei.com/~/media/CNBGV2/download/program/Industries-5G/5G-Impact-on-Industry-Verticals.pdf

Global Enabling Sustainability Initiative; Deloitte. *Digital with Purpose: Delivering a SMARTer 2030.* 2019. Retrieved from https://gesi.org/research/download/36

Goedde, L. et al. *Agriculture's Connected Future: How Technology can Yield New Growth.* McKinsey & Company, 2020. Retrieved from https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

Gooch, M. et al. *The Avoidable Crisis of Food Waste: Technical Report.* Value Chain Management International & Second Harvest, 2019. Retrieved from https://www.secondharvest.ca/getmedia/58c2527f-928a-4b6f-843a-c0a6b4d09692/The-Avoidable-Crisis-of-Food-Waste-Technical-Report.pdf

Gough, D.; Oliver, S.; Thomas, J. *An Introduction to Systematic Reviews.* SAGE Publishing, 2017. Retrieved from https://uk.sagepub.com/sites/default/files/upm-assets/81596_book_item_81596.pdf

Government of Canada. *2022 Budget: A Plan to Grow Our Economy and Make Life More Affordable.* 2022. Retrieved from https://budget.gc.ca/2022/pdf/budget-2022-en.pdf

Greenberg, B. et al. *5G in Government: The Future of Hyperconnected Public Services.* Deloitte, 2020. Retrieved from https://www2.deloitte.com/us/en/insights/industry/public-sector/future-of-5g-government.html

Grijpink, F. et al. *Connected World: An Evolution in Connectivity Beyond the 5G Revolution.* McKinsey & Company, 2020. Retrieved from https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/connected-world-an-evolution-in-connectivity-beyond-the-5g-revolution

Grijpink, F. et al. *How Tapping Connectivity in Oil and Gas can Fuel Higher Performance.* McKinsey & Company, 2020. Retrieved from https://www.mckinsey.com/industries/oil-and-gas/our-insights/how-tapping-connectivity-in-oil-and-gas-can-fuel-higher-performance

GSMA. *5G Spectrum: GSMA Public Policy Position.* 2022. Retrieved from https://www.gsma.com/spectrum/wp-content/uploads/2021/04/5G-Spectrum-Positions.pdf

GSMA. *Study on Socio-Economic Benefits of 5G Services Provided in mmWave Bands.* 2018. Retrieved from https://www.gsma.com/spectrum/wp-content/uploads/2019/10/mmWave-5G-benefits.pdf

GSMA. *The Socio-Economic Benefits of Mid-Band 5G Services.* 2022. Retrieved from https://www.gsma.com/spectrum/wp-content/uploads/2022/02/mid-band-5G-spectrum-benefits.pdf

Guillemette, Y; Turner, D. *The Long Game: Fiscal Outlooks to 2060 Underline Need for Structural Reform.* OECD Economic Policy Papers 29, 2019. Retrieved from https://doi.org/10.1787/a112307e-en

Hafner, M; Yerushalmi, E; Dufresne, E; Gkousis, E. *The potential socio-economic impact of telemedicine in Canada*. Rand Europe, 2021. Retrieved from https://www.rand.org/content/dam/rand/pubs/research_reports/RRA1200/RRA1274-1/RAND_RRA1274-1.pdf.

He, W.; Goodkind, D.; Kowal, P. *An Aging World: 2015.* United States Census Bureau, International Population Reports, P95/16-1, 2016. Retrieved from https://www.researchgate.net/profile/Paul-Kowal/publication/299528572_An_Aging_World_2015/links/56fd4be108ae17c8efaa1132/An-Aging-World-2015.pdf

Hong, E.; Ryu, J.; Lee, E. *Entering the 5G Era: Lessons from Korea.* World Bank Group Korea Office, 2021. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/35780/Entering-the-5G-Era-Lessons-from-Korea.pdf

Hwangbo, H. et al. *Store Layout Optimization Using Indoor Positioning System.* International Journal of Distributed Sensor Networks 13:2, 2017. Retrieved from https://journals.sagepub.com/doi/10.1177/1550147717692585

Intergovernmental Panel in Climate Change. *Climate Change 2022: Mitigation of Climate Change.* 2022. Retrieved from https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf

International Energy Agency. *Digitalization & Energy.* 2017. Retrieved from https://iea.blob.core.windows.net/assets/b1e6600c-4e40-4d9c-809d-1d1724c763d5/DigitalizationandEnergy3.pdf

International Energy Agency. *World Energy Outlook 2021.* 2021. Retrieved from https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf

International Telecommunication Union. *IMT Vision - Framework and Overall Objective of the Future Development of IMT for 2020 and Beyond.* Radiocommunication Sector of ITU, 2015. Retrieved from https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

Karelis, V. et al. *Fuel for Innovation: Greece's Race to 5G.* Accenture, 2020. Retrieved from https://www.accenture.com/_acnmedia/PDF-130/Accenture-Greece-Race-to-5G-Full-Report.pdf

Kaza, S. et al. *What a Waste 2.0: a Global Snapshot of Solid Waste Management to 2050.* Urban Development, 2018. Retrieved from https://openknowledge.worldbank.org/handle/10986/30317

Keskinian, D. et al. *Accelerating 5G in Canada: The Role of 5G in the Fight Against Climate Change.* Accenture, 2020. Retrieved from https://www.cwta.ca/wp-content/uploads/2020/10/5G_Role_In_Fight_Against_Climate_Change.pdf

Khan, K. S. et al. *Five Steps to Conducting a Systematic Review.* Journal of the Royal Society of Medicine 96:3, 2003, 118-121. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC539417/

King, J.; Perry, C. *Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings.* American Council for an Energy-Efficient Economy, 2017. Retrieved from https://www.aceee.org/sites/default/files/publications/researchreports/a1701.pdf

Kirli, D. et al. *Smart Contracts in Energy Systems: A Systematic Review of Fundamental Approaches and Implementations.* Renewable and Sustainable Energy Reviews 158, 2022. Retrieved from https://doi.org/10.1016/j.rser.2021.112013

Kopparapo, S. et al. *Retail Analytics: 5G's Impact & Opportunities.* ACS Solutions, 2020. Retrieved from https://acsicorp.com/wp-content/uploads/2021/02/Whitepaper-Prototype-5G-Retail-Case-Study.pdf

Longo, E. et al. *A 5G-Enabled Smart Waste Management System for University Campus.* Sensors 21:24, 2021, 8278. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8709486/

Mahmud, K. et al. *Nitrogen Losses and Potential Mitigation Strategies for a Sustainable Agroecosystem.* Sustainability 13:4, 2021, 2400. Retrieved from https://www.mdpi.com/2071-1050/13/4/2400/htm

Mai, T. et al. *Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States.* National Renewable Energy Laboratory, 2018. Retrieved from https://www.nrel.gov/docs/fy18osti/71500.pdf

Malmodin, J.; Bergmark, P. *Exploring the Effect of ICT Solutions on GHG Emissions in 2030.* Ericsson Research, 2015. Retrieved from https://www.ericsson.com/48d92a/assets/local/reports-papers/research-papers/icts-potential-reduce-greenhouse-gas-emissions-2030.pdf

Martel, L. *The Labour Force in Canada and its Regions: Projections.* Statistics Canada, 2019. Retrieved from https://www150.statcan.gc.ca/n1/pub/75-006-x/2019001/article/00004-eng.htm

Massar, M. et al. *Impacts of Autonomous Vehicles on Greenhouse Gas Emissions—Positive or Negative?* International Journal of Environmental Research and Public Health 18, 2021, 5567. Retrieved from https://doi.org/10.3390/ijerph18115567

Mbow, C. et al. *Food Security. In: Special Report on Climate Change and Land.* IPCC, 2019. Retrieved from https://www.ipcc.ch/srccl/chapter/chapter-5/

Medin, M.; Louie, G. *The 5G Ecosystem: Risks and Opportunities for DoD.* Defense Innovation Board, 2019. Retrieved from https://media.defense.gov/2019/Apr/03/2002109302/-1/-1/0/DIB_5G_STUDY_04.03.19.PDF

Mendoza, J. et al. *5G for Construction: Use Cases and Solutions.* Electronics 10:14, 2021, 1713. Retrieved from https://doi.org/10.3390/electronics10141713

OECD. *Enhancing the Contribution of Digitalisation to the Smart Cities of the Future.* 2019. Retrieved from https://www.oecd.org/cfe/regionaldevelopment/Smart-Cities-FINAL.pdf

Ofcom. *Connected Nations 2021, UK Report.* 2021. Retrieved from https://www.ofcom.org.uk/__data/assets/pdf_file/0035/229688/connected-nations-2021-uk.pdf

Pigott, T. D.; Polanin, J. R. *Methodological Guidance Paper: High-Quality Meta-Analysis in a Systematic Review.* Review of Educational Research 90:1, 2019, 24-46. Retrieved from https://journals.sagepub.com/doi/full/10.3102/0034654319877153

Pörtner, H.-O. et al. *Summary for Policymakers.* IPCC, 2022. Retrieved from https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

PRC Ministry of Industry and Information Technology. *"Set Sail" Action Plan for 5G Applications (2021-2023).* 2021. Retrieved from https://cset.georgetown.edu/wp-content/uploads/t0339_5G_action_plan_draft_EN.pdf

Public Policy Forum. *Future Proof: Connecting Post-Pandemic Canada.* 2021. Retrieved from https://ppforum.ca/wp-content/uploads/2021/09/FutureProof-ConnectingPost-PandemicCanada-OCT2021-PPF-EN.pdf

PWC. *5G in Healthcare.* 2020. Retrieved from https://www.pwc.com/gx/en/industries/tmt/5g/pwc-5g-in-healthcare.pdf

PWC. *5G, the Digital Economy, and Canada's Global Competitiveness.* 2021. Retrieved from https://www.pwc.com/ca/en/communications/publications/5g-the-digital-economy-and-canadas-global-competitiveness.pdf

PWC. *The Evolution of Canada's Telecom Industry and the Growing Digital Economy.* 2021. Retrieved from https://www.pwc.com/ca/en/communications/publications/the-evolution-of-canadas-telecom-industry-and-the-growing-digital-economy.pdf

PWC. *The Global Economic Impact of 5G.* 2021. Retrieved from https://www.pwc.com/gx/en/tmt/5g/global-economic-impact-5g.pdf

PWC. *The Importance of a Healthy Telecommunications Industry to Canada's High Tech Success.* 2020. Retrieved from https://www.pwc.com/ca/en/communications/publications/761378-the-importance-of-a-healthy-telecommunications-industry-to-canadas-high-tech-success.pdf

PWC. *Understanding the Cost and Quality of Networks across the G20.* 2021. Retrieved from https://www.pwc.com/ca/en/communications/assets/understanding-the-cost-and-quality-of-networks-across-the-g20-en.pdf

Ritchie, H.; Roser, M.; Rosado, P. *CO_2 and Greenhouse Gas Emissions.* Our World in Data, 2020. Retrieved from https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

Safer, D. et al. *Fuel for Innovation: Canada's Path in the Race to 5G.* Accenture, 2018. Retrieved from https://www.5gcc.ca/wp-content/uploads/2018/06/CWTA-Accenture-Whitepaper-5G-Economic-Impact_Updates_WEB_06-19-2018.pdf

Safer, D.; Soliman, M.; Alexa, A. *Accelerating 5G in Canada: Benefits for Cities and Rural Communities.* Accenture, 2019. Retrieved from https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf

Samoun, M. B. et al. *Going Digital is Hard for Oil and Gas Companies - but the Payoff is Worth it.* BCG, 2019. Retrieved from https://web-assets.bcg.com/img-src/BCG-Going-Digital-Is-Hard-for-Oil-and-Gas-Companies-but-the-Payoff-Is-Worth-It-Mar-2019_tcm9-215951.pdf

Schneider, E. C. et al. *Mirror, Mirror 2021 - Reflecting Poorly: Health Care in the U.S. Compared to Other High-Income Countries.* Commonwealth Fund, 2021. Retrieved from https://www.commonwealthfund.org/publications/fund-reports/2021/aug/mirror-mirror-2021-reflecting-poorly

Schrijver, R. *Precision Agriculture and the Future of Farming in Europe.* European Parliamentary Research Service Scientific Foresight Unit, 2016. Retrieved from https://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf

Siddiqui, F. et al. *The Big Inversion: How 5G+ Technologies will Create New Value for Industries in a post-COVID World.* Bell Labs Consulting, 2021. Retrieved from https://d1p0gxnqcu0lvz.cloudfront.net/documents/Big_Inversion_whitepaper_Bell_Labs_Consulting_2021.pdf

SIS International Research. *5G Technology Trends: A Survey of 5G Stakeholders in Telecommunications.* 2022. Retrieved from https://www.jabil.com/dam/jcr:e51424bb-b754-4665-93ff-0d631eef2194/2022-5G-technology-trends-report.pdf

Song, Y. et al. *Applications of the Internet of Things (IoT) in Smart Logistics: A Comprehensive Survey.* IEEE Internet of Things Journal 8:6, 2021, 4250-4274. Retrieved from https://www.csit.carleton.ca/~fyu/Papers/09241736.pdf

Stanford, J. *Where are the Robots? The Surprising Deceleration of Technology in Canadian Workplaces.* Centre for Future Work, 2022. Retrieved from https://centreforfuturework.ca/wp-content/uploads/2022/04/Where-Are-The-Robots.pdf

Stewart, L.; Moher, D.; Shekelle, P. *Why Prospective Registration of Systematic Reviews Makes Sense.* Systematic Reviews 1:7, 2012. Retrieved from https://systematicreviewsjournal.biomedcentral.com/track/pdf/10.1186/2046-4053-1-7.pdf

Subedi, R.; Greenberg, T. L.; Roshanafshar, S. *Does Geography Matter in Mortality? An Analysis of Potentially Avoidable Mortality by Remoteness Index in Canada.* Statistics Canada, 2019. Retrieved from https://www150.statcan.gc.ca/n1/pub/82-003-x/2019005/article/00001-eng.htm

Surtees, L. *The Next Generation Network Imperative: The Future is Now.* International Data Corporation Canada, 2019. Retrieved from https://www.cengn.ca/wp-content/uploads/2021/08/CENGN_ExecSummaryRecs.pdf

Teece, D. J. *5G Mobile: Impact on the Health Care Sector.* Tusher Center for Intellectual Capital, U.C. Berkeley, 2017. Retrieved from https://haas.berkeley.edu/wp-content/uploads/5g-mobile-impact-on-the-health-care-sector.pdf

TELUS Business; Samsung. *Improving Public Safety Outcomes with Mission Critical Communications & 5G.* 2021. Retrieved from https://assets.ctfassets.net/rz9m1rynx8pv/5xKzLUrfrCAqsCH0e5dNqx/c02b93c43c84fc7bb2243d2fef77d656/TELUS-Samsung-Whitepaper-Public-Safety-Feb22-English.pdf

Tian, W. et al. *Telerobotic Spinal Surgery Based on 5G Network: The First 12 Cases.* Neurospine 17:1, 2020, 114-120. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7136105/

Tortora, G.; Caramella, D. *Autonomous Delivery of Medical Material Through Drones in a Future Pandemic.* HealthManagement.org 22:1, 2022, 24-26. Retrieved from https://healthmanagement.org/uploads/article_attachment/autonomous-deliver-of-medical-material-through-drones-in-a-future-pandemic.pdf

UNEP DTU Partnership; United Nations Environment Programme. *Reducing Consumer Food Waste Using Green and Digital Technologies.* 2021. Retrieved from https://unepdtu.org/wp-content/uploads/2022/03/reducing-consumer-food-waste-using-green-and-digital-technologies.pdf

United States Government Accountability Office. *5G Wireless: Capabilities and Challenges for an Evolving Network.* 2020. Retrieved from https://www.gao.gov/assets/gao-21-26sp.pdf

Úrbez-Torres, J. R. *Demystifying the Status of Grapevine Viruses in British Columbia.* Agriculture and Agri-Food Canada, 2016. Retrieved from https://brocku.ca/ccovi/wp-content/uploads/sites/125/2016-03-02.-CCOVI-Lecture-Series.-Urbez-Torres-Grapevine-viruses-in-BC.pdf

Vahidi, A.; Sciarretta, A. *Energy Saving Potentials of Connected and Automated Vehicles.* Transportation Research Part C: Emerging Technologies 95, 2018, 822-843. Retrieved from https://doi.org/10.1016/j.trc.2018.09.001

Vatsanidou, A. et al. *Life Cycle Assessment of Variable Rate Fertilizer Application in a Pear Orchard.* Sustainability 12:17, 2020, 6893. Retrieved from https://doi.org/10.3390/su12176893

Wen, L. et al. *Using a 5G Network in Hospitals to Reduce Nosocomial Infection During the COVID-19 Pandemic.* Communications Medicine 2:51, 2022. Retrieved from https://doi.org/10.1038/s43856-022-00118-3

WNS. *Top Trends in Banking & Financial Services.* 2018. Retrieved from https://www.wns.com/Portals/0/Documents/Articles/PDFFiles/600/180/Top%20Trends%20in%20Banking%20&%20Financial%20Services%20Final.pdf

Woetzel, J. et al. *Smart Cities: Digital Solutions for a More Livable Future.* McKinsey & Company, 2018. Retrieved from https://www.mckinsey.com/business-functions/operations/our-insights/smart-cities-digital-solutions-for-a-more-livable-future

Wood, R. *Falling Behind: Comparing 5G Spectrum Policies in Canada and OECD Countries.* Analysis Mason, 2021. Retrieved from https://www.analysysmason.com/contentassets/3142cca88f924253be79605a6703503a/analysys_mason_5g_spectrum_canada_nov2021_rdnt0.pdf

World Economic Forum. *5G-Next Generation Networks Programme: Repository of Use Cases.* 2019. Retrieved from https://www3.weforum.org/docs/WEF_The_Impact_of_5G.pdf

Zhang, C. et al. *Privacy-Preserving Contact Tracing in 5G-Integrated and Blockchain-Based Medical Applications.* Computer Standards & Interfaces 77, 2021. Retrieved from https://doi.org/10.1016/j.csi.2021.103520