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GREEN 5G: BUILDING A SUSTAINABLE WORLD

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1 Executive summary

The planet is facing a climate emergency which, if not tackled immediately, threatens every aspect of life. 5G is being deployed at a time when energy efficiency is a matter of life or death, and it can play a significant role in helping every industry to hit sustainability goals by enabling them to transform their processes and behaviour.

Modern lifestyles have driven a sharp increase in energy usage, 85% of which was still based on fossil fuels in 2018. Use of fossil fuels is one of the key factors driving higher emissions of greenhouse gas (GHG), which contribute to global warming. This, in turn, has multiple dangerous impacts on the environment and on human life, such as natural disasters and the destruction of human and animal habitats. GHG emissions rose by 1.5% per year between 2008 and 2018, according to the United Nations (UN) Emissions Gap Report 2019, and total GHG emissions reached a record high of 55.3 gigatonnes of carbon dioxide equivalent ($GtCO_{2e}$) in 2018.

The rising use of technologies such as cloud computing and mobile connectivity supports new experiences in every aspect of business and personal life, but it is essential that these benefits can be delivered without any detrimental impact on the environment. National and international policies are targeting a dramatic increase in energy efficiency, and a sharp shift from fossil fuels to renewable sources of energy such as solar, wind and water. This will entail a completely new approach to energy use, which must be adopted by every industry and individual. This is where 5G is an important enabler.

1.1 Governments and industries are setting ambitious targets

Recent years have seen many governments and international organisations initiate sustainability and climate protection programmes, many with targets based on those contained in the UN Framework Convention on Climate Change, agreed in Paris in 2016. To date, 77 countries and major sub-national economies have set net-zero emission targets by 2050.

Government leadership is important, but not enough on its own. Every industry needs to define its own targets and a clear roadmap to reach them. The telecoms industry is taking a lead by addressing its own energy efficiency. The cellular industry was the world's first, in 2016, to commit to achieving the UN Sustainable Development Goals (SDGs), setting an industry goal of net-zero emissions by 2050.[1]

The way that operators deploy 5G will play a significant role in this. For the first time, energy efficiency is one of the main considerations when planning and optimising new mobile networks, and many techniques – from smart power for base stations to artificial intelligence (AI)-enabled preventive maintenance – will make 5G networks the most sustainable ever.

1. See https://www.mobileworldlive.com/huawei-updates/legacy-rat-exit-help-sustainable-development-of-communication-networks/

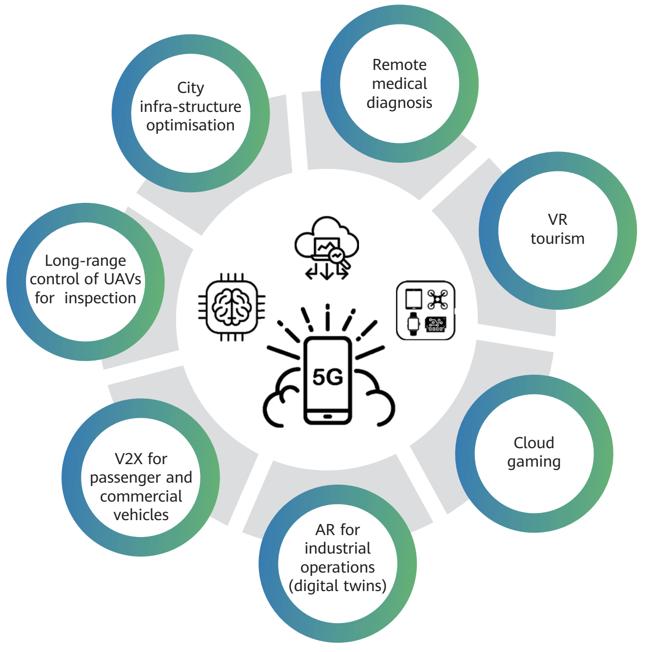
2. ITU, Summary of SMART 2020 Report, see https://www.itu.int/md/T05-FG.ICT-C-0004/en

1.2 5G is a significant enabler of energy efficiency

But far more significant is the ability of 5G to help other industries to hit their climate goals, known as the "enabling effect". According to the International Telecommunication Union (ITU) SMART 2020 report,[2] the scale of the enabling effect, across all ICT, will be equivalent to 15% of all global emissions by the end of 2020.

The 5G enabling effect arises from changes to processes and behaviour, which are supported by a high-capacity, ubiquitous and low-latency 5G network. Together with virtualisation, edge computing, AI-enabled analytics and cloud, 5G can help industries to implement new processes as an integral part of an energy efficiency programme, by supporting the most efficient and flexible allocation of resources. Figure 1.1 illustrates an array of use cases 5G can enable across multiple industry verticals. With enhanced mobile broadband (eMBB) underpinning many new ways to work and communicate, there has been considerable focus on ensuring that eMBB usage is as energy efficient as possible.

Figure 1.1: 5G's enabling effect in other industry verticals[3]



This intelligent use of resources can help to reduce energy consumption in many ways, such as: support for smart energy management; reduced requirement for office space and business travel; efficient just-in-time supply chains enabled by predictive analytics; and intelligent automated management of the movement of vehicles carrying people and goods.

Analysys Mason has conducted analysis of the impact of 5G on energy efficiency in three industries which require energy efficiency transformation most urgently – energy, healthcare and manufacturing – all of which currently have high GHG emissions. The modelling involved lifecycle assessment (LCA) and operation parameter comparison. The research and modelling showed that, in these sectors, 5G can have a significant effect, when combined with other technologies such as cloud, AI and the Internet of Things (IoT), plus other changes such as the adoption of renewable energy sources.

3. UAV means an unmanned aerial vehicle controlled by a computer, such as a drone; VR refers to virtual reality; AR refers to augmented reality; V2X refers to vehicle to everything (communications between a vehicle and other vehicles, roadside infrastructure, etc.); digital twin refers to a digital replica of a physical entity, which can help to optimise the operation and maintenance of physical assets.

Transport *use case: 5G unmanned aerial vehicles (UAVs) for gas-pipe inspection in Shanghai, China*	The environmental impact, on top of operational and business efficiency, of deploying 5G UAVs for gas-pipe inspection is significant. If the results observed in this case study were extrapolated across the globe, replacing human inspection with 5G UAVs could reduce the aggregate GHG emissions associated with gas-pipe inspection by 39%, from 5.3 megatonnes (Mt) to 3.2Mt. The savings would be equivalent to the energy required to charge a smartphone for everyone in the world for 100 days – assuming each person has only one and charges it every three days.
Healthcare *use case: 5G-enabled remote computed tomography (CT) consultation in less affluent areas of China*	The adoption of 5G consultations has saved four medical experts from needing to take regular flights to regional hospitals, while the number and quality of consultations and diagnoses has remained unchanged. The elimination of road and air travel (the main source of GHG emissions in this case study) led to a massive 99% reduction in GHG emissions associated with these expert consultation sessions.
Manufacturing *use case: 5G-enabled AI cameras for plant inspection*	A leading smartphone manufacturer in Guangdong, China has replaced manual quality assurance (QA) checks along its assembly lines with a system of 5G-connected AI cameras, connected to an edge server. The speed of inspection has increased by nearly 18 times, and per-unit smartphone energy consumption has reduced to 6% of the previous level.

There are many other sectors where 5G and other related technologies can have a dramatic impact on sustainability. Some of these are particularly important because they affect every industry. For instance, transport contributes around one-third of total emissions in many regions, so there is considerable interest in using 5G to support rising levels of vehicle autonomy, so that vehicles, powered by renewable sources of electricity, have the real-time information they need to make the best decisions about routeing, parking and so on, and thus use power most efficiently and avoid traffic congestion and pollution.

Smart cities are among the best examples of how 5G can interact with other emerging technologies, including AI analytics, edge computing and massive IoT, to support a fully efficient, digital and sustainable way of living, working and travelling. Smart-city programmes, like those of the C40 Cities,[4] have dramatic results, with connectivity as a key enabler. In Europe, for instance, London, Berlin and Madrid have reduced GHG emissions of motor vehicles by 30% each from their peak rates, and Copenhagen by 61%.

4. C40 is a network of 96 major world cities, committed to addressing climate change.

1.3 Governments, operators and industries need to act now

To achieve the kind of results summarised above, governments, regulators, mobile network operators (MNOs) and the industries all have a part to play. This white paper sets out the details of what is achievable with the use of 5G, and what all these stakeholders need to do to make that happen, including:

- Governments can facilitate cooperation between different stakeholders to adopt common platforms and best practice.
- Regulators can lower barriers to 5G deployment by making spectrum and city infrastructure available in a timely and affordable way.
- MNOs can work to form strong relationships with all other stakeholders, to set common objectives and roadmaps for 5G-enabled efficiency, and ensure these are central to 5G planning and deployment.

It is only by all stakeholders, countries and industries working together that 5G can fulfil its maximum potential to enhance energy efficiency and help avert climate-change disaster.

2 ICT can play a key role in essential global efforts to improve energy efficiency and reduce GHG emissions

Since the late 19th century[5] humans have been aware of how their actions can cause climate change, but it was only in the 1970s that this became a significant area of international study.[6] During the 21st century, it has become clear that the effects of global warming pose a huge threat to the environment and to life as we know it.

As humans have developed new transport, industrial, technology and lifestyle systems, so our consumption of energy has increased, mainly based on fossil fuels such as oil and coal. In 2018, fossil fuels were the source of about 85% of primary energy consumption (that is, the total energy demand, excluding energy carriers used for non-energy purposes) worldwide, and the growth of carbon dioxide (CO_2) emissions from energy use continues to rise every year.[7]

Combined with other trends such as deforestation, this has driven higher emissions of GHG,[8] especially CO_2, which contributes to global warming by thickening the layer of gases surrounding the earth and limiting the escape of heat.

2.1 The need to improve energy sustainability is becoming critical

Global warming has multiple dangerous impacts on the environment and on human life. These include increased droughts; communities being displaced as their regions become too hot for habitation; rising sea levels with an associated rise in flooding; and larger numbers of natural disasters such as typhoons and wildfires.[9] All these lead to destruction of human and animal habitat. An increase in the Earth's temperature of just 1.5 to 2.0 degrees Celsius (ºC) above pre-industrial temperatures will destroy critical infrastructure such as irrigation lines and vulnerable habitats such as low-lying coastal regions and islands.[10]

The urgency of the crisis is increasingly recognised by national and supra-national governments. If these trends are not reversed, there will be breakdown of societies and natural ecosystems, with dramatic effects on the Earth. To address this crisis requires a completely different approach to energy usage. This does not mean a reduction in overall energy consumption, but a dramatic increase in energy efficiency, and a sharp shift from the use of fossil fuels to renewable sources of energy such as solar, wind and water.

Global warming is accelerating – the facts

- Since the Industrial Revolution, which introduced machinery powered by coal and gas, atmospheric CO_2 concentration has increased by about 40%, to above 400 parts per million (ppm).[11] Current CO_2 levels are 100 ppm higher than at any time in the past million years and probably the past 25 million years. That increase of 100 ppm over 120 years would, before the industrial age, have taken 5,000 to 20,000 years.
- Assessments by the UN's Intergovernmental Panel on Climate Change (IPCC) suggest that the Earth's climate warmed by 0.85ºC between 1880 and 2012,[12] with human activity being a significant contributing factor since the early days of the Industrial Revolution.
- GHG emissions rose by 1.5% per year between 2008 and 2018, according to the UN Emissions Gap Report 2019. Total GHG emissions reached a record high of 55.3 $GtCO_{2e}$ in 2018.[13]
- The same report found that fossil-fuel CO_2 emissions from domestic energy usage and from industry grew by 2%, reaching a record 37.5 $GtCO_2$ in 2018.[13]
- Worldwide, annual energy production is currently the equivalent of around 20 billion tonnes of oil. If current patterns of growth in energy consumption continue, despite assuming a moderate acceleration in energy production from renewable sources, CO_2 emissions would reach 47.5 Gt by 2030.[14]

Improving overall energy efficiency is only one dimension of the challenge. Another is to shift from carbon to non-carbon energy sources. Currently, only about 8% of energy production is generated from renewable sources.

As well as academic work and inter-government efforts, sustainability has risen to the top of the agenda for many industries, including telecoms. MNOs, like many other companies, need to rethink their usage of energy and their impact on the environment, and this will have a profound effect on the way they plan and deploy their next-generation networks. The challenge was summed up in December 2019 by José María Álvarez-Pallete, CEO of Telefónica, who said: "The central axis of our strategy requires innovative, intelligent and sustainable technology solutions that generate a positive impact on the environment and help manage the digital transition."[15]

5. See https://www.theguardian.com/environment/2011/mar/02/when-discover-climate-change
6. See https://archive.org/details/sciencechallenge00nati/page/n3/mode/2up
7. See https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf
8. For a brief introduction to greenhouse gases, please refer to Annex A.
9. See https://www.ipcc.ch/site/assets/uploads/2018/03/WGIIAR5_SPM_Top_Level_Findings-1.pdf
10. See https://www.ipcc.ch/sr15/chapter/chapter-3/
11. See https://www.massaudubon.org/our-conservation-work/climate-change/why-we-care/greenhouse-gases
12. https://www.eia.gov/energyexplained/energy-and-the-environment/greenhouse-gases-and-the-climate.php
13. UN Emissions Gap Report 2019, see https://wedocs.unep.org/bitstream/handle/20.500.11822/30797/EGR2019.pdf
14. UN Trade and Development report 2019, see https://unctad.org/en/PublicationsLibrary/tdr2019_en.pdf
15. Letter from Telefónica CEO, see https://www.telefonica.com/ext/the-new-telefonica/letter-ceo-alvarez-pallete.pdf

2.2 International bodies are setting aggressive targets to slow global warming

The actions of individual industries and companies to combat climate change will take place within a framework set by governments and by international organisations such as the UN, the G20 and the European Union (EU).

The past few years have seen many of these groups setting ambitious targets for energy efficiency and emission reduction in a bid to reverse the dangerous trends outlined above, as summarised in Figure 2.1.

Figure 2.1: Selected targets on energy efficiency and emission reduction [Source: Analysys Mason, 2020]

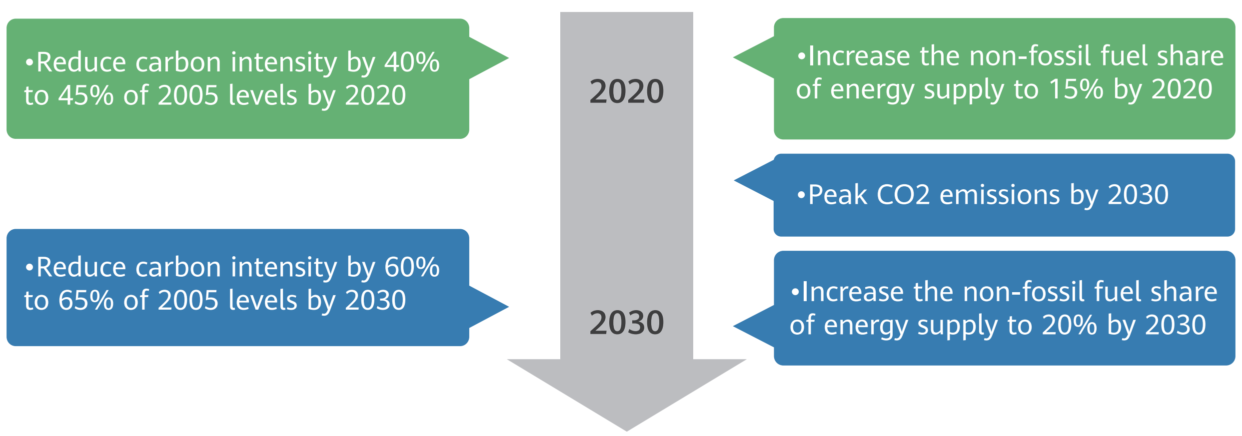
Organisation	Initiative	Summary of targets
United Nations	UN Framework Convention on Climate Change – Paris Agreement[16]	The Paris Agreement was signed in 2016 and as of February 2020, 189 members were party to it. Its key stated goal is to keep the increase in global average temperature well below 2ºC more than pre-industrial levels; and to pursue efforts to limit the increase to 1.5ºC more than pre-industrial levels. Among significant emitters, Iran and Turkey are non-signatories and the USA has announced its intention to withdraw. In one of its moderate scenarios, The UN's Inter-governmental Panel on Climate Change (IPCC) proposes a reduction of gross CO_2 emissions of 41% by 2030 relative to 2010, in conjunction with an increase in total energy production of 21%.
European Union	European Green Deal[17]	The European Green Deal's ambition is to have net-zero GHG emissions by 2050. Economic growth is to be decoupled from resource usage levels in order to reduce environment-related risks to society, health and the economy. Nearer term, key targets for 2030 are: • at least 40% cuts in GHG emissions (from 1990 levels) • at least 32% share for renewable energy • at least 32.5% improvement in energy efficiency. According to the European Commission, at least 25% of the EU's long-term budget should be dedicated to climate action. So far, it estimates EUR260 billion (USD290 billion) of additional annual investment is needed to accomplish the 2030 climate target.[18]
C40 Cities	Global Green New Deal[19]	C40 Cities is a cooperative group of major global cities led by their Mayors. In October 2019, a group of 96 cities including Copenhagen, Paris, Rio de Janeiro and Sydney agreed support for a Global Green New Deal, which would engage all city stakeholders as well as climate activists. The key objective is to set policies that will help to achieve the target set by the Paris Agreement (see above).
International Maritime Organisation (IMO)	Marine Environment Protection Committee (MEPC)[20]	In April 2018, the MEPC set out a vision to reduce GHG emissions from international shipping and eliminate them during this century. The initial target is to reduce annual GHG emissions by at least 50% by 2050 compared to 2008.

In addition to these international groups, some individual countries are taking actions to reduce emissions and increase the use of renewable energy. To date, 77 countries and major sub-national economies (such as Scotland) have set net-zero emission targets by 2050, and four G20 members (the EU, the UK, France and Italy)[21] are implementing legislation.

Some selective examples of advanced national programmes include:

- Canada's targets for reducing emissions are 17% by 2020, and 30% by 2030 (both compared to 2005)
- Japan's targets are a 3.8% reduction by 2020 (compared to 2005), and 26% by 2030 (compared to 2013)[22]
- Brazil's target is a 6% reduction by 2030 (compared to 2010)[23]
- China introduced an action plan in 2018, to encourage energy efficiency in major industries and reduce its reliance on coal. The power grid will be upgraded with efficient "ultra-supercritical" plants, which produce more energy with less reliance on coal.[24] The government is also encouraging households to make the transition from coal to natural gas.[25] A more-detailed timeline of targets is presented in Figure 2.2.
- India recognised low-carbon development as a key goal in its Twelfth Five-Year Plan in 2016[26] and it subsequently made a Paris Agreement pledge to reduce GHG emissions per unit of gross domestic product (GDP) by 33–35% by 2030 (compared to 2005).[27] India has also committed to ensuring that 40% of its installed power capacity is from non-fossil sources (renewables, hydroelectric and nuclear) by 2030.

Figure 2.2: China's overall targets [Source: government ministry websites, 2020]



16. See https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
17. See https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
18. See https://www.forbes.com/sites/anagarciavaldivia/2019/12/12/europes-green-deal-plan-to-become-the-worlds-first-climate-neutral-continent-by-2050/#2af0c892476f
19. See https://www.c40.org/other/the-global-green-new-deal
20. See http://www.imo.org/en/MediaCentre/HotTopics/GHG/Pages/default.aspx
21. See https://www.bbc.co.uk/newsround/50556433
22. See https://www.wri.org/resources/charts-graphs/ghg-emissions-targets-annual-reduction
23. See https://climateactiontracker.org/countries/russian-federation/
24. See https://chinapower.csis.org/china-greenhouse-gas-emissions/
25. Energy production and consumer evolution strategy 2016–2030, see http://www.gov.cn/xinwen/2017-04/25/5230568/files/286514af354e41578c57ca38d5c4935b.pdf
26. See https://www.sciencedirect.com/science/article/pii/S167492781630034X
27. See https://www.downtoearth.org.in/blog/climate-change/is-india-on-track-to-meet-its-paris-commitments-67345

3 Exploding demand for connectivity makes sustainability the key ICT challenge

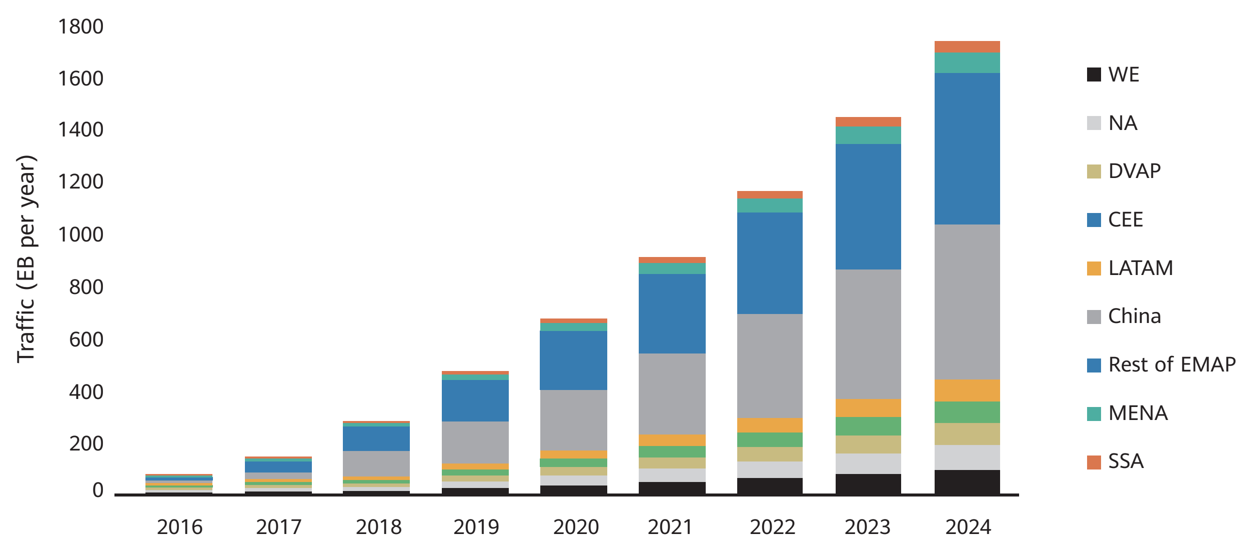
3.1 5G will help to support rising data usage in a sustainable way

Sustainability strategies within the ICT sector are setting aggressive targets for emissions reduction, but in doing so, they must assume continuing dramatic growth in usage of data and connectivity. This poses a significant challenge for developers of next-generation ICT technology, since they must reduce emissions while supporting a moving target in terms of consumption – and this requires a step change in energy efficiency. 5G will play a critical role in addressing this challenge, as it will be capable of supporting a significant increase in data usage by many industry sectors, while simultaneously enabling those industries to increase their energy efficiency by operating more flexibly and efficiently.

Many trends are contributing to the rising use of data transmitted over fixed and mobile networks. Changes in the way people work, play and communicate have been enabled by modern technology, and continue to drive its usage.

Cellular data traffic is projected to grow by 6.2 times between 2018 and 2024 in emerging economies, and by 3.1 times in developed markets over the same period.[28] By 2025 there are forecast to be 100 billion connections, including 40 billion smart devices.[29]

Figure 3.1: Cellular data traffic forecast, by region, 2016–2024 [Source: Analysys Mason, 2020][30]



28. Wireless data network traffic forecast, April 2020, see https://www.analysysmason.com/Research/Content/Regional-forecasts-/wireless-traffic-forecast-rdnt0/#16%20April%202019
29. Huawei Global Industry Vision (GIV) 2025, see https://www.huawei.com/en/press-events/news/2018/4/Huawei-Global-Industry-Vision-2025
30. WE = Western Europe, NA = North America, DVAP = Developed Asia–Pacific, CEE = Central and Eastern Europe, LATAM = Latin America, EMAP = Emerging Asia–Pacific, MENA = Middle East and North Africa, SSA = Sub-Saharan Africa.

The introduction of 5G will help to support this data usage, while helping to enable digital transformation across many industries, because of 5G's enhanced support for very low latency, high bandwidth and massive numbers of devices.

The combination of fixed and mobile 5G, with enhanced fibre to the home (FTTH) and Wi-Fi 6,[31] will all bring affordable broadband connectivity to more people and locations, while enabling a wide range of new use cases. This, in turn, will "enable further economic growth and pervasive digitalisation of a hyper-connected society", including the "Internet of Everything", as set out by the GSMA in its document Road to 5G: Introduction and Migration.[32]

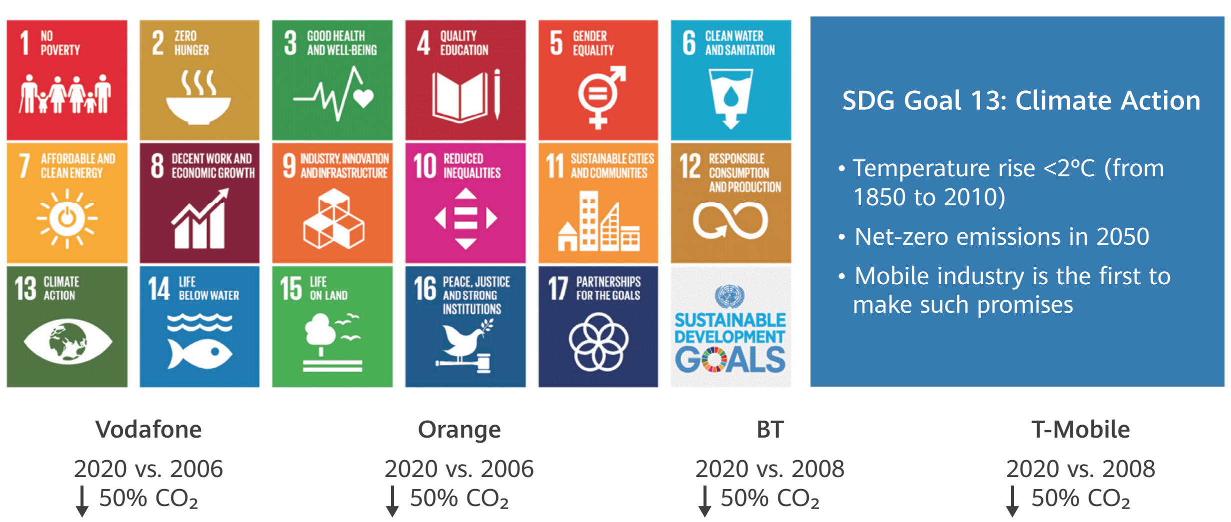
These ambitious visions for what 5G can deliver to industry and society will generate new business models for MNOs and drive rapid roll-out. According to Huawei's Global Industry Vision (GIV), by 2025 6.5 million 5G base stations will have been deployed, and there will be 2.8 billion 5G users worldwide.

3.2 5G must also help all industries to improve their own energy efficiency

However, it is essential that the 5G expansion does not just enable new digital processes and use cases for many industries – it also needs to help transform their energy efficiency. This is a central goal for the 5G community in the 2020s, as we will explore in Section 4. For instance, as part of the GSMA initiative, together with The Carbon Trust, more than 50 MNOs are now disclosing their carbon footprint, energy and GHG emissions via the internationally recognised CDP global disclosure system.

Indeed, the mobile industry was the world's first, in 2016, to commit to achieving the UN Sustainable Development Goals (SDGs), setting an industry goal of net-zero emissions by 2050.[33]

Figure 3.2: Wireless industry client action goals [Source: GSMA, 2019[34]]



31. Wi-Fi 6 is the latest generation of Wi-Fi standards, which is emerging in parallel with 5G.

32. GSMA, Road to 5G: Introduction and Migration, April 2018, see https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

33. See https://www.mobileworldlive.com/huawei-updates/legacy-rat-exit-help-sustainable-development-of-communication-networks/

34. GSMA 2019 Mobile Industry SDG Impact Report, see https://www.gsma.com/betterfuture/2019sdgimpactreport/

The ability of modern networks to make other industries, not just telecoms, more energy efficient is known as the "enabling effect". By increasing connectivity and efficiency and driving behaviour change in all sectors, mobile networks help to avoid emissions. Even before 5G, the effect was visible – in 2018, according to the GSMA, the enabling effect of mobile communications globally was estimated to be around 2,135 million tonnes CO_{2e} – similar to the total GHG emissions by Russia in 2017.[35]

According to the ITU's SMART 2020 report,[36] the carbon footprint of the ICT industry amounts to 2% of global emissions, with a compound annual growth rate (CAGR) of 6%. However, that growth is offset by the enabling effect, because ICT allows other industries to benefit from increased energy efficiencies. The ITU report found that this ICT-enabled opportunity would be equivalent to 15% of all global emissions by 2020.[37]

Of course, 5G is part of a broader evolution of ICT platforms which encompasses several trends that will be significant for adopting a new approach to energy consumption.

These flexible, agile 5G networks also help vertical industries to operate in new ways. Huawei's Global Industry Vision 2025[38] provides examples of the impact of intelligent cloud-based connectivity on several industries, which are explored further in Section 5. For instance, in the transportation industry, more than 200 million vehicles will be connected to 5G networks and 100% of new vehicles will be connected to the internet by 2025. When intelligence is incorporated into manufacturing, ICT will converge with operational technology (OT) at an accelerated pace. This will generate positive returns for innovation, the industry, the value chain and the ecosystem as a whole.

To rise to the dual challenge of supporting high data usage and high energy efficiency, MNOs are rethinking their usage of energy and their impact on the environment. This was summed up in December 2019 by José María Álvarez-Pallete, CEO of Telefónica, who said: "The central axis of our strategy requires innovative, intelligent and sustainable technology solutions that generate a positive impact on the environment and help manage the digital transition."[39]

35. GSMA, The Enablement Effect, February 2020, see https://www.gsma.com/betterfuture/wp-content/uploads/2019/12/GSMA_Enablement_Effect.pdf

36. ITU, Summary of SMART 2020 Report, see https://www.itu.int/md/T05-FG.ICT-C-0004/en

37. See https://www.itu.int/dms_pub/itu-t/oth/4B/04/T4B0400000B0011PDFE.pdf

38. See https://www.huawei.com/en/press-events/news/2018/4/Huawei-Global-Industry-Vision-2025

39. Analysys Mason, 'Sustainability rises to the top of European operators' agendas', December 2019, see https://www.analysysmason.com/Research/Content/Comments/european-operator-sustainability-rdns0/

4 5G can significantly improve the energy efficiency of mobile broadband

As outlined in Section 3, the rising demand for connectivity and data is driving the usage of broadband networks, and the proportion of that traffic carried on cellular networks is increasing. This trend will intensify as 5G deployments continue. At the same time, however, operators now need to consider energy efficiency just as much as they consider data and cost efficiency, when they plan and optimise their networks.

Telecoms industry associations are also putting targets and roadmaps in place to help support that growth in data traffic while achieving sustainability goals. For instance, 3GPP's 5G specification calls for a 90% reduction in energy use compared to 4G technologies,[40] while the ITU has published a set of toolkits,[41] announced in February 2020, to support ICT companies in reducing GHG emissions by 45% by 2030 – the level the ITU believes is required for compliance with the Paris Agreement. According to the GSMA, 29 operator groups (accounting for 30% of all mobile connections) worldwide are already committed to science-based targets for emissions reduction, such as those included in a set of ITU standards published in 2020.[42]

A significant factor in achieving their goals will be the deployment of 5G. 5G provides some inherent energy improvements compared to previous generations of mobile technology, and to maximise the effects, a multi-layered approach can be taken to its deployment. This includes enhanced power management at equipment level; new siting solutions such as liquid cooling, to reduce the need for air conditioning; and flexible use of resources such as spectrum. Together, these strategies combine to provide a brand-new way to deploy and run mobile networks, which can achieve per-bit energy efficiency up to 50 times higher than with 4G.[43]

4.1 5G's power efficiency will be unlocked by a multi-layered approach to network deployment

On a per-bit basis, 5G standards are more power efficient than their predecessors, but by 2030 5G networks will be supporting up to 1,000 times more data than 4G did in 2018. To support the rising use of cellular connectivity in the 5G era, while reducing energy consumption and emissions on a per-bit basis, changes are needed at all levels of the network to support the maximum end-to-end effect. It will be crucial for MNOs to adopt approaches to network planning, deployment and management that have energy efficiency as the leading criterion and are implemented end to end.

Leveraging the innate spectral efficiency of the 5G air interface and power amplifier is important, of course, but further efficiencies can be combined across three levels – the base-station equipment level, site level and network level. There is a widening range of techniques that can be used across these three levels of 5G network operation, some of which are summarised in Figure 4.1 below:

40. GSMA, Energy Efficiency: An Overview, see https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/
41. See https://www.itu.int/en/mediacentre/Pages/PR04-2020-ICT-industry-to-reduce-greenhouse-gas-emissions-by-45-percent-by-2030.aspx
42. See https://www.edie.net/news/6/Science-based-pathway-for-net-zero-emissions-established-for-telecoms-sector/
43. Huawei 2012 Lab, see https://www.huawei.com/en/news/2019/9/global-ict-energy-efficiency-summit-5g-network

Figure 4.1: Techniques to improve energy efficiency in 5G network operations [Source: Analysys Mason, 2020]

Layer of operation	Selected power efficiency mechanism
Base-station equipment	• Efficient 5G power amplifiers • Base-station automatic wake-up/sleep including shutdown on symbol, channel or carrier basis • AI prediction to wake base stations pre-emptively
Site	• Renewable energy sources for on-grid and off-grid sites, including solar power (the cost of which has fallen by as much as 80% in the last ten years) • Smart lithium batteries • One site, one cabinet • Liquid cooling to reduce the need for air conditioning
Network	• Flexible cooperation between 5G and LTE spectrum and radios, to deliver the right amount of capacity for a given task, at the lowest practical power level • Intelligent power management from end to end • Hierarchical caching, where data and content that is used frequently is cached close to the user – perhaps in an edge compute node – rather than at the macro cell • Device-to-device (D2D) communications is a 5G technique which allows for connectivity without involving base-station hardware

Together, these techniques can greatly increase the energy efficiency of cellular networks, while reducing GHG emissions.

The device side will be important too, with new techniques to power them efficiently (the goal for 5G device manufacturers and MNOs is to increase battery life to at least three days for smartphones and up to 15 years for cellular IoT devices, in order to make some emerging use cases practicable[44]).

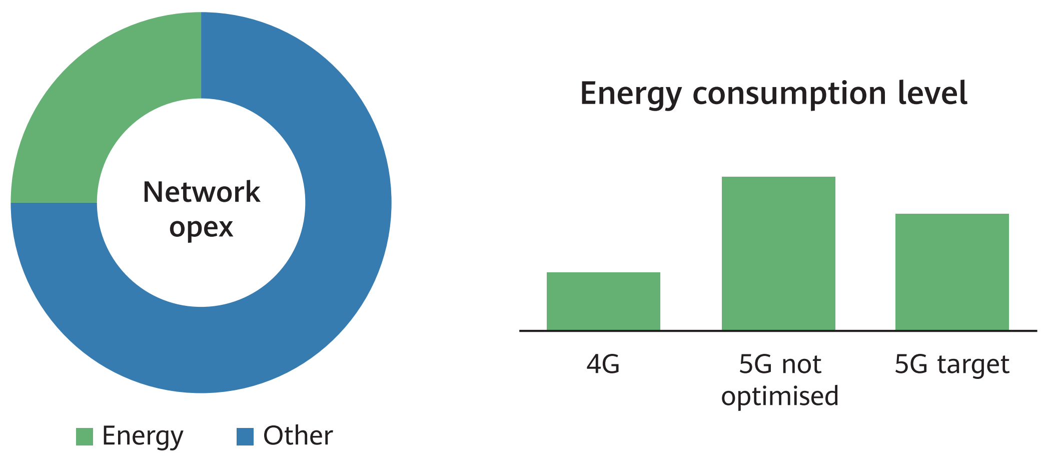
Without these best practices, as mentioned in Figure 4.1, a 5G network – despite improved bit/joule power consumption – could typically use over 140% more power than a 4G one with similar coverage area,[45] because of the greater density of base stations, antennas, cloud infrastructure and user devices. By contrast, if an MNO adopts the full range of power and site optimisation techniques for its 5G roll-out, power consumption can be kept stable even in a denser network.

As well as helping MNOs to meet sustainability targets, the strategies mentioned above, if deployed holistically, will significantly reduce their operating costs, compared to deploying 5G in the same way as 4G. Some estimates put the current annual global energy cost for running mobile networks at about USD25 billion,[46] but MNOs are targeting reductions of up to 40% in their energy bills by 2030, according to a consensus of 62 MNOs surveyed by Analysys Mason.

The impact of intelligent energy management on MNO costs is illustrated in Figure 4.2, for the case of Orange.

44. See https://www.a10networks.com/blog/5g-energy-efficiency-explained/
45. See https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7448820
46. See https://www.ericsson.com/495d5c/assets/local/about-ericsson/sustainability-and-corporate-responsibility/documents/2020/breaking-the-energy-curve-report.pdf

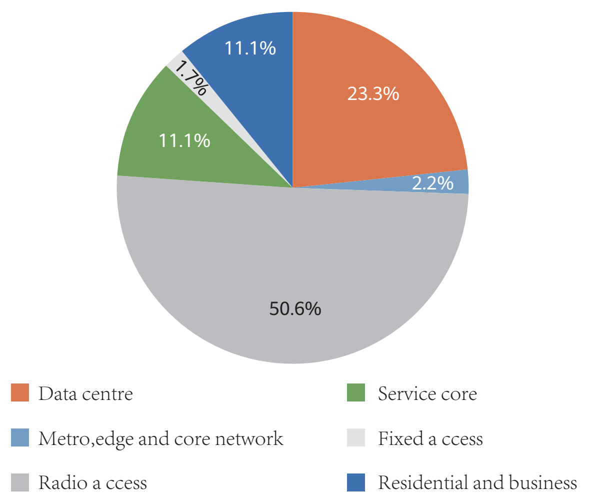
Figure 4.2: Impact of energy optimisation on operating costs [Source: Orange, 2019[47]]



4.2 The largest efficiencies can be achieved at base station and site levels

The most challenging elements of a mobile network, in energy consumption terms, are the base stations, which account for about 57% of total power usage of a typical cellular network.[48] By 2025, that figure will be lower as 5G becomes more prevalent, but the radio access network (RAN) will still be the biggest consumer of energy. For a converged operator, the RAN could account for around 50% of its total network energy consumption across fixed and mobile in 2025, according to a study by three European universities (see Figure 4.3).

Figure 4.3: Energy consumption breakdown by network element, 2025 [Source: University of Split, 2019[49]]



Within the base station, the largest energy consumer is the radio-frequency (RF) equipment (power amplifier plus transceivers and cables), which typically uses about 65% of total energy, followed by cooling (17.5%), digital signal processing/baseband (10%), and the AC/DC converter (7.5%).

47. See https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/
48. See https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6679251/
49. University of Split, see https://www.mdpi.com/1424-8220/19/22/4864/htm

Since base stations account for such a high percentage of power consumption, it is imperative that they only consume power when they are actively handling data and signalling, and that MNOs implement their sites with a network-wide smart power system. Traditional (4G and earlier) mobile networks spend only about 15% to 20% of overall power consumption on actual data transfer. The rest is wasted because of heat loss in power amplifiers, equipment kept running when no data is being transmitted, and inefficient rectifiers, cooling systems and battery units.[50] New approaches need to eliminate the energy wastage, or harness that wasted power for other purposes. For example, cell switch-off techniques can reduce base-station energy consumption by up to 40% by turning RF chains[51] off and only keeping backhaul links alive; the base station is only changed to active mode when a signal is sensed.[52]

One MNO found that turning off the power amplifier symbol at a site could cut power consumption by more than 7%, without any service degradation. A study by McKinsey found that the biggest impact on RAN energy consumption and cost, in a typical MNO scenario, came from two actions – procuring green energy, and introducing smart shutdown techniques across multiple sites and radio networks. These techniques will increasingly be coordinated from the cloud, and in future, shutdown decisions will be aided by AI. The McKinsey study found that a combination of different techniques could reduce energy consumption by almost half, as shown in Figure 4.4.

Figure 4.4: Indicative examples of techniques to reduce RAN energy consumption [Source: McKinsey, 2020[53]]

Technique	Potential reduction in energy consumption
Site-level and multisite sleep and shutdown, adaptive power	8% of total
2G/3G shutdown	3% of total
New cooling systems, reflective paint, insulation	3% of total
Purchase green energy	30% of total
Competitive energy sourcing	5% of total

50. See https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-case-for-committing-to-greener-telecom-networks
51. RF chain refers to a cascade of electronics components used for radio frequency engineering.
52. See https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6679251/
53. See https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-case-for-committing-to-greener-telecom-networks

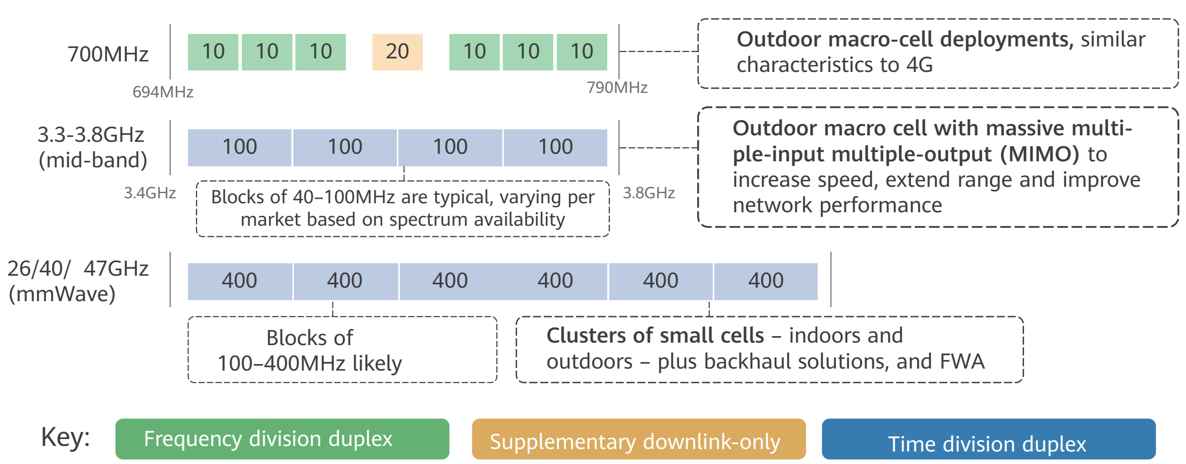
4.3 At the network level, the right combination of spectrum and radios will maximise efficiency

Two important strategies for reducing energy consumption at network level are to use the most efficient combinations of spectrum bands available, and to minimise the number of radio technologies in use (through selective sunsetting, or dynamic spectrum usage).

The first generation of 5G roll-outs are mainly taking place in mid- and low-band spectrum, using a similar site grid to that of 4G. However, as the demand for data consumption continues to rise, some MNOs will move to augment capacity by adding millimetre-wave spectrum in dense hotspots. On a per-bit basis, spectrum in higher bands is the most energy efficient, but this requires more base stations than when using low bands. Therefore, careful network planning is important to enable MNOs to achieve the optimal balance between capacity and coverage, and to deliver this with the lowest possible power consumption.

By using the best combination of low and high bands for a given usage scenario, the spectral efficiency of 5G could see it consume just 10% of the energy of today's 4G networks on a per-bit basis, by 2030.[54] An illustration of the multiple spectrum bands used by 5G is presented in Figure 4.5.

Figure 4.5: Multiple spectrum bands used in 5G [Source: Analysys Mason, 2020]



Another network-level approach to saving energy is to 'sunset' older radio technologies, which are less energy efficient than 5G.

Many MNOs are currently running 2G, 3G, 4G and 5G networks in parallel. Sunsetting the legacy networks can significantly reduce total network energy consumption because older technologies, with lower energy efficiency, are removed; and the total number of antennas and base stations is reduced, together with their requirement for space and power.

As of January 2020, a total of 23 GSM networks run by national MNOs had been switched off completely, as well as four networks using regional 2G-like technologies (NTT DoCoMo's PDC in Japan, and the Personal Handyphone System (PHS) used for low-cost services in China, Japan and Thailand). There have also been five total sunsets of 3G (W-CDMA) networks and eight complete sunsets of CDMA networks.[55]

54. Huawei, Curtailing carbon emissions – can 5G help?, see https://carrier.huawei.com/~/media/CNBGV2/download/program/Industries-5G/Curtailing-Carbon-Emissions-Can-5G-Help.pdf

55. TechUK, see https://www.techuk.org/component/techuksecurity/security/download/16165?file=The_Potential_Impact_of_Switching_Off_2G_in_the_UK_Real_Wireless_Report_for_the_UK_SPF_16165.pdf&Itemid=181&return=aHR0cHM6Ly93d3cudGVjaHVrLm9yZy9pbnNpZ2h0cy9yZXBvcnRzL2l0ZW0vMTYxNjUtdGhlLXBvdGVudGlhbC1pbXBhY3Qtb2Ytc3dpdGNoaW5nLW9mZi0yZy1pbi10aGUtdWs=

Firm dates before 2026 have been set for sunsets of a further 15 GSM, 13 W-CDMA and three CDMA networks. The main rationale for these closures is to release 2G spectrum for later-generation technologies which are more efficient in terms of operating costs, performance and energy efficiency.

Where a full sunset of a 2G or 3G network is impractical, because a high number of users or machine-to-machine devices still rely on these connections, other approaches are emerging to improve the energy efficiency of a multi-RAT[56] network, as well as free up more spectrum for 5G. These include:[57]

- SingleRAN platforms, in which a single base station supports 2G, 3G, 4G and 5G, replacing multiple pieces of equipment and reducing total power consumption
- Dynamic spectrum sharing (DSS), which allows 5G to make use of older networks' spectrum, sharing it on a dynamic basis according to the users which are present. This boosts spectrum and energy efficiency for 5G even where an MNO is not ready to sunset the older networks and refarm all the spectrum.

4.4 5G's energy efficiency will be amplified by emerging power management systems

New approaches to power efficiency and management are emerging which, though not 5G-specific, will be adopted in future to enhance the systems described above and make 5G networks even more power efficient. In particular, AI will enrich the improvements achieved at all three levels (i.e. base station, site and network).

Examples of these emerging techniques include those outlined below.

Energy harvesting

Energy harvesting technologies 'scavenge' energy from the local environment or even from RF signals themselves, providing renewable energy to power huge numbers of IoT devices.[58]

Artificial intelligence/machine learning (AI/ML)

AI/ML is already used extensively in the cloud world to reduce energy consumption, by turning elements on and off pre-emptively rather than waiting for traffic levels to change before reacting.

AI-based decisions are helped by the emergence of new ways to capture data, from passive infrastructure and power supplies as well as the base stations' in-built sensors. Many tower operators are installing IoT sensors on their infrastructure to monitor energy usage and quality of service, in real time. For example, tower operator Telxius has deployed infrastructure IoT systems which inform AI-enabled decision processes.[59] A typical cell tower deployment includes 8 to 10 sensors for equipment such as HVAC (heating, ventilation and air conditioning) and off-grid power units.

In 5G networks, MNOs are starting to adopt AI/ML techniques to support network automation in an intelligent, proactive way. For instance, self-organising networks (SON) increasingly include AI capabilities to help them make near real-time decisions about changes to handover, spectrum usage and, of course, power.

In the disaggregated 5G core and RAN, there will be dynamic scaling of resources to support a steady stream of new

56. Multiple radio access technology, whereby a mobile device can connect to more than one type of wireless network, i.e. 3G and 4G.

57. Analysys Mason, Spectrum scarcity and heavy traffic drive emerging Asia–Pacific operators to consider 2G/3G migration, see https://www.analysysmason.com/Research/Content/Comments/EMAP-2G-3G-migration-RDNS0-RDRP0/#05%20September%202017

58. See http://www.whebgroup.com/5g-and-sustainability/

59. See https://www.sigfox.com/en/news/sigfox-monitors-telxius-telecommunication-towers

functionality and locations. AI-based rules will be needed to achieve the complex tasks of allocating resources in the most power-efficient way and deciding when elements can be shut down.

For example, Vodafone has used AI to optimise network coverage in response to hotspots and improve handovers between cells, thereby reducing network energy consumption by around 15%.[60] In South Africa, Huawei's PowerStar AI-based energy saving solution was shown to reduce the average power consumption of a base station by over 11.6%.

End-to-end intelligent power systems

The combination of cloud infrastructure and AI in 5G networks will enable MNOs to move towards fully intelligent power systems, with a more complete view of the network than just the 5G RAN and core alone. A cloud-based system can co-ordinate base stations, power supplies, edge infrastructure, backhaul units and other equipment across multiple layers and domains, so that power supplies become intelligent and efficiencies are made throughout the network (the "bit manages the Watt" concept, as Huawei terms it).

Over time, full AI-based intelligent energy will emerge, in which different levels of power are automatically made available depending on the time of day or application. In this scenario, power availability (PAV) levels will be identified for different applications using the MNO's network, according to their criticality. Those with the highest levels of criticality, such as telemedicine, can be assigned the highest level of network battery availability (smart batteries will have a higher threshold before they power down).

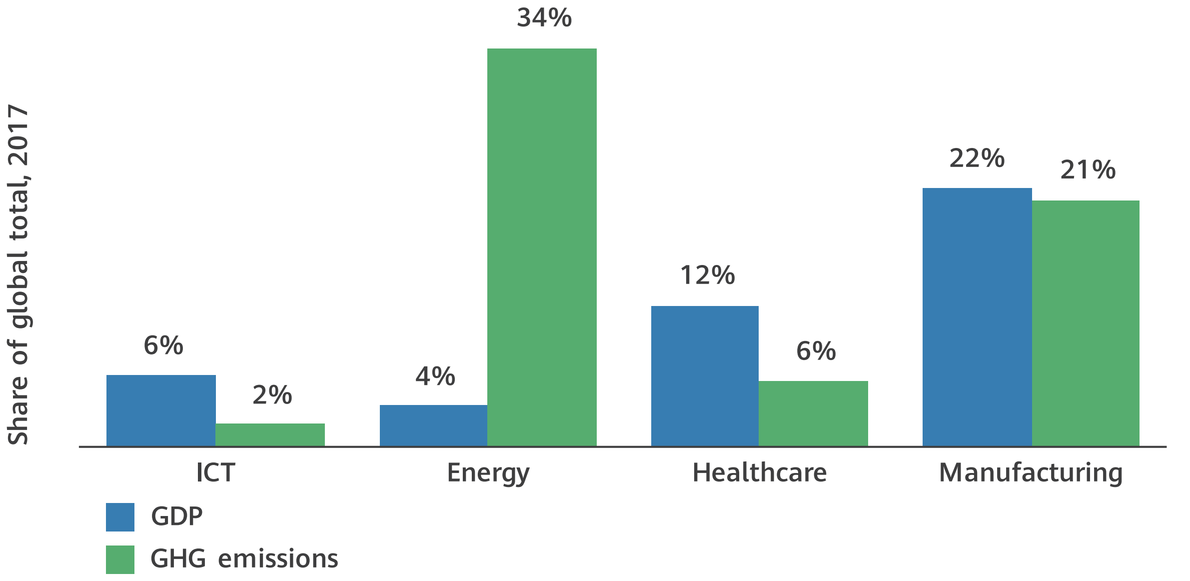
60. GSMA, AI in Network Use Cases in China, see https://www.gsma.com/futurenetworks/wp-content/uploads/2019/10/AI-in-Networks-Use-Case-V.03-231019-Document.pdf

5 5G and ICT can improve energy efficiency in many industry verticals

The ICT industry's contribution to GHG emissions is less than 2% of the global total, while it accounts for about 6% of total value added[61] among OECD countries[62] and for over 7% of China's GDP.[63] That relative ratio means that merely making telecoms networks more energy efficient will only have a minor effect on climate change. 5G will only have a meaningful effect on global energy usage if it has a significant impact on the energy efficiency of other sectors.

In this section, we present detailed modelling results from lifecycle assessment (LCA) and operation parameter comparison in three sectors which have high GHG emissions, namely energy (Section 5.2), healthcare (Section 5.3) and manufacturing (Section 5.4), to demonstrate quantifiable benefits brought about by 5G.[64] These three sectors account for around 61% of global GHG emissions, but 38% of global GDP, as illustrated in Figure 5.1. We also provide qualitative case studies on smart-city and transportation use cases.

Figure 5.1: Contribution of selected industries to global GDP and GHG emissions, 2017 [Source: national and international agencies, 2020[65]]



61. Value added refers to the value generated by producing goods and services, measured as the value of output minus the value of intermediate consumption.

62. OECD, see https://data.oecd.org/ict/ict-value-added.htm

63. The China Academy of Information and communications Technology, see http://www.caict.ac.cn/pphd/zb/ict/2019/am/201812/t20181218_190874.htm

64. For further details of the methodology, assumption and data sources used in the LCA modelling, please refer to Annex B. It should be noted that results for GHG emission reduction obtained through the LCA modelling are based on 5G commercial deployments from China and reflect the specific characteristics of that country: for this reason, different results could be obtained if the same use cases were modelled for deployments in other countries.

65. See https://energypost.eu/dnv-gl-energys-shrinking-share-of-growing-global-gdp-shows-how-we-can-afford-transition/, https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data, https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS, https://www.carbonbrief.org/healthcare-in-worlds-largest-economies-accounts-for-4-of-global-emissions, https://data.worldbank.org/indicator/NV.IND.TOTL.ZS and https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

As discussed in the following subsections, our modelling and analysis demonstrate that 5G could have a significant environmental impact on these industries (measured in terms of GHG reduction), enabling new ways of operating that would be impossible, or unaffordable, without 5G.

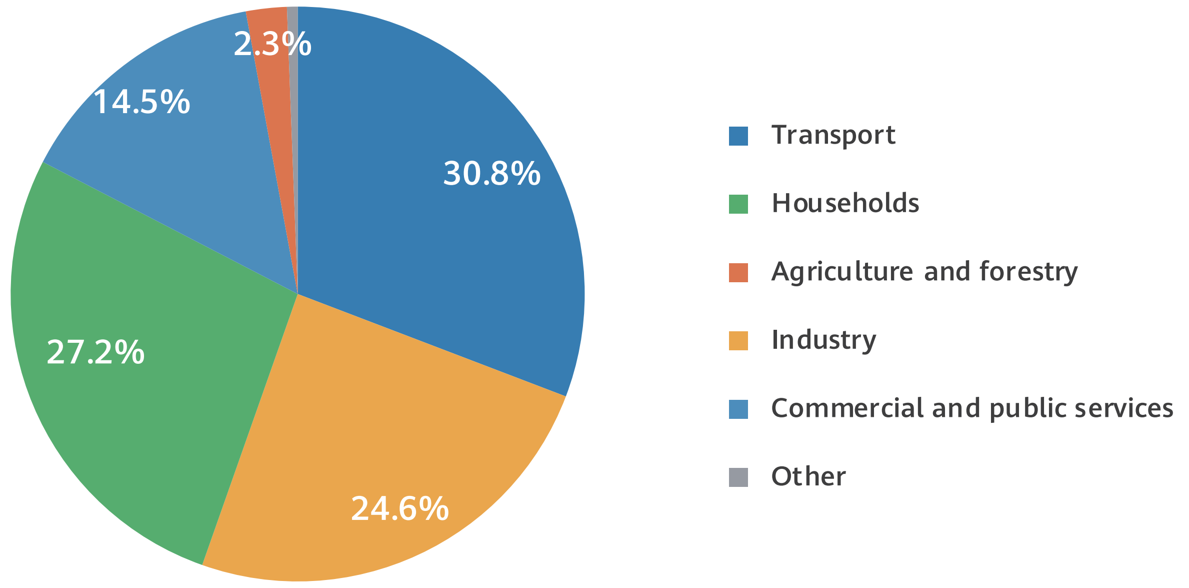
We have also found that, in these sectors which most urgently require energy efficiency transformation, 5G can have a significant effect, when combined with other technologies such as cloud, AI and IoT, and with other changes such as adoption of renewable energy sources.

5.1 The combination of 5G and ICT technologies such as AI, IoT and cloud can improve energy efficiency in other industries

As described in Section 4, considerable efforts are being made to reduce 5G energy consumption on a per-bit basis. While it is important for 5G networks to be energy efficient in themselves, the really transformational impact will come when 5G can enable many other industries – including those with significantly higher power consumption levels than telecoms – to operate in far more energy-efficient ways. According to the ITU's SMART 2020 report,[66] the scale of ICT-enabled energy efficiency across all industries was found to be equivalent to 15% of all global emissions by 2020.

As figures for the EU indicate (see Figure 5.2), the biggest consumers of energy are transport, industry and households, so if technology can increase efficiency and reduce emissions in these areas of life, it will have a bigger impact on climate change than the deployment of 5G networks per se.

Figure 5.2: Energy consumption by sector in the EU [Source: Eurostat, 2017]



The enabling effect, as outlined in Section 3.2 earlier, relies on changes to processes and behaviour which are supported by a high-capacity, ubiquitous and low-latency mobile network. Some examples of how such a network can reduce an industry's energy consumption include:

- Support for smart energy management for all sectors, including the enhancement of smart-grid and smart-metering systems with 5G connectivity, IoT-based monitoring and AI-enabled analytics to support actions such as predictive switch-off of machinery, city infrastructure or household appliances
- A reduction in the requirement for office space or travel because of improved conferencing, including virtual reality, which means employees can work from anywhere
- Efficient 'just-in-time' supply chains enabled by constant monitoring of goods, vehicles and facilities throughout the chain, with low wastage and proactive planning
- Intelligent management of movement of vehicles carrying people and goods within smart cities, to reduce unnecessary journeys
- Support for smart power management in buildings and infrastructure.

These factors are enabled by a combination of high-speed, low-latency 5G and other technologies such as AI/ML and edge cloud. Together with billions of connected IoT devices, these support hyperconnectivity, allowing users to interact in new ways that have lower energy overheads – avoiding the need for travel, for instance. This combination of technologies also underpins network slicing, which allocates precisely the network and computing resources that are required for a certain industry and a certain task, for as long as they are required: once the task is over, the virtual slice of resources can be switched off and be re-used somewhere else. Slicing will allow industries to have dedicated virtual networks suited to their requirements, but without the need to over-provision them, and so waste resources.

Some examples of the 5G enablement effect, when combined with other technologies, are given below.

- The UK government has committed to reduce energy consumption and carbon emissions in the long term. The Department for Transport has identified vehicle monitoring and energy efficiency as critical issues in the fleet management sector. To address these issues and optimise energy consumption, the government launched several telematics initiatives. For example, telematics systems have been deployed in 600 police operational vehicles in order to measure fuel consumption and GHG emissions. The benefits generated through use of these systems include 1) a reduction of 120 vehicles, after identification of the vehicle utilisation rate; and 2) a reduction in GHG emissions and fuel cost savings of more than GBP382,000.[67]

- As a result of government initiatives and company environmental sustainability targets, a major financial institution in Taiwan has set a goal of reducing its GHG emission by 30% between 2016 and 2050. To improve its energy efficiency and increase its operational sustainability, the company has implemented AIenabled building energy optimisation solutions across its 189 branches. The solutions successfully have reduced the average electricity usage of each branch by between 5% and 15%. Energy consumption per employee also decreased by 9.1% in 2018.[68]

- A cement production factory in Slovenia faced the challenge of adapting its facilities and infrastructure to comply with European energy-related regulatory requirements. The factory consumed more than 90GWh of electricity and 8GWh of gas annually. In 2017, it launched an energy management project involving a smart-energy solution based on wireless LoRaWAN technology. The solution increased visibility of the factory's energy consumption within each production process and enabled more accurate real-time monitoring. After deploying the solution, the factory successfully reduced its GHG emissions and energy consumption.[69]

66. ITU, Summary of SMART 2020 Report, see https://www.itu.int/md/T05-FG.ICT-C-0004/en

67. UK Department of Transport, How fleets can use technology to manage driver behaviour and vehicle efficiency, see https://energysavingtrust.org.uk/sites/default/files/EST_Telematics%20guide.pdf

68. See https://www.hnfhc.com.tw/HNFHC/csr/a.do?id=3b662943d0000002a113

- A property developer in Hong Kong has established a ten-year plan to promote sustainable development, with the aim of reducing GHG emissions by 35% by 2025. It collaborated with an AI system and platform provider to construct an AI-enabled "Green Building" in the city. The AI-based data platform enabled energy savings to be made through predictive usage and automated operation of utility system, and predictive maintenance. The building has successfully reduced the energy consumption associated with its daily operations.[70]

5.2 5G and improved sustainability in action – Energy

This section presents a detailed case study on the implementation of 5G unmanned aerial vehicles (UAVs) for gas-pipe inspection in Shanghai, China, looking at both operational and commercial efficiency as well as the environmental impact through the prism of lifecycle assessment. The results of this local initiative provide the basis for estimating the impact of adopting 5G UAVs for gas-pipe inspection on a global scale.

Introduction to the 5G UAV case study

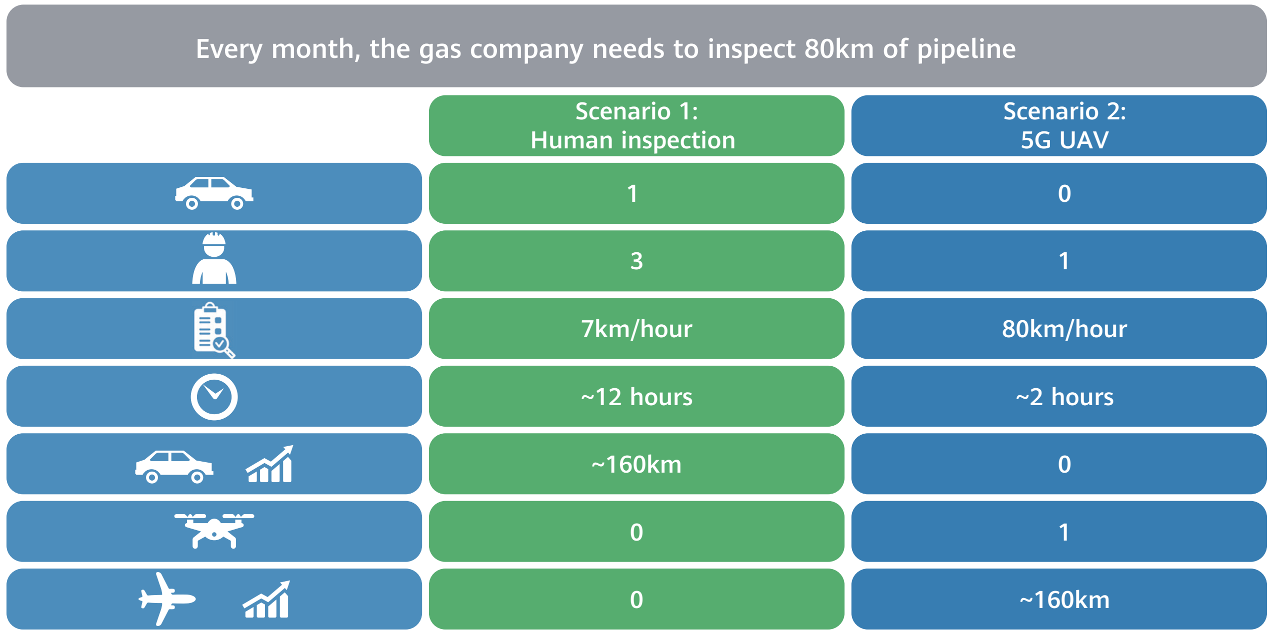
Remote controlled UAVs can operate across a significantly wider area than land-based vehicles in order to relay high-quality images in real time for processing/analytics. This can make it much easier to inspect or survey sites that may be dangerous or difficult to access, thus alleviating safety concerns related to the substantial time and intensive labour required for human inspection.

UAV inspection requires ultra-reliable low-latency communication (URLLC) connectivity, high symmetric throughput and advanced image processing supported by mobile edge computing (MEC), which the current generation of 4G/LTE networks cannot support.

In 2019, a Shanghai-based gas company began using a UAV, powered by aviation diesel, to carry out inspections of large sections of its gas pipeline. The UAV was equipped with 5G CPE and high-quality 4K cameras. This solution replaced the traditional approach of using a petrol-powered vehicle plus a team of three inspectors. Figure 5.3 illustrates the operation parameter comparison between the business-as-usual (BAU) scenario (Scenario 1) involving human inspection and a 5G UAV scenario (Scenario 2).

69. See https://www.smart-energy.com/industry-sectors/policy-regulation/smart-factory-one-of-the-top-10-most-energy-efficient/
70. See https://www.hkgbc.org.hk/tch/news-events/greenmag-plus/2020/Jan-2020/Jan-2020.jsp

Figure 5.3: Operation parameter comparison for gas-pipe inspection [Source: Analysys Mason, 2020]



Management observed that the number of staff and vehicles as well as the working hours needed to complete the routine inspection were the areas in which the most significant efficiency gains could be made by switching from human inspection to UAV. With contiguous 5G network coverage, an inspector controls the UAV remotely as it flies over the gas pipe and transmits its video feed in 4K. The processing and assessment of follow-up actions or updates to the events database in the vicinity of the UAV is carried out in real time, enabled by mobile edge computing. Throughout the inspection, the UAV flies at a steady cruising speed of 80km per hour. In contrast, the human inspection is carried out at only 7km per hour on the outward journey, with the vehicle able to drive at full speed (80km per hour) on its return journey to the starting point. The 5G UAV approach translates into a six-fold efficiency gain, in terms of working hours per inspection. In addition, inspection staff no longer need to get close to the pipe themselves, which eliminates their exposure to potential hazards and bad weather.

As well as the efficiency gains, the adoption of 5G UAV has led to a sizeable reduction in the natural resources required to operationalise the inspections. Figure 5.4 presents a more-detailed comparison of natural resources needed for one round of inspection under the two scenarios.

Figure 5.4: Comparison of natural resources consumption for one round of inspection [Source: Analysys Mason, 2020]

	Scenario 1: Human inspection	Scenario 2: 5G UAV
Petrol for vehicles	9 litres	n/a
Diesel for UAVs	n/a	0.8 litres

The fuel economy of UAVs is significantly better than that of petrol-powered vehicles: while a litre of petrol can sustain a vehicle for around 6km on average, a litre of aviation diesel can power a UAV for 195km, more than enough for one routine inspection. Given that UAVs also take the optimal route, the amount of fuel required for one round of inspection is very substantially reduced.

Environmental benefits measured through lifecycle assessment (LCA)

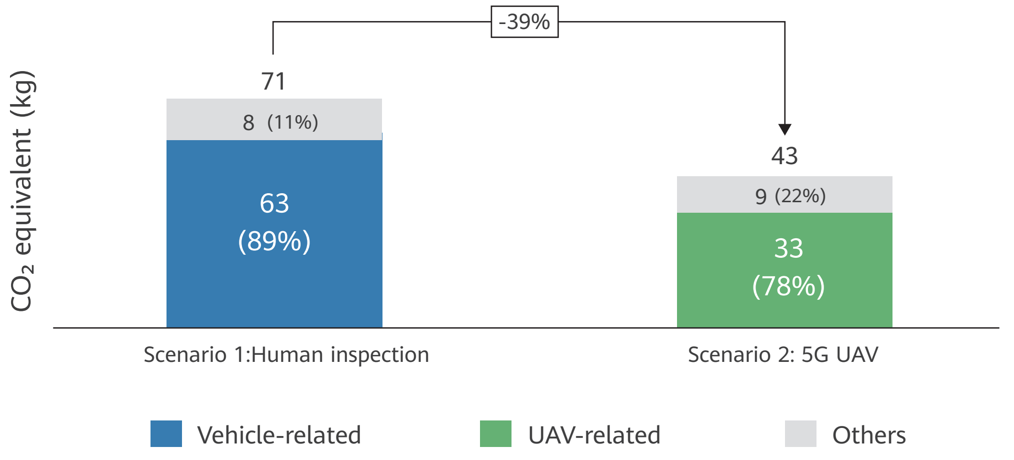
Analysys Mason has also used LCA to evaluate the environmental benefits of adopting 5G-equipped UAVs. LCA quantifies the environmental impact, measured as GHG in terms of CO_2 equivalent. (For further details of the methodology, please refer to Annex B.)

The LCA comprehensively accounts for the carbon footprint of key inputs and products used in both scenarios across all stages – from supply chain (including raw material extraction, production, distribution and end of life) to direct use – all adjusted to reflect their usage in each scenario.

In the case of gas-pipe inspection, the LCA analysis includes GHG emissions resulting from:

- driving of the vehicle during human inspection, including tail-pipe emissions, the petrol fuel supply chain and a proportionate allocation of embodied emissions resulting from production and maintenance of the vehicle over its lifetime
- use of the UAV, including emissions during flight, the aviation diesel fuel supply chain and a proportionate allocation of emissions resulting from its manufacture and maintenance over its lifetime
- use of smartphones and personal computers (PCs), including a proportionate allocation of emissions resulting from their manufacture and maintenance over their lifetimes
- use of wireless networks for 5G CPE on the UAV, including a proportionate allocation of emissions resulting from manufacture over the CPE's lifetime.

Figure 5.5 compares the results from the two scenarios for one round of routine inspection



The GHG emission reduction achieved by 5G UAV is nearly 40%.

Vehicle-related emission consists of tail-pipe and the petrol supply chain, as well as the embodied emissions in the production and maintenance of vehicles. Of these, tail-pipe emissions are the biggest single source, contributing to 71% of total GHG emissions in Scenario 1. Emissions related to the supply chain of the petrol used are just under 20% of the total. Due to the short period of usage for one monthly inspection relative to the entire lifespan of the vehicle (i.e. ~160km vs. 250,000km), the embodied emissions attributable to the vehicle's production and maintenance account for about 10% of the vehicle-related total.

UAV-related emissions are about 50% the level of vehicle-related emissions, both covering the same distance of 160km for the inspection. The GHG emission reduction could be even greater, if the length of pipes subject to inspection was extended, but still within the operating range of the UAV.

From further investigation of the breakdown of GHG emission sources for 5G UAV, we note that its composition differs significantly from emissions from a petrol-powered vehicle, especially among the supply chain for fuels, and relevant production and maintenance.

Due to the higher fuel economy of aviation diesel, the GHG emission associated with this supply chain accounts for less than 1% of UAV-related emissions. In contrast, because a UAV motor can only run for a small number of flight hours before it is replaced, the embodied emissions associated with UAV production and maintenance contribute around 20% of UAV-related emissions, compared with 10% for equivalent components in the petrol-powered vehicle.

The combined relative contributions from other key inputs – such as smartphones, PCs and 5G network – are insignificant, in the low single digits.

Estimated impact if 5G UAVs are adopted worldwide

Our analysis demonstrates a significant environmental impact from deploying 5G UAVs for natural gas-pipe inspection, aside from the obvious improvements in operational and business efficiency. This is particularly relevant as 5G roll-out gains momentum in more and more countries, and as the economies of scale from procuring industrial UAVs improve.

GHG emissions associated with human inspection of a unit length of pipe would certainly differ between mature and emerging economies, due to variations in manufacturing and emission standards for vehicles (the largest source of GHG emissions, as identified earlier). Meanwhile, the GHG emission associated with inspection via 5G UAVs could remain unchanged from the value calculated in the case study in Shanghai due to the highly concentrated market landscape for industrial UAV manufacturing.

The length of gas pipe addressable by 5G UAVs, across both mature and emerging economies around the world, is estimated to be more than 0.5 million km, based on an assumption that the majority of natural gas pipe is buried underground, and so unsuitable for UAV or human inspection.[71] The worldwide GHG emissions from human inspection over the course of a single year, using emission factors specific to gas pipes in mature and emerging economies, amount to 5.3Mt. If 5G UAVs were deployed instead, the resulting GHG emissions would reduce dramatically, to 3.2Mt.

A potential saving of 2.3Mt of GHG is equivalent to charging a single smartphone nearly 740 billion times or charging a smartphone for everyone in the world for 100 days – assuming each person has one smartphone and charges it every three days.

71. The total length of natural gas pipeline globally is around 2.6 million kilometres according to countries' national authorities and industry associations, including Canadian Association of Petroleum Producers, Australian Pipeline Industry Association, ENTSOG, French Energy Regulatory Commission, Chinese National Energy Administration, Gazprom, etc.

5.3 5G and improved sustainability in action – Healthcare

The ongoing COVID-19 pandemic has brought unprecedented challenges to many aspects of people's lives. For example, it has provided even more urgent impetus for digitalisation in the provision of healthcare, given the requirements for social distancing, coupled with the need for people to continue seeking medical expertise in real time despite the physical barriers.

This section provides a snapshot of how the UK's National Health Service (NHS) has been tackling the pandemic, especially in the provision of primary healthcare. We also include a detailed case study on the implementation of 5G-enabled remote CT consultation in less affluent areas of China, illustrating the benefits that 5G could bring in a post-COVID-19 world.

The digital response to COVID-19 by the UK's NHS

In the UK, healthcare is typically structured into primary, secondary and tertiary services.[72] The NHS estimates that 307 million patient consultations normally take place at GP surgeries each year. The NHS has long recognised the potential for technologies such as telehealth, telecare and self-care apps to transform the way people engage in and control their own healthcare. Although early efforts to digitalise the NHS have already yielded some benefits,[73] the roll-out and adoption of telemedicine, where clinicians provide consultations to patients remotely, has not been as smooth, due to variations in IT capability across different NHS trusts.[74]

After the UK government announced a lockdown for the entire UK population due to the COVID-19 pandemic on 23 March 2020, this led to fast-tracking of the implementation of real-time telemedicine across NHS primary and secondary care. For instance, all NHS trusts were given access to Microsoft Teams (part of the Office 365 suite) in March 2020, months ahead of the original schedule.

As a way of meeting the social distancing requirements, all primary healthcare providers have been providing virtual consultations, many involving patient triage via phone and Microsoft Teams. It is estimated that there have been around 25.5 million virtual consultations per month. There has also been a significant rise in the use of NHS Digital functionality, from 65.4 million to 115 million transactions/uses per month,[75] including a huge increase in registrations to use the NHS App (from 200,hh000 to 22.2 million).[76] In the week of 22 to 28 March, Microsoft Teams registered over 230 million sessions, comprising conference calls and chats.

Case study of 5G-enabled CT consultation

It is well-established practice for doctors to use CT scans to help diagnose patients' conditions and to guide the formulation of suitable treatment plans. In China, hospitals in second- and third-tier cities have regularly invited highly experienced medical experts from tier-one cities to carry out on-site consultation and differential diagnosis. This is due to a lack of local expertise and the limitations of the traditional CT, which only provides images and lacks collaboration features such as annotations and multi-screen discussions. Since the middle of 2019, hospitals in less-affluent tier-three cities have replaced on-site CT consultations with 5G-enabed remote CT consultations. Figure 5.6 summarises the operation parameter comparison we have made between the face-to-face consultation scenario and the remote 5G consultation scenario.

Figure 5.6: Operation parameter comparison for CT consultation [Source: Analysys Mason, 2020]

Medical experts from Chengdu and Shanghai regularly advise on treatment plans for patients from hospitals in less affluent parts of China using CT scans

	Scenario 1: Face-to-face consultation	Scenario 2: Face-to-face consultation
	4	4
	4	0
	~24 consultations/day	~24 consultations/day
	~8 hours	~13 hours
	~320km	0
	~ 8000km	0
	1 pair of PC and CT displays	3 pairs of PC and CT displays

The adoption of 5G remote consultations means that four medical experts (two CT imaging experts and two medical experts) in Chengdu and Shanghai no longer have to make regular flights to tier-three cities, and they make additional time savings due to avoiding flight delays and traffic jams on the way to and from the airports. Meanwhile, the number and quality of consultations and diagnoses for patients remains unchanged. Moreover, a minority of patients from tier-three cities who might otherwise take time off work to travel to Chengdu or Shanghai need not undertake such journeys, thus eliminating a major cause of disruption to their and their families' lives.

Environmental benefits measured through lifecycle assessment (LCA)

The environmental benefits of 5G-enabled CT consultations relative to face-to-face consultations can be very substantial, as the GHG emissions of vehicles and aircrafts previously used by the medical experts are completely eliminated, at the cost of additional monitors to display CT scans and high-throughput, low-latency 5G CPE.

The LCA we have carried out relating to CT consultations takes account of GHG emissions resulting from:

- the use of vehicles, including tail-pipe emissions, the petrol fuel supply chain and a proportionate allocation for the embodied emissions in the production and maintenance of vehicles
- the use of passenger aircraft, including usage, the aviation diesel fuel supply chain and a proportionate allocation of

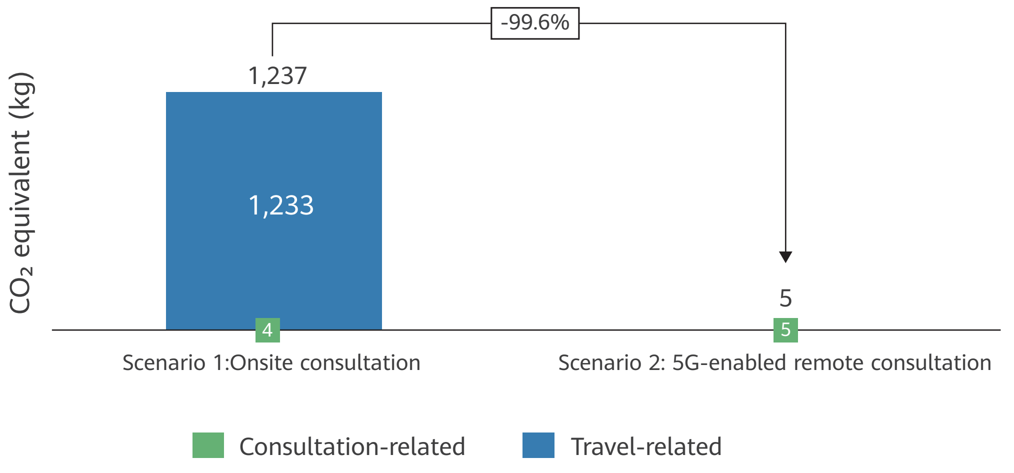
72. Primary healthcare provides the first point of contact in the healthcare system, acting as the 'front door' to the NHS. This includes general practice (GP), community, pharmacy, dental and optometry (eye health) services. General practitioner doctors (GPs) make referrals to secondary care in order to obtain a medical diagnosis for patients' diseases or conditions. Secondary healthcare offers specialist treatment and support, mostly provided in hospital. Tertiary healthcare refers to highly specialised treatment such as neurosurgery, transplants and secure forensic mental health services.
73. Within telehealth, a 23% reduction in missed appointments was achieved through the introduction of a free SMS service, and a 25% increase was achieved in the number of patients who could be supported by community nurses (by reducing unnecessary visits). Similarly, within telecare, the use of personal pendants or bracelet alarms, fall detectors, intruder detectors linked to a response centre, and family alert pagers have enabled older people to live independently in their own homes for longer.
74. An NHS Trust is an organisational unit of the NHS, serving a geographical area or a medically specialised function. There are over 200 NHS trusts in the UK as of 2020.
75. NHS Digital usage includes NHS website visits, NHS App registrations, NHS pathways via triage software and 111/999 calls, NHS 111 online for urgent healthcare, NHS patient logins and electronic prescribing services, see https://digital.nhs.uk/news-and-events/news/increase-in-nhs-tech-usage
76. See https://digital.nhs.uk/coronavirus/nhs-digital-tech-analytics

emissions resulting from aircraft manufacture and maintenance over their lifetimes

- the use of PCs and monitors, including a proportionate allocation of emissions resulting from their manufacture and maintenance over their lifetimes
- the use of wireless networks for the 5G CPE, including a proportionate allocation of emissions resulting from its manufacture over the CPE's lifetime.

The reduction in GHG emissions achieved through 5G-enabled remote CT consultations (Scenario 2) is a massive 99% (see Figure 5.7): the biggest source of GHG emissions in the 5G-enabled scenario is the use of CT scanners (80%+), which accounts for a mere 0.3% in the onsite consultation scenario (Scenario 1).

Figure 5.7: Comparison of results on environmental impact from LCA on CT consultations [Source: Analysys Mason, 2020]



5.4 5G and improved sustainability in action – Manufacturing

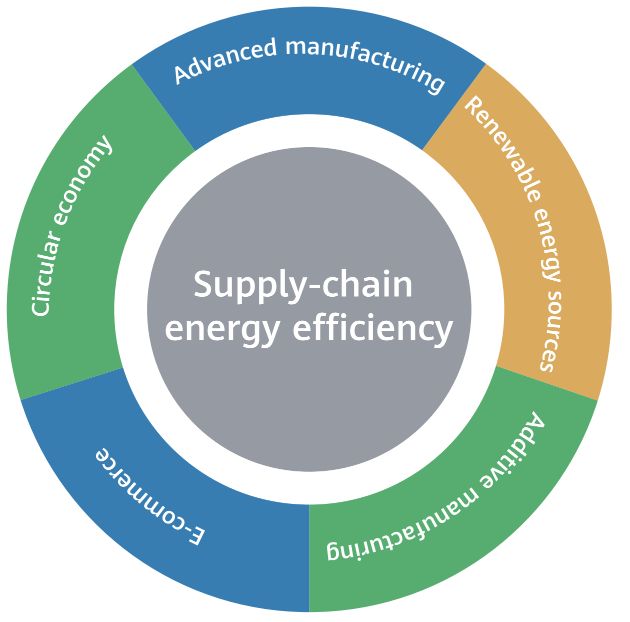
Manufacturing is one of the biggest consumers of energy and so the most amenable to improvements enabled by 5G and other technologies. Manufacturing plants vary significantly in terms of their level of technology adoption. At one end of the spectrum are fully automated facilities, but these usually primarily rely on fixed, proprietary networks. Facilities of this kind can reduce their energy consumption and increase their agility by connecting next-generation robots and machines wirelessly with 5G, using digital twins to support predictive maintenance and reduce faults, while AI analytics can be used to analyse output, efficiency, power consumption and other factors in order to optimise performance.

At the other end of the scale are smaller, less high-tech plants with large numbers of manual processes and legacy machinery. These have the opportunity to move directly to wireless IoT as they start to connect their machines and people to boost efficiency.

Another important aspect of the manufacturing industry is its heavy use of transport to move parts and finished goods around the supply chain. Efficient supply-chain coordination and AI-enhanced planning can save significant amounts of energy through a reduction in vehicle journeys, reduced warehousing and less wastage.

Figure 5.8 shows the various aspects of supply-chain management which can be improved, in terms of energy efficiency, through the adoption of a 5G-connected IoT strategy supported by predictive AI analytics.

Figure 5.8: Supply-chain management aspects that can be improved [Source: Analysys Mason, 2020]



Manufacturing is one of the most demanding verticals, as its processes require ultra-low latency, ultra-high availability and reliable indoor coverage in harsh environments. 5G can provide the necessary improvements compared to other connectivity technologies in this environment, as outlined by the EU's 5GPPP project[77] –delivering high wireless performance, the management of heterogeneous technologies, security and trust, as well as excellent internet connectivity, and flexible network and service management.

The 5G-PPP "Factories of the Future" research roadmap is focused on technologies that will support the following requirements, while delivering significant improvements in terms of sustainability and energy efficiency:

- reconfigurable, adaptive and evolving factories capable of small-scale, on-demand production
- high-performance production combining flexibility, productivity, precision and zero defects to save energy and resources
- safe and attractive workplaces
- near-to-zero emissions (including noise and vibration).

These goals are at the heart of the digitalisation roadmap set out by the European Factories-of-the-Future Research Association (EFFRA), which outlines a list of changes, each reliant on the effective interconnection of machinery, robots, production lines, products, sensors and operators to one another and to back-end systems. There are three main elements in the roadmap, which eventually lead to the goal of fully sustainable factories:

- *smart factories:* automated operation of the shop floor, integrated embedded computers, real-time monitoring, adaptive control, autonomous actuation and cooperative machine-to-machine interaction
- *digital factories:* agile analysis of vast amounts of digital information, knowledge management, informed planning and complex simulation and collaborative engineering support
- *virtual factories:* connected and collaborative enterprises and highly flexible global supply chains.

77. 5GPPP, 5G and the Factories of the Future, see https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Factories-of-the-Future-Vertical-Sector.pdf

Inside factories, 5G will facilitate manufacturing procedures,[78] including more-efficient production lines (e.g. with machine vision, and high-definition (HD) video for managing processes), automated guided vehicles (AGVs) in factories (e.g. autonomous transportation) and machine control, with latency of less than 5ms using URLLC. Outside factories, 5G could help the manufacturing sector to improve product lifecycle management, for example by enabling predictive maintenance and bringing responsive design to products. Communication between companies can also be facilitated by 5G, enabling better end-to-end tracking of goods at lower cost, or data exchanges for simulations or collaborative design.

A study by McKinsey set out five main ways in which 5G could revolutionise manufacturing:[79]

- *Cloud control of machines* – virtualising traditional programmable logic controllers (PLCs) in the cloud, enabling machines to be controlled wirelessly in real time at a fraction of the current cost and power consumption
- *Augmented reality* – to support streaming of high-quality instructions to workers or robots on the shop floor, guiding them through complex processes
- *Perceptive AI eyes* on the factory floor with real-time data streaming to the cloud to support live video analytics, thus reducing faults, wastage, downtime and saving power
- *High-speed decisioning,* with 5G allowing massive amounts of data to be ingested, processed and actioned in near real time
- *Shop-floor IoT* – unlike 4G and Wi-Fi, 5G can support high connection density with tens of thousands of sensors, enabling the analysis of industrial data at scale.

Case study of 5G-enabled AI cameras for manufacturing inspection

With advances in image processing powered by AI, the manufacturing vertical is poised to benefit from precise and efficient location recognition and sorting of raw materials, measurement of product-in-progress, and inspection of label and other defects.

The deployment of AI solutions based on mobile edge computing and 5G could help manufacturing companies avoid the need for time-consuming 'rewiring' of their complex production processes. Furthermore, the flexibility inherent in wireless networks would enable such companies to adapt to market requirements at short notice.

A leading smartphone manufacturer in Guangdong (China) used to carry out manual quality assurance (QA) checks, such as ensuring correct labels were applied to the finished product, the physical dimension of the finished products complied with the pre-set standards, etc. As QA checks are effectively the last phase before the smartphones are packaged and shipped across China and the rest of the world, management was keen to improve the efficiency of these activities.

In 2019, the company fitted each of its three assembly lines with 100 AI cameras, all connected to the 5G network and a local MEC server to carry out the QA checks alongside a smaller team of workers who supervise the operation of the AI cameras. The operation parameter comparison between human inspection and AI camera inspection is presented in Figure 5.9.

78. Huawei, Position paper 5G applications See https://www-file.huawei.com/-/media/corporate/pdf/public-policy/position_paper_5g_applications.pdf

79. See https://www.mckinsey.com/business-functions/operations/our-insights/operations-blog/five-ways-that-5g-will-revolutionize-manufacturing

Figure 5.9: Operation parameter comparison for smartphone manufacturing QA checks [Source: Analysys Mason, 2020]

On a daily basis, a smartphone manufacturer in Guangdong China needs to carry out quality checks on finished products from three assembly lines

	Scenario 1: Human inspection	Scenario 2: AI camera inspection
	3	3
	21	4
	0	300
	0	1
	1 unit/minute/ person	2.7 unit/minute/ camera
	~ 8000km	~8 hours
	21 600 units/day	384 000 units/day
	0	8MB/unit
	0	3.1TB/day

Management observed a near 18-fold increase in the throughput of the assembly lines following the introduction of AI cameras. The cameras have also made the assembly lines more energy efficient: energy consumption remained unchanged, but the per-unit smartphone energy consumption was reduced to just 6% of the previous level.

5.5 5G and improved sustainability in action – Transportation

Transportation is perhaps the sector where 5G can have the most dramatic impact on sustainability, because it contributes about one-third of total emissions in many regions, and it forms part of every other industry sector.

Global transportation GHG emissions increased by only 0.6% in 2018 (compared with 1.6% annually in the past decade) owing to efficiency improvements, electrification and greater use of biofuels.[80] But the challenge to keep that curve turning downwards is significant, especially in relation to road vehicles, which account for nearly 75% of transport GHG emissions.

Like 5G itself, transportation is a key enabler of other verticals and of daily life, as well as being an industry in its own right. Improved energy efficiency in transport will contribute to the sustainability of other sectors, particularly those where complex transport systems are interlinked, such as in a smart city or a logistics operation.

Energy efficiency measures in transportation can take many forms, including managing travel demand through measures like congestion charges in cities, to reduce travel frequency and distance; shifting travel from energy-intensive modes like air and road to water-, pedestrian- or cycling-based alternatives; electrification; and logistical and operational efficiencies. All of these measures can be supported by 5G, combined with cloud-based IoT systems and AI-enhanced analytics. These

80. International Energy Agency, see https://www.iea.org/reports/tracking-transport-2019

technologies can improve the energy efficiency of transportation in several ways:

- *Supporting increasing degrees of autonomy,* so that cars, trucks, trains and other vehicles – powered by renewable sources of electricity – have the real-time information to make the best decisions about routing, parking and so on, to use power most efficiently and avoid traffic congestion and pollution. This will also increase safety. The number of connections to cars alone will reach 831 million by 2027 according to Analysys Mason (see Figure 5.10).
- *Allowing the introduction of intelligent transport systems,* which enable cloud-based platforms to orchestrate the movements of all the vehicles in an area such as a city, as well as all the relevant infrastructure such as traffic lights or parking spaces. In this way, it is possible to maximise efficient traffic flows, deliveries and routeing on a near real-time basis.
- *Route optimisation and use of Cooperative ITS (C-ITS)*[81] are enabling a significant reduction in energy consumption and travel times. Collecting useful traffic and road condition information through vehicle ITS platforms will also increase the amount of useful data provided to the whole supply chain.

Figure 5.10: Predictions for the growth of cellular automotive IoT, 2018 to 2027 [Source: Analysys Mason][82]

1.3 billion	The number of passenger cars worldwide will grow from 1 billion in 2018 to over 1.3 billion in 2027, making a huge addressable market for IoT
55%	55% of IoT connectivity revenue will come from the automotive sector in 2027, despite a decline in automotive's share of connections to 21%
831 million	The number of embedded and aftermarket connections worldwide will grow from 96 million and 68 million, respectively, in 2018 to 690 million and 141 million, respectively, in 2027
56%	56% of passenger cars worldwide will have either an embedded or an aftermarket connection by 2027
96 million	The number of 5G automotive connections will reach 96 million in 2027
USD9-billion	Automotive connectivity will generate USD9 billion in revenue in 2027

Existing wireless technologies have gone some way to support connected vehicles and applications such as near real-time navigation. Derivatives of LTE and Wi-Fi are both used to support V2X (vehicle-to-everything) applications in which vehicles communicate with one another, with surrounding infrastructure and with cloud-based systems to make intelligent decisions about routeing, congestion, best time to travel and so on. But to support V2X services in every part of a country, and to enable safety-critical applications, different network capabilities are needed. These include ubiquitous coverage, extremely high availability and reliability, and support for vehicles, such as trains, moving at very high speeds.

In addition, the network will need to support the requirements of transport-based applications such as tracking millions of parcels carried by delivery vehicles or drones; or delivering infotainment to passengers including high-quality, interactive and AR content.

All this requires a horizontal multiservice network that is flexible enough to support the wide variety of applications that the automotive and transport ecosystems require now, and may require in future (see Figure 5.11).

Figure 5.11: Features of cellular connectivity required by individual automotive and transportation services [Source: Analysys Mason, 2020]

Service	Capacity	Coverage	Latency	Reliability
Route optimisation and use of cooperative ITS (C-ITS)	■		■	■
Advanced driver assistance systems		■	■	■
Fleet management	■	■	■	■
Aftermarket services	■	■		
Connected road infrastructure services	■	■		
Convenience and infotainment	■	■	■	
Vehicle-as-a-sensor	■			
Logistics and connected goods		■		

Upcoming 5G standards include further capabilities that will have a specific impact on transportation and automotive systems and their sustainability. 3GPP Release 16, due to be published in late 2020, will include advanced V2X features primarily based on low latency, for use cases such as platooning. Release 16 will also include specifications for a Future Mobile Communication System for Railways. In addition, it will support generic improvements which will be particularly important for transport, such as ultra-precise positioning and massive sensor connectivity.

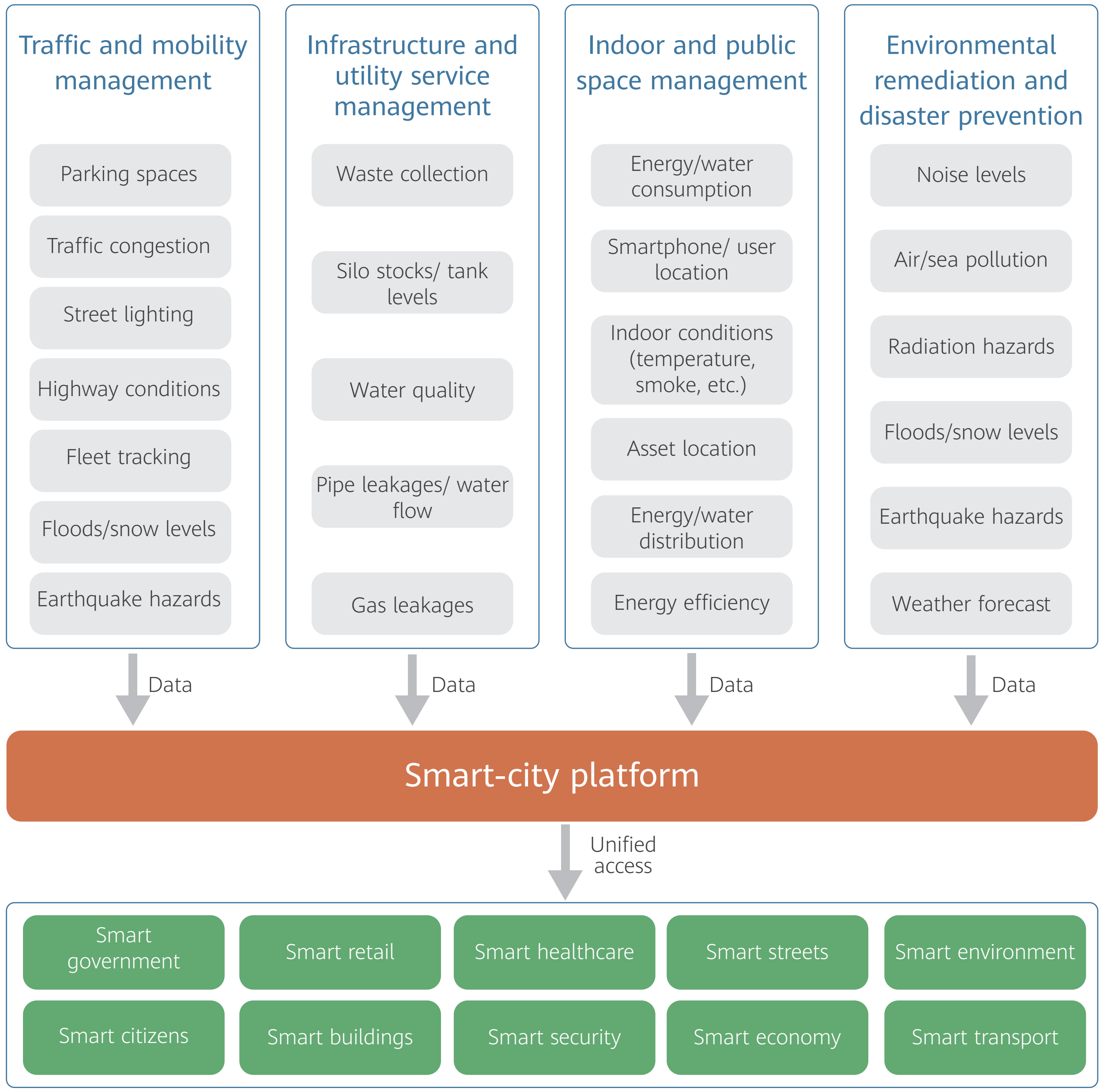
5.6 5G and improved sustainability in action – Smart city

Smart cities are among the best examples of how 5G can interact with other emerging technologies, including AI-enhanced big-data analysis, edge computing and IoT deployed to massive numbers of devices, to support a fully efficient, digital and sustainable way of living, working and travelling. This is because a city is made up of a large number of interlocking infrastructures, processes and systems including energy management, transportation, citizen services, lighting, waste management, smart building management, security and safety, and so on. Energy efficiencies can be made in each of these individual areas using 5G and IoT, but if all of the areas are addressed together, via a unified platform, the impact will be greater than the sum of its parts. These intertwined processes are illustrated in Figure 5.12.

81. C-ITS refers to Cooperation Intelligent Transport Systems, which deliver improved service levels for the user compared with siloed systems.

82. Analysys Mason, IoT in the automotive sector: trends and forecasts 2018–2027, see https://www.analysysmason.com/research/content/short-reports/iot-automotive-forecast-rdme0/

Figure 5.12: A smart-city framework comprising a myriad of systems, services and processes [Source: Analysys Mason, 2020]



With 5G, all the people, sensors and processes can be connected in near real time and their overall energy usage monitored and optimised from the cloud, taking account of factors such as the weather.

The results of this coordinated approach to cities can be significant, as seen in the progress made by the C40 Cities, a cooperative group of major global cities led by their Mayors. This group has been monitoring the cities which have already passed their peak level of GHG emissions and are now reducing these rapidly through smart-city initiatives. As of October 2019, 30 had reached that point. Since hitting peak levels of GHG emissions, the 30 cities have reduced emissions by an average of 22%. Some of the most significant reductions have occurred in London, Berlin and Madrid, which averaged around 30% each, while Copenhagen lowered emissions by 61% (though from a smaller peak, of 4 million tonnes of CO_2 equivalent in 1991, compared to London's peak of 50 million tonnes in 2000).

Some of the initiatives which have helped in achieving these reductions include deploying more than 66,000 electric buses across the C40 city streets (compared to 100 in 2009) and commitments by 24 of the cities to achieve 100% renewable electricity by 2030.[83]

Many municipal governments expect 5G to improve or accelerate these results by allowing different initiatives to interconnect better and to share data. For example, 5G can enhance the use of 'carbonomics', whereby cities leverage their carbon footprint as a form of currency to encourage changes of behaviour by businesses and citizens. In Indonesia, ride-hailing companies Gojek and Grab have been testing electric motorbikes in order to reduce energy consumption as part of carbonomics schemes. But this would have a higher impact if the ride-hailing apps showed how much carbon different types of vehicles emit, to encourage consumers to make a more-sustainable choice. Such real-time data systems can be supported by wireless connectivity, and 5G adds further capabilities such as video or virtual reality views of the proposed journey and its carbon footprint.

The highly scalable and context-aware nature of 5G networks can support the wide diversity of IoT and other applications required for a smart city, each with its own requirements in terms of pricing, mobility, latency, network reliability and resilience.

One particularly important 5G capability for smart cities, in which each process has very different connectivity requirements, will be network slicing. For example, the availability of network slicing will enable a use case with requirements for low latency and high availability (such as environmental or delivery drones) to have a separate virtual slice of the network, optimised for those requirements. Meanwhile, another service – such as smart meter or infrastructure sensor monitoring – could have another slice optimised for low data rates and less stringent latency and quality-of-service levels. Slicing enables each service to have access to the precise capabilities it needs, while saving energy because resources are allocated where they are needed, without wastage from over-provisioning.

A recent Oracle survey demonstrated the level of interest in 5G capabilities among cities, finding that 49% of network and IT executives in municipalities are exploring 5G-enabled smart-city services.[84]

Two examples of 5G-enabled smart-city projects are outlined below.

Langkawi, Malaysia[85]	Langkawi has deployed a smart signal system that uses HD video and AI to monitor traffic conditions. The system collects data on traffic patterns – such as the number of vehicles, wait times, drivers' behaviour when the weather changes – from connected traffic lights, and uses machine learning to, for example, shorten the waiting time at intersections and reduce traffic congestion. With 5G, the transmission time for HD video is significantly reduced, enabling the control centre to make real-time decisions for better traffic management.
Singapore	Singapore has created a Smart Nation platform based on an open-data ecosystem. By making datasets gathered by government agencies publicly available and accessible through online portals, residents and businesses are able to co-create smart-city applications for their own needs and share them. For instance, more than 40 mobile apps and services have been developed to address residents' transport needs, using data provided by the Land Transport Authority. With 5G, data can be more easily collected in open portals like this, and it can then be aggregated and analysed to support many decisions in different areas, while agile software development techniques like continuous integration and continuous delivery (CI/CD) can generate a steady flow of applications addressing every city task, but based on common data.

83. See https://www.citylab.com/environment/2019/10/c40-peak-carbon-co2-emissions-highest-cities-climate-summit/599644/

84. See https://www.oracle.com/a/ocom/docs/dc/em/bedigital5gsmartecosystemsarethefuturewhitepaper.pdf?source=:ow:lp:cpo::RC_BUMK181211P00133:LPD100775600&intcmp=:ow:lp:cpo::RC_BUMK181211P00133:LPD100775600&elqTrackId=bb03f99be7124d5798c78fb30b22e7da&elqaid=79428&elqat=2

85. See https://www.businesstimes.com.sg/asean-business/2020-will-be-the-year-of-making-smart-cities-sustainable

6 Conclusions and recommendations

6.1 Conclusions

- Climate change is threatening every aspect of everyday life, and indeed our entire planet. Every industry has a responsibility to increase energy efficiency and reduce GHG emissions to help deal with the crisis. The UN Emissions Gap Report 2019 found that emissions were driven primarily by energy usage and industry, whose emissions grew by 2% in 2018 alone.
- Technology has an important role to play in helping to enable industries and citizens to achieve sustainability targets. The combination of advanced connectivity, cloud computing, AI and the IoT provides a platform with unprecedented potential to make all industries, cities and communities more energy efficient. If every object, person and vehicle is connected, the data they produce can be shared, correlated and analysed, using AI, to support smart and dynamic decisions about power consumption in every aspect of society.
- According to the ITU's Smart2020 report,[86] the carbon footprint of the ICT industry is 2% of global emissions, with a CAGR of 6%. However, that growth is offset by the enabling effect on other sectors, because ICT allows other industries to benefit from increased energy efficiencies. The ITU report found that this ICT-enabled opportunity would be equivalent to 15% of all global emissions by 2020.
- Within a broad ICT platform, 5G has a leading part to play because of its combination of high bandwidth, real-time response, high reliability and support for huge numbers of devices and sensors. These capabilities enable 5G to provide connectivity so that billions of items can be connected to the cloud. They are also an important enabler of digital transformation in many industries, by making it easier for them to adopt new practices and processes to reduce energy consumption.
- Among the industries in which 5G – and interlocking technologies like cloud, AI and IoT – are expected to have the greatest impact on energy efficiency are healthcare, manufacturing, transportation and energy
  - In the energy sector, 5G UAVs can carry out gas-pipe inspection with greater efficiency and lower cost (both commercially and environmentally). Analysis using an LCA approach shows a 60% reduction in GHG emissions from a commercial deployment in Shanghai. If such an approach were to be adopted globally, the GHG emissions saving would be sufficient to charge everyone's smartphone in the world for 100 days
  - In the healthcare sector, 5G-enabled remote CT consultations can eliminate GHG emissions associated with some activities (e.g. medical experts in China travelling to less-developed cities)
  - Smart cities and intelligent transport systems have the potential to improve power efficiency in all aspects of life.
- Of course, these trends will be accompanied by a huge rise in mobile data traffic. Mobile data traffic is projected to grow by 6.2 times between 2018 and 2024 in emerging economies, and by 3.1 times in developed markets over the same period. By 2025 there are forecast to be 100 billion connections, by which time 85% of enterprise applications will be on the cloud, 86% of global companies will have adopted AI, and data utilisation rates[87] will have skyrocketed to 80%. All of these developments threaten to drive up the energy consumed by networks and offset the efficiency gains made elsewhere.
- For this reason, it is important that 5G is deployed in an intelligent way, to ensure it consumes as little power as possible. Dynamic, AI-enabled processes to turn base stations off when idle, or to allocate network resources only when required by an application – possibly in a virtual dedicated slice – will be important in helping MNOs meet their commitment to the UN Sustainable Development Goals (SDGs), with an industry goal of net-zero emissions by 2050.[88]

6.2 Recommendations for governments and regulators

- Lower barriers to the optimal deployment of 5G and other key technologies
  - Make 5G spectrum available in a timely way and incentivise network build-out in industrial locations, including remote manufacturing plants or agricultural regions. In particular, open up millimetre-wave spectrum, which has a high impact on the energy efficiency of industrial 5G networks
  - Make city infrastructure easily available for the deployment of 5G small cells to achieve blanket coverage for smart cities.
- Facilitate cooperation among different industrial stakeholders, including infrastructure owners, utilities, transport authorities, cities, MNOs and vertical industry representatives.
- Encourage the development of common platforms that encourage a unified approach to managing power usage.

6.3 Recommendations for mobile operators

- Even if not deploying 5G this year, start planning and procuring the most energy-efficient equipment and processes, including cloud-based power management platforms.
- Consider switching off legacy networks, replacing them with SingleRAN architectures, or adopting dynamic spectrum sharing.
- Plan to support ubiquitous coverage so that every industry can benefit from 5G – work with stakeholders such as site owners to plan small cells to fill urban, rural and indoor gaps in a cost-effective way.
- Form strong links with key vertical market stakeholders, such as municipalities, transport operators and utilities, to set common objectives for 5G-enabled energy efficiency, and to encourage co-investment in ICT platforms.

86. ITU, Summary of SMART 2020 Report, see https://www.itu.int/md/T05-FG.ICT-C-0004/en

87. Data utilisation refers to the percentage of data available to global enterprises that is used or analysed.

88. See https://www.mobileworldlive.com/huawei-updates/legacy-rat-exit-help-sustainable-development-of-communication-networks/

Annex A

Introduction to greenhouse gases

The sun constantly bombards the Earth with huge amounts of radiation. About 30% of this is reflected back to space by clouds or ice, while the remaining 70% is absorbed by the sea, land and atmosphere. This absorption causes them to warm up and release heat in the form of infrared thermal radiation, which passes out of the atmosphere into space. The balance between incoming and outgoing radiation keeps the earth's overall average temperature at about 15ºC, according to NASA.

However, this balance is disrupted by changes in the layer of greenhouse gases, such as CO_2, nitrous oxide (N_2O) and methane (CH_4), which trap heat in the atmosphere around the Earth. As more coal, oil and gas are burned, this layer becomes thicker, which stops heat from escaping through it into space, and thus leads to global warming. Other trends contribute to this process too, notably deforestation, since plants trap CO_2.

Scientists have attributed many changes on Earth to the effects of climate change. Examples include changes in the migration and habitation patterns of animals, as their habitats are eroded; increased acidity in the oceans with reduced ice cover; reduced yields from crops and fishing. In turn, these changes lead to food and water scarcity, driving further dislocation and a breakdown of ecosystems among humans and animals.

Annex B

Methodology for lifecycle assessment

This annex explains the modelling approach that Analysys Mason used to assess the GHG emissions associated with use cases such as energy and healthcare. We adopted an LCA approach, largely following ISO14040[89] and ISO14044[90] standards to assess the environmental impact of the selected use cases.

The explanation is structured in a similar way to how we conducted the LCA: the acquisition of lifecycle inventory (LCI) data, goal and scope definition, LCA, impact assessment, global extrapolation of country-level results, and finally uncertainty and limitations. Small World Consulting, a leading consultancy in supply-chain carbon accounting, provided advice on the development of the LCA models.

B.1 Methodology overview

The use cases discussed in Section 5 rely on good-quality carbon emissions data for each type of equipment and activity, as well as the structured LCA approach. LCA offers a comprehensive view of the carbon footprint of products, from raw materials provision, through production, distribution and operation to end-of-life stages. Having defined the detailed scope of both business-as-usual and 5G-enabled scenarios, we then investigated the key influential factors that determine the modelling of GHG emissions as well as energy consumption. Based on data from an external LCI database, we conducted a thorough inventory analysis and impact assessment, to produce an accurate and concise result for the relevant 5G and sustainability use cases.

B.2 Acquisition of inventory data

The inventory data used for the LCA modelling was sourced from reports and databases of key industry players and research institutions. All data has been cross-validated to ensure consistency and accuracy, with the core metrics based on the Ecoinvent LCI database. As well as drawing on Analysys Mason's existing extensive research, the LCA modelling relied on data and information from the following sources, among others:

- Data from academic journals and institutions (e.g. Ecoinvent, Journal of Cleaner Production, Journal of Industrial Ecology, Journal of Urban and Environmental Engineering, Nature Communications, PLOS One, RAND Corporation, Transportation Research Part D)
- Data from consulting companies (e.g. Analysys Mason, Small World Consulting)
- Data from industry vendors (e.g. DJI, Ericsson, GE, Philips, Toshiba, TYJW, Yuneec)
- Data from government and public institutions (e.g. Department for Transport of the UK government, the US Department of Transportation, Centre for Sustainable Communications).

89. ISO 14040:2006, see https://www.iso.org/standard/37456.html
90. ISO 14044:2006, see https://www.iso.org/standard/38498.html

B.3 Goal and scope definition

The goal and scope of the LCA were defined and evaluated thoroughly in order to make full use of the LCA approach. We designed two distinctive scenarios for each use case – the business-as-usual scenario and an 5G-enabled scenario – in order to evaluate the environmental benefits of 5G. The functional unit and system boundary were also outlined, to demonstrate the scope of the consequent lifecycle inventory (LCI) analysis and impact assessment. Critical assumptions related to key activities involved in each use case scenario were made based on discussions with industry experts and extensive desktop research. Figure B.3 illustrates how these concepts fit together when quantifying the environmental impact.

Example from the UAV use case

The UAV use case includes two scenarios:

- In the first scenario the inspection of an 80km natural gas-pipe network in China is conducted using human labour, which involves driving up to or close to points of interest, walking and climbing utility towers. Each inspection team uses one light passenger vehicles, powered by petrol. An hour of inspection can cover 7km of pipe. The total time required for one round of inspection is around 12 hours and the total car driving distance during the inspection is 160km.
- In the second scenario the inspection is conducted by a UAV, combined with 5G connectivity. The inspection team comprises one 5G-equipped drone, powered by aviation diesel. Total UAV flying distance during the inspection is 160km. The UAV can inspect 80km of pipe per hour. The total time required for one round of inspection is approximately 2 hours.

Figure B.1 lists the equipment and activities used in both scenarios and indicates whether they are considered a key influence factor in assessing GHG emissions. Figure B.2 provides the relevant detailed assumptions and background to each scenario.

Figure B.1: Equipment and activities involved in UAV use case [Source: Analysys Mason, 2020]

Category	Sub-category	Equipment/activity	Key influence factor?
Supply chain	Hardware	Car	Yes
		UAV	Yes
		PC	Yes
		Data management software and platform	No
		Petrol	Yes
		Diesel	Yes
		Communication devices	Yes
	Organisation (labour and other admin/ supporting activities)	Back-office labour	No
		UAV management staff	No
		Vehicle maintenance	Yes
		UAV maintenance	No
Direct use	Onsite inspection	Wireless networks (5G)	Yes
		Data analysis	No
		UAV inspection (controlling UAV, communication, diesel consumption)	No
		Use of UAV (diesel consumption)	Yes
		Transportation of UAV control team (petrol consumption)	Yes
	Back-office monitoring	Back-office monitoring	No

Figure B.2: Assumptions and scenario background for UAV use case [Source: Analysys Mason, 2020]

Activity	Label	Text
UAV related	Assumption	The weight of a UAV (drone) is set to 15kg. This assumption is based on public information on a range of commercial and industrial drones from UAV manufacturer websites such as TYJW. The main reference suggests the maximum payload weight of industrial drones ranges between 13kg and 40kg.
		The lifespan of a UAV (drone) is set to 200 hours. This value was used to calculate what proportion of carbon emissions associated with the production of a UAV should be attributed to it. The main reference source suggests that the life expectancy of an industrial drone ranges between 66 hours and more than 200 hours. This data source comes from UAV manufacturer websites such as TYJW or DJI.
	Scenario setting	The total drone flying distance is set to 160km. This includes a return trip along the whole 80km pipe.
		A UAV can travel 80km per hour when carrying out inspections.
Fuel related	Assumption	The weight of diesel used for a UAV is set to 0.85kg per litre. The source for this data is an academic publication, "Advances in Clean Hydrocarbon Fuel Processing".
		UAV fuel consumption is estimated to be 195km per litre. This data is based on an external study on delivery drones, published in a research report from Rand Corporation.
		The weight of petrol used for the passenger cars is set to 0.73kg per litre. The source for this data is an academic publication, "Advances in Clean Hydrocarbon Fuel Processing".
		Car petrol consumption is set at 17.9km per litre. This data is based on the average new car fuel consumption data in a statistics report from the UK Department for Transport.
Other	Assumption	The average lifespan of a PC/desktop computer is set to four years. This assumption is based on public information for a range of PC models.
		The average lifespan of a smartphone is set to four years. This assumption is based on public information for a range of smartphone models.

B.4 Lifecycle assessment

In the goal and scope definition phase, the activities and equipment associated with each scenario are determined. The next step of the LCA builds on results from lifecycle inventories of activities associated with each scenario in terms of required materials and energy. Each step of the lifecycle assessment was classified as belonging to either the supply-chain phase (including the carbon emissions embodied in the end product) or the direct-use phase (including the energy consumed by activities in each scenario). The raw data for each process step (such as end-point device, costs of networks, vehicle transportation) was selected carefully to ensure that it accurately reflected the relevant scenario. To consolidate the carbon footprint from different types of product and activity, product lifecycle carbon emission and operating carbon costs were converted to kilograms of CO_2 to quantify the final impact assessment. The results for emissions embodied in the production of the end devices were allocated proportionately, based on actual usage relative to their respective lifespans. Figure B.3 illustrates how these concepts fit together in quantifying the environmental impact.

Example from the UAV use case

The LCA carried out on the UAV use case included emissions resulting from:

- driving of light passenger vehicles, including exhaust emissions, the petrol fuel supply chain and a proportional allocation of emissions resulting from the production and maintenance of vehicles over their lifetime
- use of UAV, including emissions during flights, the aviation diesel fuel supply chain and a proportionate allocation of emissions resulting from their manufacture and maintenance over its lifetime
- use of smartphones and PCs, including a proportionate allocation of emissions resulting from their manufacture and maintenance over their lifetimes
- use of wireless networks for 5G CPE on UAV, including a proportionate allocation of emissions resulting from manufacture.

Although this LCA accounts for supply-chain and direct-use activities that are essential for the use case, we consider the carbon emissions from some activities to be negligible. For instance, the LCA excludes the production activities of tools/equipment used to manufacture the listed hardware. The system also excludes most human labour activities associated with the inspection.

Figure B.3 illustrates the process used to calculate the GHG emissions of the UAV use case. Figure B.4, Figure B.5 and Figure B.6 provide further detail on the numerical values used in the calculation.

Figure B.3: Overview of carbon footprint calculation for the UAV use case [Source: Analysys Mason, 2020]

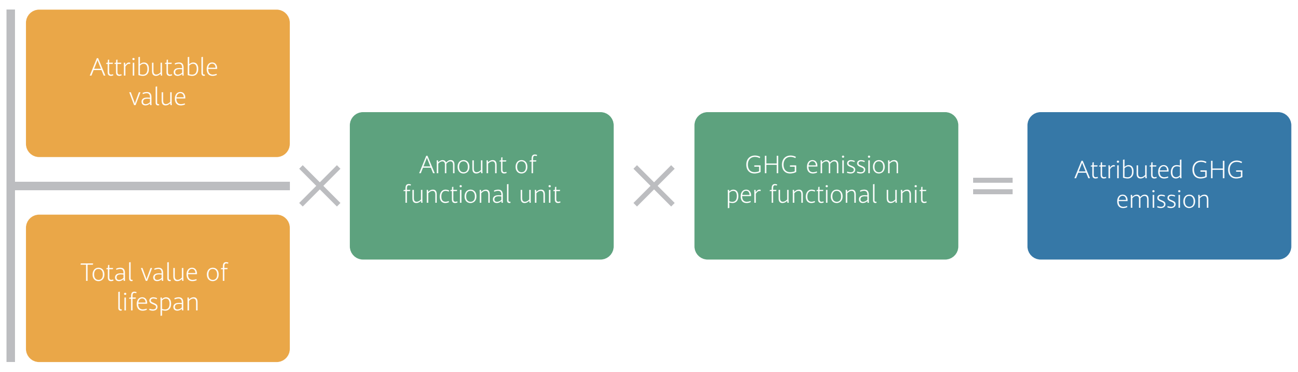


Figure B.4: Attribution percentage calculation of UAV use case [Source: Analysys Mason, 2020]

Activity	Attribution unit (based on time or distance)	Total attribution units	Total value (lifetime of a product or services)	Attribution percentage
UAV	Hour	2	200	1%
PC	Month	1	48	2.08%
Use of UAV (diesel consumption)	-	-	-	100.00%
Production of diesel	-	-	-	100.00%
Use of wireless networks	Month	1	12	8.33%

Figure B.5: Total carbon footprint calculation of UAV use case [Source: Analysys Mason, 2020]

Activity	Amount of functional unit (kg, km or unit)	GHG emission per functional unit (CO_2 in kg)	Functional unit	Total GHG emission (CO_2 in kg)
UAV	15	48.60	per kg	729
PC	1	242.85	per unit	243
Use of UAV (diesel consumption)	160	0.16	per km	26
Production of diesel	0.7	0.45	per kg	0.32
Use of wireless networks	1	51.00	per unit	51

Figure B.6: Attributed carbon footprint calculation of UAV use case [Source: Analysys Mason, 2020]

Activity	Attribution percentage	Total GHG emission (CO_2 in kg)	Attributed GHG emission (CO_2 in kg)
UAV	1%	729	7.29
PC	2.08%	243	5.06
Use of UAV (diesel consumption)	100.00%	26	26
Production of diesel	100.00%	0.32	0.32
Use of wireless networks	8.33%	51	4.25

B.5 Impact assessment

The total carbon cost of each use-case scenario was estimated by adding the cumulative emissions from two phases:

- ***direct-use phase:*** emissions generated by all equipment during the use phase
- ***supply-chain phase:*** emissions generated during the manufacture, transport and maintenance of the equipment.

Once the carbon costs of both scenarios for each use case (BAU and 5G) had been calculated, we were able to determine the total carbon reduction per functional unit of each use case.

Example from the UAV use case

Figure B.7: GHG emissions by scenario and phase (in kg of CO2) [Source: Analysys Mason, 2020]

	Supply-chain phase (CO_2 in kg)	Direct-use phase (CO_2 in kg)	Total emissions (CO_2 in kg)
UAV inspection	26.45	44.12	70.57
Human labour inspection	12.66	30.05	42.71
Emission reduction rate	52.1%	31.9%	39.5%

B.6 Global extrapolation of country-level results

The UAV use case includes an additional step to generate the estimated carbon emission results at a global level. Due to the different processes adopted for manufacturing and use of the equipment and materials across countries and regions, the carbon emission results may vary across locations. In the LCA we categorised all countries into one of two region types – developed and emerging – based on their economic situation as well as industrialisation maturity. We then used corresponding LCI data to extrapolate the carbon emission results to the regional level.

Example from the unmanned aerial vehicle (UAV) use case

We used the following steps to make a global extrapolation of the country-level results:

1. Collect information on total natural gas pipeline length across countries and categorise into "developed region" and "emerging region", including a calculation of the burial rate (i.e. the share of pipeline that is buried underground)
2. Model the use case based on lifecycle inventory data for Europe (to represent the developed region) and outside Europe (to represent the emerging region). Whenever region-specific LCI data was unavailable, the default location of the LCI data was set to worldwide
3. Extrapolate the use-case results (for an 80km pipe network) to the length of pipe networks worldwide
4. Add up the GHG emission results from the two regions.

Annex C

Data sources and bibliography

Title/topic	Author/owners	Year of publication/ access	Link
The Energy Implications of Drones for Package Delivery	RAND Corporation	2017	https://www.rand.org/pubs/research_reports/RR1718z1.html
Vehicle Survivability and Travel Mileage Schedules	US Department of Transportation	2006	https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/809952
UAV Products	TYJW	2020	http://en.tianyujingwei.com/
Advances in Clean Hydrocarbon Fuel Processing	Woodhead Publishing Limited	2011	https://www.sciencedirect.com/topics/engineering/diesel-fuel
Average new car and light goods vehicle (LGV) fuel consumption	UK Department for Transport statistics	2018	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/850276/env0103.ods
How much fuel per passenger an aircraft is consuming?	Openairlines	2018	https://blog.openairlines.com/how-much-fuel-per-passenger-an-aircraft-is-consuming
Product Environmental Information	Huawei	2020	https://consumer.huawei.com/en/support/product-environmental-information/
Lifecycle Modelling and Assessment of Unmanned Aerial Vehicles (Drones) CO_{2e} Emissions	Transportation Research Part D	2017	http://web.cecs.pdx.edu/~maf/Journals/2017_Lifecycle_modeling_Drone_CO_{2e}_emissions.pdf
Energy use and life cycle greenhouse gas emissions of drones for commercial package delivery	Nature Communications	2018	https://www.nature.com/articles/s41467-017-02411-5.pdf
Carbon Footprint of Telemedicine Solutions – Unexplored Opportunity for Reducing Carbon Emissions in the Health Sector	PLOS One	2014	https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0105040&type=printable
A predictive model for the estimation of carbon dioxide emissions of magnetic resonance imaging units and computed tomography scanners	Journal of Urban and Environmental Engineering	2018	https://www.researchgate.net/publication/333308936_A_PREDICTIVE_MODEL_FOR_THE_ESTIMATION_OF_CARBON_DIOXIDE_EMISSIONS_OF_MAGNETIC_RESONANCE_IMAGING_MRI_UNITS_AND_COMPUTED_TOMOGRAPHY_CT_SCANNERS
LCI data	Ecoinvent 3.6 LCI database	2020	-
Smart Grid – enabling energy efficiency and low-carbon transition	UK, Foreign & Commonwealth Office	2014	https://www.gov.uk/government/publications/factsheet-on-smart-grid-development-in-the-uk

7 About the authors

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