A blueprint for green networks

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Executive summary

Fast-growing mobile communications services are consuming more energy than ever before. For operators, energy conservation and emission reductions are not just a social responsibility but also a critical requirement for energy cost savings. The rapid increase in wholesale energy prices is further forcing operators to prioritise the topic of energy efficiency. Operators that delay their necessary full-scale energy-efficiency transformation or fail to embed energy efficiency as part of their network transformation will endanger their long-term competitiveness.

Given the pressing demand from some early-adopter operators for high energy-efficiency network deployment, network vendors are launching more and more advanced energy-efficient product portfolios with lower loss rates and higher efficiency by promoting innovation in terms of design, materials and manufacturing processes. These solutions can apply to a wide range of areas since energy efficiency is a holistic field, which includes antennas, radios, passive infrastructure, core network and data centres, and network management software.

Power consumption needs to be considered as a system engineering concept rather than focusing on any specific component. On average, the radio access network (RAN) is responsible for 73% of a mobile operator’s total energy consumption; the cell site therefore represents the low-hanging fruit to target. Equipment integration, site simplicity, passive cooling and AI-driven network shutdown solutions can help operators quickly improve their energy-related metrics in the short term. In the longer term, complex network transformation and user migration to 5G can boost energy efficiency further.

5G is the first wireless technology designed to be energy efficient and to use available resources more efficiently. To achieve this promised efficiency gain, operators need to reconsider how they approach mobile networks and invest in full-scale network transformation. Future-proof networks do not include many air-conditioning units, shelters or site cabinets; instead, they are using highly integrated radios and antennas with heat sinks and V-shaped heat exchangers in their back. These sites are controlled with AI-driven network management software, which collects real-time information on network load, capacity, weather and nearby events and forecasts optimal performance paths without impacting user experience. Indeed, the blueprint for future wireless networks is very much inked in green.

1. Mobile industry trends and the potential conflict with carbon neutrality

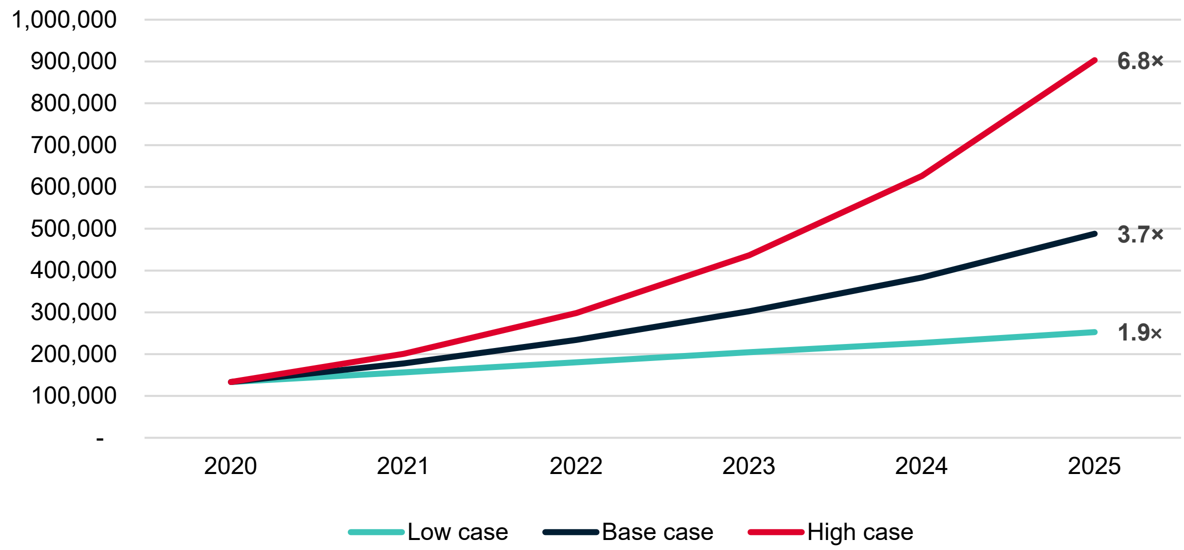
1.1 Mobile industry thriving but more energy is being used than ever before

Though 5G adoption continues to proceed at varying pace, our long-term forecast of 25% penetration globally in the telco customer base by 2025 remains.

A primary, if under-recognised, implication of 5G subscriber growth is a cascade effect from higher data traffic volumes leading to increased power consumption. Higher speeds and capacity levels – combined with a resurgence of unlimited data tariffs – mean that the average monthly data usage of 5G subscribers by 2025 (approximately 30 GB) is likely to be 3–4× that of LTE. This is, however, a global average, meaning that prevailing rates will be higher in advanced economies with more affluent populations who have a propensity for video streaming and other bandwidth-hungry applications – even if fibre/home Wi-Fi handles 75–80% of the overall load.

To illustrate the outlook, we show power consumption across mobile networks in aggregate under different scenarios in Figure 1. Mobile networks account for around 133,000 GWh of electricity per year, approximately 0.6–0.8% of total global consumption. In the base case scenario, cellular data traffic is on a 20% annual growth trajectory, with electricity costs (per GB) flat. The low and high case scenarios take into account both data traffic and power costs in directions that reduce and increase power consumption, respectively.

Figure 1: Even in a best case (low) scenario, mobile networks are on course to almost double their power consumption between 2020 and 2025
GWh per year



Assumptions:

Base case: Constant price of electricity per GB, with a five-year CAGR for data traffic growth of 30%.
Low case: Price of electricity per GB declines 5% per year, with a five-year CAGR for data traffic growth of 20%.
High case: Price of electricity per GB increases 5% per year, with a five-year CAGR for data traffic growth of 40%.

Source: GSMA Intelligence, Ericsson

There are several observations:

- Without intervention, power consumption by mobile networks rises in all scenarios to 2025
- The baseline case is a 3.7× rise by 2025, relative to the 133,000 GWh (roughly 0.6-0.8% of total global electricity consumption) in 2020.
- The best (low) and worst (high) case scenarios range from a 2× to a 7× increase by 2025, relative to 2020.

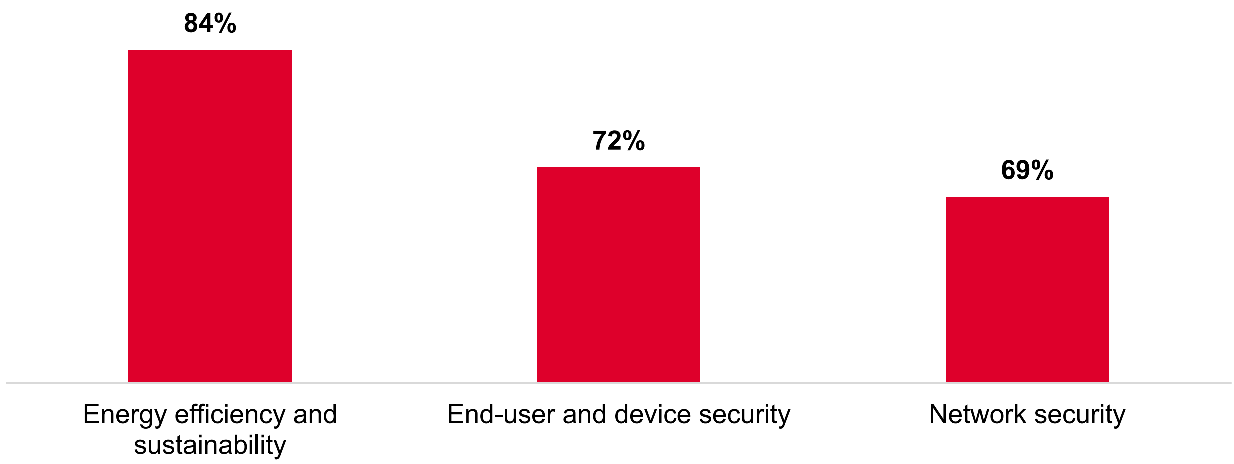
These are, of course, only projections. Assumptions may need to change over time, particularly for power costs given the current fluctuations in wholesale gas prices as a result of the Russian invasion of Ukraine.

However, these scenarios illustrate a fundamental point: 5G necessitates a shift to more energy-efficient networks and renewables to avoid an unsustainable rise in power demands.

1.2 The importance of energy efficiency

An important indicator of change comes from our survey of mobile operators assessing their network transformation priorities (see Figure 2). Our latest findings from June and July 2022 suggest that energy efficiency and sustainability is now the top priority among network managers and buyers, with nearly 85% rating it 'very' or 'extremely' important. The significance of this cannot be understated, given that even 2–3 years ago sustainability remained under the radar as an issue more in the domain of corporate social responsibility rather than anything close to a core strategic priority. It also confirms that network energy efficiency has, and will remain, a key competitive differentiator among the major vendors as 5G and other enterprise networks are rolled out – just as price, service-level agreements (SLAs) and other aspects of managed service contracts have predominated the last 20 years.

Figure 2: 2022 is the year of energy efficiency and renewables
How important are the following priorities as a part of your current network transformation strategy? (Percentage of operators that rated a priority as 'very' or 'extremely' important)

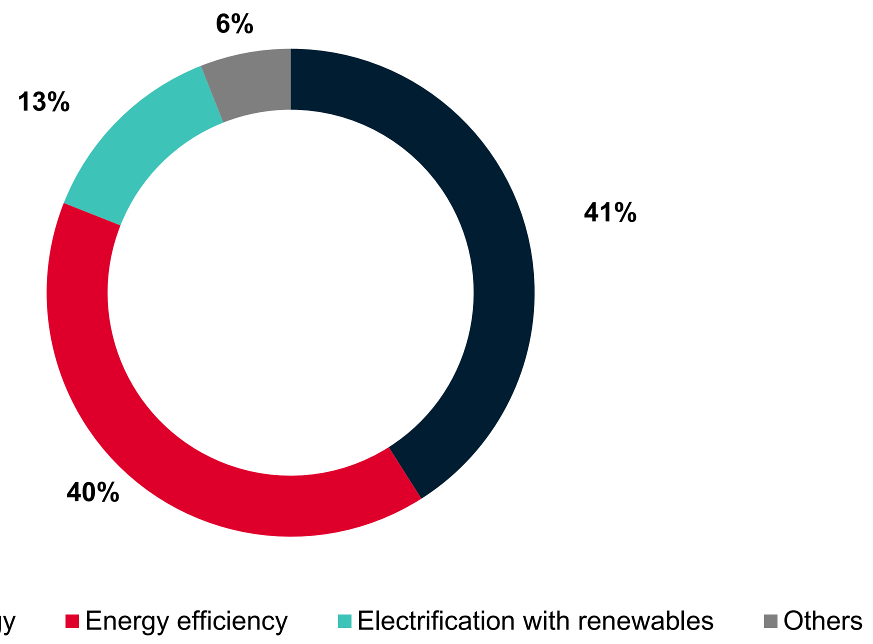


Source: GSMA Intelligence Operators in Focus: Network Transformation Survey 2022 (N=100 worldwide)

According to the International Renewable Energy Agency (IRENA), CO_2 emission reductions of 94% can be expected from renewables and energy efficiency. These are the two main tools that operators should rely on to reduce carbon-related emissions and achieve their decarbonisation goals. Operators should deploy energy-efficient technologies immediately to remain on a decarbonisation pathway culminating in net zero by 2050 (or earlier).

Figure 3: Renewables and improved energy efficiency are the main ways to reduce energy-related CO2 emissions

Expected percentage of CO_2 emission reductions by 2050



Source: IRENA

1.3 Addressing energy efficiency and green development methodology

The green imperative is foremost the result of climate change and the need to blunt it. The agreement from the Paris Accord of limiting temperature rises to 1.5°C above pre-industrial levels this century remains the central objective. Telecoms operators are in the thick of it both because of their direct emissions – which accounts for just under 1% of global electricity consumption – and the enabling effect of connectivity to help other sectors lower their carbon footprints.[1]

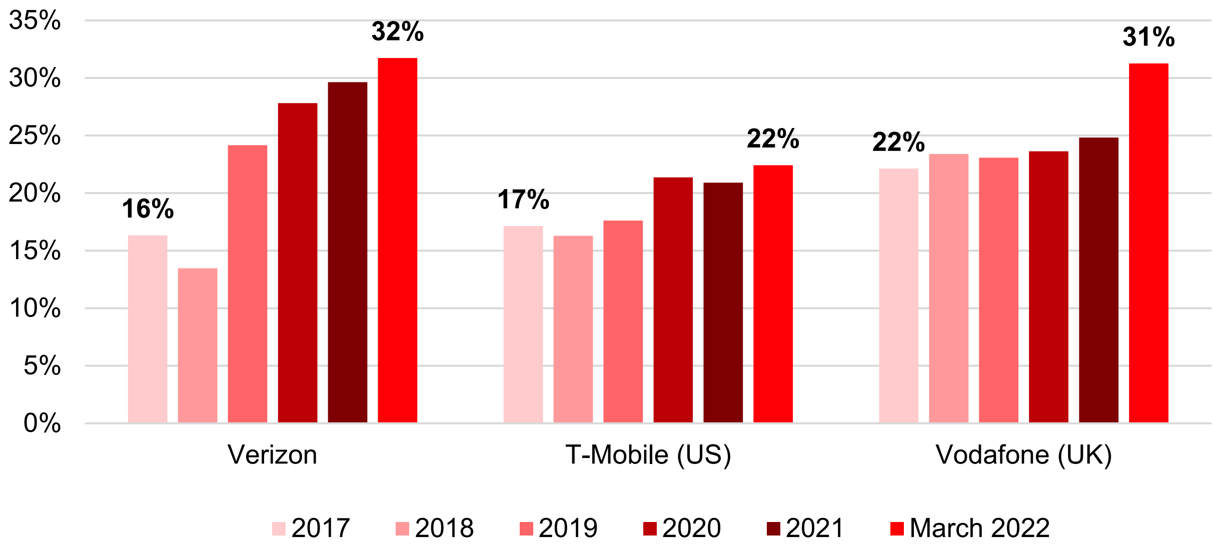
There are financial reasons for operators as well. Energy still accounts for, on average, 20–40% of telco opex (and 80–90% of network spend excluding site rental costs). The shift to renewables and efficiency gains should bring this down. However, combined with ongoing capex costs of the 5G network upgrade cycle, pressure continues to be exerted on free cash flow.

Figure 4 brings this into relief. Taking the results of two major US operators, Verizon and T-Mobile, and Vodafone in the UK, it can be seen that capital intensity continues to rise as a share of revenue. While this ratio has historically varied within a range of 15–25% of revenue depending on the stage of the mobile technology cycle, it is now over 30% for Verizon and Vodafone. The

[1] For further information, see Industry pathways to net zero: mobile and digital technology in support of industry decarbonisation, GSMA Intelligence, 2021

positive is that this highlights the funding into network investment that drives coverage and capacity expansions. The challenge, however, is the pressure on cash flow in an environment of low mobile revenue growth, which currently sits at around zero or in the low single digits in most high-income countries. There is a prospect of incremental revenues from B2B 5G connectivity, cloud, managed services and new(er) offerings in the private networks space, which would very much help here.

Figure 4: The cost of doing business keeps going up, putting more pressure on growth
Capex intensity (percentage of mobile service revenue)



Source: GSMA Intelligence

The challenges in upgrading networks and shifting to renewables are a mix of supply constraints, costs, inertia and political factors. Europe is the global leader in renewable energy consumption per capita, while the US, India and some of the GCC states – despite being oil-based economies – are increasing production of solar photovoltaics (PV) and wind capacity, which is a positive indicator. Access to the mains grid remains patchy in several developing regions, which has necessitated a reliance on diesel in rural and remote locales (diesel accounts for over 10% of total energy usage across all mobile operators), which is a costly fuel that emits high levels of carbon dioxide. There is a fairly clear correlation between the geographic areas where the above constraints are most prevalent and weaker commitments to net zero. While this is understandable, a global rebalancing on climate commitments (e.g. in Africa and most of Asia) is needed if the telecoms sector as a whole is to achieve net zero by 2050.

The International Energy Agency (IEA) adopts the view that energy efficiency is 'the first fuel' – energy-efficiency improvements can alleviate the contradiction between energy consumption growth and green development. Energy-efficiency improvements in mobile and digital technology will account for more than 40% of the total carbon emission reductions required by industries to 2030. For operators to achieve net zero as early as possible and fulfill their commitments, they need to both invest in renewable energy and improve network energy efficiency.

2. Targets and indicators to measure and optimise energy efficiency

2.1 Metering energy efficiency is crucial

The 2021 UN Climate Change Conference (COP26) represented an important moment to determine the progress of governments and businesses in addressing the impacts of climate change over the prior five years. The ITU has predicted that the ICT industry must cut carbon emissions by a minimum of 45% by 2030 to meet UN climate change goals. The telecoms sector is unique in the sense that its output (e.g. data traffic and the number of served connections) is always increasing, while its offered services (e.g. quality of service and service coverage) continue to improve rapidly.

Because of the ubiquity and importance of the wireless telecommunications industry, measuring its climate impact is essential – since you can't manage what you can't measure. However, measuring efficiency and setting targets is not a simple task: every mobile operator is different, as they operate in unique environments and use different processes, standards and equipment to measure their energy efficiency and emission targets. As the telecoms industry is truly global – with over 800 mobile operators and strong growth potential – universal indicators, approaches and well-defined targets are needed.

Measuring energy efficiency

In the process of exploring the green development and energy-efficiency improvement of the ICT sector, one of the greatest challenges for mobile operators is figuring out how to effectively and scientifically implement network energy-efficiency index management. The first step is to fully understand the requirements of 'metric metering', which comprises a set of mechanisms and methods that include the whole process of measurement, reporting, analysis, presentation, policy formulation and optimisation suggestions. This can help operators build a standardised, intelligent and visual management system of energy efficiency.

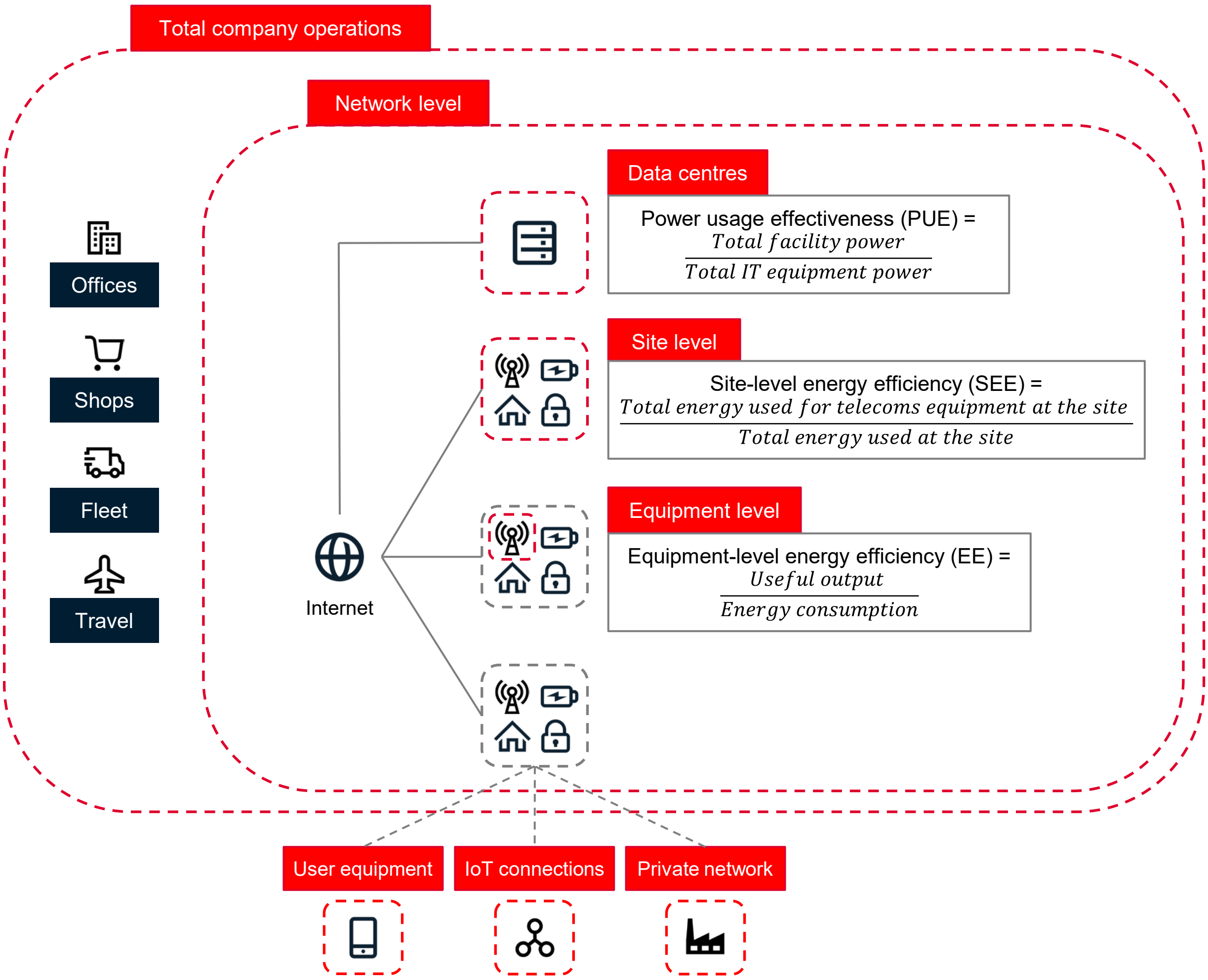
In terms of indicator measurement and reporting standardisation, standard sampling points and sampling frequencies can be defined for the hierarchical architecture of mobile and fixed networks. In terms of indicator visualisation, the operator's energy-efficiency management system can not only display indicators at the site, network and operation layers but also the available resources of the domain-based network, such as the RAN, backhaul and core, to support the formulation and delivery of energy-efficiency optimisation policies.

2.2 Energy efficiency in the 5G era

The basic principle of measuring cross-sectoral energy efficiency is simple, which is to determine how much energy is needed to deliver one unit of output. Measuring energy efficiency for cellular networks, however, is more complex, as the output of the industry is continuously changing: in the 2G era, the output was mainly voice and SMS; in the 3G and 4G eras it was voice, data traffic and SMS; and in the 5G era the range of offered services has branched out even more. Because of this variety in cellular and digital services, there is no one way to measure energy efficiency with just a single KPI, especially because operators are operating multi-generational networks, often 2G, 3G and/or 4G in combination with 5G.

In the case of a mobile network operator, energy efficiency can also be interpreted at different levels. Different metrics can be more suitable, depending on if the focus is on one piece of equipment, a site, the whole network or even the entire operation of a mobile operator.

Figure 5: Different levels of energy efficiency in cellular telecommunications



Source: GSMA Intelligence, expert interviews

Equipment-level energy efficiency

Each piece of network equipment has its own energy-efficiency characteristic. Although this can be affected by many external factors, such as weather or data and voice traffic, this serves as a basic indicator of energy efficiency for wireless infrastructure. Equipment-level energy efficiency can be measured with a data traffic/energy metric.

Site-level energy efficiency

Site-level energy efficiency (SEE) refers to the energy efficiency of an entire cellular base station, including a wide range of telecoms equipment and other supporting passive infrastructure, such as energy conversion and transmission, security, cooling and power back-ups. SEE can be measured by dividing the total telecoms equipment energy consumption by the total site energy consumption.

This value can be between 0 and 1, with a higher value meaning that operators need to use less energy for the passive infrastructure to operate the site. SEE is a useful tool to measure the significance of the passive infrastructure's energy use.

Network-level energy efficiency

A mix of KPIs can help operators measure the relative efficiency of their networks in the era of multi-generational networks, including 2G, 3G, 4G and 5G. Four KPIs combined can provide a comprehensive evaluation of network-level energy efficiency:

- data traffic per unit of energy consumption
- number of connections per unit of energy consumption
- number of cell sites per unit of energy consumption
- revenue per unit of energy consumption.

Based on the standard of ITU-T and ETSI, mobile network data energy efficiency is the ratio between the data volume and the energy consumption during the same period, expressed in bit/J.

Operator-level efficiency

In addition to the physical mobile network, the total energy efficiency of a mobile operator also includes other operations, such as the fleet, shops, offices and staff travel. The same energy-efficiency metrics as above (data traffic per energy, connection per energy, cell site per energy and revenue per energy) can be used to measure the total energy efficiency of a mobile operator.

The ITU-T has also completed a recommendation that defines a KPI named network carbon data intensity energy (NCIe), which represents the intensity of carbon emissions relative to the level of network traffic.

Data centres

According to GSMA Intelligence analysis, mobile operators are using 9% of their energy in centralised data centres. The most commonly used metric for reporting the energy efficiency of data centres is the power usage effectiveness (PUE). This evaluates the performance of the data centre by calculating the ratio of the energy used as a whole as compared with the energy used by just the telecommunications or IT equipment alone.

2.3 The value of partnerships

Building partnerships is essential for operators to improve their energy efficiency and for the global fight against climate change. While partnerships between mobile operators are valuable, cross-industry partnerships are also vital for a number of different reasons. Cross-industry partnerships and collaborations can help operators to share the latest, most advanced technologies and processes while also providing access to know-how. Teaming up with startups can help to boost innovation and test new, more energy-efficient technologies. Partnerships can also help to exploit synergies, such as some industries' waste being a resource somewhere else. A good example is the heat generated by telecoms equipment: while mobile operators are keen to get rid of the heat generated by their equipment, many other industries would like to produce or purchase heat more efficiently. Thus, partnerships can help to connect the demand for heat and the excess heat, and to form new collaborations, such as a utility provider buying the extra heat generated from an operator’s data centre and using this for commercial or industrial facilities.

Energy sourcing, transportation and optimisation can all fall outside of an operator’s comfort zone. Operating advanced energy management tools requires specific expertise and the use of cutting-edge optimisation methods demands a unique skill set. Even larger operators may not have the required talent, knowledge and/or capacity to execute the necessary transformation, which would endanger their long-term competitiveness. Partnering with utility or energy management companies, tech startups or governments can therefore be essential for acquiring knowledge, buying resources or having smooth capex cycles with energy-saving-as-a-service business models.

The addressable market is significant for green solutions in the telecoms sector and this includes opportunities for smaller vendors. Companies from the energy sector should tailor their offerings to the unique needs of operators. Network vendors can also benefit from cooperating with energy suppliers and energy management companies or building their own energy-efficiency product portfolio. Partnerships across the ecosystem will be central to achieving the target of carbon neutrality along with sustained revenue growth.

Case study: Orange

With a target of achieving net-zero carbon emissions by 2040 (Scopes 1, 2 and 3), Orange’s strategy toward going green revolves around three focal points: set specific goals, create accurate key KPIs and work with partners to deliver a broader impact.

Setting intermediary goals

Orange's Engage 2025 strategic plan commits to reducing Scope 1 and 2 emissions by 30% by 2025 (compared to 2015). This commitment was approved and validated by the Science Based Targets Initiative (SBTi).

Governance is central to driving the action plan, as energy saving sits at the junction of corporate social responsibility, finance, technology and sourcing, all of which must push in the same direction to have a meaningful impact.

Four KPIs

Each of the business units and countries where Orange operates is tasked with implementing an effective, context-specific action plan. To drive this programme, Orange has set up a high-level energy dashboard comprising four KPIs:

- an economic KPI (ENOV), which is a ratio of IT and energy opex over revenue, where a decrease of one point in this KPI results in a corresponding one-point loss in EBITDA
- technical KPIs about RAN efficiency (RAN kWh/Gb and RAN/kWh/site)
- the power usage effectiveness (PUE)
- ecological efficiency, measured through the renewable energy ratio (RER).

All these KPIs are driven by energy consumption. Energy type directly impacts emissions, while procurement determines energy cost. Hence, the energy sourcing strategy is vital. By using energy-efficient equipment, Orange can optimise energy usage metrics.

Orange has required that energy-saving features be built in at the design stage of network deployment. All the products that Orange sources are assessed from the perspective of energy efficiency, which in turn guides decision-making in investment and operations.

50+ key actions

The Orange Energy Action Plan is based on more than 50 field-proven actions. Each country selects the actions that are most relevant to them, a quarterly report benchmarks the markets and Orange then works with the poorest performers to formulate and implement an improvement plan.

Orange also has established energy plans with their partners, such as equipment vendors, tower companies, energy service companies and RAN-sharing JVs, which must be aligned with the energy-efficiency strategies of Orange.

Energy costs in Europe today are high and they are expected to remain high. A robust sourcing strategy across organisational domains (finance, corporate social responsibility, IT and sourcing) is required, including a precise forecast on energy needs, cost and carbon impact (comparing forecasts with the actual situation) and energy-efficiency pilot programmes by using the right equipment, equipment swapping and retirement.

Thus, the first focus of the action plan is to reduce the overall amount of energy spent and the second is to optimise sourcing costs. The strategy mainly focuses on Scope 1 and Scope 2 emissions; the current challenge is to extend the actions to Scope 3 and drive ecosystem-wide improvements that fully support Orange Group’s strategy.

3. Achieving efficiency through the whole network

In the 5G era and beyond there will be an increase in data consumption, connected devices, network coverage and cell towers. Every network is different and each operator is impacted differently by local regulations, climate and market structure. In some markets, mobile operators can access reliable electricity, while in other markets the electricity grid is not reliable and operators need to rely on a back-up power supply. However, energy-efficiency improvements are a universal tool to tackle climate change and improve operators' cost functions. Energy use can be a significant cost, but it is also an area with many opportunities for opex savings if the required capital investments/upgrades are made to network equipment. The topic of energy efficiency cannot simply be assigned to any department because by its nature energy efficiency horizontally impacts every area of an operator, requiring a wide range of skills and cross-department harmonisation. Operators have a large number of solutions available to them if they want to improve their overall energy efficiency.

Figure 6: Estimated cost and impact of large-scale deployment of network improvements from an energy-efficiency viewpoint

Source: GSMA Intelligence estimates, expert interviews

Figure 7: Areas of energy-efficiency improvement

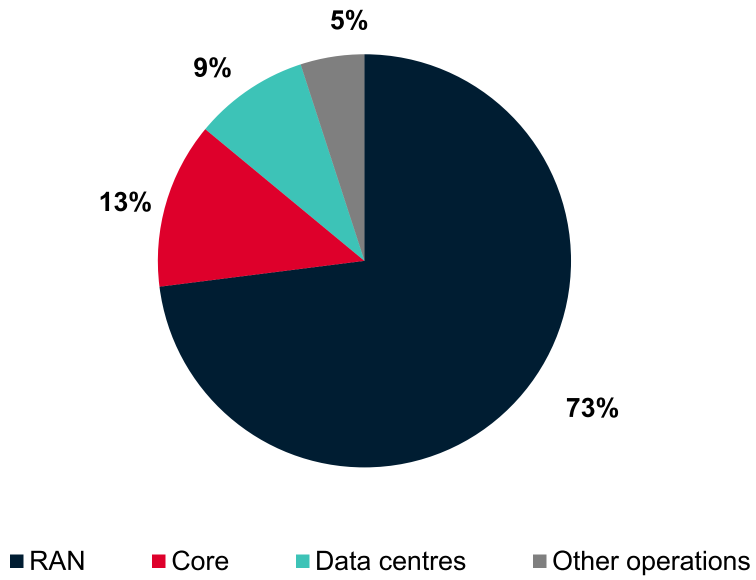
Site simplification and physical modernisation	Using lean site designs, simplified sites with pooled baseband units and multi-generational equipment, and avoiding shelter or cabinets can all help to improve overall energy efficiency.
Spectrum refarming and user migration	As legacy wireless technologies approach the end of their lifecycle, refarming valuable spectrum and migrating users to newer technologies can significantly improve energy efficiency.
Highly integrated hardware	The use of highly integrated radio devices and ultra-wideband AAUs can help operators to use shared power modules and decrease cable loss.
Advanced cooling solutions	Prioritising outdoor equipment placement and passive thermal management, and reducing site complexity and cable loss can improve overall energy efficiency.
AI and resource optimisation	Symbol, channel and carrier shutdown, real-time analysis and cross-cell optimisation can all help operators to use their energy resources in a more efficient manner.

Source: GSMA Intelligence estimates, expert interviews

3.1 Network layers and energy efficiency

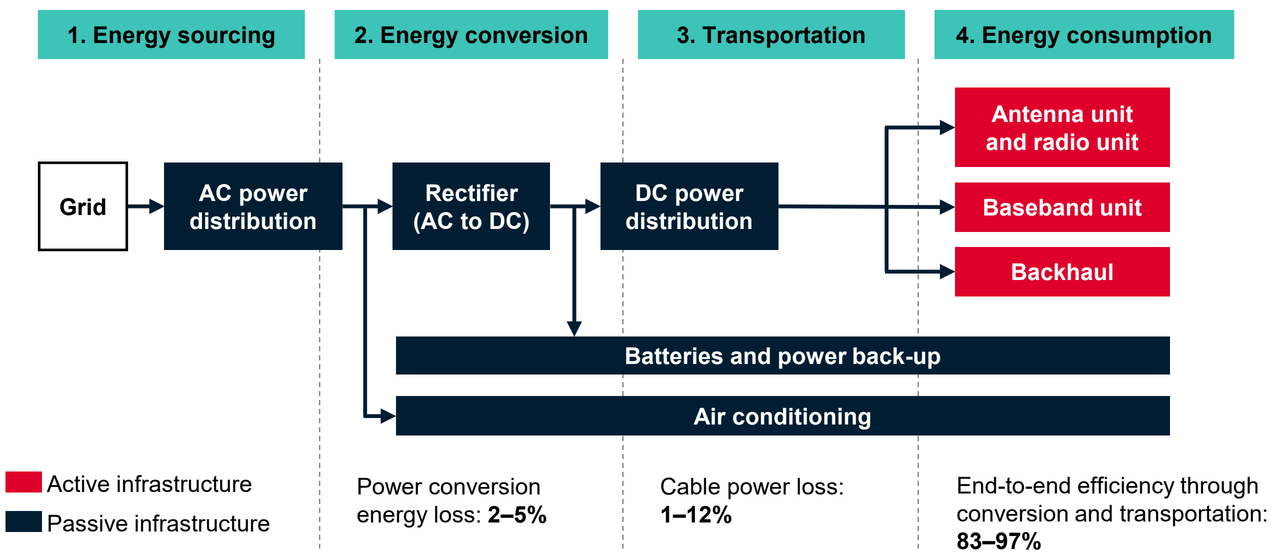
According to GSMA Intelligence's model and analysis, mobile operators are using most of their energy in the RAN (see Figure 8). While new cellular technologies are significantly more efficient, the overall power consumption in the RAN is soaring. To significantly improve the overall, end-to-end energy efficiency in the RAN, operators need to adopt a holistic view.

Figure 8: Where mobile operators are using their energy



Source: GSMA Intelligence

Figure 9: End-to-end network energy efficiency



Source: GSMA Intelligence, expert interviews

3.2 Passive infrastructure

The role of passive infrastructure is to support, defend and supply the active network elements. There are significant variations between mobile sites, the regulatory and physical environments they operate in and the traffic load experienced, based on country or location, so improving the energy efficiency of passive infrastructure can be a complex and labour-intensive task. Also, depending on the climate and the quality of the electricity grid, passive infrastructure (especially air-conditioning) can be responsible for a significant part of operators' energy use, meaning the stakes can be high.

While in the 2G and 3G eras many operators used general-purpose passive network elements (batteries, air-conditioning, rectifiers etc.), equipment vendors introduced purpose-built products. General-purpose equipment is less efficient, needs more maintenance or is simply not feasible because mobile operators have unique needs, including:

- special insulation to avoid dust, heavy rain and exterior temperature effects
- anti-theft and vandalism features
- high-capacity fuel tanks, automatic oil and fuel refilling and sensors for the generator to avoid frequent refill and maintenance site visits
- special lightning protection system because mobile sites are taller than their surroundings.

Rectifiers

Energy utility providers sell alternating current (AC) electricity, while most of the site-level energy consumption happens in direct current (DC). AC is an electric current that periodically reverses direction and changes its magnitude continuously with time; DC electricity flows in one direction only. For this reason, each cell site needs to have a rectifier module. There has been significant improvement in past years for rectifiers and converting electricity as efficiently as possible. In the future, a common standardised AC and DC voltage system can help the reuse and mix and match of different equipment.

Site batteries

In off-grid areas, mobile operators are often forced to use diesel generators to guarantee the reliability of the power supply for base stations. This is less than ideal considering generators emit high levels of carbon dioxide and have onerous cost implications associated with refuelling, particularly in hard-to-reach, sparsely populated areas requiring labour call-outs and security protection. Lithium batteries have emerged as a more environmentally friendly and cost-efficient alternative. These have a smaller and lighter form factor compared to traditional lead acid batteries, saving space after installation. Lithium batteries also have a significantly longer expected lifespan (five or six years on average); the commonly used lead acid batteries are expected to be efficient for a much shorter period (around three years).

Further favourable aspects of lithium batteries include the improved charge and discharge capacities and related savings potential from the battery configuration. Back-up batteries are fully charged at all times and discharge only when there is a power outage. By using a cycle-type lithium battery capable of daily charge and discharge, smart power control with a DC power controller can be performed, enabling a flexible and efficient power supply to radio equipment. Supplementing the batteries with a digital control system can help to optimise the load on the tower as well as the energy source for the tower. Hybrid and integrated battery systems enable flexibility and are more energy efficient and sustainable.

The importance of data harvesting

Energy management and optimisation is a particularly data-intensive area around the passive infrastructure. Network equipment does not usually measure energy consumption and many parts of the passive infrastructure simply lack metering. Most operators currently have no or limited information on their passive infrastructures. Even if the equipment has the metering capacity, recording the data would be labour intensive and not in real time. After operators deploy the required sensors and build the data pipelines, they will be able to have a view of the energy usage from passive infrastructure and increase the impact of AI.

Case study: Ufone

e& Group (formerly known as Etisalat) has formulated climate change and reducing the carbon footprint through operations as one of its key strategic pillars.

As one of the major operating companies of e& group, PTCL & Ufone Pakistan sets a target of net zero by 2050, to support Pakistan's target of a carbon-free Society and e& Group's target of net zero in the ICT sector by 2050.

Ufone is driving positive change when it comes to handling the issue of climate change. It used renewable energy solutions, such as solar hybrid solutions, on all sites with a 0 W diesel generator running and reduced the emission factor from 1.34 to 0. Ufone transformed 2,000 sites with a hybrid lithium solution and reduced CO_2 emissions by 50%. In 2022, it achieved a reduction of 1,800 metric tons CO_2 at 460 sites. Ufone also identified poor SEE (80%) at its indoor sites and determined the major factors were air conditioning and old rectifier modules. It converted 200 indoor sites to outdoor sites with high-efficiency rectifiers and cooling, improving SEE to 95%.

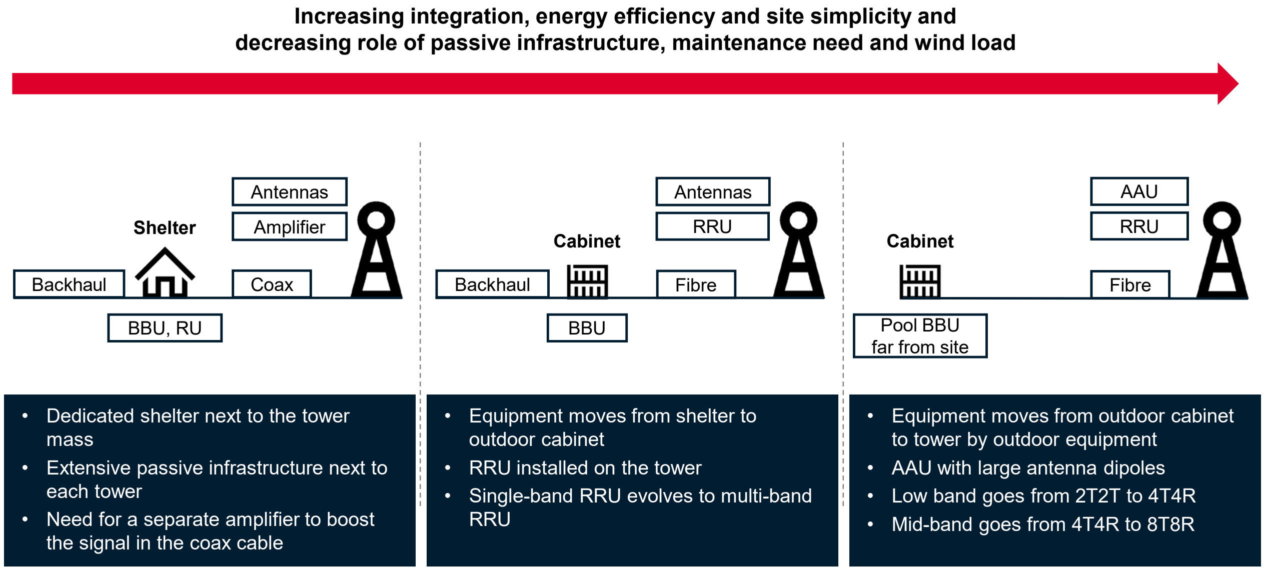
Ufone has also implemented a supplier-tested solar access solution at five existing sites initially and achieved a reduction of 15 metric tons of CO_2 emissions annually. Nationwide, it has deployed 800 sites with solar solutions. Ufone identified sites that have ample space for solar installation and currently expects a yearly saving of 331,982 litres of diesel (800 metric tons of CO_2 emissions), which is equivalent to planting 25,000 trees.

3.3 Site strategy evolution

Over the past 30 years, cellular sites have developed at a rapid pace, based on the number of served connections, offered speeds, skyrocketing traffic load and new functionalities from operators. In parallel with this, operators not only installed higher-capacity and more efficient equipment but also reorganised their site structure significantly. There are two trends that currently determine the energy efficiency of the sites: centralisation and simplification. Centralisation of certain network functions (such as the baseband unit) helps to find a more energy-efficient network structure driven by economies of scale, while simplification can help to shake off redundant or integrated equipment.

Rapid growth in bandwidth demand and fierce competition have led to network operators racing to deploy fibre infrastructure as fast as they can. The spread of optical fibre and the appearance of integrated equipment helped sites to become leaner and more agile. New materials and cooling technologies are also helping to place the equipment outdoors and to simplify the site structure. High-capacity and ultra-wideband active antenna units (AAU) and integrated radio remote units (RRU) are helping operators to simplify their network even further.

Figure 10: Evolution of the mobile site



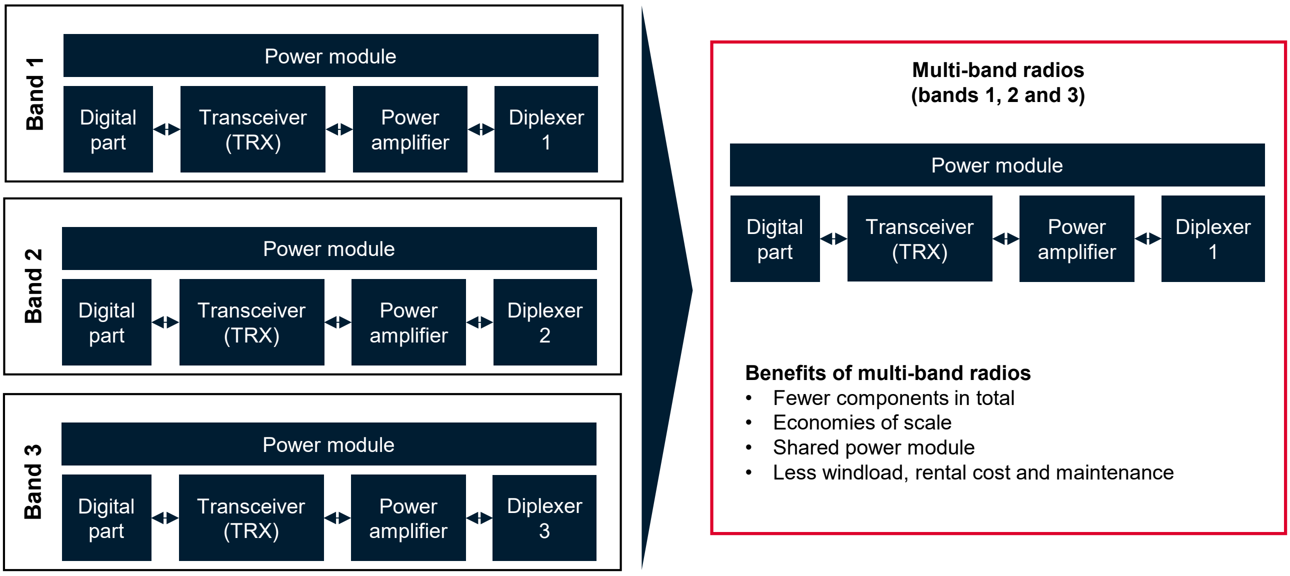
Baseband unit (BBU), radio unit (RU), remote radio unit (RRU), active antenna unit (AAU)

Source: GSMA Intelligence, expert interviews

Multi-band, integrated equipment integration

Equipment integration facilitates simplification and network evolution, in addition to bringing down the overall energy costs. Recent developments have enabled multiple bands and radio access technologies to be deployed into one single radio module with full power-sharing between multi-bands and radio technologies. These dual-, tri- and quad-band radios (multi-band) connect to the same antenna system, reducing the amount of power used on a per-band basis. This convergence minimises the volume of equipment deployed, simplifies the site structure and relaxes site deployment requirements. In the not-too-distant future, more bands are expected to be introduced for mobile networks and the level of integration is expected to increase. This means one single module is expected to provide services for the whole cell site. Additionally, integrated radios decrease site rental costs and the overall wind load of the site. As an example, operators reported site-level energy savings of approximately 30% after a large-scale RRU modernisation project with multi-band RRUs. Overall, this higher integration of radios with power-sharing features can be a significant part of energy-efficiency improvements.

Figure 11: Multi-band radios and their impact on energy efficiency



Source: GSMA Intelligence, expert interviews

Massive MIMO antennas and the use of ultra-wideband technologies

Massive multiple-input multiple-output (MIMO) technologies can effectively bring down the level of energy consumption. Massive MIMO requires an increased number of antennas compared with traditional MIMO technology. Laboratory tests suggest that the increased number of antennas improves energy efficiency, transmitting and receiving more data for a given amount of energy. Additionally, they can save space by using fewer active antenna units and other networking elements.

Shannon's capacity formula shows the relationship between power consumption versus network capacity, and this can be transformed from exponential to linear when massive MIMOs are adopted. Newly integrated antennas with larger and a higher number of antenna arrays can increase efficiency gains and improve the energy concentration. They are also helpful for reducing the output power. But they still provide the same user experience. Furthermore, high integration antenna designs also mean fewer cables between equipment, thus less cable loss, which will improve overall energy efficiency. Advanced software with power-saving features from time domain/spatial domain/frequency domain/power domain, such as channel dynamic muting, can further significantly reduce power consumption.

Equipment vendors are also trying to deploy active and passive combined antenna systems using innovations such as beam-through antennas. This means an active antenna system is installed behind passive antenna systems and they can use multi-standard radio supporting 2G through to 5G. While the antennas are typically passive, the use of AAUs will increase energy efficiency, as the loss of copper jumper cables is minimised by the leverage of signal direct injection feeding technology.

Power consumption can be considered a system engineering concept rather than focusing on just specific components to find cross-functional synergies. Multi-band radios and massive MIMO technologies with an increased number of arrays are the best way to improve the mobile site network capacity from an energy-efficiency viewpoint, instead of purely increasing the power. However, commercial off-the-shelf (COTS) and general-purpose hardware tend to have lower energy efficiency compared to custom-built hardware. This may be offset to a degree via centralisation, where much of the processing power is moved off the cell site and the cell site has fronthaul and aggregation equipment moved to the centralised site. The perennial struggle is expected to continue in the background: on one hand, the network load, radio frequency output power and operational bandwidth are expected to increase energy use; on the other hand, energy efficiency in also expected to improve and limit energy use.

Case study: China Telecom

China Telecom believes that green and low-carbon development is not only a requirement for promoting high-quality social development but also for realising the green transformation of China's telecoms industry. China Telecom aims to build a green network through new technologies, models and operations.

The power consumption of a single site of 5G equipment in the industry is generally around 5,000 W, which is significantly higher than current levels of power consumption from 2G, 3G and 4G sites. This will bring challenges to the existing power supply system in the form of insufficient power supply system capacity and a substantial increase in electricity costs. China Telecom and Huawei used the iTelecomPower site energy solution to build a simplified green site, which offers the following advantages:

- It has an integrated fan-free design, high-power natural heat dissipation, and man-free maintenance.
- It has a high-density and compact design, with only a small volume (1/10 of the traditional cabinet) that can be hung on the wall and pole, free of rent fees.
- The energy efficiency is improved to more than 97%
- The verification of the existing network shows that compared with the traditional site method, using this solution can save 6,000 kWh of electricity and reduce carbon emissions by 4 metric tons per site per year.

Based on big data and AI technology, China Telecom has independently developed E-Surfing Blue Energy, a unified network-wide smart energy-saving platform for base stations to achieve safe and automatic energy savings. The system has four innovative capabilities of network-wide digital perception, intelligent decision analysis, security automatic control and digital operation, and achieves the effect of smart energy saving under the condition of ensuring user experience. By the end of 2021, China Telecom's base station smart energy-saving system had been deployed in 31 provinces across the country, managing more than 1.3 million 5G sectors, increasing 5G energy-saving efficiency by 15% and reducing carbon dioxide emissions by more than 500,000 metric tons per year.

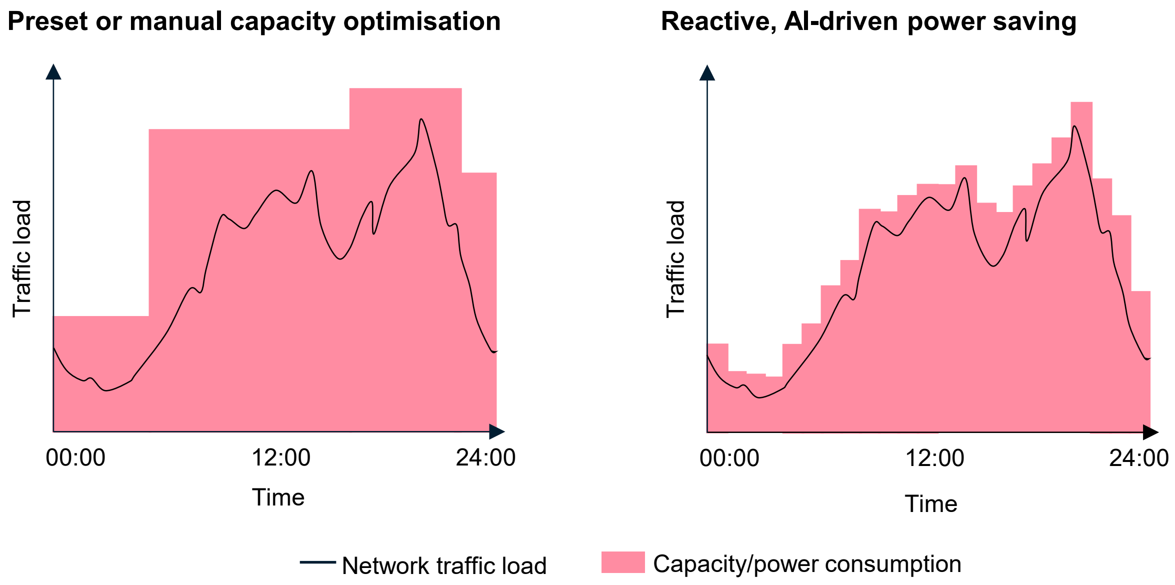
3.4 Use of AI in optimisation

AI is delivering enhanced experiences and new capabilities to the telecoms industry in more ways than ever before. AI can accelerate future innovations and novel machine-learning (ML) techniques can fuel advancements across a wide range of technology areas. Not only is AI able to solve difficult wireless system challenges and make the network more efficient, but there are also significant natural synergies between AI and 5G. Holistic and end-to-end AI and ML can provide a ubiquitous system-level approach that improves energy efficiency across hardware, software and algorithms. Energy management is very data heavy and operators cannot efficiently process information and make real-time decisions at scale without the use of AI. Because AI allows vast amounts of data from different sources to be analysed quickly and efficiently, it expands the potential for several energy-saving opportunities across the whole network.

If the algorithm can assess data related to real-time demand, traffic patterns and network resource availability, then AI can enable quick, automated decision-making to facilitate a huge variety of use cases. This includes managing and allocating resources in a more energy-efficient manner or even planning new networks more efficiently. Operators will handle an ever-increasing amount of information in the future regarding their network operations, and AI will become increasingly important for efficiently analysing, processing and translating this into actionable insights.

AI-driven shutdown and sleep solutions can forecast data traffic based on historical patterns, weather, nearby events and other factors, before identifying the necessary thresholds and activation and sleep periods. Based on the information, the algorithm can shut down power amplifiers, transceivers and other larger network elements to save energy.

Figure 12: AI-driven network shutdown solutions can help to synchronise net capacity to the instantaneous traffic load



Source: GSMA Intelligence, expert interviews

Shutdown solutions are the low-hanging fruit, but AI will also have a fundamental role in network design. Network design is the foundation of energy-efficient networks. Operators are deploying a wide range of new cells during the start of the 5G era, including mmWave cells and small cells integrated into street furniture, street lamps or even indoor sites. Propagation analysis and site selection are complex and labour-intensive tasks; AI can help here, not just to speed up the process but also to make it more accurate. An AI algorithm first creates a propagation map, then after some additional input from the operator, an optimal network configuration can be reached. Initial on-site performance checks can feed input back into the algorithm to validate and fine-tune the network planning.

Being able to manage demand at the cell site and bind data management and energy management together is crucial. For example, one tower may be more efficient than another nearby and data can be moved from the less efficient tower to the more efficient tower so that the data processing and energy usage gets shifted around. In addition, there is a trend toward decentralisation of functionality (and thus data processing and energy usage) toward the edge, which impacts the cell site. It is also possible to go on- and off-grid with the latest microgrid control systems and support the grid from a demand/response point of view.

Case study: Deutsche Telekom

Deutsche Telekom (DT) has made energy efficiency a core element of its group strategy and DT's Corporate Responsibility Strategy is derived from this. It covers three action areas: climate protection and resource efficiency; digital responsibility; and digital participation. The climate strategy translates the first action area into concrete measures. This is how DT ensures that climate protection measures are closely connected with its core business. To support the climate strategy and achieve the ambitious DT Group targets, the national companies have developed and implemented their own climate protection strategies, concepts and measures. DT's integrated climate strategy is based on four pillars: emissions from the value chain; renewable energy; energy efficiency; and enablement (positive climate protection effects for its customers).

DT's core business consists of operating and expanding its network, providing the foundation for digital participation. As of 2021, Deutsche Telekom's entire network was green, with 100% of its power coming from renewable sources. Also, by providing innovative, network-based solutions, DT supports its customers in reducing their own CO_2 emissions and contributing to climate protection.

DT aims to stabilise its energy consumption by 2024. To achieve this goal, despite growing data traffic and ongoing network expansion, DT plans to double its energy efficiency or the ratio of network data traffic to the electricity required to move it. In a DT Group-wide technology-innovation project, DT is studying and developing new ways of making its network operations even more energy-efficient and sustainable.

To ensure the energy consumption grows much less than the amounts of data transmitted, the operator is pursuing various approaches, including:

- reducing the energy consumed in its mobile network operations via RAN software
- improving the energy efficiency in its mobile network operation via multi-band integrated cellular base stations
- developing solutions for energy-autonomous cellular base stations to allow multiple renewable energy power supplies.

3.5 Network sunsets, spectrum refarming and user migration

With the arrival of 5G, the commercial pressure to retire 2G/3G networks and refarm frequencies increased. As legacy wireless technologies approach the end of their lifecycle as licences end, operators are in a great position to disable or refarm particular spectrum within their RANs. As wireless technologies are improving rapidly, the telecommunications ecosystem is rolling out a new technological generation approximately every 10 years. Each mobile generation is more energy efficient than the before. More efficient power amplifiers, advancements in signalling technologies and radio processing and improvements in spectral efficiency have all helped newer wireless generations to do more with less energy.

Several 2G and 3G networks have already closed and many more shutdowns have been announced. Before network closure, operators have many decisions to make and considerations to take into account to ensure that the impact on their customers and business partners is minimised.

2G, 3G, 4G, 5G and, in the foreseeable future, 6G will coexist and operators will find it increasingly difficult to maintain these different technologies at the same time in an energy-efficient way. Mobile operators need to take a balanced approach, which avoids harming existing customers with 2G or 3G user equipment but also aims to use the most energy-efficient technologies without causing long-lasting competitive disadvantages.

The 5G efficiency gain

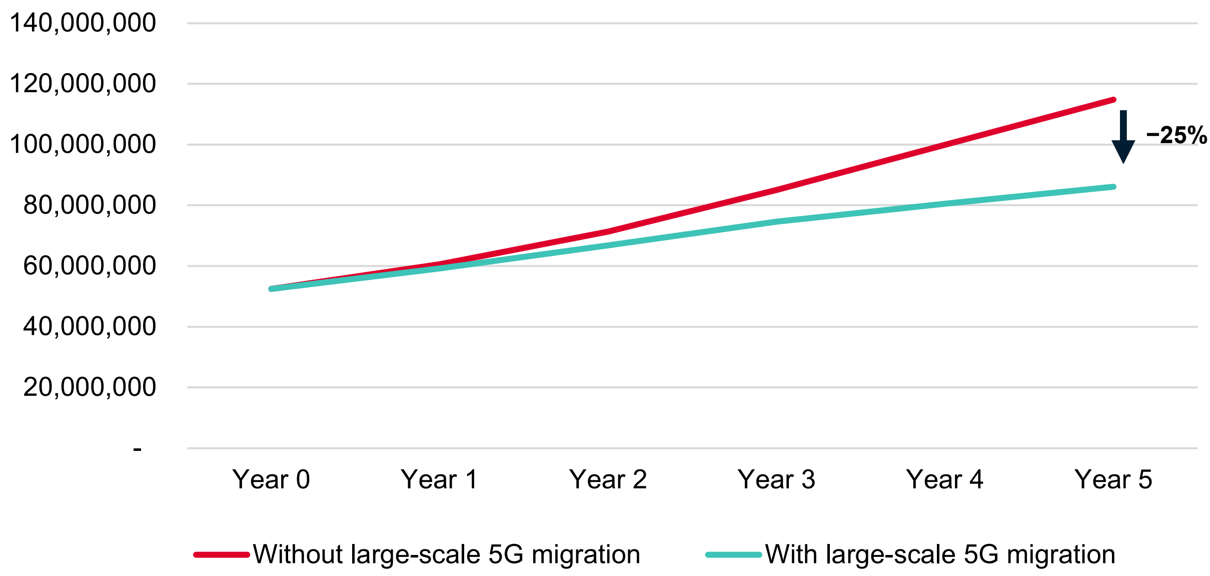
Each wireless technology generation is more energy efficient than its predecessor – but 5G is the first cellular technology designed to be more energy efficient and sustainable. Energy efficiency improved by approximately 10 times from 3G to 4G, while it improved by around 13 times from 4G to 5G. Thus encouraging users to migrate from 2G/3G to 4G/5G will significantly improve efficiency and reduce both energy consumption and carbon emissions.

Figure 13: Efficiency difference between different wireless technologies

	3G (1T2R)	4G (4T4R)	5G (64T64R)
Total energy expenditure (GB/kWh)	10	96	1335

Source: Huawei

Figure 14: The impact of 5G migration on energy consumption
Power consumption (kWh)



Source: Huawei

Energy efficiency improvements can be translated into carbon emission reductions. For example, downloading an average length HD movie with a 3G network emits around 200 g of CO_2; downloading the same HD movie with 5G emits only around 10 g of CO_2. More broadly, 1 million 2G/3G subscribers migrating to a 5G network would mean a reduction of 45,600 tons of CO_2 emissions per year, equivalent to planting 2.3 million trees, which is about 20 km^2 of land.

3.6 The evolution of cooling technologies

Networking infrastructure, including base stations, distributed units, core networks and data centres, must be kept within the maximum recommended operating temperature of critical equipment to ensure reliable service. Telecommunications infrastructure is exposed to a heat load, which is the combination of two factors: heat generated by each of the electrical components and heat transferred into the enclosure from sun exposure.

Mobile operators are in a unique situation from a cooling perspective. First, their assets are widely distributed and often located in remote areas under challenging conditions. Second, networks are exposed to a constantly increasing processing load, and traffic increases and edge computing will exacerbate this in the near future. Mobile networks and their edge cores are expected to take over more processing from the user equipment, meaning the processing will happen on the operator's premises.

The constantly increasing geographical coverage area of cellular networks brings new challenges for operators. Extreme heat and temperature fluctuations in high-altitude locations require state-of-the-art methods for cost-efficient cooling. In addition, enclosures located outdoors require a watertight seal to keep precipitation and contaminants, such as dust and humidity, from entering and damaging electrical equipment.

The difference between active and passive cooling

To tackle and ease the difficulties and risks that arise as a result of excess heat, infrastructure vendors employ different cooling technologies to manage thermal conditions. These methods can be divided into two main categories: active (forced) and passive cooling technologies.

Passive cooling achieves high levels of natural convection and heat dissipation by utilising the design of the equipment and the materials to maximise the radiation and convection heat transfer modes. In architectural design, the air is used as heat sinks to absorb or dissipate excess heat.

Active or forced cooling relies on an external device to enhance heat transfer and some kind of fluid or airflow increases the heat removal. Active cooling solutions include forced air through a fan or blower and forced liquid, which can be used to optimise the thermal management of the equipment.

Passive cooling capabilities take centre stage

Since the beginning of the 2G era, cooling was a fundamental question of site design and passive infrastructure improved significantly parallel with active network elements. As the role of shelters, cabinets and indoor equipment set-ups minimised in the past decade, outdoor equipment and passive cooling became more important. Active cooling systems require extra electricity use, network complexity space, in addition to higher site rental costs. This results in both higher capex and opex costs, compared to passive cooling. Passive thermal management solutions are cost- and energy-efficient solutions that rely on heat dissipation to maintain optimal operating temperatures. The vision of an energy-efficient network includes outdoor equipment placement and passive cooling solutions, which is works hand in hand with the trend of site simplification. The leading equipment vendors have therefore invested significant resources to improving mainly the passive cooling capabilities of their products in recent years.

Figure 15: Advanced cooling solutions

New materials (passive)	**Using materials with advanced thermodynamic characteristics** Aluminium has been the main material used for network equipment, but new composites with advanced thermodynamic features have recently been introduced.
Design (passive)	**Design methods to remove unnecessary heat** New equipment design methods can help operators get rid of the waste heat produced and therefore reduce the amount of related cooling infrastructure needed. V-shaped heat exchangers, AlSi6 outer shells, flapping wings and butterfly designs can all utilise natural conduction, convection and radiation to cool components.
Components (passive)	**Advanced components** Power amplifiers and chipsets are largely contributing to the total power consumption of the radio frequency hardware. High-efficiency power amplifiers and advanced 5 nm chipsets are helping operators to improve overall energy efficiency.
Liquid cooling (active)	**Liquid cooling to save extra heat** While air cooling systems can be noisy and require regular maintenance, liquid cooling can overcome these issues. Liquid is also much more efficient in the transmission and transfer of heat and adding liquid cooling systems can transform and save the captured waste heat produced by the base station during operation. This can then be circulated and reused for other purposes. For example, it can be redirected to a building's heating system for free or at a price, or even traded. Local climate and surroundings can limit the use of liquid cooling solutions.

Source: GSMA Intelligence, expert interviews

3.7 Increasing importance of the software layer

Efforts over the last decade around software-defined networking have helped centralise the network's intelligence and control at the software layer. Software features allowing control and modular upgrades will likely become the default. There is also an indirect impact in that the decline of hardware-centric innovation decreases the need for physical activity such as site visits, logistics, shipping, servicing and maintenance. Less physical activity decreases energy consumption and limits the climate impact of upcoming network updates and new features.

4. What does the network of the future look like?

In general, an energy-efficient wireless network is built on site simplicity and advanced passive cooling technologies, frequently harvesting data from almost every part of the network and turning them into actionable insights. An energy-efficient network takes advantage of the purpose-built network elements' improved characteristics and uses about as much energy as needed at the moment without impacting user experience. The separate equipment on site and the number of site visits are also limited to the minimum. Further, frequent software updates are helping network elements to improve their energy efficiency day by day. The combination of these factors can help operators to build a future-proof, energy-efficient network that improves their overall competitiveness, satisfy their customers and is also sustainable.

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