GSMA Intelligence

5G energy efficiencies: green is the new black (the sequel)

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In context: the energy-saving imperative

To help tackle climate change and reduce network operating costs, energy saving has become a priority for the telecoms industry. While mobile networks provide near-ubiquitous access to connectivity, convenience and entertainment, greater use of smartphones for video and other bandwidth-hungry services over 4G/5G will drive parallel rises in traffic and energy consumption – unless there is intervention to improve efficiency and increase the use of renewables.

In November 2020, GSMA Intelligence published the flagship report, *5G energy efficiencies: green is the new black*. Much has changed since then. Given the growing strategic importance of the topic for the telecoms industry, this research revisits the 2020 report's main questions and conclusions.

This edition examines how networks consume energy and how site, RAN and network-wide innovations can help boost efficiency. It also delves into initiatives network operators and technology vendors have rolled out over the past three years targeting energy-efficiency gains, net zero, and climate KPIs and reporting. The research establishes the context and rationale for improving energy efficiency among operators and their supply chain, as 5G enters a new phase. From an energy perspective, the new stage is about cost efficiencies, network performance, densification, energy security and carbon emission reduction efforts.

The energy-efficient network of the not-too-distant future

While traditional network infrastructure includes extensive air-conditioning units as well as shelters and site cabinets to house equipment, new architectures will use the following:

- highly integrated radios and antennas with heat sinks
- software for control and adjustment, with hardware more commoditised
- individual sites and whole networks controlled with AI-driven network management software. This collects real-time information on network load, capacity, weather and nearby events, and forecasts optimal performance paths without impacting user experience.

The change in network strategy means energy efficiency is now a core objective – just as security and performance are. This report aims to help understand the factors helping or hindering that goal, and the outlook for the next five years on a technological and competitive level.

1. The imperative to reduce emissions

1.1 Telecoms among the global leaders on commitments

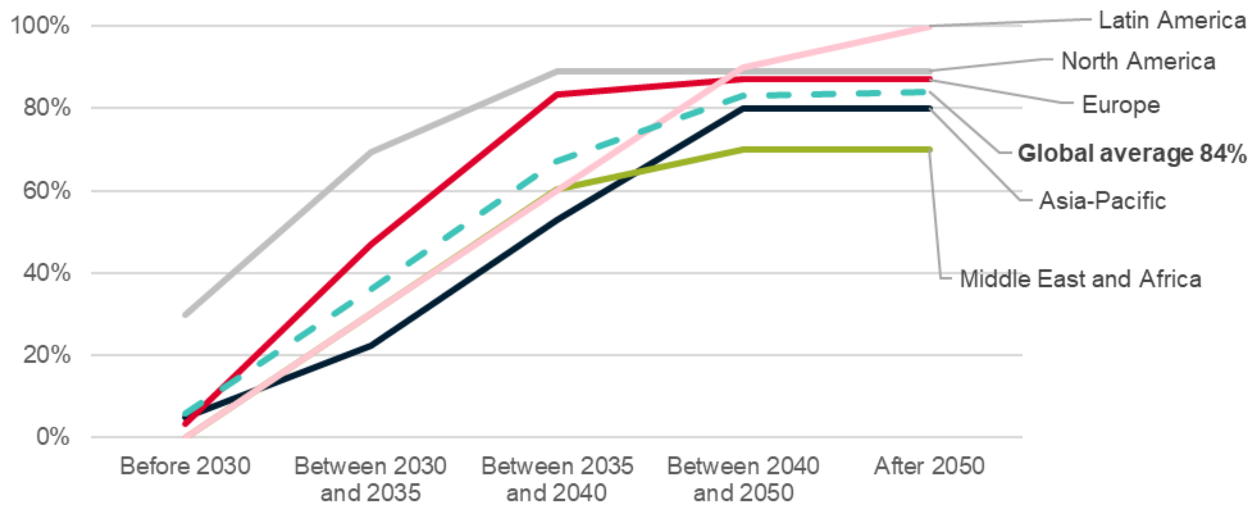
The imperative to reduce CO2 emissions has environmental and business rationales. GSMA Intelligence has written extensively on both, with the latter a focus in the *Green is Good for Business* series. The analysis in this report focuses on energy and the environmental dimension.

Environmental commitments are anchored in the Paris Accord of 2015. The 1.5°C trajectory has a net-zero target date of 2050, implying 50% reductions in each of the preceding three decades (50% CO2 reductions on 2020 levels by 2030 and so forth). Political efforts to embed climate objectives as part of national development and economic transformations have been highlighted at the various global climate conferences (COPs) held since 2015. Government action on the climate issue resembles an inverted pyramid shape: almost all countries (95%) have ratified the Paris Accord but only 57% have committed to net zero on the 2050 (or sooner) timeline.

In many cases, the private sector has been a leading force in stepping up to net-zero timelines, as part of corporate transformation to a sustainable operating model. The telecoms industry is among the global leaders in this respect. Indications from CDP submissions and GSMA Intelligence's own survey data suggest around 85% of operators have committed to net zero (see Figure 1). The majority are working to a 2050 timeline, but several have made more aggressive commitments. Vodafone, Telefónica, Deutsche Telekom and MTN, for example, have committed to a 2040 timeline.

There is, however, regional variation. Europe continues to be a leading region; it has benefitted from climate being a management and political priority, and from efficient access to renewables. US and Canadian groups are also at the forefront, as are those in the Gulf. By contrast, commitment rates are lower in Africa and Southeast Asia but on the rise. China has committed to a 2060 glidepath.

Figure 1: Cumulative share of operators committed to net zero, by date



Note: figures based on survey of operators so do not represent the true total in the industry. Based on CDP submissions, we believe the actual figure to be lower.

Source: GSMA Intelligence based on survey of telecoms operators, June/July 2023 (N=100)

1.2 Measuring progress so far

While measuring industry commitments to net zero is one indicator of climate action, it is equally important to assess the rate of progress each year and the factors influencing this. This is particularly true now and in the near term, as the 50% reductions per decade mean the 2030 delta will be the most difficult to hit (the law of large numbers).

Figure 2 presents analysis of progress versus commitments for a series of tier-1 operators. It shows the annual reduction in CO2 emissions from the most recent reporting period (2022) compared to the required reduction implied by a company's stated net-zero target year.

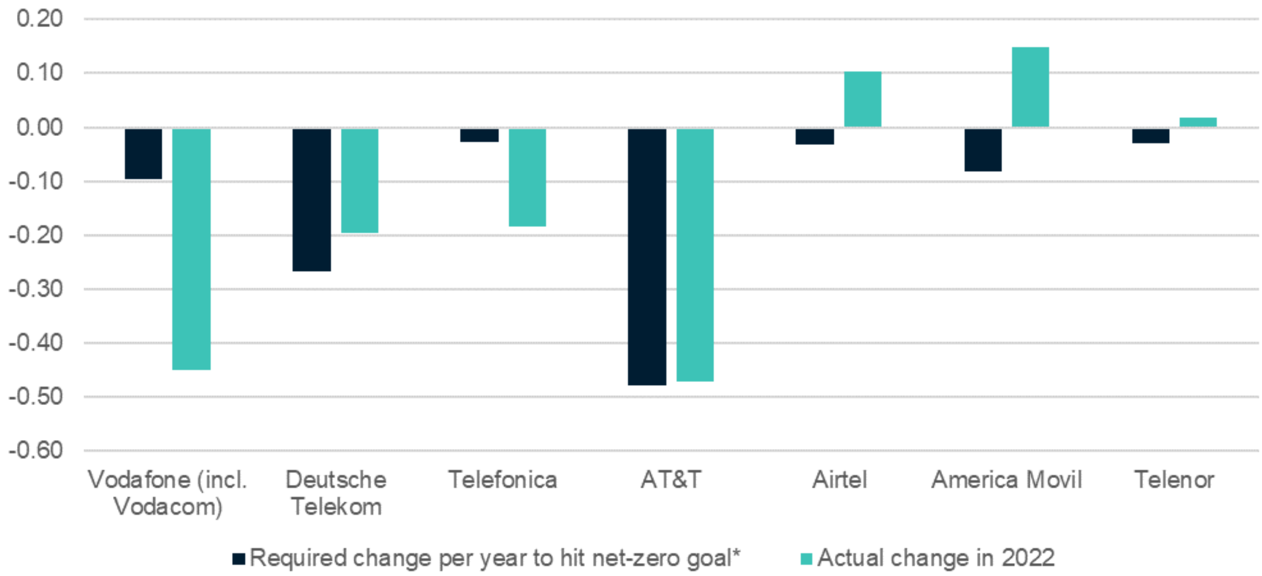
- Two of the seven operators – Vodafone and Telefónica – are running ahead of schedule, and by a significant margin (approximately 3–4× the required run rate). This reflects their early commitments (pre-pandemic) and aggressive company-wide shift to renewables and prioritisation of energy efficiency in the network, which accounts for 80–90% of operator energy consumption.

- Two groups – AT&T and Telenor – are broadly on track, meaning their deltas are in line with the requirement implied by their publicly stated net-zero goal (AT&T targeting 2035 for Scope 1 and 2; Telenor targeting 2035 for Scope 1, 2 and 3).

- The others are behind schedule, with various factors at play.

Figure 2: Are operators on track to achieve net zero?

Annual change in CO_2 emissions (tonnes, million)



*Calculated as emissions (Scope 1 and 2 only) in 2021 divided by the number of years between 2021 and the stated target year to achieve net zero. As Scope 3 emissions are excluded, this shows aims to show directionality rather than a precise quantification of progress.

Source: GSMA Intelligence, CDP, company websites

2. How networks consume energy

2.1 Energy use across the network

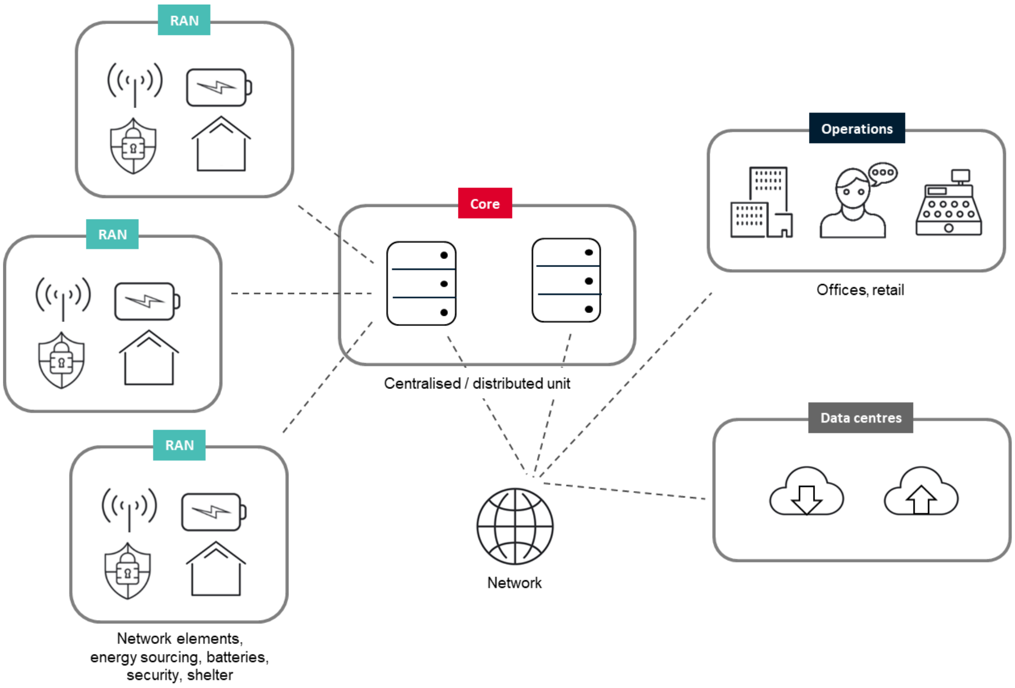
Networks account for around 90% of energy usage for a typical mobile operator. With energy also accounting for 20–40% of overall opex, efficiencies are a priority, particularly in the context of ongoing capex requirements and low revenue growth.

Figure 3 shows a basic network architecture. Analysis of data directly from operators as part of the GSMA Intelligence Energy Efficiency Benchmarking Tool indicates that energy use is split between the following:

- RAN: 75–80%
  - radios and antennas
  - baseband
  - backhaul links
  - passive support (e.g. cooling)
- core and datacentres (owned by operators, excluding leased capacity): 10–15%
- other operations: 5–10%
  - offices and property
  - shops
  - distribution and logistics
  - corporate travel.

The radio access layer represents the ‘low-hanging fruit’ and has therefore been the main target of energy efficiencies.

Figure 3: Basic network architecture: where energy is used



Source: GSMA Intelligence

2.2 Energy at the industry level

The importance of efficiencies can be seen at an overall industry level. The telecoms sector accounts for around 1% of global electricity usage, equivalent to around 300 terrawatt hours per year. Hyperscalers also account for around 1% (excluding bitcoin mining); most of this is through datacentre processing and cooling. Adding in handset/device manufacturing and content distribution brings the total ICT sector contribution to around 3.5–4.0% of global energy.

The telecoms operator and cloud shares of total energy should moderate slightly over the rest of the decade to 2030 as efficiencies are harvested. Their shares of emissions will also reduce, given the higher preponderance of renewables compared to other industries. However, without network upgrades and better access to renewables, the overall volume of energy and emissions would still increase considerably.

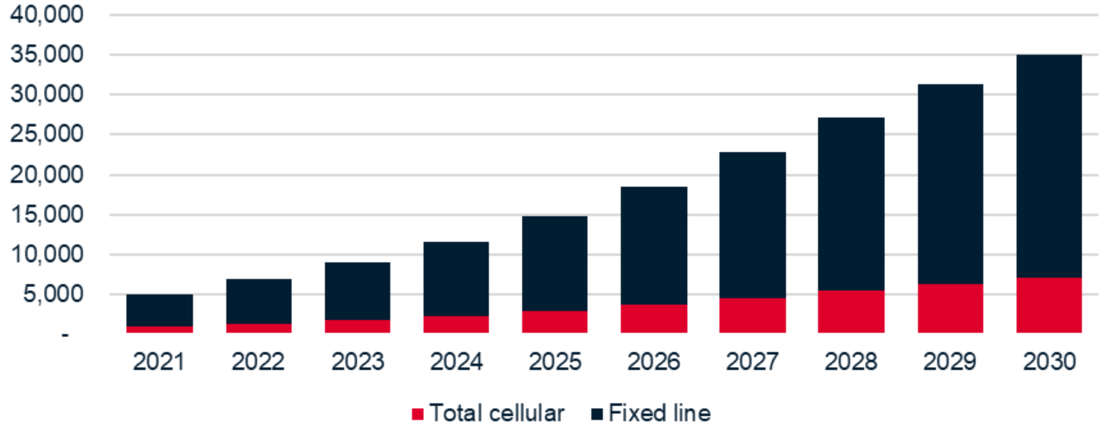
2.3 The effect of 5G and enterprise digitisation on data traffic

Cellular and fibre traffic volumes will rise sixfold over the next seven years. 5G accounts for around 15% of the customer base at present. We expect this to rise to 25% by 2025 and around 55% by 2030. The average data usage for a 5G smartphone user is around 3–4× that for a 4G user.

On the enterprise front, data usage is typically less intense but through a high volume of industrial and other IoT devices. Total IoT connections (including licensed and unlicensed spectrum) will reach approximately 37 billion by 2030. Enterprise verticals will drive the majority of the incremental gain between now and then, accounting for around two thirds of the base.

Figure 4: Traffic over mobile and fixed networks will rise sixfold between now and 2030

Exabytes per year



Source: GSMA Intelligence, Ericsson

The impact of rising traffic on energy usage comes not so much from a pure volume rise but the uneven distribution in data processing. 5G service in high footfall areas (such as city centres, airports and sports venues) and FWA require a higher density of sites and capacity provisioning, as the locations tend to have the highest busy-hour loads. Enterprise workloads are increasingly being processed in the cloud and at the edge to facilitate low-latency applications (e.g. robotics or traffic systems). The same Pareto-style challenge in lumpiness can occur where a minority of datacentres or edge nodes handle a majority of traffic. Improvements are being implemented in the form of more efficient GPU chips, natural cooling and dynamic shifting (where traffic is offloaded to datacentres with lower utilisation). However, the imperative for efficiencies will remain, given the sheer volume of workloads.

3. Network innovation for energy efficiency

Since the last report three years ago, we have seen further evidence of energy efficiency growing as a driver of network transformation. Energy security, high energy prices and increasing data traffic from 5G are spurring interest in energy efficiencies.

New energy-saving offerings cover the entire value chain, including testing companies with power and emissions measurement applications, equipment providers with lighter, more integrated RAN solutions, and a range of new software offerings to help operators use only the resources necessary and steer traffic to the most efficient network layer.

3.1 AI is helping drive energy efficiency

A few years ago shutdown solutions were limited to the time domain (simple sleep modes). Now, new solutions are saving network resources in the frequency domain (carrier boosting) and the spectral domain (per node or sector). The areas where operators can use AI or machine learning have expanded significantly, with solutions commercially available across spectrum management, passive infrastructure and transport network optimisation, for example.

Operators' use of artificial intelligence can include the following areas:

- beam management
- mobility enhancement
- scheduler optimisation
- propagation testing
- link simulation
- deployment optimisation.

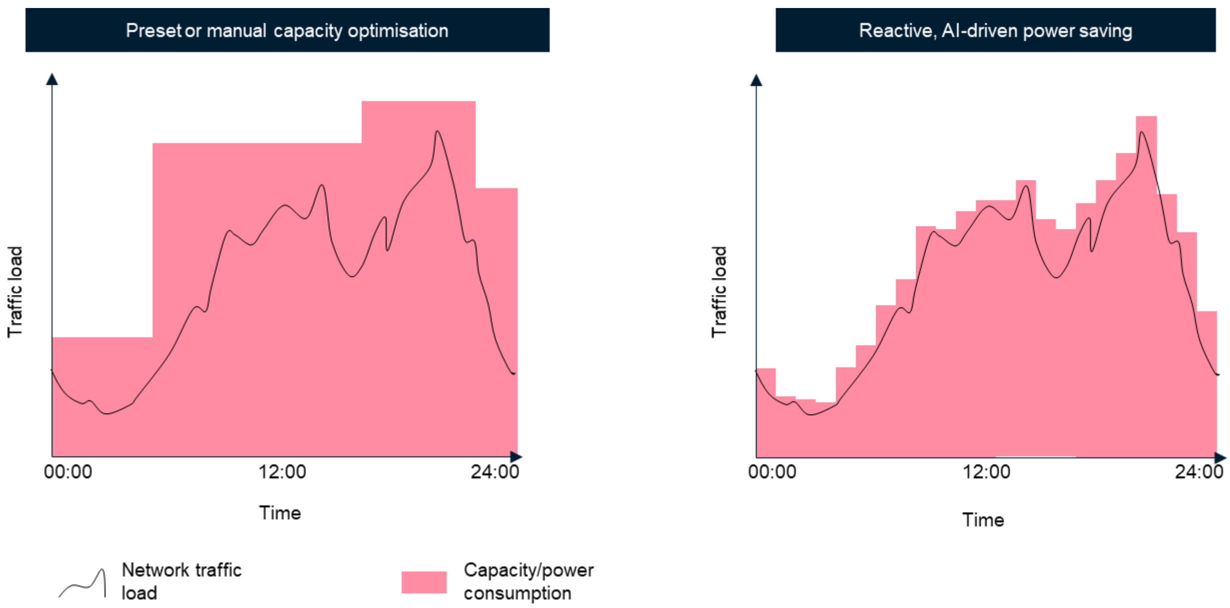
Key to the attraction of AI-driven solutions is that they are not capex- or hardware-intensive and require little time to launch. Two particular areas of interest are traffic steering and interference sensing. These solutions can not only turn different network elements on and off; they can pick the optimal layer, use the most energy-efficient spectrum and steer traffic to where it uses the least amount of energy.

Energy management is data dependent. Without AI, operators cannot efficiently process information and make real-time decisions at scale. While operators may in the past have taken a wait-and-see approach to these new solutions, many have recently started to monitor, test and trust in them.

AI-powered sleep modes are impacting energy efficiency in three main areas:

- Antennas – Massive MIMO sleep modes can dynamically deactivate and activate antenna branches to match network capacity with actual traffic needs.
- Radios – Putting the radio units into idle/sleep modes or even turning them off helps use only the necessary amount of radio computing resource.
- Spectrum – Selecting and migrating users to the ideal spectrum band can improve overall energy efficiency. The dynamic activation and deactivation of different spectrum carriers based on the actual traffic need can save energy for mobile operators. Different spectrum bands are suited to different numbers of users and traffic loads.

Figure 5: AI-driven network shutdown solutions can help match net capacity to current traffic load



Source: GSMA Intelligence, ZTE

New AI- and ML-powered solutions are delivering new capabilities and efficiency improvements to operators in more ways than ever before. They allow network equipment to perceive, reason, understand and offer new ways to solve technical challenges. Holistic and end-to-end AI and ML can provide a ubiquitous, system-level approach that improves energy efficiency across hardware, software and algorithms.

3.2 Coverage extension solutions are enabling energy saving

The propagation characteristics of higher spectrum bands are different to lower bands from an energy efficiency perspective. As 5G (and likely 6G) heavily relies on higher spectrum bands, operators need to rethink the basic architecture of traditional cellular networks and introduce coverage extensions and distributed solutions.

Distributed solutions are easier to customise and update, and smaller coverage gaps can be handled with smaller network elements. There are currently four main types of distributed coverage enhancement solution: micro active antenna units (AAUs), integrated access backhaul (IAB), network control repeater (NCR) and reconfigurable intelligent surface (RIS). While lower bands can easily penetrate thick walls without significantly losing signal strength, the same wall can easily absorb the majority of higher-frequency signals, transforming them into heat. Most demand for connectivity is generated indoors and traditionally served from outdoors. The propagation characteristics of the higher frequency bands therefore encourage network architects to choose the higher frequency to get around, rather than penetrate, thick-walled buildings. Before selecting the technology for their mmWave network, operators should consider energy efficiency and include sustainability as a factor in their decision-making.

Reconfigurable intelligent surface

Network coverage can be significantly improved with a new reflection point between the antenna and user equipment. This intermediate network element is a reconfigurable intelligent surface (see *Using RIS to go around, rather than through, obstacles*). It is a piece of equipment around the size of a pizza box, with surfaces that have reflection, refraction and absorption properties (thanks to small antennas). The reflective material elements can be adapted to a specific radio channel environment. Driving RIS is the technological progress in programmable materials that can control electromagnetic waves, with key enablers including the shrinking form factors of network elements, new materials and advanced network management software.

There are two main types of RIS: passive and active. While passive RIS reflects a fixed outgoing beam, active RIS achieves beam steering and user tracking, effectively enhancing the coverage range of base stations and ensuring an optimal user experience, even when the user is on the move.

Figure 6: Coverage expansion through RIS

Source: GSMA Intelligence, ZTE

3.3 Innovative materials and methods are aiding cooling

Network infrastructure, including base stations, distributed units, core networks and data centres, must be kept below the maximum recommended operating temperature for critical equipment to ensure reliable service. Telecoms infrastructure is exposed to a heat load that is the result of two factors: heat generated by electrical components and heat transferred into the enclosure from sun exposure.

Why cooling is important

Mobile operators are in a unique situation in terms of cooling. First, their assets are widely distributed and often located in remote areas with challenging conditions. Second, networks are exposed to a constantly increasing processing load; traffic increases and edge computing will exacerbate this in the near future. Mobile networks and their edge cores are expected to take more processing away from user equipment, meaning it 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 prevent precipitation and contaminants (such as dust and humidity) from entering and damaging electrical equipment.

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

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

- Active cooling solutions include forced air through a fan or blower, and forced liquid. These can be used to optimise the thermal management of the equipment.

New developments in cooling

Despite the industry's focus recently shifting from hardware to software, there is significant innovation on the hardware side and in materials used. In many cases, innovations in cooling hardware must work together with software innovations.

Synthetic diamond

Increased computing capacity will result in more pressure from a thermodynamic perspective. This means equipment needs to cool down more quickly and handle more of the increased excess heat. Vendors have started to use new materials and design elements in equipment and equipment covers. An example is synthetic diamond. Unlike most electrical insulators, diamond is an excellent conductor of heat because of the strong covalent bonding within the crystal. The thermal conductivity of pure diamond is the highest of any known solid. As the price of synthetic diamonds has started to decrease, vendors are expected to increasingly use this material (soon to be commercialised on a wide scale).

Water-retention solutions

As reactive AI-driven power-saving shutdown solutions gain popularity, rapid temperature changes can be a challenge for network designers. Shutdown and sleep solutions quickly turn different parts of the network equipment on and off, so the temperature inside can quickly drop or increase by over 50°C within a short period of time. When the air cools quickly, its moisture capacity is reduced and airborne water vapour condenses to form water. When this occurs through the air's contact with a colder surface, dew will form. This can impact the materials used and cause problems with condensation in the equipment, as excess water harms the electrical components. As the role of AI is only expected to grow, temperature fluctuation and precipitation will increase in importance. Vendors and operators are expected to tackle this issue using water-retention solutions.

3.4 Renewables are evolving

Mobile operators have been using renewable energy since the 2G period, but the scale and methods used have improved. There are three main ways for operators to use renewable energy, each with different strengths and weaknesses:

- **Power purchase agreements (PPAs)** are long-term commitments between buyers and renewable electricity generators, reducing buyer risk for new projects. The agreements allow access to project finance while locking in a low and stable price for buyers.

- **Renewable energy certificates** are effectively transferrable proof of renewable energy generation. These can be purchased in any market and do not typically require long-term commitments. They can be used to reduce Scope 2, market-based emissions.

- **Electricity generation** is usually from on-site solar photovoltaic (PV) installations, wind turbines or biomass, often coupled with battery storage. The main drawback is limited space for on-site generation; urban, capacity-focused sites rarely have enough space for sufficient on-site generation.

Onsite electricity generation

While certificates are generally the most popular option for accessing renewables for many operators (due to their simplicity and global availability), operators have significant assets in the land/areas they rent or lease. Mobile operators have been generating solar for decades, but on a small scale with limited efficiency. Onsite renewable generation by operators has faced two main issues: limited expertise within the organisation, and tools and equipment that are multipurpose and so not always suitable for particular environments.

Over the past two decades, operators have further developed their expertise and built capacity, while vendors have started to offer tailored batteries, generators, solar panels and electric switches suited to operators' particular deployment scenarios. This has helped operators increase the renewable energy ratio to 20-40%. A self-sustaining site is no longer that far off in the future.

Figure 7: The development of onsite electricity production

Past: **the old times**	**Present:** **introducing intelligence**	**Future:** **the self-sustaining model**
• Basic solar photovoltaic (PV) applications work independently of energy storage systems. • Reliance on generic, lead-acid batteries without energy management software, which limits efficiency.	• New advanced solutions include energy storage working in step with PV generation to reduce waste during sunnier periods. • Intelligence can calculate expected duration of sunshine, to ensure the battery is full by sunset.	• The latest batteries can last for more than 6,000 cycles. Operators can use battery capabilities more efficiently, install more PV panels and rely on weather forecasts. • Hard-to-reach areas and remote islands can benefit from this model of almost self-sustainability. Some remaining energy needs still depend on diesel generators.
Estimated renewable energy ratio: **5–15%**	Estimated renewable energy ratio: **20–40%**	Estimated renewable energy ratio: **80–95%**

Source: GSMA Intelligence

4. A vision of the future

Maximising every kWh of electricity with AI

AI and machine learning represent the next frontier of energy-saving solutions. Operators have an opportunity to not just change the way they provide services, but to redefine the environmental impact. AI-driven symbol, channel and carrier shutdown, real-time analysis and cross-cell optimisation are expected to define energy efficiency in telecoms. These solutions will help operators use their energy resources in a more efficient manner.

To allow AI and ML to use only as much energy as is required, operators need to harvest their data to identify the redundant kWh and predict near-term energy consumption. If data harvesting and security allow, operators can limit further redundant radio waves and idling through real-time decision-making and reactive software.

Technology vendors have spent a significant amount of resources on improving their AI solutions to make mature and reliable options available. Many of these work in multivendor environments, and are easier and quicker to deploy than physical network equipment. Compared to hardware, software has a lower market entry cost, while less commitment and capex-heavy investment are needed to develop network optimisation software.

Simplicity and distribution

The energy-efficient wireless networks of the future will be built on site simplicity and advanced passive cooling technologies, regularly harvesting data from almost every part of the network and turning it into actionable insights. An energy-efficient network takes advantage of the improved characteristics of purpose-built network elements and uses only as much energy as is needed at that moment, without impacting user experience. Further, regular software updates can help network elements improve energy efficiency day by day. Together, these factors can help operators build a future-proof, energy-efficient network that improves their overall competitiveness and meets the needs of customers.

Operators as virtual power plants

Aside from providing connectivity services, operators are also well-positioned with distributed assets, rented land, batteries and solar panels to provide new, energy-related services for other, as yet untapped operator business models. The global energy sector is changing rapidly; a number of trends are creating an opportunity for new energy services:

- On the supply side, a large amount and range of renewable energy sources are being connected to the electricity grid. Despite their advantages, solar and wind are unpredictable; the energy supply can change in minutes. The predictability of the energy supply can erode significantly as the proportion of solar or wind in the energy mix increases.

- On the demand side, there is a global electric vehicle revolution. This transition away from internal combustion engines heavily impacts not just the load on the electricity grid but also the temporal distribution of electricity demand.

As the grid grows in complexity, so too does demand for better management of the network and its inputs and outputs, as well as extra electricity storage to balance out rapidly changing supply and demand. Mobile operators are well positioned to start offering virtual power plant (VPP) services. They can digitally integrate their power sources, optimise energy consumption, balance out peaks and troughs and offer reliability to the grid as traditional power plants or energy management companies do.

The importance of passive infrastructure

To improve energy efficiency and achieve carbon-neutral targets, network operators and tower companies will need to invest in advanced passive infrastructure. Passive infrastructure can include a range of different technologies to help improve site-level energy efficiency:

- power sourcing (electricity grid, solar panels or generator)

- power conversion (AC to DC)

- power storage (Li-ion/lead-acid battery)

- supporting functions and security (cameras, sensors)

- power management systems.

Migration to newer cellular technologies drives energy efficiency

Although the first large-scale 5G launch was in 2019, there remains some scepticism around 5G's energy efficiency. 5G new radio (NR) is significantly more efficient than 4G and 3G, but overall electricity consumption will rise in the 5G era unless there are mitigation measures. The energy-saving measures built into the 5G NR standard could be offset by rising data traffic and new 5G use cases, resulting in higher levels of energy consumption overall. However, upon reaching a critical mass of 5G connections and appropriate network optimisation, 5G's superiority in terms of energy efficiency will be clear.

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