GSMA Intelligence

Going green: measuring the energy efficiency of mobile networks

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Our team of analysts and experts produce regular thought-leading research reports across a range of industry topics.

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Executive summary

Background

Sustained cost pressures and commitments to net zero have made energy efficiency a strategic priority for telecoms operators; sustainability registered as a top network transformation priority for operators around the world in 2023. Partnering with a global set of mobile operators, GSMA Intelligence leveraged its independent position and analytical capabilities to launch its Mobile Energy Efficiency Benchmarking project in 2020. The benchmark is based on fully anonymised, real-world data inputs, with a goal of quantifying network energy consumption, efficiency levels and fuel sources.

With each successive year, operator participation in the benchmarking project has grown. The result is a unique, increasingly salient, network-level, global data set on energy efficiency yielding so far not measured datapoints alongside insights into sustainability trends, technologies and best practices. GSMA Intelligence is grateful for the 17 operator groups that participated in the project: AIS, Bharti Airtel India, Chunghwa Telecom, Deutsche Telekom, e&, Ethio Telecom, Globe, M1, MTN, Optus, Orange, Singtel, Telecom Argentina, Telecom Italia, Telefónica, Telkomsel and Veon. The 17 operators not only provided data about 65 networks in 59 countries but also actively participated in workshops and provided useful insights for this report. Overall, these operators serve almost 1.6 billion mobile connections globally, representing 19% of total cellular connections.

Highlights

Our modelling and analysis resulted in a number of findings at a global level:

- 76% of the energy of the participating operators is consumed in the radio access network (RAN). The network core and owned data centres (19%) and other operations (5%) account for the rest.
- In the markets covered, the average primary energy efficiency ratio in the RAN reached 6.83 GB/kWh. According to our data set, this also indicates that operators used on average 0.15 kWh of energy to transfer 1 GB of data across their RAN networks.
- In terms of other RAN efficiency ratios, one mobile connection required an average of 14 kWh of energy during the 12 months, while one cell network site used on average 22 MWh over the year.
- On average, 73% of operators' energy came from the electricity grid mix, 21% came from purchased and generated renewables and the remaining 6% came from diesel generation. Diesel generation was generally higher in developing regions where grid and renewables access is less prevalent.
- Participating operators used 71% of their total energy in the active infrastructure and only 29% was consumed in the passive infrastructure, to support, defend and supply the active network elements.

These figures are averages from a specific subset of operators. Even within the sample group, there is significant variation – and this would apply to the industry overall too. The results should therefore be interpreted at a high level rather than be predictive for any one country or operator.

Next steps

2023 was the third year of tracking energy efficiency by GSMA Intelligence. We intend to extend this into a multi-year study with a wider group of industry participants to increase the representativeness and direct applicability of the research. GSMA Intelligence hopes that the benchmark will aid best-practice guidance on the rationale and means of becoming more energy efficient, given this is an industry-wide rather than company-specific challenge.

1. Project rationale

Sustained cost pressures and commitments to net zero have made energy efficiency a strategic priority for telecoms operators; sustainability registered as a top network transformation for operators around the world in 2023.[1] Partnering with a global set of mobile operators, GSMA Intelligence leveraged its independent position and analytical capabilities to launch its Energy Efficiency Benchmarking project in 2020. The benchmark is based on fully anonymised, real-world data inputs, with a goal of quantifying network energy consumption, efficiency levels and fuel sources. The research is set against a context of broader efforts to help tackle climate change and embed sustainable business practices into the telecoms industry and its supply chain.

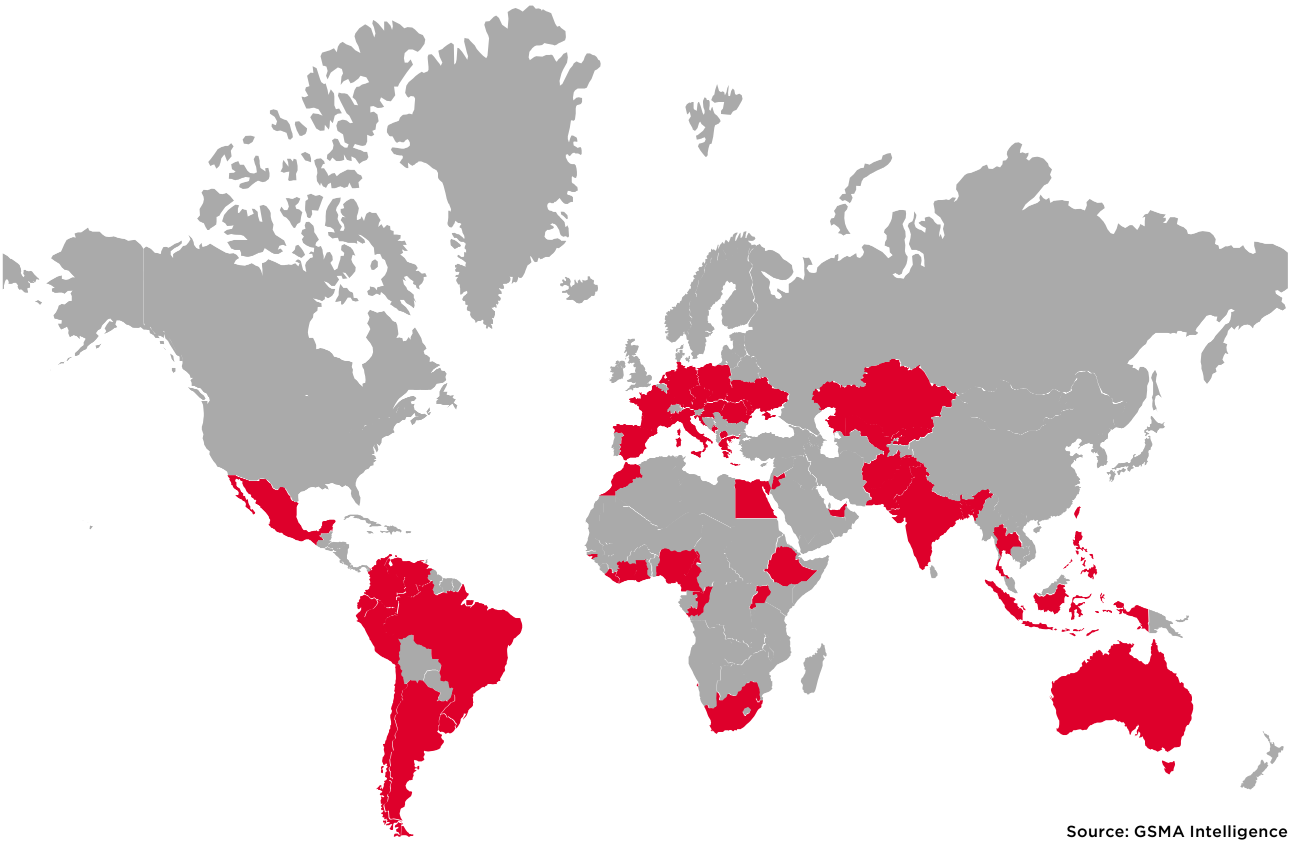
The GSMA Climate Action Taskforce – which now has more than 60 operators globally as members – shares, promotes and works together on climate topics such as energy efficiency, renewables, supplier engagement and the use of connectivity for climate mitigation and adaptation.

17 operators participated in this project: AIS, Bharti Airtel India, Chunghwa Telecom, Deutsche Telekom, e&, Ethio Telecom, Globe, M1, MTN, Optus, Orange, Singtel, Telecom Argentina, Telecom Italia, Telefónica, Telkomsel and Veon. The data provided by these groups spans 65 networks in 59 countries.

[1] Operators in Focus: Network Transformation Survey Dashboard 2023, GSMA Intelligence, 2023

Figure 1

Countries included in the Mobile Energy Efficiency Benchmarking



Source: GSMA Intelligence

Based on a range of energy-related metrics and more than 3,500 data points gathered, we derived insights on:

- energy efficiency
- diesel versus renewable energy usage
- consumption distribution across different parts of an operator network (RAN, core network and data centres, and operations related to mobile networks)
- 5G's energy efficiency
- active and passive infrastructure.

2. Methodology

Selection of a comparable KPI

The goal of the Mobile Energy Efficiency Benchmarking tool is to help operators measure the relative efficiency of their networks. The basic principle of efficiency is simple: how much energy is needed to deliver one unit of output. In the context of mobile networks, this means the amount of energy needed to transmit 1 GB of data (voice also requires energy but its load is negligible compared to data). However, measuring energy efficiency can be carried out in various ways.

Based on the standard of ITU-T and the European Telecommunications Standards Institute (ETSI), mobile network data energy efficiency is the ratio between the data volume and the energy consumption during the same period. Thus, the metric for energy efficiency is useful output over energy consumption.[2] 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.

Each measure has its pros and cons, so the exercise of selection becomes a question of balance. We have primarily chosen the first method – data traffic per unit of energy consumption – as it is the most easily comparable and meaningful KPI to monitor over time.

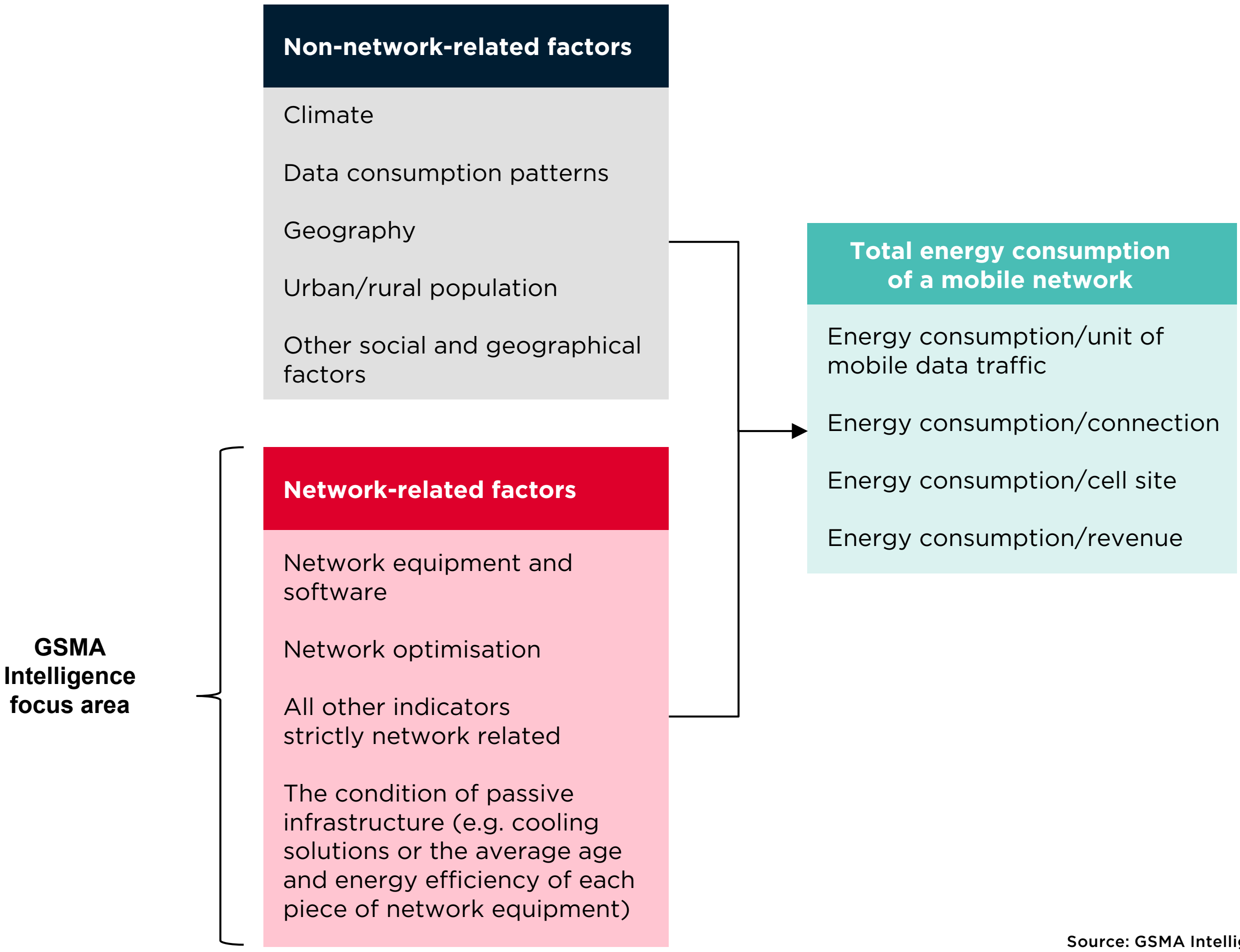
Normalisation

Comparing multiple networks in different countries with different characteristics – such as climate, population density and data consumption levels – is a complex task.

[2] The ITU defines energy efficiency and explains the recommended methods to measure energy efficiency in more detail in Energy efficiency measurement and metrics for telecommunication networks.

Figure 2

Factors affecting energy usage



Source: GSMA Intelligence

To normalise the results and allow like-for-like comparisons, we divided the explanatory variables into:

- non-network-related variables – those outside the operator's control (e.g. population distribution and climate)
- network-related factors – those within the sphere of control of the operator.

Regression analysis

Data inputs from the participating operators include energy usage, data traffic, number of cell sites and fuel consumption split between diesel and renewables. To avoid seasonality and outlier periods, the data covers the full-year period of 2022. After normalisation, we ran a regression analysis of variables against energy consumption to understand which have the highest correlations. Conclusions were then drawn on benchmark levels for energy consumption, fuel sourcing and efficiency ratios.

See the Appendix for more details on our methodology.

3. Benchmarking results

Categorising energy consumption

The direct energy consumption of the operators can be categorised into three groups:

- **RAN energy consumption:** This comprises energy consumed by the RAN, which includes BTS, Node B, eNodeB and gNodeB energy usage and all associated infrastructure energy usage such as from air-conditioning, inverters and rectifiers. It includes energy usage from repeaters and all energy consumption associated with backhaul transport. It excludes picocell, femtocell and core network energy usage, as well as mobile radio services.

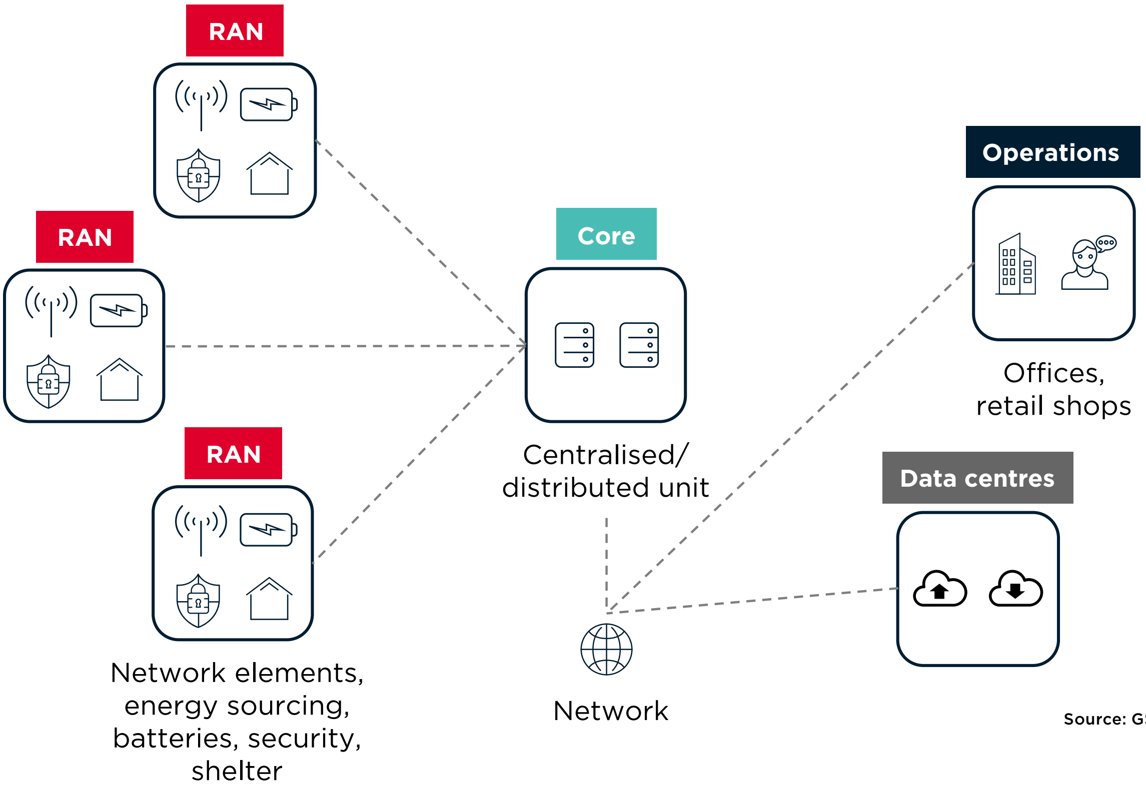
- **Core and data centre energy consumption:**[3] This comprises energy consumed by the core network and data centres related to the mobile network, which are the physical sites that host operators' IT, including OSS and BSS and intranet infrastructure. Our analysis only includes energy consumption for data centres owned by an operator; it does not include energy consumption related to leased or outsourced capacity from web-scale providers such as AWS, Microsoft and Google. It also includes all energy consumption associated with backhaul transport.

- **Other operations:** This comprises energy consumed by the mobile operator for its own operations. This includes offices, shops, retail activity and logistics.

[3] After the first year of this study, we decided to combine the core network and data centre energy consumption categories. Driven by digital transformation, especially virtualisation, many operators cannot separate their core and data centre energy consumption as they previously could. These functions have been collocated together and electricity consumption metering can no longer be separated.

Figure 3

Where mobile operators use energy in their network operations



Source: GSMA Intelligence

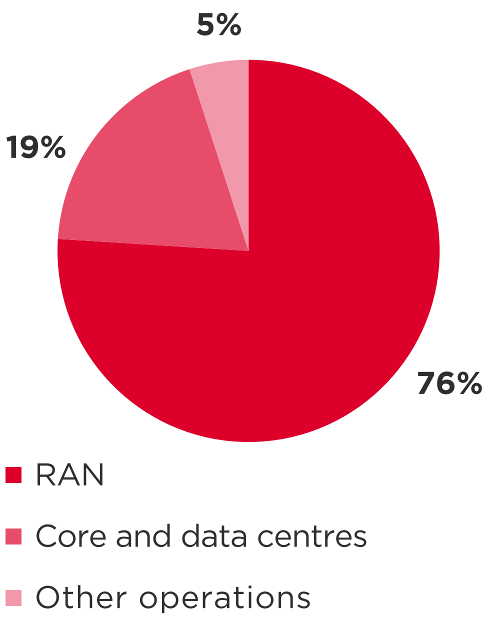
Findings

Consumption

- The majority of energy (76%) is consumed in the RAN. Providing coverage across thousands of square kilometres, transforming energy into radio waves, and receiving and processing incoming signals are still energy-intensive functions.
- The remaining distribution of consumption comprises data centres and core network (19%) and operations (5%).

Figure 4

Where mobile operators use energy in their network operations



Source: GSMA Intelligence

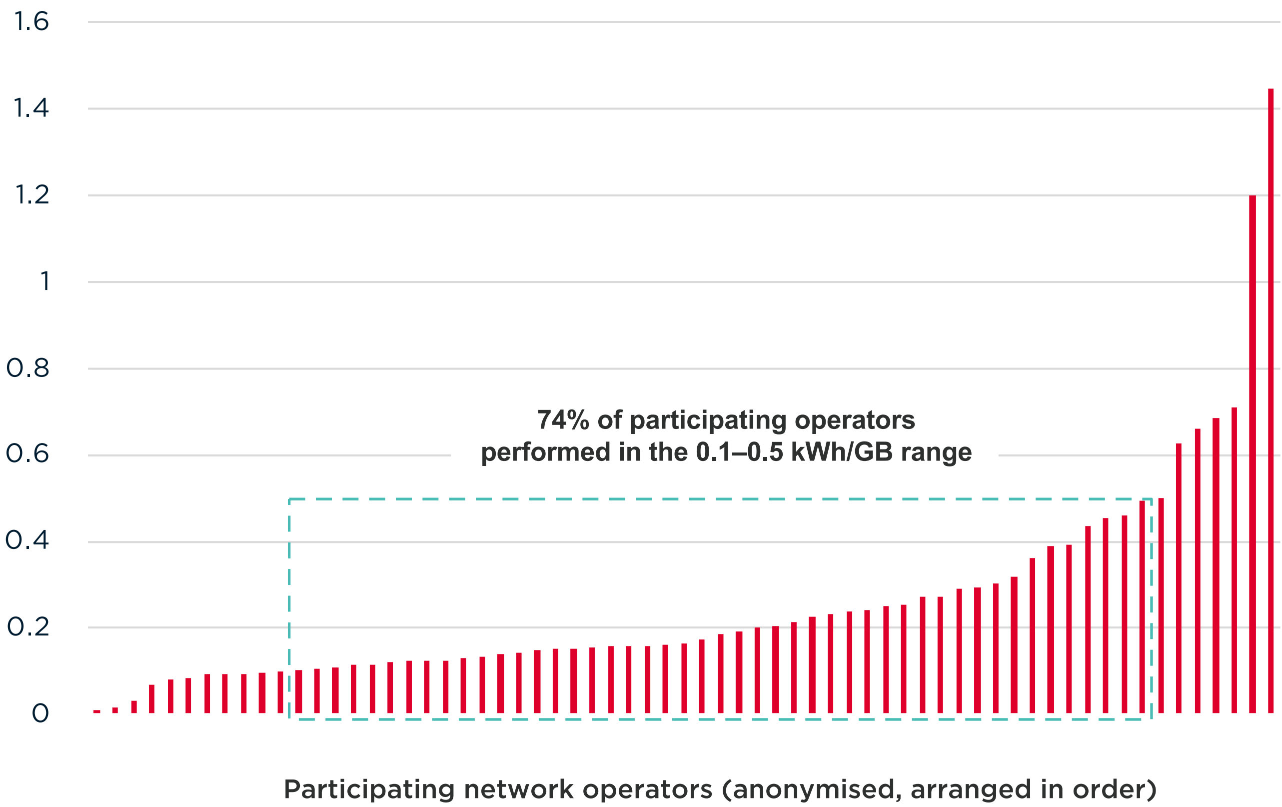
Note: Data based on GSMA Intelligence's Mobile Energy Efficiency Benchmarking project in 2024 with 65 mobile networks.

Efficiency

- Energy efficiency was measured primarily using the data traffic per unit of energy consumption ratio across the RAN. In the markets covered, this averaged 6.83 GB/kWh during 2022. According to our data set, this also indicates that operators used on average 0.15 kWh of energy to transfer 1 GB of data in their RAN network. GSMA Intelligence also used three secondary efficiency ratios, which aimed to measure energy efficiency from different angles:
  - For the 65 operators covered, one mobile connection required an average of 14 kWh of energy in the RAN during the 12-month period.
  - On average, one network site used around 22 MWh for the same one-year period.
  - From a energy intensity point of view, one network operator used on average 227 MWh of energy to generate €1 million in revenue.
- It is worth noting that the above values are averages for the participating operators, and the range of values is wide, with some metrics differing by a factor of 20. Furthermore, as the list of the participating operators changed significantly, we could not present any scientifically evaluable result in terms of year-on-year change. The number of networks that participated in the first three years of this project was too low for the results to be representative.
- Of the participating operators, 74% performed in the 0.1–0.5 kWh/GB range (see Figure 5), meaning that most of the included networks used 0.1–0.5 kWh to transfer 1 GB of data. Values outside of this range can be explained by inefficient networks, consumer habits or low data traffic per connection.

Figure 5

Overall energy efficiency of participating operators (kWh/GB)



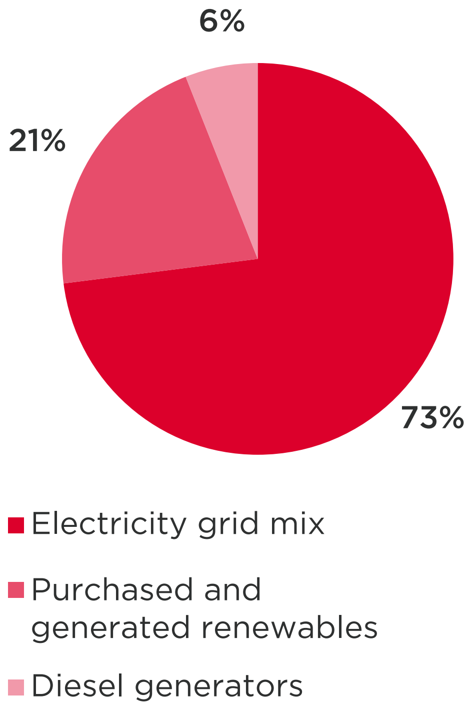
Source: GSMA Intelligence

Fuel sources: renewables versus diesel

- 73% of the energy consumed by the participating operators came from their electricity grid mix, 21% came from purchased and generated renewables and 6% came from diesel generators.
- Renewables are mostly purchased via renewable energy certificates and power purchase agreements. On-site solar accounts for less than 1% of total energy consumption.
- European operators are at the forefront of renewables usage. European network operators can access renewable energy more easily via the grid and many have set ambitious goals. Some already have network operations powered 100% by electricity from renewable sources.
- Diesel usage is more concentrated in developing regions where grid and renewable electricity access is less prevalent. Despite operators being at the forefront of the use of renewables, they need an immediately available energy source in bad-grid, off-grid and hard-to-reach areas to provide critical infrastructure in developing regions and bridge the digital divide for underserved communities.
- Diesel usage is more common in South Asia, the Middle East and Sub-Saharan Africa. However, even in Europe, it accounts for 1–5% of consumption. The network that used the most diesel, on a relative basis, is in Asia. The network with the second-highest usage of diesel is in Africa, which was followed by a number of other African networks. Diesel usage is not a region-specific trend but rather related to electricity grid conditions.

Figure 6

Source of used energy for mobile operators



Source: GSMA Intelligence

Note: Data based on GSMA Intelligence's Mobile Energy Efficiency Benchmarking project in 2024 with 65 mobile networks. The electricity grid mix includes fossil fuels (coal, gas, oil), nuclear and renewables (e.g. hydro, wind, solar), with significant variation between countries and regions.

4. Outlook and implications

The findings and implications from the benchmark analysis should be interpreted in the context of several broad shifts in the sustainability arena. We outline these below.

How to build and operate an energy-efficient cellular network

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 improved characteristics of the purpose-built network elements 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 a minimum. Further, network elements are improving their energy efficiency day by day due to frequent software updates. The combination of these factors can help operators to build a future-proof, energy-efficient and sustainable network that improves their overall competitiveness and satisfies their customers.

GSMA Intelligence identified five main areas where operators can improve their energy efficiency (see Figure 7).

Figure 7:

Five main areas to improve energy efficiency

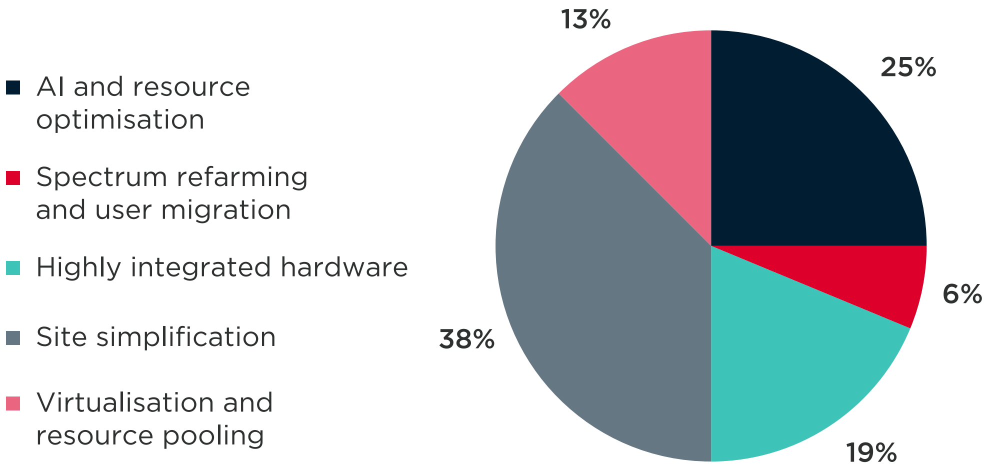
Site simplification and physical modernisation	Using lean site designs, simplified sites with pooled baseband units and multi-generational equipment, and avoiding shelter or cabinets can all help to improve overall energy efficiency.
Spectrum refarming and user migration	As legacy wireless technologies approach the end of their lifecycle, refarming valuable spectrum and migration 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

Figure 8:

The best methods to improve energy efficiency

What is the most effective method to improve energy efficiency in the active infrastructure? (Percentage of operators)



Source: GSMA Intelligence Workshop Operator Survey 2023

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.

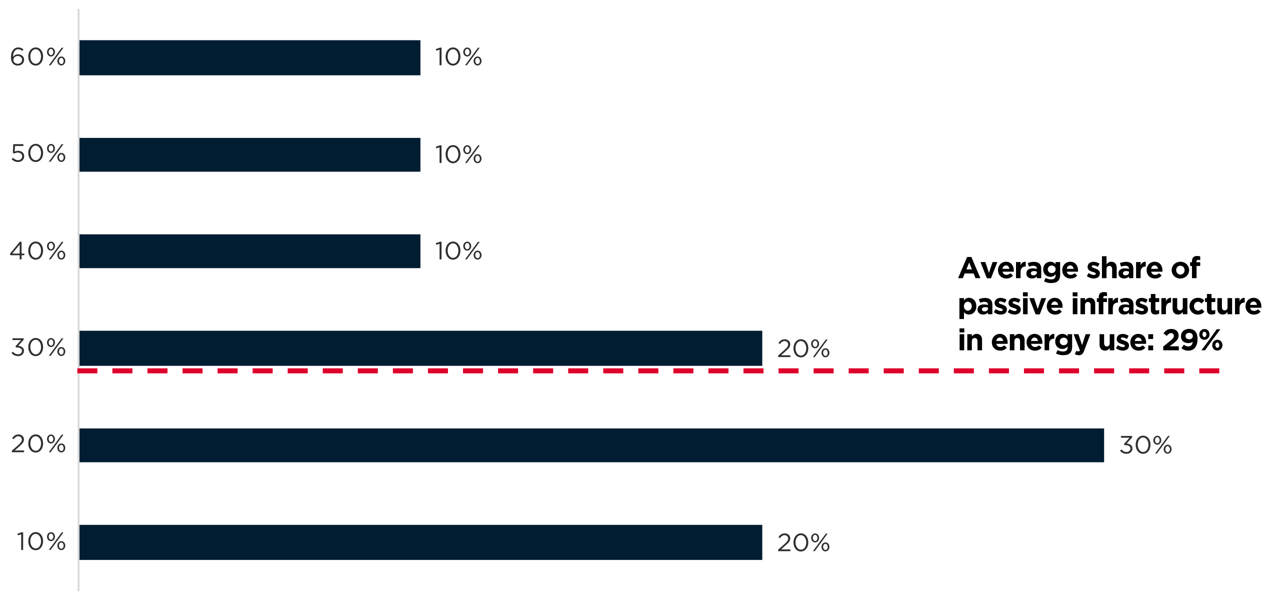
During the third edition of the Mobile Energy Efficiency Benchmarking project, GSMA intelligence asked participating operators what proportion of their energy consumption is related to passive infrastructure. Based on this, on average, 29% of the total energy is spent on passive infrastructure and the remaining 71% is consumed in the active infrastructure.

We also asked the participating operators about the biggest bottlenecks to improving energy efficiency in the passive infrastructure. The majority of operators were in agreement on the top three bottlenecks: capex intensity, available space on site and vandalism. During the workshops, network operators also pointed to the inflexibility of landlords, the poor condition of the electricity grid, lack of internal experience and administrative permits as bottlenecks.

Figure 9

The role of passive infrastructure

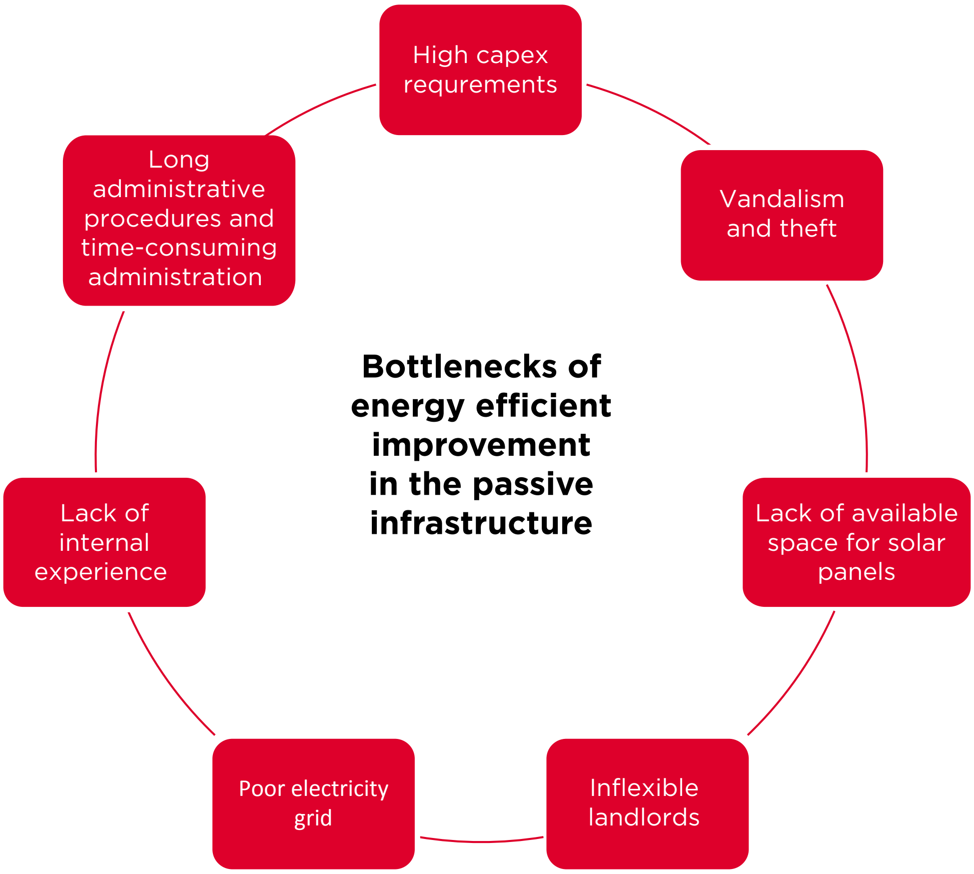
What percentage of your total energy consumption is related to the passive infrastructure?
(Percentage of operators)



Source: GSMA Intelligence Workshop Operator Survey 2023

Figure 10

The bottlenecks of passive infrastructure



Source: GSMA Intelligence Workshop Operator Survey 2023

Back in the 2G and 3G eras, when 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 and also needs more maintenance.

Such equipment may also simply not be 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 systems because mobile sites are taller than their surroundings.

Sustainable 5G

As 5G becomes more pervasive, the energy consumption demand on mobile networks will rise. Energy-saving measures built into the 5G new radio (NR) standard may be offset by rising data traffic, resulting in overall higher levels of energy consumption and emissions. However, the energy strategies of operators take a holistic perspective that includes retiring legacy networks, using more renewables and buying power-efficient equipment.

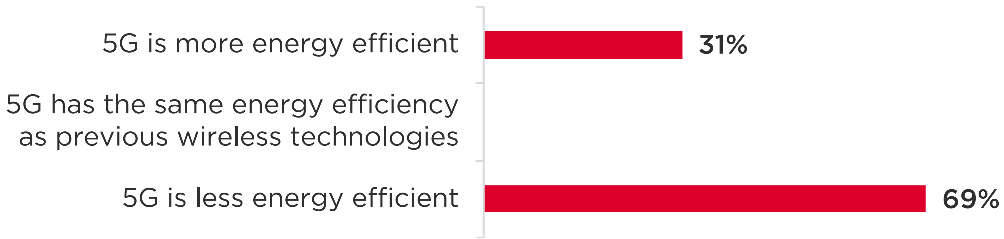
Each wireless technology generation is more energy efficient than its predecessor – but 5G is the first cellular technology designed to be more energy efficient and sustainable. Energy efficiency improved by severalfold from 3G to 4G and it improved even more from 4G to 5G. Thus, encouraging users to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

During the workshops, GSMA Intelligence asked operators about their experience with 5G deployments (see Figures 11 and 12). Despite 5G's theoretical energy efficiency being well known, we wanted to have a deeper understanding of the real-life experience of the operators in the short and long terms, too.

Figure 11

5G's energy efficiency in the short term

What is the impact of 5G on overall energy efficiency in the short term?
(Percentage of operators)

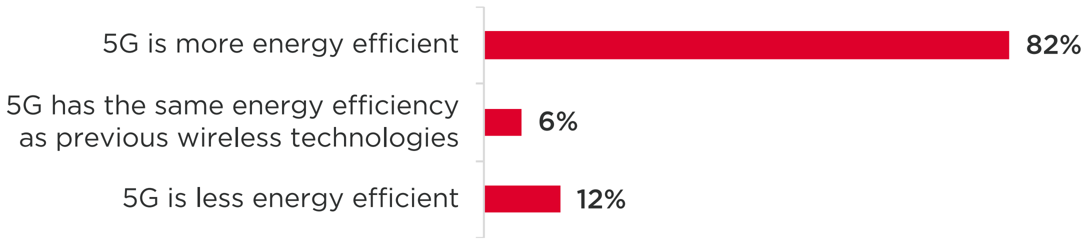


Source: GSMA Intelligence Workshop Operator Survey 2024

Figure 12

5G's energy efficiency in the long term

What is the impact of 5G on overall energy efficiency in the long term?
(Percentage of operators)



Source: GSMA Intelligence Workshop Operator Survey 2024

The results indicate that operators' real-life experiences support the statement that 5G is more energy efficient in the long run. However, this energy efficiency is not necessarily perceptible immediately. This temporary inconsistency can be caused by mainly two factors:

- A whole new 5G layer is introduced and a relatively small number of connections are using the layer in the beginning. After 5G penetration increases and the number of connections reaches the critical mass, 5G's superior energy efficiency becomes palpable.
- After operators introduce a new network layer, there is a transitional period while the engineers optimise the network performance and gain enough knowledge to operate the new 5G layer efficiently.

An earlier GSMA Intelligence report[4] provided an overview of efficiency strategies. The benchmark analysis presented in the current report is complementary and will need to be updated over time to account for the mixed effect in the mobile customer base that will gradually increase in favour of 5G.

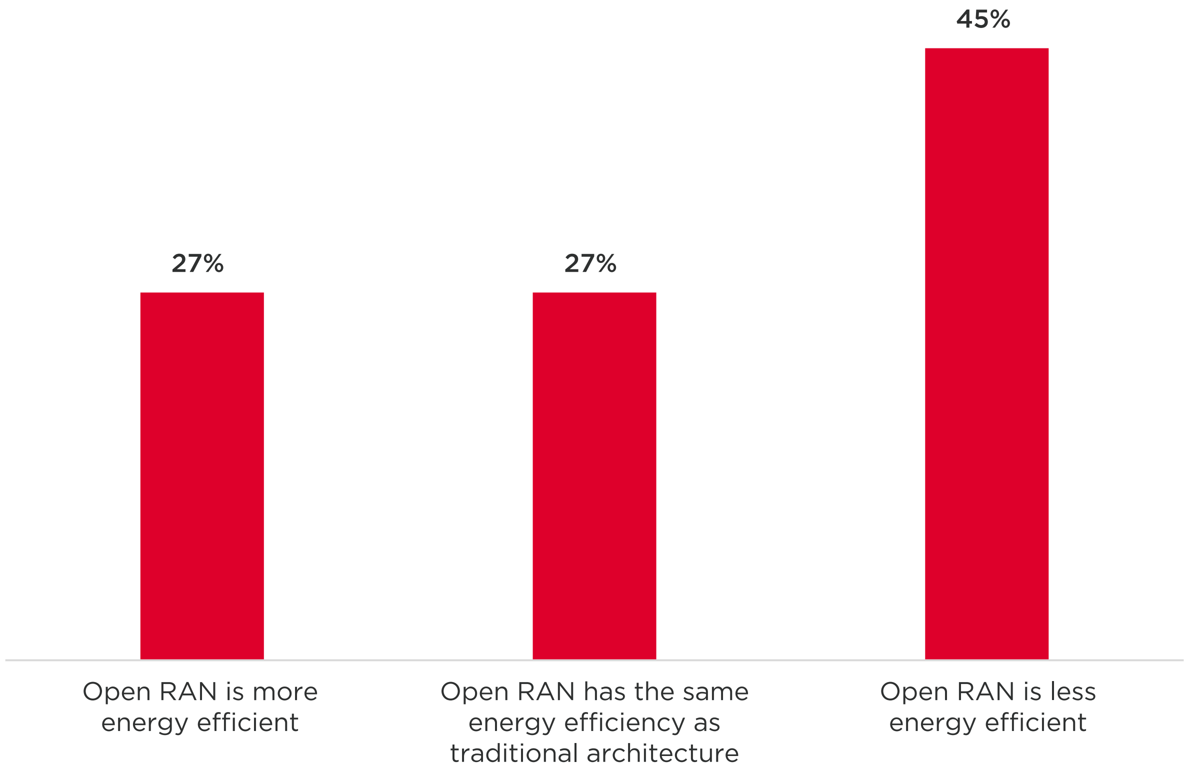
Open RAN and energy efficiency

The energy-efficiency implications of open RAN are not yet certain. While many operators claimed that they could improve some of their energy-efficiency metrics after open RAN deployments, others reported the opposite.

Figure 13

Open RAN and energy efficiency

What is the impact of open RAN deployments on energy efficiency (used energy/data traffic)?
(Percentage of operators)



Source: GSMA Intelligence Workshop Operator Survey 2024

[4] A blueprint for green networks, GSMA Intelligence, 2022

While a few operators and vendors could 'mix and match' their latest open RAN deployment and achieve significant energy-efficiency gains, most of the early experiences show similar or less energy-efficient output. In the case of open RAN, the technology itself is less mature and the deployment experience of operators and system integrators is lower than that of traditional vendors. Also, x86-based architecture is less energy efficient than tailor-made, telco proprietary solutions. Currently, most of the open RAN equipment is less compact, weighs more and has more wind load.

Measuring energy efficiency in the 5G era

In the process of exploring energy-efficiency improvements for mobile operators, one of the greatest challenges is figuring out how to effectively and scientifically implement network energy-efficiency index management.

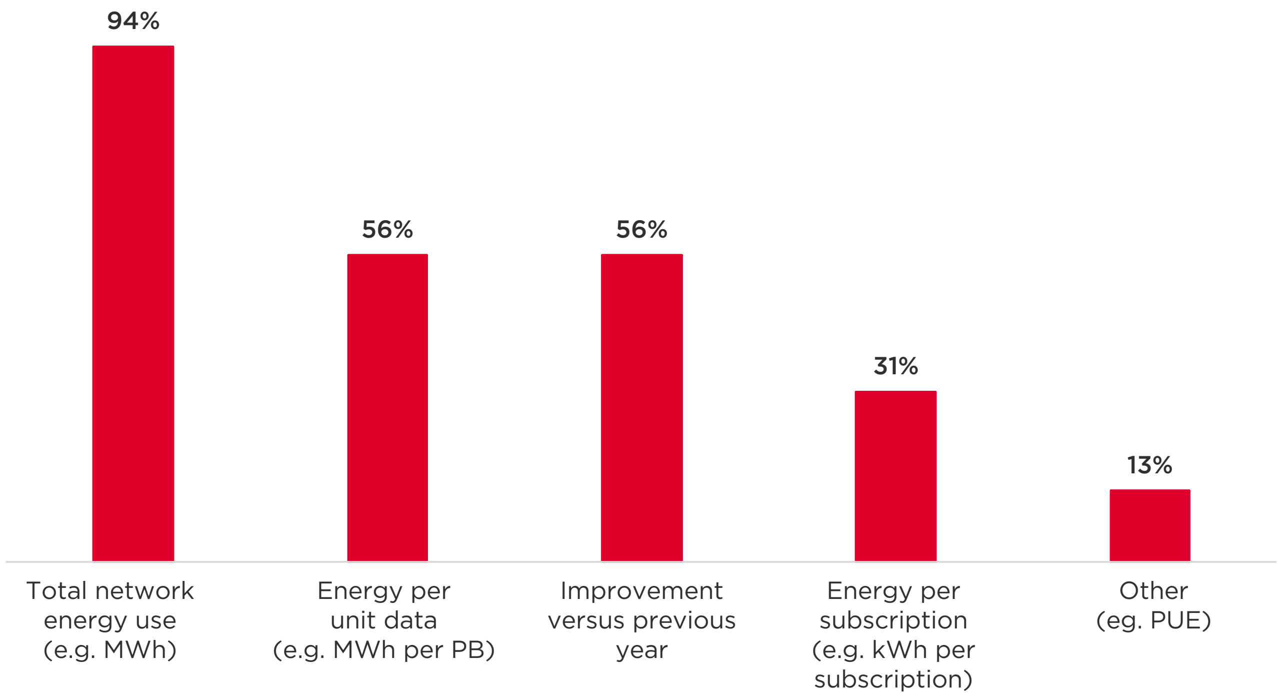
The first step is to fully understand the requirements of 'metric metering', which comprises a set of mechanisms and methods that include the whole process of measurement, reporting, analysis, presentation, policy formulation and optimisation suggestions. This can help operators build a standardised, 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 display not only indicators at the site and 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.

Figure 14

Most important energy-efficiency indicators

Which of the following energy indicators do you track?
(Percentage of operators)



Source: GSMA Intelligence Workshop Operator Survey 2024

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 running multi-generational networks, often 2G, 3G and/or 4G in combination with 5G.

Figure 15

Top reasons for measuring energy efficiency

How important are the following factors in measuring energy-efficiency indicators for your company?

More important (↑)

- Track our company's progress over time (including targets)
- Better understand and manage energy costs
- To comply with reporting requirements/regulations
- To include them in voluntary reporting and disclosures
- Compare networks within our company
- Compare with other operators/networks
- Other (energy mix, finding optimum capex/opex relation)

Source: GSMA Intelligence Workshop Operator Survey 2024

In the case of a mobile 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. According to a survey we conducted during the project in January 2024, nearly 90% of operators think their company will need to report more on efficiency metrics in the future.

Overall, measuring, comparing and benchmarking energy efficiency in the 5G era is a complex task. Multi-generational (2G, 3G, 4G and 5G) mobile networks are operating in different social and geographical environments, and separating energy from 2G, 3G, 4G, 5G and fixed services can be challenging without an all-encompassing, real-time metering system. GSMA Intelligence published a report[5] that further elaborates on this issue and the different levels of energy efficiency.

[5] A blueprint for green networks, GSMA Intelligence, 2022

The value of partnerships

Building partnerships is essential for operators to improve their energy efficiency. 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 working with energy suppliers and energy management companies or building their own energy-efficiency product portfolio. Partnerships across the ecosystem will be key to achieving improved energy efficiency.

Climate targets

For operators seeking improvements in energy efficiency, one of the key drivers is the decarbonisation of networks in line with the latest science on climate change. In February 2019, the GSMA Board, comprising members from the largest mobile network operators in the world, set a milestone ambition to transform the mobile industry to reach net-zero carbon emissions by 2050 at the latest. This was followed by the publication of a decarbonisation pathway in 2020 that is aligned with limiting global heating to 1.5°C.

In 2023, the GSMA published a report[6] which concluded that the industry continues to align around the 1.5°C decarbonisation pathway. As of the end of 2023, 70 operators committed to near-term science-based targets (representing over 60% by revenue and nearly half by number of connections) had committed to rapidly cutting their emissions over the next decade.

To support the achievement of climate targets, the mobile industry is also seeing higher levels of climate disclosure, including more detailed figures on energy consumption. Globally, around 80% of operators by revenue and around two thirds by connections disclose their climate impacts. According to the same GSMA report, mobile operators have improved the quality of their disclosures significantly in recent years.

[6] Mobile Net Zero: State of the Industry on Climate Action 2023, GSMA, 2023

5. How to get involved

Decarbonisation and sustainability will continue to be a key strategic priority area for the telecoms sector over the next decade as operators play their part in the global response to climate change. A sustainable approach also helps to foster innovation and engender enthusiasm and loyalty from employees, customers and suppliers. Mobile operators are increasingly placing a green agenda at the heart of their business strategies, driving the wider industry's contribution to the SDGs. To support these aspirations, GSMA Intelligence will continue to run an extended version of a similar energy efficiency benchmarking activity in 2024, based on new 2023 data.

However, to make the results as representative and impactful as possible across all regions, we would like to increase the range of participating operators. In addition to public-facing research and best practice guidelines, participating operators will receive customised reports on their own network energy efficiency compared to industry averages on an anonymised basis.

For more information on the next round of the Mobile Energy Efficiency Benchmarking project or to be involved directly, please contact any of the following individuals:

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Appendix

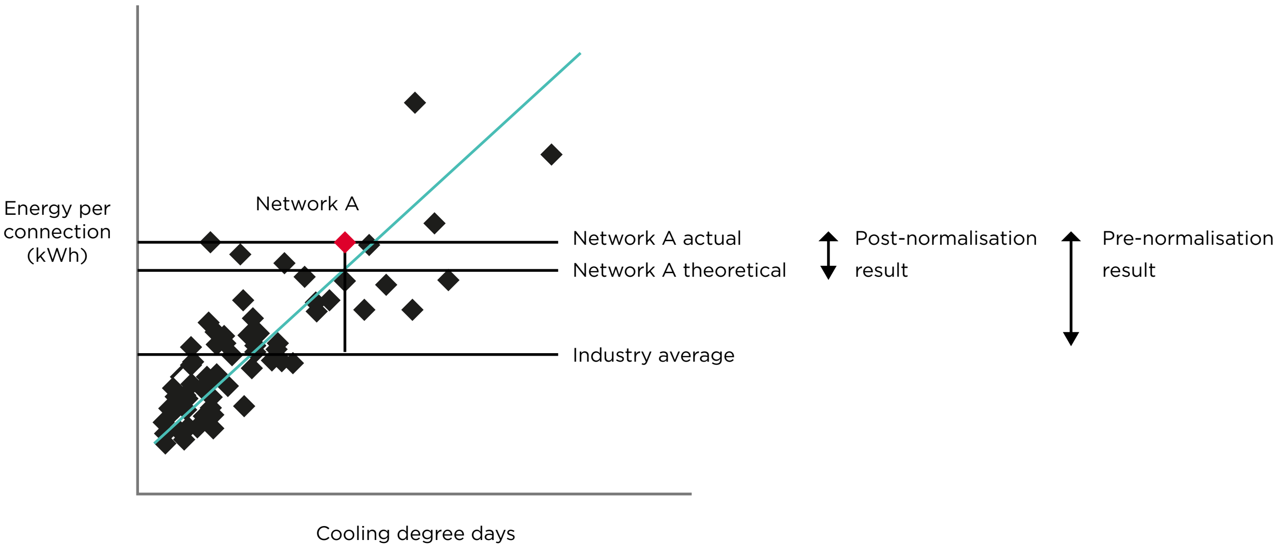
Normalisation

Regression analysis produces a set of results that enable a mathematic equation to be written to explain the relationship. With this equation, we can calculate the theoretical energy per connection for a network, using the network's values for each of the independent variables. Subtracting the network's actual value from the theoretical value gives a measure of whether the network is overperforming or underperforming. This approach can be extended to multiple networks.

Without the normalisation process, the efficiency ratios would be compared to an industry average. This could be misleading since many other impacts would be included that are not the responsibility of the mobile network operators. For example, just because a network is located in a warm climate with a consequent high demand for air-conditioning does not necessarily translate to a poor energy-efficiency reading.

Figure A1

Actual versus theoretical energy consumption



Source: GSMA Intelligence

Key factors influencing energy efficiency

After testing several potential explanatory variables, three non-network factors were identified to normalise the data. GSMA Intelligence aimed to extract those factors outside an operator's control from the original energy per unit of traffic value. These variables enable us to normalise the result from three different angles:

- **Network traffic:** The average monthly mobile data traffic per mobile subscriber during 2022.
- **Climate:** A cooling degree day (CDD) is a measurement designed to quantify the demand for energy needed to cool buildings.
- **Network density:** The number of connections per cell site. The average size of the area that the cell site covers has an impact on energy efficiency/consumption. This measure accounts for population density, market share and topology.

Thanks to the subtraction of these different variables, the real network-related attributes come to the forefront in the benchmarking.

The result of the benchmarking gives us a diverse picture: top performers can be found in different regions; network efficiency does not directly correlate with how developed a market is; and there is a difference of 20× between the worst and best performers, before normalisation.

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