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SUSTAINABILITY ASSESSMENT: TELCO TECHNOLOGY SUPPLIERS

TECHNOLOGY ANALYSIS REPORT | October 17, 2022

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1. INTRODUCTION, OBJECTIVES, AND SCOPE

1.1. INTRODUCTION

ABI Research conducted a previous in-depth study, Sustainability Index: Telco Operators, that provided a comprehensive framework for highlighting sustainability challenges and sustainability initiatives across the telecoms industry. In that report, ABI Research selected a globally representative set of 10 telecommunications operators that are sustainability leaders in the industry and evaluated their sustainability efforts in six categories: renewable energy, network upgrades, energy efficiency, waste disposal and circular economy, green buildings and vehicles, and reporting and governance.

As a result of that study, ABI Research identified key action items for a telco operator to take for reducing its overall environmental impact:

- Switch to renewable energy for purchased electricity.
- Migrate to 5G.
- Replace copper with fiber.
- Invest in latest generation massive Multiple-Input, Multiple-Output (mMIMO) technologies (e.g., use advanced chipsets and Gallium Nitride (GaN) Power Amplifiers (PAs) for higher efficiency at higher output levels and frequencies, etc.).
- Implement eco-design principles (e.g., light weighting, device repairability, and durability) and purchase energy efficient network equipment.
- Recycle or reuse network equipment and e-waste (e.g., copper cables, network equipment, mobile phones, and other devices).
- Implement Artificial Intelligence (AI)-enabled software across the network (e.g., for network optimization, anomaly detection, and Power Savings Features (PSFs), such as using AI/Machine Learning (ML) to plan for traffic, while dynamically optimizing the Radio Access Network (RAN) performance based on data traffic and network activity).
- Adopt digital twin technologies for network asset planning, field operations, and customer mapping.
- Move base station equipment outdoors; adopt free air and liquid cooling technologies for base stations and data centers.
- Replace diesel generators with renewable energy on-site, especially for off-grid and poor grid base stations.
- Incorporate sustainability into the company business model: track and report Scope 1, 2, and 3 carbon emissions, provide employee incentives for meeting climate targets, and increase supplier engagement and accountability for Environmental, Social, and Governance (ESG) initiatives, such as increasing Request for Proposal (RFP) weightings for

- sustainability.

Upon completion of the research, it was clear that the vast community of technology solution providers that address this market play a pivotal role in helping improve the telco sustainability landscape. This study takes the Sustainability Index: Telco Operators to the next level by highlighting the emboldened points identified in the findings above and applying them to how the supplier community is placed to support these initiatives.

1.2. OBJECTIVES

ABI Research recognizes there are substantial differences in the business models, solutions, and carbon emissions of the companies in this analysis. Companies that are manufacturing chipsets, radio equipment, and antenna masts have unique sustainability challenges and different carbon footprints versus companies providing cloud services and developing software for virtualized networks.

Understanding these differences, the objective of this report is to assess the capabilities of vendors and solution providers for designing and making equipment, and developing software that reduces energy use and waste across the telecoms industry. This assessment will also provide a tool for helping to identify "who to work with and why," explaining which companies across the sector are best positioned to support sustainability and climate-related initiatives.

In summary, this assessment should:

1. Help telco service providers decide which technologies to invest in and who to work with in their journey to build more sustainable networks and more sustainable, resilient businesses.

2. Provide insights and best practices for telco equipment vendors, while showing them how they compare to the competition.

1.3. SCOPE

ABI Research evaluated a list of more than 81 suppliers and vendors for sustainable impact and implementation, not to specifically rank companies one against the other, but to highlight their potential for supporting telco sustainability initiatives. The companies that have the greatest ability to move the needle for reducing carbon emissions and waste across the entire telecommunications supply chain received the highest scores in the sustainability assessment.

The suppliers and vendors were assessed within the following equipment categories:

- mMIMO
- 5G RAN

- 5G Open RAN
- On-site renewable energy
- Free cooling
- Liquid cooling
- AI-driven software
- Antenna solutions
- 5G cloud-native platforms

2. METHODOLOGY AND HOW TO USE THE ASSESSMENT

2.1. REPORT METHODOLOGY

The assessment of the vendors covered in this report consisted of impact criteria versus implementation criteria, providing a matrixed view of the ecosystem of companies that can best support a telco in their drive toward improved sustainability.

Defining all these processes was the Root Mean Square (RMS) methodology. Within each of the equipment categories, vendors and suppliers were scored against a set of impact and implementation criteria weighted in terms of their importance, their ability to reduce carbon emissions and waste, and the levels at which the equipment has been implemented across the industry.

Table 1: Impact and Implementation Criteria for Each Equipment Category
(Source: ABI Research)

Equipment Category	Impact Criteria	Implementation Criteria
mMIMO	Eco-design (e.g., light-weighting, ease of disassembly & recyclability, repairability, etc.)	Market share
	Innovative technologies to reduce overall power consumption	Regional geographical penetration
	Advanced features that enhance overall performance	Number of networks deployed
	Sustainable operations in manufacturing of mMIMO	Range of product portfolio
	Supply chain sustainability and supplier engagement	Features to reduce lifetime site visits
	Overall sustainability strategy for the vendor	
5G RAN	Eco-design (e.g., light-weighting, ease of disassembly & recyclability, repairability, etc.)	Market share
	Innovative technologies to reduce overall power consumption	Regional geographical penetration
	Advanced features that enhance overall performance	Number of networks deployed
	Sustainable operations in manufacturing of 5G RAN	Range of product portfolio
	Supply chain sustainability and supplier engagement	Features to reduce lifetime site visits
	Overall sustainability strategy for the vendor	
Open RAN platforms	Product portfolio (e.g., RAN-related solutions, including RAN Intelligent Controllers (RICs)	Major deployments and number of trials
	Standardization and multi-vendor interoperability	Financial and organizational health
	Network performance	Regional coverage
	Sustainable operations in manufacturing of equipment	Business models (e.g., hardware, software, and services)
	Overall sustainability strategy for the vendor	Number of partnerships
On-Site Renewable Energy Solutions (Base Station)	Eco-design (e.g., materials used, flexibility of design as solar, solar + diesel generator, solar + grid)	Market share
	Innovative technologies to reduce overall power consumption	Regional geographical penetration
	Advanced features that enhance overall performance	Number of networks deployed
	Sustainable operations in manufacturing of Photovoltaic (PV) panels, storage equipment, etc.	Features to reduce lifetime site visits
	Supply chain sustainability and supplier engagement	
	Overall sustainability strategy for the vendor	
Liquid Cooling Solutions—Data Centers	Eco-design (e.g., sustainable materials, reuse of waste hot water for electricity or heating)	Market share
	Innovative technologies to reduce overall power consumption	Regional geographical penetration
	Advanced features that enhance overall performance	Number of partners and data center solutions deployed

Equipment Category	Impact Criteria	Implementation Criteria
	Sustainable operations in manufacturing of equipment	Features to ease site installation and reduce maintenance required for field operations
	Overall sustainability strategy for the vendor	
Free Cooling (Base Station)	Eco-design (e.g., sustainable materials, design for remote monitoring, remote filter clog alarm, etc.)	Market share
	Innovative technologies to reduce overall power consumption	Regional geographical penetration
	Advanced features that enhance overall performance	Number of partners and solutions deployed
	Sustainable operations in manufacturing of equipment	Features to ease site installation and reduce maintenance required for field operations
	Overall sustainability strategy for the vendor	
AI-Driven Network Software	Eco-design, Research and Development (R&D), and testing	Market share
	Innovative technologies to reduce overall power consumption	Regional geographical penetration
	Sustainable operations in development of software	Number of networks deployed
	Overall sustainability strategy for the vendor	Range of product portfolio (e.g., network optimization, anomaly detection, customer service)
Antenna Solutions (Cellular Base Station Antenna Market)	Multi-band capabilities	Market share
	Ultra-Wideband (UWB) capabilities	Regional geographical penetration
	Innovative technologies to reduce overall power consumption	Sustainability integration into antenna deployment (e.g., digital twins for placement, etc.)
	Advanced features that enhance overall performance	Financial and organizational health
	Sustainable operations in manufacturing of antenna equipment	Antenna product portfolio
	Supply chain sustainability and supplier engagement	
	Overall sustainability strategy for the vendor	
Cloud Partners (5G Telco Cloud-Native Platforms)	Carbon emissions tracking capabilities of cloud partner	Cloud native capabilities
	Multi-vendor network functions orchestration	Extent of modularity
	Telco-grade supporting features	Multi-cloud and hybrid-cloud support
	Container orchestration and management	Telco domain range
	AI and ML capabilities for network operations	Deployment model
	Overall sustainability strategy for the vendor	

It is important to note that the weightings for the individual criteria for the categories was derived from findings of the Sustainability Index: Telco Operators. More details of the individual criteria and how they are composed and weighted can be seen in the individual category sections later in this report.

Scoring Process

The first stage of the research process scored 81 vendors within each of the nine equipment categories, allowing ABI Research to present a granular view of how individual companies are performing within each category. Thus, all equipment vendors supplying mMIMO antennas were scored for impact versus implementation (using the criteria above), then all vendors for 5G RAN were scored, then 5G Open RAN, then on-site renewable energy providers, and so on.

The second stage of the process was to provide an aggregated sustainability score, representing a view of the company in terms of industry value chain tiers. The aggregated score consisted of the individual equipment category scores rolled up into an overall score for each vendor. For example, if a vendor supplies products for six of the nine categories, then six impact and six implementation scores were computed and aggregated as a weighted average for the final score (e.g., active equipment categories were weighted higher than passive equipment categories).

It is important to note that a similar methodology was used to determine the rolled up aggregate scores as was applied in the individual equipment categories. The scores from each of the equipment categories for impact and implementation were added together and each category was weighted against the others depending on their sustainability influence. This level of weighting was derived from the previous research conducted in the Sustainability Index: Telco Operators report.

The final stage of the process took each company's aggregated, overall score (e.g., a weighted average of their component equipment category scores) and grouped the companies into relevant market segments. The segments included are:

- Traditional vendors (e.g., the major telco equipment suppliers)
- Non-traditional vendors (e.g., Open RAN and Information Technology (IT) providers)
- Software vendors (e.g., suppliers modernizing and virtualizing Communication Service Providers' (CSPs) network and RAN functionalities)
- Chipset and component vendors (e.g., chipset suppliers, processors, edge computing solutions, etc.)

2.2. ROOT MEAN SQUARE

After individual scores were established for impact and implementation, an overall company score was established using the RMS method:

$$Score = \sqrt{\frac{impact^2 + implementation^2}{2}}$$

The resulting overall scores were then ranked and used for comparisons.

The RMS method, in comparison with a straight summation or average of individual impact and implementation values, rewards companies for standout performance. For example, using this method, a company with an impact score of 9 and an implementation score of 1 would score considerably higher than a company with a score of 5 in both areas, despite the mean score being the same. ABI Research believes this is appropriate as the goal of these matrices is to highlight those companies that stand out from the others.

2.3. EQUIPMENT CATEGORIES AND COMPANIES

The first stage of the assessment compared 81 companies, scoring impact and implementation criteria for nine different telco equipment categories, including:

1). mMIMO: With 5G New Radio (NR) networks, MIMO becomes “massive” due to the increased number of antennas on the base station, which brings significant improvements in data throughput and efficiency. Companies that offer mMIMO technologies are enabling fast data rates and all the potential that 5G has for advancing digitalization, automation, and carbon-reducing activities in other industries, including smart cities, smart manufacturing, smart utility grids, telehealth, connected vehicles, and more.

The companies considered in this category were:

- Airspan
- Ericsson
- Huawei
- Mavenir
- NEC
- Nokia
- Samsung
- ZTE

2). 5G RAN: The RAN implements radio access technology connecting a device, such as a mobile phone or computer, to a core network. The RAN consists of antennas, radios, baseband (RAN compute), and RAN software, and RAN functionality is typically enabled by a silicon chip located inside both the core network and user device. 5G RAN uses 5G radio Frequency Division Duplex (FDD) frequencies to provide wireless connectivity to devices for enabling various 5G applications. As more devices are added to telco networks and more 5G use cases and applications are delivered, data traffic continues to surge around the world. Powered by next-generation silicon, companies that are building 5G RAN equipment to increase network performance, while reducing overall energy consumption (also referenced as breaking the energy curve) are contributing to sustainable networks of the future.

The companies considered in this category were:

- Airspan
- ASOCS
- Casa Systems
- Cisco
- Ericsson
- Fujitsu
- Huawei
- Intel
- Mavenir
- NEC
- Nokia
- Parallel Wireless
- Qualcomm
- Radisys
- Rakuten Symphony (Altiostar)
- Samsung
- ZTE

3). Open RAN Platforms: Open RAN represents an ongoing evolution or shift of mobile network architectures that enables operators to use non-proprietary subcomponents of network infrastructure from a variety of vendors. Open RAN is the RAN equipment designed and built for openness and interoperability. In other words, the RAN can be disaggregated and implemented in vendor-neutral hardware and software-defined technology, based on open equipment interfaces and community-developed standards. In 2021, five of Europe's largest operators,

including Deutsche Telekom (DT), Orange, Telefónica, TIM Group, and Vodafone, announced that "it is expected that Open RAN networks will gradually become more energy efficient than traditional RAN, benefitting from Open RAN concepts such as cloudification, disaggregation, and native artificial intelligence (AI)." Companies that are developing Open RAN platforms that prioritize energy efficiency will ultimately win market share, especially from operators with ambitious climate targets.

The companies considered in this category were:

- AMD (Xilinx)
- Dell
- Ericsson
- Fujitsu
- IBM (Red Hat)
- Intel
- Mavenir
- NEC
- Nokia
- Parallel Wireless
- Qualcomm (Cellwize)
- Rakuten Symphony (Altiostar)
- Samsung
- Supermicro
- VMware

4). On-Site Renewable Energy Solutions (Base Station): Operators can cut grid power usage by up to 40% (as reported by Japan's NTT DOCOMO), or they can power low-grid and off-grid sites by installing PV panels and higher-capacity batteries at base stations. Wind turbines can also provide additional renewable energy at the base station level. This equipment category is more fragmented and regionally focused than other telco equipment. However, companies that are integrating on-site renewable energy equipment to replace diesel generators, especially in remote low-grid and off-grid sites, are reducing carbon emissions in a swift and direct way.

The companies considered in this category were:

- Ameresco Solar
- Apollo Solar
- Aradatum

- Barefoot Power
- Bergey
- CableFree
- Fenix International
- GenCell Energy (Ammonia Fuel Cell Technology)
- Huawei (Advanced Hybrid Power)
- Intivation
- Nokia (Off-Grid Base Station)
- Phaesun France SAS
- Phocos
- Proven Energy
- SafeBase
- Solarkiosk
- Starfire Mobile
- Suntrica
- Tycon Systems
- Vanu (Off-Grid Networks)

5). Liquid Cooling Solutions—Data Center: Telco and data center operators are assessing liquid cooling options as processing-intensive computing applications increase. According to liquid cooling provider Vertiv, liquid cooling can be up to 3,000X more effective than using air for cooling, due to higher thermal transfer properties of water and other fluids. When compared to conventional air-conditioned cooling, liquid cooling provides some advancements for data centers, including increased energy efficiency, lower Total Cost of Ownership (TCO), a smaller carbon footprint (no refrigerant gases), and less noise. Investments in liquid cooling have increased in recent years due to increasing chip and rack densities, space constraints, pressure to reduce energy consumption and carbon emissions, water use restrictions, and less forgiving computing environments at the edge.

The companies considered in this category were:

- 3M
- Aecorsis BV
- Alfa Laval AB
- Asetek A/S
- Bitfury Group Limited
- Black Box Corporation

- Chilldyne Inc.
- CoolT Systems Inc.
- DCX The Liquid Cooling Company
- Green Revolution Cooling (GRC), Inc.
- IBM Corporation
- Iceotope Technologies Limited
- LiquidCool Solutions, Inc.
- Midas Immersion Cooling
- Mitsubishi Electric Corporation (Mitsubishi Group)
- Rittal GmbH & Co KG
- Schneider Electric SE
- Submer Technologies
- Vertiv, Co.

6). Free Cooling Centers (Base Station): Free air-cooling solutions use ambient air to cool base station equipment. Free air cooling uses smart controlled ventilation to circulate outside air for cooling, providing substantial energy savings over using the traditional refrigerated-air process.

The companies considered in this category were:

- AIRSYS
- Baran Technology
- CommScope
- Dantherm Group
- Laird Thermal Systems
- TECO
- VIKINOR
- X-LOGIC

7). AI-Driven Network Software: AI-enabled software is used for a multitude of applications across the industry, including network optimization, energy management and monitoring, anomaly detection, predictive maintenance, 5G deployment and fiber planning, customer support, and more. Nokia estimates that 78% of operators use some type of AI-driven network solution to reduce overall energy consumption. Moreover, Ericsson reports that operators deploying an Energy Infrastructure Operations solution can reduce energy-related Operational Expenditure (OPEX) by roughly 15%, reduce site visits to base station passive equipment by 15%, and reduce energy-related outages by 30%.

The companies considered in this category were:

- Cisco (through its acquisition of Sedona Systems)
- Ericsson
- Huawei
- Intel
- Nokia
- Qualcomm (Cellwize)
- RantCell
- Samsung
- ZTE

8). Antenna Solutions (Cellular Base Station Antenna Market): The passive base station antenna market has experienced a bit of a slowdown in recent years, as operators shift their focus to active 5G components and antennas to handle surging data traffic, such as mMIMO. Globally, the demand for passive antenna solutions will continue as various developing regions, such as South Asia and Africa, build out their networks, upgrading 4G equipment and transitioning to 5G networks. The reuse of network equipment from urban to rural use and from developed to developing countries will enhance circularity efforts for the industry.

The companies considered in this category were:

- ACE Technologies
- Amphenol Antenna Solutions
- Comba
- CommScope
- DENGYO
- Ericsson (through its acquisition of Kathrein)
- Hengxin Technology
- Huawei
- MOBI
- Prose (a Rosenberger company)
- Radio Frequency Systems (RFS)
- Tongyu Communication

9). Cloud Partners/ 5G Core and Edge (5G Telco Cloud-Native Platforms): Mobile Network Operators (MNOs) are increasingly looking for cloud partners that can span their core, edge, and RAN solutions, while supporting a multitude of cloud-native 5G applications and

carbon-reduction activities.

The companies considered in this category were:

- Amazon Web Services (AWS)
- Canonical
- Ericsson
- Google Cloud
- Huawei
- IBM/Red Hat
- Microsoft (Azure)
- Nokia
- VMware
- Wind River
- ZTE

2.4. HOW TO USE THE ASSESSMENT

This assessment is designed to be used in very specific ways that will enable thoughtful and comprehensive decision-making processes.

Companies can apply the overall assessment (vertical view) to various use cases:

1. A telco can view the vertical market categories and identify gaps in terms of tiers of companies or individual companies the telco is not engaged with already (i.e., if an operator is already deeply engaged with traditional vendors, then what should be the next tier of companies to work with for the next evolution).

2. A telco can understand the current partners they are working with and how they relate to others within comparable market tiers (i.e., I am working with vendor A, but they compare positively/negatively with vendors B and C).

3. A vendor can use the assessment to understand how they compare with direct competition, but also where they sit within the wider supplier ecosystem in terms of telco sustainability.

Using the individual equipment categories (horizontal view) provides readers with a new set of opportunities and use cases:

1. A telco can view the individual technology categories and ensure they are working with the best companies within those segments.

2. A technology vendor or supplier can view the assessment and see how they compare to their direct competitors in any given technology sector.

3. A technology vendor can identify best practices on how to improve their position within key sustainability segments to improve their relevance to telco customers.

4. A technology vendor can identify adjacent market segments that are ripe for their entry to become more relevant to their telco customers.

3. OVERALL ASSESSMENT RESULTS: THE VERTICAL VIEW

Once scoring was complete for the nine equipment categories, the impact and implementation scores for the categories were rolled into a final overall assessment to select the providers with the greatest ability to scale sustainable impact across the industry. As a result, the traditional network equipment providers offering products in multiple equipment categories scored higher than companies offering limited telco products. For example, Ericsson, Nokia, and Huawei competed in six different telco equipment categories, while Cisco, VMware, Dell, and AMD each competed in one category (e.g., either 5G RAN or Open RAN).

The analysis revealed multiple sustainability leaders across different segments of network infrastructure, although some categories of equipment were weighted more heavily than others. ABI Research estimates that a RAN consumes roughly 70% of the power of the network, and 5G networks are more energy intensive than 4G/Long Term Evolution (LTE), 3G, and 2G networks. For example, a 5G RAN in typical conditions consumes up to 2,700 Watts (W) in a mMIMO 64T64R configuration, whereas an LTE radio consumes roughly 800 W of power. Therefore, when scoring a company's ability to reduce energy consumption and carbon emissions across the industry, vendors supplying mMIMO, 5G RAN, and Open RAN technologies received a higher weighting for their scores in the overall assessment.

Finally, with the evolution of network virtualization (i.e., running more software on a given amount of physical hardware) and network cloudification (i.e., providing an IT environment to run workloads, and pool and share resources that can be scaled across a network), the list of total telco equipment vendors is growing. With this expansion of potential partners, several companies interviewed for this report highlighted that vendors must work together not only to optimize various layers and components of the networks, but also to address soaring levels of 5G energy consumption and respond to climate change industry wide.

The following represents the top telco equipment vendors for addressing sustainability across the industry.

Figure 1: Top Telco Equipment Vendors Addressing Sustainability Industry-Wide
(Source: ABI Research)

3.1. TOP TELCO EQUIPMENT COMPANIES BY MARKET TIER

The traditional telco market segment is likely to be the best positioned to help telcos improve their overall sustainability positioning

Table 2 outlines the results of the overall or vertical analysis. This analysis shows that the traditional telco community is the segment of the market that is likely to be the best positioned to help telcos improve their overall sustainability positioning. The next most important category is the non-traditional vendors. One anomaly to this is Intel with products overlapping multiple markets versus other chipset and component providers. This could be because of its legacy partnerships with network solution vendors, as well as its broad infrastructure positioning in adjacent technology sectors. The third most important tier of vendor is that of the software vendors and chipset and component vendors, representing the final grouping of companies that can support telco sustainability initiatives.

Table 2: Overall Sustainability Assessment Results: The Vertical View
(Source: ABI Research)

Traditional Vendors			Non-Traditional Vendors		
Company	**Score**	**Overall Ranking**	**Company**	**Score**	**Overall Ranking**
Ericsson	70.8	1	NEC	30.0	7
Nokia	64.0	2	Mavenir	25.8	9
Huawei	60.1	3	Cisco (Sedona Systems)	24.6	10
ZTE	44.8	4	Fujitsu	23.9	11
Samsung	41.4	5	Rakuten Symphony (Altiostar)	19.1	12
			CommScope	11.5	15

Chipset and Component Vendors			Software Vendors		
Company	**Score**	**Overall Ranking**	**Company**	**Score**	**Overall Ranking**
Intel	34.7	6	IBM (Red Hat)	18.1	13
Qualcomm (Cellwize)	26.9	8	VMware	15.3	14
Dell	6.8	16			
AMD (Xilinx)	5.5	17			

3.2. TRADITIONAL TELCO NETWORK EQUIPMENT VENDORS

The following is a high-level summary of sustainability initiatives and products that contributed to the impact and implementation scoring for each company.

For a more detailed analysis of the scoring and product offerings (highlighting features designed to reduce energy use and waste), see the individual telco network equipment sections (e.g., mMIMO, 5G RAN, Open RAN, etc.) following the overall results. For a listing of climate targets and company-wide environmental initiatives, see the "Sustainability Market Trends and Company Environmental Initiatives" section of this report.

3.2.1. Ericsson

Overall Score: 70.8

Overall Rank: 1

Category Rank: 1

Implementation Score: 68.1

Implementation Rank: 1

Impact Score: 73.3

Impact Rank: 1

Implementation: Ericsson led the vendor sustainability assessment overall for implementation, and the company also led all competitors in implementation of four categories of telco network equipment, including mMIMO, 5G RAN, Open RAN, and antenna solutions (including the acquisition of Kathrein that is now rolled into "Ericsson Antenna System").

While sales for all equipment vendors have been affected in recent years by COVID-19 lockdowns, supply chain limitations (for the semiconductors used in hardware), and inflationary pressures driving up the costs of all hardware components, Ericsson remains in strong demand for 5G solutions in North America, Europe, and other regions. Specifically, the company verified for this report that, as of August 10, 2022, Ericsson had deployed 125 5G networks in 55 countries, with customers in more than 180 countries. Ericsson also has 174 commercial 5G agreements or contracts with unique operators. In reporting earnings for 2Q 2022, Chief Executive Officer (CEO) Börje Ekholm stated that 50% of global 5G traffic (excluding China) is carried on Ericsson's radio networks.

Impact: ABI Research met with Ericsson's head of sustainability and other product experts to confirm the company's commitment to reducing carbon emissions and waste across its own operations and throughout the entire product portfolio. Ericsson has pledged to be net zero across its value chain by 2040, including Scope 1, 2, and 3 emissions. To accomplish this target, Ericsson aims to be net zero within its own operations by 2030, while cutting its emissions by 50% in the supply chain and its portfolio of products by 2030. For Ericsson, a focus on network energy performance and product energy management is critical to sustainability efforts, as 93.5% of its total carbon footprint comes from portfolio use of equipment. Moreover, the close co-design of Ericsson Silicon with hardware and software plays a crucial role in creating high-performing, lightweight, and energy-efficient products. In the questionnaire for this report, Ericsson stated that compared to an industry energy benchmark, the Ericsson RAN complete portfolio consumes 30% to 60% less power, due to specialized Ericsson Silicon. Ericsson Silicon is used across the portfolio for processing, including mMIMO products, baseband, radio, transport solutions, and in integrated antenna and radio solutions. As another product impact example, Ericsson is leading the way for sustainable networks with a new triple-band, tri-sector radio. The Radio 6646 extends the multiband capabilities of tri-sector products by combining 900, 800, and 700 Megahertz

(MHz) frequency bands into a single, compact radio, which is 2G to 5G-capable. This product includes a 40% reduction in energy use and a 60% reduction in weight (with less aluminum required).

To improve circularity of its products, all Ericsson Radio System (ERS) radios deployed from 2015 are 5G ready and upgradable with software only. This eliminates site visits required to change hardware. Moreover, Ericsson's Global Product Take-Back Program, available in 180 countries, helps ensure that products are recycled at their end of life with 98% of the material content recycled. For sustainable manufacturing practices, Ericsson has a World Economic Forum "Advanced 4th Industrial Revolution Lighthouse" factory (e.g., Ericsson's U.S. 5G smart factory in Lewisville, Texas). The Ericsson 5G factory has also been designated as a "Sustainability Lighthouse" for its on-site sustainability technologies and solutions.

3.2.2. Nokia

Overall Score: 64.0

Overall Rank: 2

Category Rank: 2

Implementation Score: 59.5

Implementation Rank: 2

Impact Score: 68.3

Impact Rank: 2

Implementation: Nokia finished second overall in implementation, due to its solid partnerships with global operators, market share, and increased investment in R&D. A 13% increase in R&D has been reported since 3Q 2020, indicating Nokia's pledge to further strengthening its technology leadership. Despite many new 5G vendors entering the market, Nokia and Ericsson have remained the top systems vendors with the most publicly disclosed 5G commercial launches and trials. Nokia's strong implementation scores also reflected that the company is a supporter of Open RAN technology and was the first major telco equipment vendor to join the O-RAN Alliance, while contributing to Open RAN technical specifications.

Impact: For Nokia, sustainability is a "key component of Nokia strategy and purpose." Nokia has pledged to cut its Greenhouse Gas (GHG) emissions by 50% across its entire value chain, including Scope 1, 2, and 3 emissions, by 2030 compared to a baseline year of 2019. Furthermore, Nokia has joined the RE100 and pledged 100% renewable energy use globally by

2025. The company is also deeply involved in creating 5G and associated products that are energy efficient and sustainably designed, such as Nokia's ReefShark chipset, AirScale products, and Nokia's innovative liquid cooling technology for base stations. Results from Nokia testing across several networks have shown that with its base station liquid cooling product, energy consumption by base station cooling systems can be reduced up to 90%, with base station carbon emissions reduced by up to 80% compared to traditional air-cooling systems. For sustainable manufacturing practices, Nokia has a World Economic Forum "Advanced 4th Industrial Revolution Lighthouse" (e.g., Nokia's Oulu 5G factory in Finland).

3.2.3. Huawei

Overall Score: 60.1

Overall Rank: 3

Category Rank: 3

Implementation Score: 59.5

Implementation Rank: 3

Impact Score: 60.6

Impact Rank: 3

Implementation: Huawei was a close third place, implementing and deploying a wide number of networks in China and diverse geographic regions, including the Middle East and Europe. Huawei also leads all vendors for small cell shipments (small cell installations are compact radio equipment and antennas that can be placed in streetlights, or on the sides of buildings, to increase urban 5G coverage.) In 2021, Huawei reported that more than 700 cities and 267 Fortune 500 companies had selected to work with Huawei for digital transformation. The company also touts more than 3,000 commercial contracts for industrial 5G applications. For sustainable implementation, Huawei's technologies, such as mMIMO and 5G RAN, are being developed within the context of Huawei's Green Development Program, as Huawei is increasingly incorporating sustainability efforts into its product lines and offerings. In addition to increasing its messaging around sustainability, Huawei and ZTE have notably strong implementation

strategies for cost-effective mMIMO and other telco equipment designed for densely populated, urban areas, which can be used in China and in developing markets.

Impact: Huawei, came in third place overall for impact. In Huawei's 2021 Sustainability Report, the company pledged to build technology for a "greener, cleaner environment" by focusing on three areas: reducing carbon emissions, promoting renewable energy, and contributing to a circular economy. While the pandemic lockdowns in China, supply chain issues, inflationary pressures, and other geopolitical challenges have put pressure on Huawei's bottom line, the company has continued to promote its green initiatives, such as the Green Development Program, with actionable items for CSPs to reduce carbon emissions and waste. The company is also heavily focused on network energy efficiency and overall company R&D. Today, Huawei reports 195,000 employees, with 54.8% of those employees working in R&D.

Huawei received high impact scores in several equipment categories. The company came in first place overall for on-site renewable energy solutions with the highest global market share and advanced features for renewable solutions, such as AI and real-time analytics. To build green, low-carbon 5G networks, Huawei launched GreenSite and PowerStar2.0. The GreenSite solution offers innovative architecture, site construction, and software and hardware with proprietary algorithms for improving energy efficiency by up to 20X. The PowerStar2.0 solution enables energy savings features at the site level and network level, reducing power consumption by 25% under typical configurations.

3.2.4. ZTE

Overall Score: 44.8

Overall Rank: 4

Category Rank: 4

Implementation Score: 45.4

Implementation Rank: 4

Impact Score: 44.2

Impact Rank: 5

Implementation: ZTE was also a leader in network deployment in China and other global markets with an increased focus on sustainability in recent years. ZTE has incorporated a "green path to a

digital economy," as it integrates energy efficiency in its products and throughout its manufacturing processes. ZTE's implementation strategies also include an emphasis on AI-driven network management. ZTE implementation for sustainability incorporates regular 5G shutdown mechanisms and hibernation modes, especially during off-peak times and at night, when RAN equipment continues to consume energy, even when the equipment is not active. According to ZTE, inducing a hibernation mode to Active Antenna Units (AAUs) during these periods can reduce consumption by up to 5 W, compared to normal power consumption with low traffic at 200 W. ZTE also has the largest antenna portfolio of all the vendors in this index.

Impact: ZTE's specific company-wide climate targets and measurements of carbon emissions and sustainable impact are slightly more difficult to find. However, ZTE has communicated interest in raising the ESG profile of the company and discussing energy efficiency and AI-enabled network management with the Global System for Mobile Communications Association (GSMA). ZTE did secure a fourth-place finish overall in the mMIMO equipment category and a fifth-place finish overall in 5G RAN, though its implementation scores were higher than its impact scores in both assessments. In 2022, ZTE updated its 5G RAN portfolio with the latest-generation mMIMO products, including 32TR and 64TR AAUs, supporting 192 antenna elements and 320 W, while the company also unveiled the industry's lightest mMIMO product weighing 9 Kilograms (kg) (used for a high-traffic cell site with limited space). This innovative eco-design was reflected in the scoring as lightweight, compact equipment reduces material use and enables easy installment, reducing labor expenses and material waste at the equipment's end-of-life.

3.2.5. Samsung

Overall Score: 41.4

Overall Rank: 5

Category Rank: 5

Implementation Score: 37.4

Implementation Rank: 5

Impact Score: 45.0

Impact Rank: 4

Implementation: Samsung is a leading implementer in South Korea and one of the largest vendors in this assessment by market capitalization (Forbes also lists Samsung as the

fourth-largest technology company in 2022 by sales behind Apple, Alphabet, and Microsoft); therefore, any sustainability initiative across its 5G network portfolio, including chipsets, devices, radio, and core equipment, can be scaled effectively across the industry. ABI Research's 5G group contributed to implementation scoring for several categories in this report, and in the 5G RAN implementation, Samsung came in eighth place for implementation, while scoring in fifth place for 5G RAN impact, due to innovative technologies for reducing energy consumption in its RAN products. For mMIMO solutions, Samsung came in fifth place for the sector overall and fifth place for implementation. For implementing company-wide programs, in September 2022, Samsung refreshed its environmental strategy, designating more than KRW7 trillion (US$5 billion) for green initiatives by 2030.

Impact: Samsung historically has not had the most sustainability-focused reputation in the mobile industry. However, recent announcements show great strides in sustainable impact, as Samsung has joined the RE100, a global renewable energy initiative, and pledged to be net-zero carbon emissions (Scope 1 & 2) for all operations in the Device eXperience (DX) Division by 2030, and across all global operations, including the Device Solutions (DS) Division by 2050. The DS Division includes Memory, System LSI, and the Foundry business. Samsung also recently earmarked US$5 billion for sustainability initiatives by 2030. The latter investment will go toward new technologies for more energy-efficient products, water reuse, and carbon capture techniques. With its size as one of the largest companies in this ranking and as a top 5G RAN and equipment leader, all sustainability initiatives have the potential to affect the entire industry. Moreover, Samsung also received strong scores for its technology advancements, as its fully virtualized 5G RAN has received numerous awards, including two Global Mobile (GLOMO) awards at Mobile World Congress (MWC) Barcelona 2022 for CTO Choice: Outstanding Mobile Technology and Best Mobile Technology Breakthrough. Samsung is also the second-leading smartphone provider in the United States.

Samsung currently uses 100% renewable energy in Europe, China, and the United States, and it increased its global renewable energy use by 31% from 2020 to 2021. The company also plans to expand renewable energy to facilities in Latin America and Southwest Asia by 2025; although presently, 80% of Samsung's operations are in South Korea and Vietnam. This gives the multinational conglomerate immense power in the coming years to help transform sustainable manufacturing processes and gain further access to renewable energy in South Korea and Vietnam (i.e., Samsung is Vietnam's largest foreign investor.)

3.3. NON-TRADITIONAL TELCO NETWORK EQUIPMENT AND IT VENDORS

3.3.1. NEC

Overall Score: 30.0

Overall Rank: 7

Category Rank: 1

Implementation Score: 28.6

Implementation Rank: 7

Impact Score: 31.3

Impact Rank: 7

Implementation: NEC competed in three equipment categories, including mMIMO, 5G RAN, and Open RAN. NEC scored solidly among major competitors for its wide-ranging portfolio, implementing solutions featuring disaggregated RAN components, xHaul transport, core networks, automation of operations, and systems integration services. For implementation, NEC does not have the scale of the leading traditional equipment providers; however, it is a leading firm for Open RAN innovation.

Impact: Japanese IT and electronics company, NEC, finished seventh overall for sustainable impact sector-wide, competing in the mMIMO, 5G RAN, and Open RAN categories. NEC has environmental targets set to reduce its own carbon emissions by 55% by 2030, compared to Fiscal Year (FY) 2018, and it has also joined the RE100, pledging to procure 100% renewable electricity by 2050. NEC participates in all telco network areas, from fronthaul to backhaul, including physical and virtual networks and telco service management and orchestration. NEC scored in sixth place on impact for mMIMO, eighth place on impact for 5G RAN, and fourth place on impact in Open RAN scoring. NEC's impact scores were reflective of its expertise in energy efficiency and commercializing open networks, network slicing, and AI/ML capabilities across the network, from core to edge.

3.3.2. Mavenir

Overall Score: 25.8

Overall Rank: 9

Category Rank: 2

Implementation Score: 25.5

Implementation Rank: 9

Impact Score: 26.1

Impact Rank: 10

Implementation: Mavenir competed in mMIMO, 5G RAN, and Open RAN, scoring in ninth place overall for implementation. Its mMIMO implementation lagged behind traditional competitors, as it was just announced in April 2021 that Mavenir would market its own range of mMIMO Radio Units (RUs). Mavenir finished in 12th place for Open RAN implementation. Mavenir's business strategy is to develop a single software-based automated network that operates with any cloud partner, and the company reports to be accelerating software network transformation for 250+ CSPs and enterprises in more than 120 countries covering 50% of the world's subscribers. In 2020, Mavenir was the first vendor to be named in the DISH 5G network builder (i.e., the first cloud-native Open RAN 5G network in the United States); however, overall adoption of Open RAN technologies globally has perhaps been slower than originally anticipated.

Impact: Mavenir is a private company; therefore, it does not have the same obligations and pressures as public companies for reporting financials and carbon emissions. Mavenir's Corporate Sustainability Report is somewhat light on environmental impact tracking and reporting, as Mavenir states that it has "not yet tracked energy consumption or GHG emissions associated with suppliers." However, Mavenir scored well in the overall assessment, especially for a company its size, as its products have won numerous awards for technology advancement and innovation, such as Best Telco Cloud Strategy and Best Open RAN Technology at the 5G Middle East North Africa (MENA) Awards held in Dubai in 2022.

3.3.3. Cisco

Overall Score: 24.6

Overall Rank: 10

Category Rank: 3

Implementation Score: 22.3

Implementation Rank: 11

Impact Score: 26.7

Impact Rank: 9

Implementation: In August 2022, Cisco announced that it is combining the Enterprise Networking & Cloud (EN&C) and Mass-Scale Infrastructure Group (MIG) into one entity focused on End-to-End (E2E) networking. Cisco has helped T-Mobile develop its 5G Standalone (SA) core, offers private 5G and other enterprise Wi-Fi solutions, and in March 2022, the company announced at MWC a partnership with Rakuten to develop and accelerate Open RAN and telco cloud solutions for mobile networks. In the assessment, Cisco was scored in the 5G RAN and AI-driven software categories. For 5G RAN, Cisco was seventh out of 17 vendors for implementation, and for AI-driven software, Cisco was ranked fourth for implementation.

Impact: Cisco finished near the top of all the vendors in this ranking for "Company Sustainability Strategy," or criteria related to reducing carbon emissions and waste within a company's own operations. Cisco has been making pledges to reduce its environmental impact since 2008. Today, the company aims to be carbon neutral within its own emissions by 2025 and net zero across its entire value chain by 2040. This sense of purpose for enabling digitalization and sustainability permeates throughout the company, from its product portfolio energy efficiency to the reuse and recyclability of equipment. Moreover, with Sedona's NetFusion joining the Cisco Crosswork portfolio (following Cisco's acquisition of Sedona Systems), Cisco can provide an advanced automation platform for Cisco's routed optical network solution. The Cisco Crosswork hierarchical controller (formerly known as Sedona NetFusion) is designed to simplify networks with multiple layers and multiple vendor infrastructure; it also enables 5G network slicing, routed optical networking, and disaggregation. Cisco reports an 85% increased speed in delivering services and 62% savings in TCO with this solution. These innovative products and programs helped Cisco finish ninth overall for impact, as the company continues to gain telco infrastructure market share for implementation.

3.3.4. Fujitsu

Overall Score: 23.9

Overall Rank: 11

Category Rank: 4

Implementation Score: 23.2

Implementation Rank: 11

Impact Score: 24.7

Impact Rank: 11

Implementation: Fujitsu came in sixth place for implementation of its 5G RAN and fifth place for Open RAN solutions, and the company is making great strides toward incorporating sustainability both in messaging from the CEO and in improving energy efficiency throughout the product lines. While South Korea was in a first mover's position for 5G, Japanese equipment vendors and operators have established themselves as global leaders when it comes to Open RAN technologies. As an example, KT Corporation, formerly Korea Telecom, has opened a verification facility to accelerate Open RAN for use in KT's network, using Fujitsu's 5G Open RAN base station kit, while consulting Fujitsu and NTT DOCOMO for technical support during its construction.

Impact: Fujitsu scored in fourth place for impact in the 5G RAN and sixth place for Open RAN categories, and finished 11th overall for impact, due to high scores for innovative technologies in energy efficiency. In February 2022, Fujitsu launched a "sustainable 5G vRAN," developed to deliver Carbon Dioxide (CO2) emissions reductions of over 50% by leveraging the company's AI and quantum inspired Digital Annealer technologies, optimizing network computing resources.

3.3.5. Rakuten

Overall Score: 19.1

Overall Rank: 12

Category Rank: 5

Implementation Score: 20.7

Implementation Rank: 12

Impact Score: 17.5

Impact Rank: 12

Implementation: Rakuten Symphony ranked 12th sector-wide for implementation with assessments made in the 5G RAN and Open RAN categories. Rakuten placed in 12th place for Open RAN implementation and 9th place for 5G RAN implementation. In August 2021, Rakuten Group announced that it had acquired Altiostar Networks, a U.S.-based mobile technology company, for US$1 billion. Rakuten had already been an investor of Altiostar, in addition to Cisco, Qualcomm, Telefónica, and others. As an implementation highlight, Rakuten Symphony reports to have deployed the world's largest Open RAN coverage, with more than 275,000 cells maintained with an operational headcount of only 250 people (as of April 2022).

Impact: Rakuten Symphony finished in 12th place sector-wide for impact, offering innovative, energy-aware 5G RAN and Open RAN solutions. The Rakuten business strategy is to "disrupt and democratize" the industry by leveraging the full capabilities of disaggregated networks, driven by data/analytics, the cloud, and AI. Rakuten Symphony touts deploying the world's largest Open RAN coverage. With Synergy, an energy management platform deployed across the networks, Rakuten reports a >30% reduction in energy consumption. For additional sustainability efforts, Rakuten has joined the RE100, pledging to source its operations with renewable energy by 2025. Rakuten Group has also committed to reducing its Scope 2 GHG emissions to zero by 2025.

3.3.6. CommScope

Overall Score: 11.5

Overall Rank: 15

Category Rank: 6

Implementation Score: 12.6

Implementation Rank: 15

Impact Score: 10.3

Impact Rank: 15

Implementation: CommScope is a solid network infrastructure provider based out of Hickory, North Carolina. CommScope competed in the free air cooling and antenna solutions categories, finishing in third place behind Huawei and Ericsson for implementation in the antenna solutions group and finishing first in implementation for free cooling solutions. Its scores in the overall assessment were slightly lower, due to providing mostly cooling and antenna equipment, which had lower weightings for the ability to reduce CO2 emissions versus active components and equipment, such as 5G RAN and mMIMO.

Impact: Antenna solution provider, CommScope, is making strides in addressing its environmental impact. The company published its 2021 Sustainability Report, and for the first time in 2020, CommScope was recognized by the CDP for earning an A- in the Climate Change scorecard. For this assessment, CommScope's sustainability initiatives and product offerings ranked third for impact in antenna solutions and first for impact in free cooling, as a leading provider.

3.4. CHIPSET AND COMPONENT VENDORS

3.4.1. Intel

Overall Score: 34.7

Overall Rank: 6

Category Rank: 1

Implementation Score: 31.6

Implementation Rank: 6

Impact Score: 37.6

Impact Rank: 6

Implementation: Intel led in implementation among the chipset and component providers as the largest supplier of RAN silicon. The company was scored in three categories (5G RAN, Open RAN, and AI-driven software), and Intel's implementation for Open RAN strongly led the pack of 16 vendors. Intel came in fifth place for 5G RAN implementation and fifth place for AI-driven software implementation.

Leading the company's implementation strategy, Intel established the Network and Edge Group (NEX) in 2021, as one of six Intel business units designed to facilitate growth in the telecoms market and accelerate a shift toward software-defined and fully programmable network infrastructure. For implementation scoring, Intel directly verified more than 150 FlexRAN licensees worldwide. FlexRAN is a Virtualized RAN (vRAN) reference architecture for virtualized cloud-enabled RAN networks. The hardware for FlexRAN includes Intel Xeon processors with other Intel architecture, while virtualization allows multiple companies to run software on Intel's

general-purpose processors. Intel's processors, such as the Intel Atom P5900 platform, are also used by major telco equipment vendors, such as Ericsson, Nokia, and ZTE, further increasing Intel's total telco market share. As the industry continues to transition to 5G, Intel sees network infrastructure representing a US$25 billion silicon opportunity by 2023.

Impact: Among the vendors making chipsets and network components, Intel led the group for impact in 5G RAN and Open RAN, and Intel led chipset and component vendors in the overall impact scores. At the company level, Intel has pledged to achieve net-zero GHG emissions in its operations by 2040, which is a particular challenge and ambitious target for a company that is an Integrated Device Manufacturer (IDM) and telco equipment manufacturer and supplier. An IDM is a company that both designs and builds its own semiconductor chips. For impact on the product side, Intel Xeon and Atom processors, as well as Intel Field Programmable Gate Arrays (FPGAs), are extensively used in RAN, edge, and core network infrastructure, both in traditional RAN and virtualized Open RAN. With advanced Instruction Set Architecture (ISA) and other networking-centric capabilities, the solutions handle all RAN workloads, including support for emerging capabilities with AI/ML algorithms. Moreover, a key design feature for Intel's Silicon is to meet ambitious targets for sustainability-related Key Performance Indicators (KPIs), or performance-per-watt. For example, Intel fourth-generation Xeon Scalable processors (Sapphire Rapids) will deliver up to 2X capacity gains for vRAN workloads versus third-gen Xeon, and it will provide this gain without increasing the power at all. This gain gives operators up to 2X performance-per-watt improvement.

In interviews for this report, Intel noted several additional technologies available in Intel products and solutions to enable RAN industry and telco energy savings: 1) real-time telemetry data collection of key Central Processing Unit (CPU) subsystem components (e.g., CPU loading/utilization); and 2) dynamic power management controls (P-states, C-states). These include knobs for: 1) frequency/voltage control at a per-core level (P-states); 2) multiple C-state options for putting the cores to varying levels of dormancy (e.g., sleep, hibernate, etc.), 3) ISA and built-in acceleration and optimized tool kits for AI/ML in Xeon CPUs to enable implementing ML-based algorithms for predictive approaches to energy savings (and other RAN optimization applications, such as radio resource management, traffic steering, etc.), and 3) Enablers for applications to access these technologies in the silicon (e.g., Linux drivers and platform software, Data Plane Development Kit (DPDK), FlexRAN reference software for Distributed Unit (DU) stack, etc.).

3.4.2. Qualcomm

Overall Score: 26.9

Overall Rank: 8

Category Rank: 2

Implementation Score: 26.7

Implementation Rank: 8

Impact Score: 27.16

Impact Rank: 8

Implementation: Qualcomm competed in the 5G RAN, Open RAN, and AI-driven software categories, finishing eighth overall for implementation across the industry. Qualcomm finished in fourth place for Open RAN implementation. The company is looking to develop high-performance, low-power silicon for 5G RAN and Open RAN, in addition to remaining the world's leading developer of mobile phone chips and other 5G technologies. Global inflationary pressure reducing smartphone sales and other market developments may impact Qualcomm's future 5G implementation plans. iPhone vendor Apple is widely believed to be developing its own 5G chipset technology after purchasing Intel's 5G modem business unit for US$1 billion, a move that would greatly reduce Apple's reliance on Qualcomm's products. However, to counter that loss, in July 2022, Qualcomm announced an agreement renewal with Samsung, guaranteeing that Samsung Galaxy devices and Samsung PCs would be powered by Qualcomm technologies, including chipsets and networking equipment through 2030.

Impact: Qualcomm finished in eighth place overall for impact. The company has committed to net-zero global emissions for Scopes 1, 2, and 3 carbon emissions by 2040. To note, through the years, Qualcomm has expanded into selling semiconductor products using a predominantly fabless manufacturing model. However, to address sustainability issues with outsourcing and address future growth, by 2025, Qualcomm has pledged to ensure 100% of primary semiconductor manufacturing suppliers are audited every 2 years for compliance with the Supplier Code of Conduct. By 2025, Qualcomm has also pledged to reduce the energy consumption of its flagship Snapdragon mobile platform products every year by 10%.

3.4.3. Dell

Overall Score: 6.8

Overall Rank: 16

Category Rank: 3

Implementation Score: 7.0

Implementation Rank: 16

Impact Score: 6.7

Impact Rank: 16

Implementation: Dell Technologies is another strong telco network components implementer, finishing in third place for its group, despite only competing in one equipment category for Open RAN. 5G technology can only improve with better servers and faster computing power, and Dell is increasing its market share in the telecoms industry rapidly. For products, Dell is focusing on core, edge, and RAN, with pre-integrated edge computing platforms and newly constructed telco-grade servers that meet all the environmental demands of telco equipment and workloads. Dell is also working to ensure its products support a multitude of telco partnerships and software providers, with Dell's PowerEdge portfolio, PowerSwitch networking, Dell storage, and other products. With a transition from 4G with closed architecture to 5G with open architecture (e.g., with open architecture defined as using software to run Network Functions (NFs) on standard computing hardware versus using specialized equipment), Dell is in a good position to expand its footprint and influence. The company has already secured deals with DISH Network Corp. in the United States and Orange and Vodafone in Europe to build out 5G open networks. However, to fully maximize its telco partnerships and expand its 5G implementation strategy (that goes beyond just selling servers and storage), Dell will have to continue to invest in telco talent that understands the integration requirements of complex mobile networks.

Impact: In assessing impact potential, Dell company leadership is very strong with numerous awards for ESG-related achievements, including a Platinum medal from EcoVadis (scoring in the top 1% of companies for environment, labor and human rights, ethics, and sustainable

procurement), CDP Supplier Engagement Leaderboard, and other global supply chain awards. To address climate change, Dell has pledged to reach net-zero GHG emissions across its value chain, including Scope 1, 2, and 3 emissions, by 2050. Dell also has set multiple milestones for reaching this goal, including cutting 2020 Scope 1 and 2 emissions by 50% by 2030, improving the energy efficiency of operations, and using 75% renewable energy electricity by 2030 and 100% renewable energy globally by 2040. Since 2013, the company has had a goal of reducing the energy intensity of its product portfolio by 80% (from FY 2012 to FY 2021). In the FY 2020 report, Dell had reached almost 70%, and it expects to move even closer to the goal in the final year of assessment.

3.4.4. AMD

Overall Score: 5.5

Overall Rank: 17

Category Rank: 4

Implementation Score: 5.0

Implementation Rank: 17

Impact Score: 6.0

Impact Rank: 17

Implementation: AMD finished in fourth place among chipset and components providers for telco equipment implementation, as it only competed in the Open RAN category. In February 2022, AMD announced the completion of its US$35 billion acquisition of Xilinx in an all-stock transaction. Xilinx offered industry-leading FPGAs, adaptive Systems-on-Chip (SoCs), AI engines, and other software expertise, combining that with AMD's CPUs and Graphics Processing Units (GPUs), allowing for expansion across intelligent devices and cloud and edge applications. In February 2022, Xilinx also demonstrated industry-first 5G Open RAN solutions at MWC, including a 64T64R mMIMO Open RAN radio prototype and the highest-bandwidth Open RAN radio platform.

Impact: AMD (Xilinx) finished in 4th place for impact among the chipset and component group and 17th place overall for affecting sustainable impact across the industry. AMD (Xilinx) has a goal of reducing CO2 emissions by 25% per employee over 10 years from 2016 to 2025. The company also reached a goal in 2020 of 84% solid waste recycled of total generated (from non-hazardous waste). By the end of 2020, renewable energy sources supplied 53% of total energy needs. In August 2022, the company reported that 74% of AMD suppliers were sourcing renewable energy and working toward reducing their own GHG emissions.

Note on carbon emissions for chipmakers: The world's largest chipmakers, including Intel, Samsung, and Taiwan Semiconductor Manufacturing Company (TSMC), have all committed to reducing their carbon emissions. However, among the telco network equipment providers, these have particularly noteworthy sustainability challenges. Even the fabless chip makers that sell hardware and semiconductor chips, yet do not manufacture the silicon wafers or chips used in their products, still must account for the chips' CO2 emissions in the Life Cycle Assessments (LCAs) of their products.

Telco chipset makers and component providers have particularly challenging journeys to net zero, due to the high heat and energy-intensive processes involved in the semiconductor industry

The small pieces of silicon that are essential to today's electronics and technology-driven economies are not so beneficial for their impact on the planet. Several phases of the semiconductor production process are extremely energy intensive. To begin, raw silicon must be melted down, purified, and then "grown" into large silicon rods. These rods are then sliced into thin pieces or wafers to build chips. The next steps for manufacturing also require very high temperatures, such as diffusion furnaces, ion implanters, and plasma-etching machines that layer various computing materials onto the chips. According to industry sources, the diffusion furnaces can reach 1,200° to 2,000° Fahrenheit with the wafers requiring hours in these furnaces for proper setting of the silicon. While some companies are using renewable energy sources, 70% to 80% of the world's chip production takes place in China, Japan, South Korea, and Taiwan, and the production power is sourced from fossil fuels like coal and natural gas, driving up carbon emissions. Therefore, company climate targets for chipmakers, such as Intel pledging net-zero emissions by 2040, are a significant investment and incredible undertaking, as these companies not only compete on cost for chips globally, but they also must address substantial emissions from high-heat processes that are essential to the production of their products.

3.5. SOFTWARE VENDORS

3.5.1. IBM (Red Hat)

Overall Score: 18.1

Overall Rank: 13

Category Rank: 1

Implementation Score: 18.8

Implementation Rank: 13

Impact Score: 17.34

Impact Rank: 13

Implementation: IBM Red Hat competed in three equipment categories, including Open RAN, liquid cooling solutions, and cloud-native platforms. IBM Red Hat scored slightly ahead of VMware in cloud provider implementation, yet IBM lagged behind VMware in impact and overall company sustainability initiatives. For liquid cooling solutions, IBM finished in 3rd place for implementation out of 18 vendors, and for Open RAN, IBM Red Hat finished in 10th place for implementation.

Impact: IBM (Red Hat) scored slightly higher for overall impact across the industry versus VMware, as IBM competed in three equipment categories versus two categories for VMware. IBM's liquid cooling solution was fourth overall and fourth for impact among the liquid cooling data center solutions, while IBM (Red Hat) finished third overall and fourth for impact for cloud providers.

For addressing environmental sustainability, IBM expresses a relevant, yet slightly contrarian view on Scope 3 emissions. The company states "determining such indirect Scope 3 emissions across a company's 'value chain' in a factual, reliable manner is extremely challenging if not impossible due to the lack of primary source data across multiple entities that can be credibly attributed to individual companies in question." IBM further states that "most Scope 3 emissions cited by companies are order of magnitude 'guesstimates' that are built upon layers of assumptions and generic substitutes for primary source data with widely varying degrees of

credibility and completeness." These statements raise valid and interesting questions for the Scope 3 emissions accounting recommendations defined by the GHG Protocol's Corporate Value Chain Emissions Accounting and Reporting standard.

3.5.2. VMware

Overall Score: 15.3

Overall Rank: 14

Category Rank: 2

Implementation Score: 14.4

Implementation Rank: 14

Impact Score: 16.2

Impact Rank: 14

Implementation: VMware is a virtualization and cloud computing technology company that provides 5G network services to any could-based application from the core network to the RAN edge. Sustainability is essential to VMware's core values as a company working to decarbonize the world through digital infrastructure. VMware scored first overall among 10 telco cloud partners (5G cloud-native platforms) with high implementation scores, while its Open RAN offering scored in ninth place overall and ninth place for implementation. VMware reports partnerships and service provider transformations for telco operators Singtel, KDDI, NTT DOCOMO, Airtel Africa, Telefónica, BT, and Vodafone.

Impact: VMware has been a carbon neutral-certified company across its global operations since 2018 and aims to be carbon neutral across its operations and supply chain by 2030. VMware has also purchased electricity from 100% renewable energy sources since 2019. VMware finished first overall for telco cloud partners and first for impact for cloud partners. VMware's Open RAN offering scored ninth place overall and eighth place out of 16 vendors for impact. VMware finished in first place among telco software providers for criteria scoring on company-wide sustainability efforts.

4. INDIVIDUAL CATEGORY RESULTS: THE HORIZONTAL VIEW

4.1. MMIMO

4.1.1. Technology Overview: mMIMO

mMIMO technology is one of the key components for facilitating 5G user experiences. MIMO systems have a combination of antenna expansion capabilities and complex algorithms, and they have been used in wireless communications for years. With 5G NR networks, MIMO becomes "massive" due to the increased number of antennas on the base station, which brings significant improvements in data throughput and efficiency. Thus, mMIMO is a radio technology that uses multiple antennas as both the transmitter and receiver to improve the reliability, quality, and overall capacity available for 5G radio linkage. MIMO algorithms focus on how data map into the antennas and where to focus energy externally. Both network equipment and mobile devices for 5G have more complex designs than previous generations, and these innovations help support effective coordination to make MIMO and 5G work for improved spectral and energy efficiency.

More advanced technologies, such as beamforming and spatial multiplexing, enable mMIMO AAUs. Beamforming is a processing technique for signals that support directional transmit and receive capabilities. 5G beamforming allows a 5G cell to concentrate or focus its transmission to a particular area. With beamforming, a 5G cell can direct its signal to a cell phone, laptop, or Internet of Things (IoT) device. Spatial multiplexing allows multiple antennas for both the transmitter and receiver to carry multiple data streams at the same time using the same frequency band.

mMIMO is a primary enabling technology for 5G's fast data rates and download speeds. Benefits of massive MIMO include:

- Increased network capacityBetter coverageBetter user experience
- Increased network capacity
- Better coverage
- Better user experience

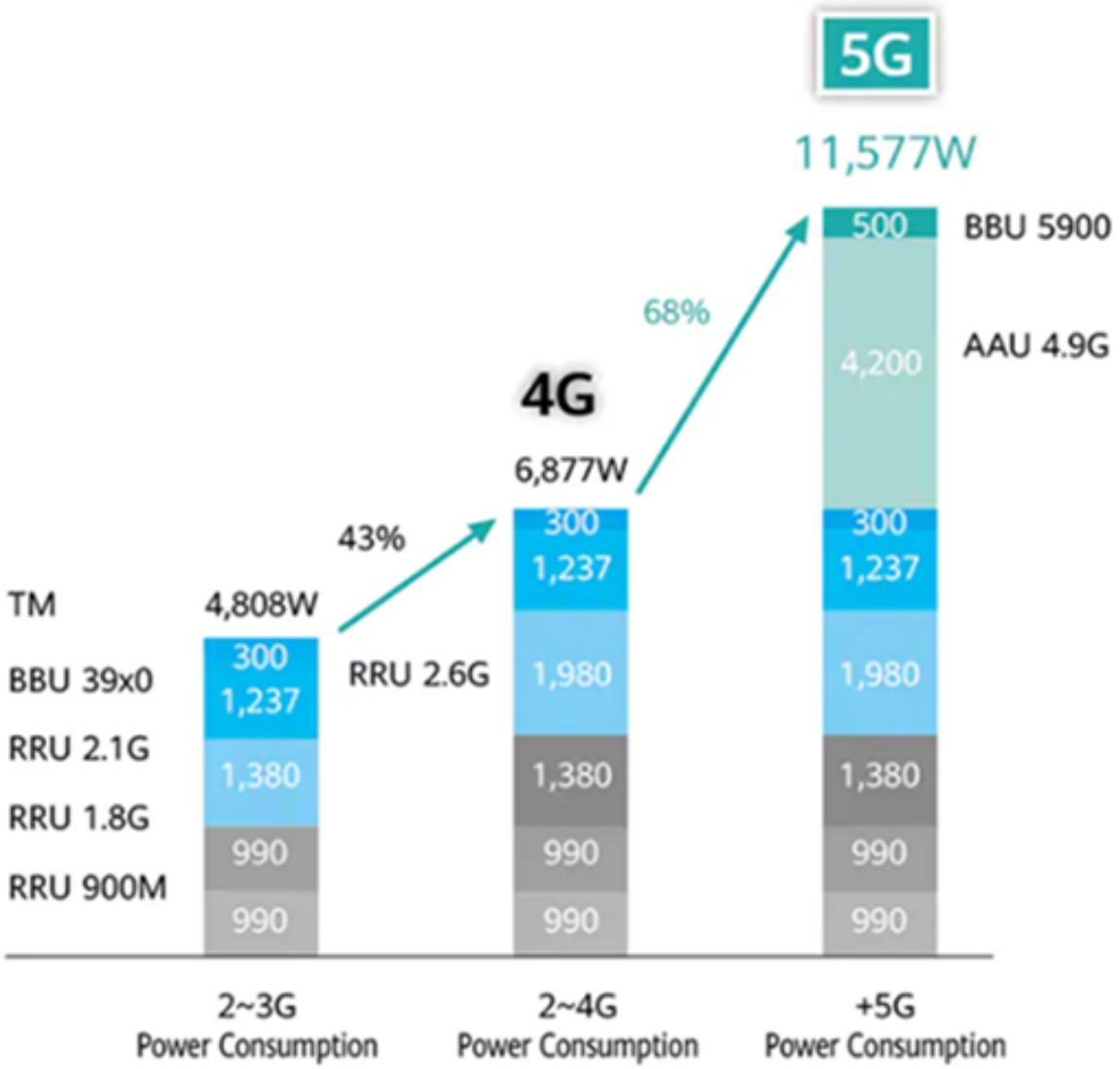
mMIMO Power Usage

The downside to 5G mMIMO is the increased power requirements of the technology. According to China Mobile, the largest operator in the world, 5G needs 3X the number of base stations for the same coverage as LTE (due to shorter signal propagation distances when transmitting at higher frequencies and the network densification required), and the energy consumption of 5G is roughly 2X to 3X of power consumed by LTE. The typical 4G LTE base station uses a 4 transmitter and 4 receiver (4T4R) array, while urban 5G sites are using 64T64R (or larger) MIMO arrays. In

efforts to reduce energy use (and carbon emissions), operators in China, South Korea, and Europe are downsizing their mMIMO requirements using 32T32R with expectations to deploy 16T16R arrays in more rural areas.

Finally, the beamforming technology used by mMIMO AAUs depends on integrating multiple radio circuits, a power-hungry combination that can use more than 1 Kilowatts (kW) of power in a single unit. Even though 5G is more energy efficient than 4G per unit of data (watt/bit), the overall power consumption is much higher.

Figure 3: mMIMO Power Consumption (2G to 3G versus 4G versus 5G)
(Source: Huawei Technologies Co.)



Typical maximum power consumption of a single 5G base station

4.1.2. Impact Criteria

- Eco-Design: Light-weighting and size of equipment design, selection of sustainable materials and inputs, ease of disassembly and recyclability, duration of product use, repairability: 30%
- Innovative Technologies to Reduce Overall Power Consumption: The capability of implementing energy efficient technologies in the production and operation of the mMIMO products to reduce overall system power consumption: 20%
- Advanced Features that Enhance Overall Performance: The capability of implementing innovative solutions in software and hardware that enhance the performance of the mMIMO solution, such as spectral efficiency and end user throughput (increasing the "enabling effect" of making other industries more sustainable): 20%
- Sustainable Operations in Manufacturing of mMIMO: The level of integration of advanced Industry 4.0 technologies and programs for sustainable operations (IoT, AI/analytics, and automation for materials, water, and energy savings) in the production of mMIMO equipment. 10%
- Supply Chain Sustainability and Supplier Engagement: The weighting of sustainability in supplier RFPs, depth of supplier engagement, participation in supply chain coalitions (CDP Supply Chain Program, etc.) 10%
- Overall Sustainability Strategy for the Vendor: This assessment includes company climate targets for carbon neutrality within the vendor's own operations and for reaching net zero across the value chain, use of renewable energy, green buildings credentials (Leadership in Energy and Environmental Design (LEED) certification, Energy Star, Building Research Establishment Environmental Assessment Method (BREEAM), Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), etc., green fleet vehicles (% of EVs, telematics), waste and circularity programming, incentives for climate targets (executives, employees), and sustainability reporting and governance. 10%

4.1.3. Implementation Criteria

- Overall mMIMO Antenna Sales Market Share: A comparison of the market share across the category of vendors, assessing total revenue and shipments for mMIMO antennas. 35%
- Antenna Sales Regional Geographical Penetration: The penetration of vendors across the different regions in terms of revenue. In regions where 5G is not commercialized, active trials will be assessed. 15%
- Number of Networks with mMIMO Solutions Deployed: Total number of MNOs that have adopted each vendor's mMIMO platforms and future contracts. 15%
- Wide Range of mMIMO Product Portfolio: The product portfolio of the vendor, including different mMIMO configurations xTxR (right sizing for energy use), Transmission (Tx) power, instantaneous bandwidth for both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) spectrum solutions, and Millimeter Wave (mmWave) solutions, as well as hybrid antennas (passive + active). 15%

- mMIMO Radio Features to Ease Cell Site Installation and Reduce Transportation Required for Field Operations: Supplying compact, lightweight mMIMO radios, enhanced features for wind load reduction, specialized brackets and solutions for easy installation, and features that reduce overall number of site visits required for maintenance. 20%

4.1.4. Results

Leaders: Ericsson, Nokia, Huawei

Mainstream: ZTE, Samsung, NEC

Followers: Mavenir, Airspan

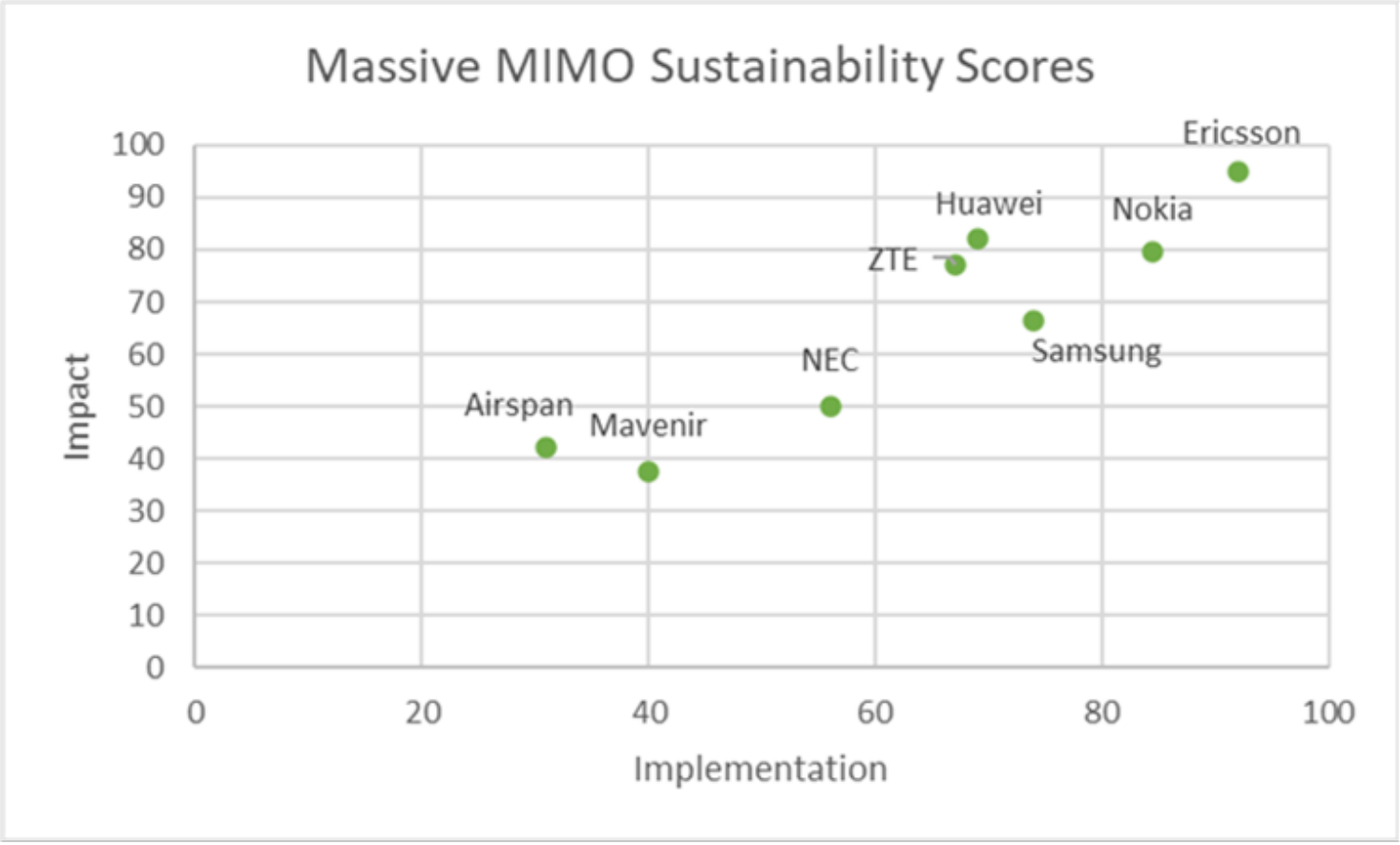


Table 3: mMIMO Vendor Ranking
(Source: ABI Research)

Company	Overall Rank	Overall Scores
Ericsson	1	93.5
Nokia	2	82.0
Huawei	3	75.8
ZTE	4	72.2
Samsung	5	70.4
NEC	6	53.1
Mavenir	7	38.8
Airspan	8	36.9

Impact Summary mMIMO

Ericsson came in first place in sustainable impact, due to its highly innovative, next-generation mMIMO products. Ericsson has been able to use its technological advancements to reduce materials and energy use of its products. Some of Ericsson's impact highlights include next-generation materials, lightweight form factor (12 kg 32TRx, 19 kg 64TRx), in-house Ericsson Silicon chip creation, Gallium Nitride (GaN) PAs, Deep Sleep and Micro Sleep Tx, and other advanced PSFs have shown >60% energy savings portfolio-wide.

Nokia came in second place overall, with a first-place finish in sustainable operations for manufacturing, a third place for eco-design, and a first place finish for innovative technologies that reduce power consumption. Nokia's ReefShark chipsets are made in-house, and coupled with Nokia's AVA Energy Efficiency service, which uses AI to manage the system, up to 20% of energy usage can be reduced, with a further 5% to 10% from ReefShark's sleep mode.

Samsung came in fifth for mMIMO overall; however, Samsung finished third for impact, due to its overall design features for reducing energy. In 2022, Samsung won the iF Design Award for its eco-friendly and flexible solution with a 30% reduction in size and weight from previous generation equipment.

Huawei came in fourth place for impact. Huawei touts its Meta AAU as a breakthrough mMIMO technology supporting an immense 384 antenna elements (double that of a traditional AAU), while improving user experiences and energy savings by 30%. Huawei finished fourth for sustainable manufacturing, and fourth for eco-design, due to its "CableFree" technology in the antenna unit (signal direct injection feeding, removing up to 100 Meters (m) of cable inside the antenna, significantly reducing the weight and the power consumption by up to 20%, and increasing antenna efficiency).

At 9 kg, ZTE presents the lightest product available in its class with its 32TRx offering and uses GaN technology in its PAs. However, ZTE finished fifth for impact behind strong competitors. NEC, Airspan, and Mavenir finished sixth, seventh, and eighth place, respectively, as they are still in the development phases for mMIMO technologies.

Implementation Summary mMIMO

As of August 2022, Ericsson has deployed 125 5G networks across 55 countries, landing the company as the overall mMIMO implementation leader

Ericsson emerged as the overall mMIMO implementation leader, due to its global market share and rollout of 5G mMIMO solutions. Ericsson has customers in more than 180 countries and, as of August 2022, Ericsson has deployed 125 5G networks across 55 countries. Huawei finished in second place for implementation in mMIMO, due to its footprint in China and across a multitude of diverse markets. Nokia was third for implementation overall and a top three implementer in this category for market share, number of MNOs with contracts, and regional rollouts. With the United Kingdom, the United States, Australia, New Zealand, and Canada proposing bans on Huawei and ZTE equipment, Ericsson and Nokia have been able to capture market share in these regions.

Samsung and ZTE were the mainstream implementers, as Samsung leads mMIMO penetration in South Korea. ZTE offers the potential to scale its technologies across China, parts of Europe, the Middle East, and South Korea.

Implementation followers for mMIMO included NEC, Airspan, and Mavenir, as these vendors are looking to increase their market share, especially in the United States and Japan.

Concluding Remarks

Overall, Ericsson secured first place in implementation and impact for the mMIMO category, due to its leading global market share for mMIMO equipment and its highly innovative and energy-efficient product line. Ericsson is designing advanced mMIMO products that are compact, ultra-lightweight, and constructed with the latest-generation silicon for optimum performance and reduction of energy and materials. Nokia fell slightly behind Ericsson and Huawei in terms of implementation, including number of operators as partners and the ability to scale impact for mMIMO. However, sustainability is integrated into Nokia's company business model and entire product portfolio, including its lightweight and modular antenna solutions and its advanced circularity practices, offering refurbished antennas and recycling schemes to reduce waste and increase reuse and recycling of its products.

Huawei has also made strong advancements with its MetaAAU offering and increased focus on sustainability initiatives company wide, summarized in the Huawei Green Development Program. However, due to the nature of private companies, Huawei, Mavenir, and Airspan have released limited public information on their waste and carbon emissions, leading to lower scores being awarded in the impact categories. Finally, in February 2022, NEC was awarded its second ribbon from the Telecom Infra Project (TIP) for 5G mMIMO Open RAN RUs complying with the latest published TIP Open RAN RU technical requirements 2.0. NEC is an active participant in several alliances for driving technology requirements for Open RAN and is the first global 5G supplier to have deployed live 5G mMIMO units that are Open RAN compliant.

4.2. 5G RAN VENDORS

4.2.1. Technology Overview: 5G RAN

vRAN allows for the baseband functions of the network, which were carried out via hardware on previous generations of mobile Internet, to be run fully on cloud-based servers

The RAN is a collection of hardware and software that spans the core components of network equipment that ensures the connectivity between the connected devices (e.g., user equipment like phones, laptops, and IoT devices) and the global Internet via radio connections. Developments in this technology are moving toward digitalization for 5G, as the vRAN allows for the baseband functions of the network, which were carried out via hardware on previous generations of mobile Internet, to be run fully on cloud-based servers. This is a huge step for telecommunication technology and has an immense impact on sustainability: the vRAN can be run on much less hardware, and because it is built virtually, this allows for much improved flexibility. Modeling, monitoring, and managing the vRAN system can be done remotely and can be deployed much more easily. Comparing this new technology with 4G LTE (and previous generations) RAN equipment, the Baseband Units (BBUs) were large and necessary pieces of hardware that required monitoring and maintenance through in-person servicing visits from specialized engineers.

The RAN coordinates many aspects of the network: it can be thought of as a controller that conducts resource management across the network, while supporting new technologies, such as mMIMO, carrier aggregation, multi-band broadcasting, and network slicing.

The benefits of virtualizing the RAN through the lens of sustainability are numerous:

- A reduction in volume of hardware needing to be manufactured
- Remote monitoring and management of systems to reduce the number of site visits

- Built in power-saving and efficiency-management software using ML and AI algorithms
- Upgradability and flexibility in programmability (a software update is all that is required to introduce new and advanced features on some chipsets)

In summary, automated management of the RAN, while implementing AI and ML, can resolve issues, predict traffic patterns, and optimize the network equipment to improve resource usage and efficiency, without compromising the user experience.

Some vendors have opted for a hybrid approach to virtualization, offering some parts of the RAN equipment as physical hardware, and some components being run virtually through RAN management software. RAN equipment can be designed to support multiple generations of networks, as some RAN solutions can consist of antennas that have multi-band capabilities, with hybrid active and passive antenna integration, supporting 5G and previous generations in a single antenna solution, reducing the amount of necessary hardware at the site. Some solutions can also be integrated into existing systems to upgrade to 5G capabilities in a modular and flexible manner. Vendors that can offer a wide range of RAN equipment and solutions that are capable of broadcasting in multiple frequency bands were awarded higher scores for technology advancements and for enabling the equipment's carbon handprint.

4.2.2. Impact Criteria

- Eco-design: Light-weighting and size of equipment design, selection of sustainable materials & inputs, ease of disassembly and recyclability, duration of product use, repairability. 30%
- Innovative Technologies to Reduce Overall Power Consumption: The capability of implementing energy efficient technologies in the production and operation of the RAN products to reduce overall system power consumption. 20%
- Advanced Features that Enhance Overall Performance: The capability of implementing innovative solutions in software and hardware that enhance the performance of the RAN components increasing the "enabling effect" of making other industries and technologies more sustainable. 20%
- Sustainable Operations in Manufacturing: The level of integration of advanced Industry 4.0 technologies and programs for sustainable operations (IoT, AI/analytics, and automation for materials, water, and energy savings) in the production of RAN equipment. 10%
- Supply Chain Sustainability and Supplier Engagement: The weighting of sustainability in supplier RFPs, depth of supplier engagement, participation in supply chain coalitions (CDP Supply Chain Program, etc.). 10%
- Overall Sustainability Strategy for the Vendor: This assessment includes company climate targets for carbon neutrality within the vendor's own operations and for reaching net zero across the value chain, use of renewable energy, green buildings credentials (LEED certification, Energy Star, BREEAM, DGNB, etc.), green fleet vehicles (% of EVs, telematics),

- waste and circularity programming, incentives for climate targets (executives, employees), and sustainability reporting and governance. 10%

4.2.3. Implementation Criteria

- Overall RAN Equipment Sales Market Share: A comparison of the market share across the category of vendors, assessing total revenue and shipments for RAN equipment. 35%
- Antenna Sales Regional Geographical Penetration: The penetration of vendors across the different regions in terms of revenue; in regions where 5G is not commercialized, active trials will be assessed. 15%
- Number of Networks with Vendor's RAN Solutions Deployed: Total number of MNOs that have adopted each vendor's RAN equipment and future contracts. 15%
- Wide Range of RAN Product Portfolio: The product portfolio of the vendor, including different antenna configurations, mMIMO, RUs, BBUs, and/or the digitalized alternatives. 15%
- RAN Equipment Features to Ease Cell Site Installation and Reduce Transportation Required for Field Operations: Supplying compact, lightweight products, enhanced features for remote optimization and management, specialized solutions for easy deployment and installation, and features that reduce overall number of site visits required for maintenance. 20%

4.2.4. Results

Leaders: Ericsson, Nokia, Huawei

Mainstream: Intel, ZTE, Fujitsu, Samsung, Cisco, NEC, Rakuten Symphony (Altiostar), Qualcomm, Parallel Wireless, Mavenir, Casa Systems

Followers: Radisys, Airspan, ASOCS

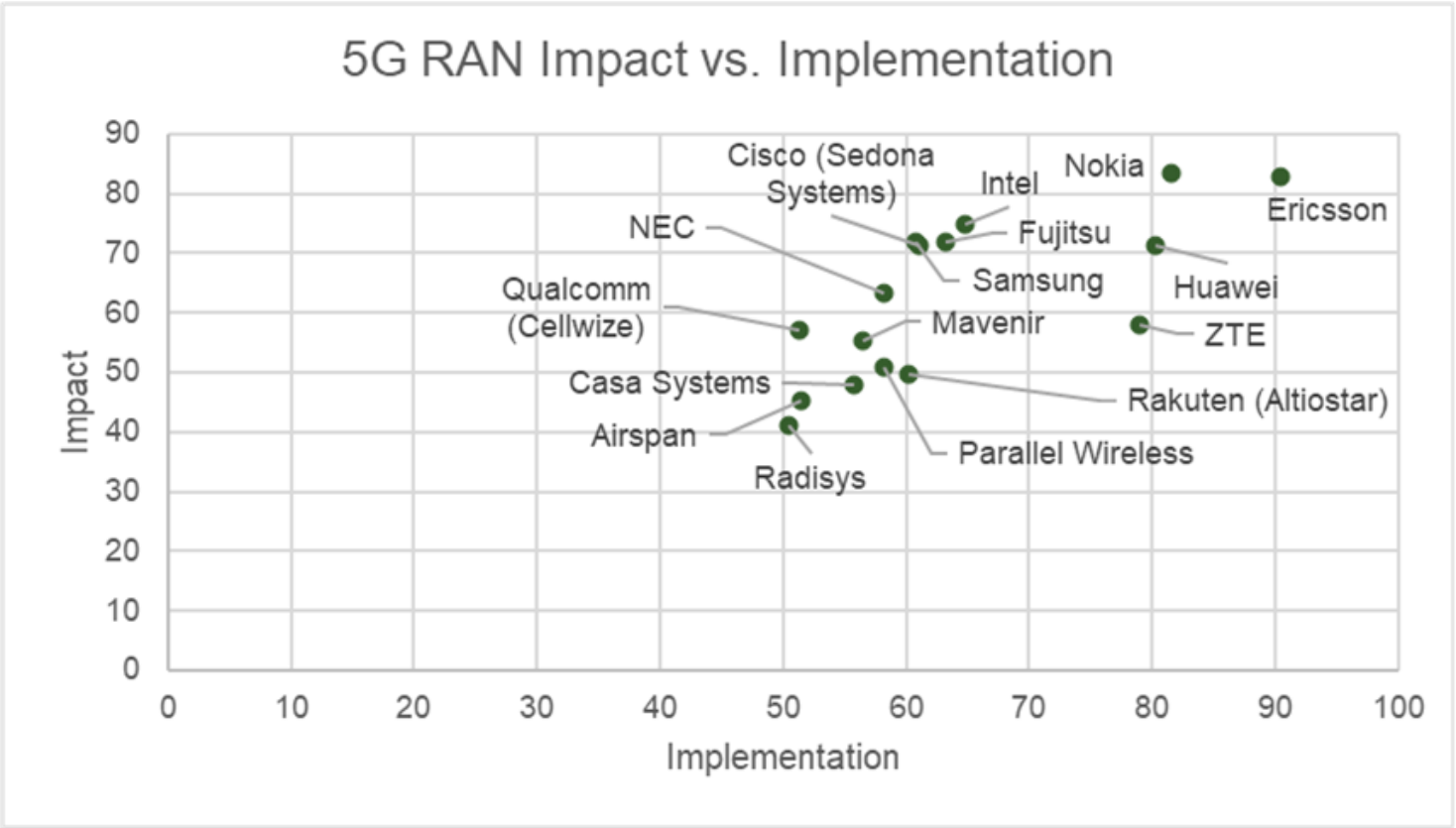


Table 4: 5G RAN Vendor Ranking
(Source: ABI Research)

Company	5G RAN Overall Scores	5G RAN Ranking
Ericsson	86.8	1
Nokia	82.5	2
Huawei	75.9	3
Intel	70.1	4
ZTE	69.3	5
Fujitsu	67.8	6
Samsung	66.5	7
Cisco	66.3	8
NEC	60.8	9
Mavenir	55.9	10
Rakuten (Altiostar)	55.3	11
Parallel Wireless	54.7	12
Qualcomm	54.3	13
Casa Systems	52.0	14
Airspan	48.5	15
Radisys	46.0	16
ASOCS	37.4	17

Impact Summary 5G RAN

Nokia placed first in the impact ranking: its circular practices and AirScale antenna range and ReefShark chipsets have set it apart, along with its innovative liquid cooling system for the larger AirScale hardware products. Nokia's antenna products manufactured from 2012 onward can be upgraded to support 5G capability with just a software update, and the Single RAN technology offers support from 2G to 5G, with an average 44% reduction in energy consumption. Nokia Intelligent RAN is an energy efficiency management software that uses ML to further reduce the network's energy consumption by 15% through zero-touch optimization, with an increase in efficiency of up to 80% seen in some current deployments.

Ericsson was second in impact, touting a new line of lightweight radios, powered by Ericsson Silicon, with reduced power consumption of around 25% compared to the previous generation. Ericsson's Cloud RAN is a solution to provide a cloud-native network through RAN virtualization, and via its Intelligent Automation Platform, the radio network can be managed autonomously and remotely, using AI for improved optimization.

Intel ranked third in impact for its reprogrammable Xeon Scalable Processors built to support its FlexRAN software, which operates for 4G and 5G to provide a cloud-native RAN solution, boosting performance by up to 62%. Intel's company-wide efforts have also gained them a high score, with an impressive 80% renewable energy usage across all their operations, and a commitment to use 100% renewable energy by 2030. Through its water recycling efforts, it is water net-positive in three countries, one of many efforts that named it #1 on Barron's 100 Most Sustainable Companies list.

Fujitsu's RAN solutions provide a wide portfolio of antennas, including 4T4R-64T64R mMIMO with 4G and 5G capabilities, in the sub-6 GHz and mmWave bands, supported by an open vRAN architecture. Samsung's open vRAN software supports a broad range of 5G equipment, including mMIMO products in the C-band and mmWave ranges, low band FDD, and wide bandwidths for mid-band TDD, and supports multiple generations of RAN from a single platform. Samsung was awarded CTO's Choice Award, and the Best Mobile Technology Breakthrough in the 2022 GLOMO Awards at MWC for its vRAN solution.

Huawei's RAN portfolio spans a vast number of antenna configurations from 2G to 5G capabilities, ranging from 4T4R to 128T128R mMIMO, supported by the PowerStar2.0 and GreenSite solutions, which enable many AI-driven PSFs that optimize efficiency. Huawei's BBUs boast the largest number of cells per unit volume and have the capacity to support mmWave technologies. Its AAU mMIMO units come in at 10 kg for the 32TRx and 19 kg for the 64TRx, well below the limit for safe single person deployment. Huawei's IntelligentRAN was more recently released (announced at the MWC 2022), compared to other vendors' solutions; until last year, the

company seemed to be publicly against the idea of virtualization and openness in the RAN equipment. The shift toward a vRAN approach shows willingness to align with more sustainable practices in developing new technology.

Cisco employs advanced circular practices for its hardware products, suppliers, and customers. Its cloud-based vRAN offering and hardware solutions can be scaled from micro to macro deployments. NEC's 5G RAN portfolio spans a wide range of antennas, including mMIMO in both C-Band and mmWave spectra, an open vRAN platform, and system integration services for the 5G ecosystem.

ZTE has a vast portfolio of antenna solutions, from 2T2R up to 128T128R, for both indoor and outdoor applications, including some integrated Active and Passive (A+P) configurations with UniSite+ to support 4G and 5G. It widely adopts GaN in its PAs and, as previously stated, currently holds the record for the lightest 32T32R mMIMO on the market. ZTE's base station antennas have V-Tooth; the innovative leaf vein inspired passive cooling system was awarded the iF Design Award 2020, and its power saving and sleep/shutdown modes can reduce power consumption of the antenna units by up to 80% in some of the new generation products.

Recently joining the 5G RAN space with its newly developed accelerator cards and the QRU100 5G RAN platform, Qualcomm has been an advocate for developing technology for the Open RAN space. With the recent acquisition of Cellwize, a software vendor that specializes in network automation software including an RIC, Qualcomm looks to be strongly moving into the 5G RAN space, building out its virtualized platform, while applying its knowledge of advanced networking chipsets. Cellwize claims that the RIC can improve capacity gain by upward of 25%, enabling an increase in data throughput of 30% and 10% improved coverage and mobility through using AI-enabled software. Qualcomm's 5G RAN platform is said to be able to support features, such as dynamic spectrum sharing, multi-operator RAN sharing, and digital beamforming for mMIMO antenna array sizes up to 64T64R, across a wide range of spectra, including mmWave.

Mavenir provides an open, E2E, cloud-native vRAN software platform. Recently, it has started to provide some hardware, including mMIMO antennas, to accompany its vRAN offering. There is limited information on the sustainability initiatives of Mavenir, due to it being a private company, which affected its impact scoring.

Parallel Wireless' "ALL G" Open RAN network controller is a Self-Organizing Network (SON) vRAN solution that supports 2G to 5G. There is limited information on which new enabling technologies (e.g., mMIMO) its Open vRAN platform supports, though Parallel Wireless claims this solution can bring advanced automation to provide MNOs with efficient and reliable resource management of the network.

Casa Systems integrates AI to manage antenna steering in their mmWave outdoor equipment, to allow for 360° rotation to ensure the strongest signal is found. Its Virtualized Central Unit (vCU) works with its Baseband Unit (BBU) hardware and can support 4G and 5G.

Airspan offers Open RAN solutions that support new technologies, such as mMIMO and mmWave antennas, compact RU hardware, and some integrated solutions. Its OpenRANGE cloud-native vRAN software can manage and optimize the 5G network through the RIC, and its AirSON (self-organizing network) can manage networks deployed on small cells.

Radisys provides fully vRAN software that is open to Open RAN standards and ready to deploy on any Commercial Off-the-Shelf (COTS) hardware. ASOCS' CYRUS product provides a vRAN solution for deploying private 5G networks on industrial manufacturing sites to enable new Industry 4.0 technologies. Its products can be scaled up to macro-size and are interoperable with any digital DAS.

Implementation Summary 5G RAN

Ericsson was awarded the top ranking for implementation with the largest global market share. Ericsson also has many significant partnerships in the 5G RAN space, and currently supplies 125 live 5G networks (with its large 5G RAN equipment portfolio) and has 174 5G contracts globally. Nokia comes in second place with the next largest share of the 5G RAN market, with 233 commercial 5G deals and 77 live 5G networks.

Ericsson currently supplies 125 live 5G networks and has 174 5G contracts globally

Huawei has deployed many well-established networks across China, and the wider Asia-Pacific region, and more recently in the Middle East; however, due to recent sanctions on its equipment in parts of Europe and North America, its top spot in 5G RAN market share has been overtaken by Ericsson. Huawei's breadth of portfolio equipment, coupled with its on-site renewable energy generation solutions, show it is still very much a sustainable player in the 5G RAN market.

ZTE's extensive product portfolio has gained it a high implementation score, along with the fourth-largest market share. It is the second-largest vendor in China, and is also active in Thailand, the Middle East, Africa, and South America. Recent sanctions have also affected deployment in North America and Europe. Samsung follows ZTE with the next-largest market share, with Samsung's 5G RAN equipment being deployed in many networks with top tier network providers around the world.

Intel's FlexRAN solution and CPUs are widely adopted by many 5G infrastructure vendors to support their hardware with an open ecosystem in networks around the world. Its numerous

partnerships in the 5G RAN and Open RAN space have allowed them to saturate the market and become a leader in the Open RAN community. Another vendor operating in the Open RAN space is Fujitsu. Fujitsu's vRAN supports public and private 5G networks, and micro and macro 5G deployments, with a recent addition of mMIMO radios to its product offerings.

Cisco's business models implement many sustainable practices and circular operations, such as its take-back, refurbishing, and recycling scheme for many of its products, known as Cisco Refresh. Cisco also managed to increase some market share, along with Samsung, after Huawei's and ZTE's products were banned in certain markets.

Rakuten Symphony has deployed numerous 5G networks using Altiostar's vRAN technology around the world, particularly in Japan and, more recently, in Europe, the United States, and other parts of Asia. NEC also has well-established partnerships and has deployed many 5G networks across Japan, and, more recently, entered the 5G RAN space in the United States and Europe.

Parallel Wireless' "ALL G" Open vRAN software solution has been deployed with many major network operators. Similarly, Mavenir has established many Tier One partnerships in the Open RAN space, which has allowed it to deploy its solutions to more than 120 countries worldwide. Casa Systems has delivered its 5G RAN solutions and built many partnerships in the Open RAN space around the world, including in North and South America, Europe, and Asia-Pacific.

Airspan recently partnered with Altiostar, in collaboration with Rakuten Symphony, to deploy its collective network solutions in Japan. It has deployed its network equipment in more than 100 countries and boasts more than 1 million base station deployments worldwide. Airspan has also taken on an ambitious project with GoGo, providing air-to-ground 5G network coverage for aviation.

Qualcomm is a well-established chipmaker for many applications; however, for the 5G RAN space it is considered a newcomer, which is reflected in the implementation ranking. The company recently released its Open RAN-compliant accelerator cards, an AI-enabled Radio Frequency (RF) modem module that supports mmWave, and a vRAN system to a multitude of vendors for interoperability testing, but has yet to fully deploy these in commercial networks.

Radisys has deployed its 5G vRAN solutions in the United States, India, and China, and ASOCS vRAN solutions, mainly suited to SA deployments for industry, and has penetrated the market mainly in Europe, North America, and Asia-Pacific.

Concluding Remarks

Ericsson designs and builds RAN hardware equipment with sustainability in mind

Ericsson secured the overall top spot for 5G RAN equipment, leading market share with its large portfolio of efficient products. Its wide range of RAN hardware equipment is designed and built with sustainability in mind, accompanied by its virtualized RAN software, deployed on the in-house Ericsson Silicon on Chip. Ericsson also engages with its suppliers and has asked them to declare Science Based Targets initiative (SBTi) emissions targets in line with the 1.5°C Paris Agreement by 2025. To date, an impressive 90% of these suppliers have set sustainability targets.

Nokia closely followed Ericsson with its range of products and vRAN operating on its ReefShark chipsets (also built in-house) to support all generations of radio access technologies and wide range of other RAN hardware. Nokia implements significant sustainability initiatives, such as its take-back and recycling schemes, which contribute to its high rates of product reuse (9% in 2021) and recycling (82%): Nokia has set an ambitious target to be 95% circular in its practices by 2030.

Huawei's product designs, especially the BladeAAU, have made waves for sustainability. The ease of deployment at legacy sites reduces the carbon footprint significantly, and its large antenna arrays can provide much improved efficiency and capacity to densely populated areas for 5G and previous generations in a single site solution.

Intel's flexibly reprogrammable Xeon processors are found in many 5G RAN products, and its FlexRAN Open vRAN architecture is widely adopted across many networks worldwide. Intel has an immense number of partners, and it is carrying out multiple sustainability initiatives, including purchasing renewable energy, greening its manufacturing chemistry, practicing water stewardship, and increasing product energy efficiency.

4.3. OPEN RAN VENDORS (OPEN RAN PLATFORMS)

4.3.1. Technology Overview: Open RAN

Open RAN technology is the RAN equipment designed and built with openness and interoperability in mind. The components of the RAN equipment are the same, though the hardware and software are now able to be integrated within any other network components from a multitude of other equipment vendors. This prevents vendor "lock-in," allowing telco network providers to select different products to build their 5G networks from different infrastructure providers to suit their needs.

Some of the challenges with Open RAN are that the interoperable architecture does mean more complexity. For example, anomaly detection may be more difficult in a disaggregated RAN due to poor configuration or other issues resulting from using different vendors with different technology upgrade schedules. This could result in lower latency or downtime. The decentralization of RAN functionality can also leave a network with increased security concerns.

The O-RAN Alliance holds events to allow these partners to partake in "plugfests," where vendors can perform interoperability testing for their equipment with other vendors and network providers

O-RAN Alliance: The O-RAN alliance is a collective of network providers and technology vendors that are collaborating to enable 5G openness across RAN equipment. This group was formed from prior alliances, known as the xRAN Forum and C-RAN, that consisted of a smaller subset of vendors that had the same goal of moving toward an open, interoperable, and vRAN ecosystem for 5G and beyond. The group holds events to allow these partners to partake in "plugfests," where vendors can perform interoperability testing for their equipment with other vendors and network providers. The alliance has provided a few iterations of the interoperability standards since its creation in 2018 and continues to refine the specifications as the technology evolves. Since March 2022, there have been 52 new specifications released, with more being developed with each iteration of interoperability testing events.

As of September 2022, there are 31 network providers and more than 300 equipment vendors that are members of the O-RAN Alliance. Some equipment vendors are seemingly more present and involved in developing the standards and specifications than others, though the O-RAN Alliance is governed by network providers, meaning they ultimately have the say in enabling the widespread openness of the RAN equipment market.

Holding an open ecosystem for 5G RAN equipment means that not only do the network providers benefit from flexibility, being able to choose the best of the best from a wide range of vendors and products, but also from many impactful sustainability benefits, too. Many 5G RAN equipment vendors tout the reduction of energy consumption and efficiency of their products, and now after adopting an open approach to integration, network providers will be able to select the products that best align with their business practices, enabling them to meet their sustainability targets, while not compromising network performance or user experience.

Other notable groups in the Open RAN space are the Linux Foundation (LF), which, in collaboration with the O-RAN Alliance, created the O-RAN Software Community (ORAN SC). Its mission is to "support the creation of software for the RAN and leverage other LF network projects, while addressing the challenges in performance, scale, and The 3rd Generation Partnership Project (3GPP) alignment."

Furthermore, the TIP is a collective of hundreds of companies that span the telecoms industry, and are "working together to develop, test and deploy open, disaggregated, and standards-based solutions that deliver the high-quality connectivity that the world needs – now and in the decades to come." TIP gives out awards to technology vendors that meet the standards of Open RAN, and for other advancements in interoperable telco infrastructure.

Finally, many partnerships have bloomed through the formation of the O-RAN Alliance, uniting vendors that hold the same ideals surrounding evolving technology to "transform the Radio Access Network industry toward truly open, intelligent, virtualized and fully interoperable RAN." There are also significantly more members of the O-RAN Alliance than those covered in this analysis. ABI Research has selected a subset of these vendors to highlight the sustainability efforts of companies that are offering a variety of Open RAN solutions, with overall energy reduction of equipment (e.g., latest-generation silicon), development of energy monitoring software solutions, and other sustainability considerations in their business strategies.

4.3.2. Impact Criteria

- Product Portfolio: A wide range of product portfolio options can offer customers a great opportunity to deploy network solutions that are right sized to meet specific connectivity needs (optimizing energy use). This criterion measures RAN-related solutions, including RICs. 30%
- Standardization and Multi-Vendor Interoperability: Standardization can help broaden network deployments. Multi-vendor interoperability can also be used to evaluate robust and flexible vendor solutions, including innovative network architecture with high adaptability/flexibility and sustainability. A vendor with membership in more Open RAN standards organizations and alliances will score higher. 15%
- Network Performance: The ability of the vendor to support the use of critical technology of the generation, such as mMIMO for Open RAN. Vendors that can offer support for mMIMO or supply mMIMO, will be able to meet the higher network performance requirements of mobile operators. Improved network performance will enhance the "enabling effect" of making other industries more sustainable. 15%
- Sustainable Operations in Development: The level of integration of sustainability in the production and development of Open RAN hardware and software. 10%
- Overall Sustainability Strategy for the Vendor: This assessment includes company climate targets for carbon neutrality within the vendor's own operations and for reaching net zero across the value chain, use of renewable energy, green buildings credentials (LEED certification, Energy Star, BREEAM, DGNB, etc.), green fleet vehicles (% of EVs, telematics), waste and circularity programming, incentives for climate targets (executives, employees), and sustainability reporting and governance. 10%

4.3.3. Implementation Criteria

- Major Deployments and Trials: The size of deployment and/or trial projects that the vendor has reflects its Open RAN activities and the success of the business. The more operators a vendor works with the better the scoring for the vendor. Working with CSP sustainability leaders will also produce higher scores. 30%
- Financial and Organizational Health: This criterion shows the company's financial strength to run business and capability to fund internal operations and R&D for Open RAN. The vendor is assessed through its financial metrics (e.g., annual revenue, operating profits).

- Greater profits are required for R&D investments in energy efficiency, etc. 20%
- Regional Coverage: The vendor with a global footprint indicates its better understanding of regional-specific network deployment requirements. The accumulated experience can also help the company position itself well toward business sustainability. 15%
- Business Models: More dynamic and agile business models can help the company be well positioned in the market for profitability and reduce time to market. Vendors that have the capability to deliver hardware, software, and management services will score higher in this criterion. 20%
- Partnerships: The capability to deploy multi-vendor interoperable E2E network solutions to meet CSPs' requirements can help the company position itself in the marketplace. This requires the company to have strong vendor partnerships for comprehensive products/service provisioning. This criterion assesses the number of a vendor's partners and business relationships for working across the value chain to reduce CO2 emissions and waste. 15%

4.3.4. RESULTS

Leaders: Intel, Ericsson, Nokia

Mainstream: Fujitsu, Qualcomm, Dell, Samsung, NEC, VMware

Followers: Mavenir, IBM (Red Hat), AMD (Xilinx), Rakuten (Altiostar), Airspan, Parallel Wireless, Supermicro

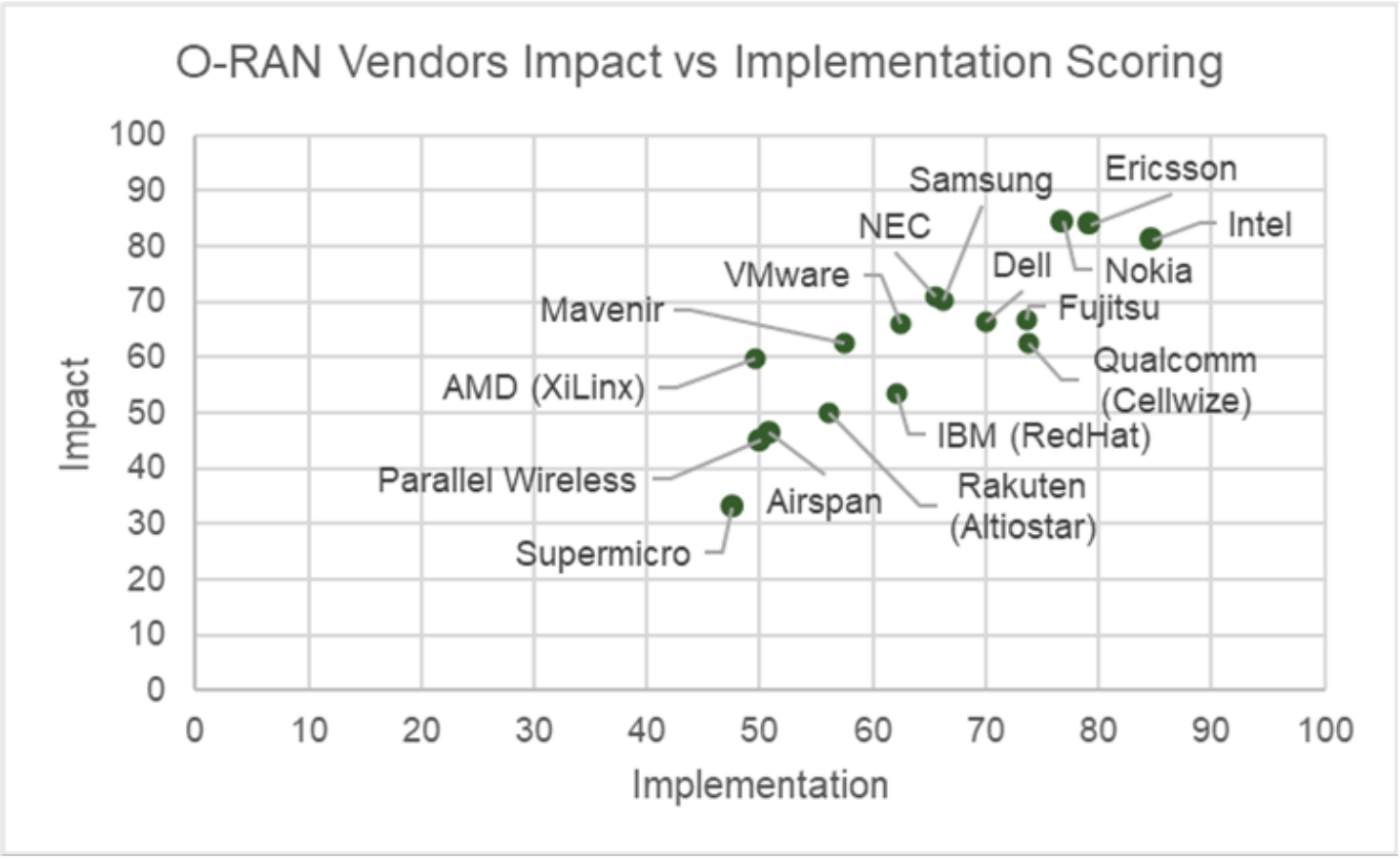


Table 5: Open RAN Vendor Ranking
(Source: ABI Research)

Company	Open RAN Overall Scores	Open RAN Ranking
Intel	83.02	1
Ericsson	81.63	2
Nokia	80.71	3
Fujitsu	70.29	4
Qualcomm	68.53	5
Dell	68.30	6
Samsung	68.22	7
NEC	68.22	8
VMware	64.32	10
Mavenir	60.13	9
IBM (Red Hat)	57.94	11
AMD (Xilinx)	54.97	12
Rakuten (Altiostar)	53.25	13
Airspan	48.67	14
Parallel Wireless	47.57	15
Supermicro	40.92	16

Impact Summary Open RAN

Nokia came in first place in the rankings for its Open RAN impact scores with its wide portfolio and contributions to patents and standards and high-performance RAN products, which secured it the top spot. Ericsson closely followed with its Open RAN portfolio and strong company-wide efforts in sustainability.

Third place in the Open RAN impact ranking went to Intel, offering its FlexRAN software that has been developed and refined for over 10 years, run on its Xeon scalable processors, which are widely deployed in the 5G RAN ecosystem due to a longstanding presence in the Open RAN space.

NEC came in fourth place, scoring highly for its product portfolio of 18 open RUs, and its neutrORAN platform, which has been adopted by the U.K. government to enable 5G capability in more rural settings. NEC was awarded the TIP Open RAN Requirements Compliant Ribbon for all its mMIMO products in 2021. Samsung's product portfolio also gained it a high impact score, with a longstanding connection to Open RAN (as a leading contributor to the xRAN Forum prior to Open RAN's conception in 2019), and multiple awards for its innovative vRAN solution that is being widely adopted by network operators worldwide.

Fujitsu's Open RAN solution landed it in fifth place in the impact ranking: it consists of a set of dual- and tri-band RUs (which have the TIP Requirements Compliance Ribbon), with antenna configuration from 4T4R up to a recent addition of a 64T64R mMIMO.

Dell is providing edge servers, Open RAN Accelerator cards, its Bare Metal Orchestrator (a software solution to manage server deployments), and an RIC for its open ecosystem contributions.

VMware's Open RAN solution consists of a vRAN (Virtualized Distributed Unit (vDU) and Virtualized Central Unit (vCU)), which supports a Non-Real-Time (non-RT) distributed RIC, and a near-Real-Time (near-RT) distributed RIC and cloud automation. The VMware RIC is based on Intel's FlexRAN architecture, enabling flexibility in programmability for the vRAN platform. Furthermore, VMware's commitments to carbon neutrality and 100% renewable energy usage by the end of 2020 were achieved 2 years ahead of target.

Mavenir has long established its place in the Open RAN market, as its cloud-native Open RIC automates and manages network resources, and has won multiple awards, including the "Best OpenRAN Technology" and "Best OpenRAN Solution" from 5G World in 2020 and 2021, and the "Best OpenRAN solution" and "Best Network Disaggregation Solution" from Layer123 in 2020 and 2022, respectively. Mavenir recently released some Open RAN-compliant hardware solutions, including macro and micro RRUs, and mMIMO and mmWave antennas, under its OpenBeam

brand, to advance its Open RAN offerings.

Qualcomm's impact scores were awarded for its Open vRAN built on specialized accelerator cards. Qualcomm's sustainable manufacturing practices and development of energy efficient products have gained it a strong score.

Xilinx, recently acquired by AMD, entered the Open RAN space with its cutting-edge radio and CU/DU system technologies, and earlier this year, also announced a prototype 64T64R mMIMO radio and the highest bandwidth Open RAN radio platform, offering 400 MHz Instantaneous Bandwidth (IBW), being one of the first chipsets to meet the next wave of 5G NR requirements, implementing Skyworks' high-efficiency PA. Xilinx's Open vRAN solution runs on its T1 Telco accelerator cards, using AMD's high-performance servers to deliver an open, cost- and power-efficient RAN solution.

Red Hat (a subsidiary of IBM) offers its OpenShift Container Platform that supports 5G SA networks, running on Intel's Xeon processors, enabling applications to be distributed as cloud-based solutions in a flexible manner. Its cloud computing platform OpenStack can also be leveraged to virtualize resources, such as RAN hardware, and manage them for remote accessibility and flexibility for users.

Rakuten Symphony is a collective of technology companies, with Rakuten Mobile at the head. Altiostar was acquired by the Rakuten Symphony group in 2021, and now delivers its Open vRAN solution as a part of Rakuten Symphony. The Altiostar Open vRAN solutions leverage a common set of hardware and software that enables a multitude of RAN hardware equipment to be deployed into the network easily. The vRAN supports a wide range of mMIMO antenna configurations, macro and micro cells, across multiple frequency bands. Since the acquisition, there is limited information on the sustainability impact of Altiostar, as it is no longer its own entity, though the sustainability initiatives for Rakuten Symphony are well documented. This was reflected in the impact scoring.

Airspan, Parallel Wireless, and Supermicro were awarded lower scores for impact due to limited available information on their sustainability initiatives.

Implementation Summary Open RAN

Intel's FlexRAN architecture is widely adopted by many other telco equipment vendors around the world

Intel was awarded the highest implementation score of all the Open RAN vendors. Intel's FlexRAN architecture is widely adopted by many other telco equipment vendors around the world. Intel

actively participates in the interoperability plugfest testing events, and it has many active partnerships in the Open RAN ecosystem. DT's O-RAN Town initiative—a fully autonomous, open 4G/5G network in Neubrandenberg, showcasing many vendors' Open RAN-capable network technologies in a real-world deployment—is built on Intel's FlexRAN architecture, supporting the Open RAN Cloud framework. This means that all vendors participating in this project are establishing close-knit partnerships to develop and enhance Open RAN technology, while demonstrating the flexibility and interoperability of their RAN equipment, with Intel's software underlying all operations.

In second place, Ericsson scored high for its numerous contributions to patents and standards in the Open RAN space and its significant market share. Its Open RAN portfolio is adopted around the world, and with many partnerships, Ericsson has contributed to the Open RAN market space, supplying 125 5G networks across 55 countries with its equipment.

Despite criticism from other vendors regarding its infrequent attendance at Open RAN plugfest interoperability testing events, Nokia has contributed greatly to generating standards and patents for Open RAN technology. Nokia is well established in the 5G RAN space and has many partners of all sizes in this industry to allow it to further develop and branch out into the Open RAN space. Its fully-integrated E2E solutions are deployed in networks in more than 100 countries, with long-term contracts in place to supply the network technology.

Qualcomm's presence spans many regions of the world, deploying its 5G Open RAN solutions that support mmWave and sub-6 GHz spectrum. Qualcomm recently demonstrated how its 5G Open RIC is suited for Industrial IoT (IIoT) applications at MWC 2022 in Barcelona, and it has recently partnered with Rakuten Mobile to deploy the first fully vRAN at scale in Japan.

Fujitsu has attended multiple plugfest events over the last few years to ensure the interoperability of its RUs. Its Open RAN equipment has been deployed in Asia, Europe, and North America, and Fujitsu actively participates in DT's O-RAN Town initiative with their RUs deployed across the network. Dell also participates in the DT's O-RAN Town, providing its server hardware to support the network. Dell currently has two servers and an accelerator card that are Open RAN compliant, and its solutions are deployed worldwide, covering Europe, Asia, and the Americas.

Well established and renowned for its quality networking solutions, Samsung's fully virtualized open E2E 5G RAN solution, including support for mMIMO radios, has been deployed across Asia, Europe, and the United States.

NEC provided DT's O-RAN Town with its 32T32R mMIMO RUs. NEC's Open RAN products are deployed in well-established networks in Japan, its originating country, and around the rest of the world. NEC has attended the majority of the plugfests over the last few years and been awarded

the TIP Requirements Compliance Ribbon for its mMIMO portfolio. The large-scale NeutrORAN project showcases NEC's Open RAN-compliant technologies for deployment in more rural settings, backed by the U.K. government.

VMware has also attended a few plugfest events over the last couple of years and deployed its solutions with top tier CSPs. Its partnerships span a wide range of companies due to its solutions spanning many applications, though it holds a close relationship with IBM. Its telco cloud platform can be deployed in public and private networks, or slices thereof, and a wide range of options for flexibility in network configuration. Red Hat (IBM subsidiary) has many partnerships in the Open RAN space: it has defined its OpenShift container platform and verifies vendors' compatibility for its Open RAN ecosystem to drive the adoption of Kubernetes (K8) cloud-based networking.

Mavenir provides cloud-native Open RAN software, and its OpenBeam hardware, across Europe, the United States, the Middle East, Asia, Australia, and Africa. Mavenir's software is used for the DUs and CUs in DT's O-RAN Town project, supporting all RUs, including mMIMO antennas. It has been very active in participating in interoperability testing and is building up a lot of partnerships in the Open RAN space. Being a smaller private company, Mavenir has the flexibility to choose how it presents its products to the market: it recently announced its flexible E2E solution, wherein it offers a choice of Open RAN components and service integration to be built together to suit the needs of the customer.

Altiostar's deployments cover Europe, Asia, the Middle East, and the Americas. Its main partnerships are those within the Rakuten Symphony group; however, it has collaborated with many other vendors within the Open RAN community. Airspan also has many partnerships and has deployed its E2E hardware and software solutions across Europe, the Middle East, Asia-Pacific, and the Americas.

Parallel Wireless demonstrated its Open RAN capabilities at MWC, deployed its ALL-G Open RAN solutions with many Tier One vendors across the globe, and has many partnerships with Open RAN vendors; however, it has not officially participated in any O-RAN plugfests.

Xilinx has attended a few plugfest events, and given demonstrations of Open Air Interface, its open source vRAN system. Leaning on AMD's extensive market coverage, it has many partnerships that allow it to develop and deploy its Open RAN solutions. Last in the implementation ranking was Supermicro, which has provided baseband server hardware in the DT O-RAN Town initiative and collaborated with Intel on multiple occasions. Its solutions are deployed across Europe, Asia, the United States, and Russia.

Concluding Remarks: Open RAN

Intel's FlexRAN architecture underlies many O-RAN networks its flexible Xeon processors allow other vendors to easily build the solution that best suits their needs

Intel was awarded the highest score overall for Open RAN platform. Its FlexRAN architecture underlies many O-RAN networks, and the flexibility of its Xeon processors allows other vendors to easily build the solution that best suits their needs. Its sustainability initiatives, particularly efforts in product energy efficiency and optimizing manufacturing processes, secured Intel the top spot.

Ericsson was second in the overall Open RAN ranking, with its innovative and interoperable antenna solutions taking a large market share, and its significant contributions to the standards and patents of Open RAN equipment. Nokia closely followed with its Open RAN portfolio. Both Ericsson and Nokia have collectively contributed to more than 1,000 specification standards patents for Open RAN.

Following the top three leaders of this ranking were Fujitsu, Qualcomm, Dell, Samsung, and NEC. While these companies provide vastly different portfolios of Open RAN products, their company-wide efforts, partnerships, and global deployments have earned them decent scores for their sustainability efforts in the Open RAN space.

Mavenir, VMware, Red Hat, Xilinx, and Altiostar were awarded similar scores for their sustainability efforts in the Open RAN space. Airspan, Parallel Wireless, and Supermicro achieved the lowest scores due to limited information regarding their sustainability initiatives for their Open RAN portfolios.

Finally, there are many vendors that are not covered in this report. These diverse vendors are coming together to collaborate on determining the best approaches in deploying open and interoperable network equipment. At present, there are several networks that have solutions deployed that are deemed interoperable, although the number of genuinely open networks is relatively small. Initiatives, such as DT's O-RAN town, and plugfest events showcase the latest advancements in Open RAN technology, and as more vendors join the O-RAN Alliance, then the development of technology integration can be advanced further and faster, with each new generation of radio technology.

4.4. ON-SITE RENEWABLE ENERGY SOLUTIONS (BASE STATION)

4.4.1. Technology Overview: On-Site Renewable Energy Solutions (Base Station)

According to the World Resources Institute, more than a billion people around the world lack electricity and many more have an inadequate power supply. For telco operators with networks in Africa, South America, South Asia, Southeast Asia, and Australia, power supply is not always stable, with major investments required for upgrading local power grids. Coastal and island locations can be disconnected from major power sources inland. Even in the United States, many locations, especially in the western United States and Alaska, are isolated from a reliable power supply, while the Federal Communications Commission (FCC) reports that 19 million Americans still lack access to fixed broadband at designated speeds. In rural areas, nearly one-fourth of the population lacks access to broadband services, opening a niche market for on-site renewable energy and self-powered cellular towers.

The Cost of Using Diesel Generators for Remote Cell Sites

Rising diesel prices and falling renewable energy equipment costs are also contributing to a greater use of on-site renewable energy. Historically, off-grid base stations have been primarily powered by generators running on diesel fuel. Diesel generators are low cost and they are a reliable source of power. However, using diesel fuel comes with price volatility, carbon emissions (one liter of diesel, which weighs approximately 840 Grams (g), produces carbon dioxide at 2.68 kg Carbon Dioxide Equivalent (CO_2e)), and it can be difficult to transport the fuel to certain remote locations. Often, the cost of transporting the fuel and maintenance team costs can exceed the cost of the fuel.

Moreover, the costs of operating diesel generators are typically tracked year-to-year, without adding up the cumulative costs of the fuel, transportation, and labor together. In contrast, on-site renewable energy equipment comes with an upfront cost; however, its operational costs over the lifetime of the equipment can be significantly cheaper than resupplying a remote station with diesel fuel, especially in a wind- or solar-rich region.

Return on Investment (ROI) for On-Site Renewable Energy Equipment

On-site renewable energy can provide an ROI over the lifetime of renewable energy equipment, such as installing PV panels at a cellular base station. Multiple operators have reported, on average, a break-even of installing renewable energy base station equipment between 4 and 10 years, while the lifetime of the equipment is 15 to 20 years. These ROI calculations depend on a number of variables, including the region of network operations, number of hours of sunlight and/or wind energy, upfront CAPEX of equipment, regionally-based tax credits on equipment, and other variables.

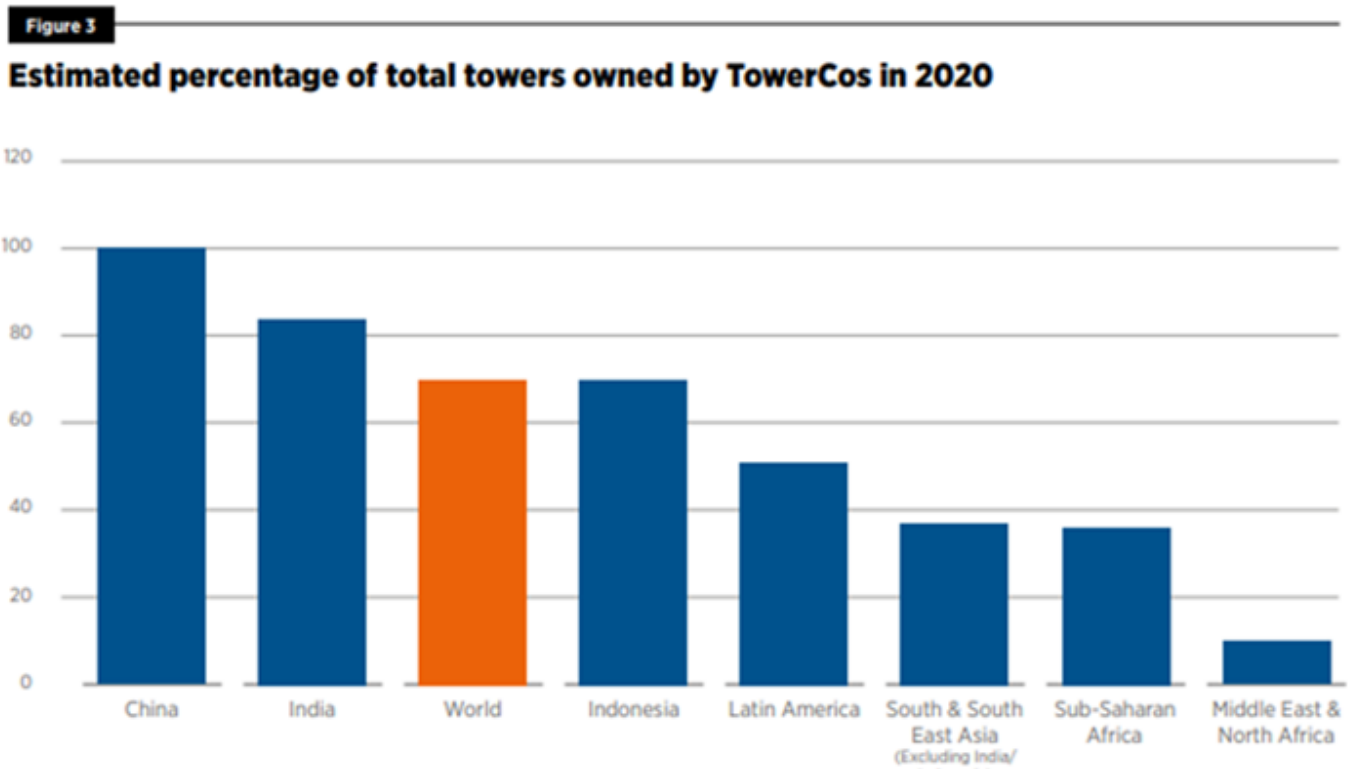
309,000 total towers are still running on diesel fuel, offering an opportunity to transition these locations to renewable energy

In 2021, the GSMA reported 5.21 million total towers globally, growing at 4% annually. Among these towers, 67,800 towers are powered by renewable energy, with 41,000 of those towers designated as off-grid and poor-grid towers. There are 350,000 off-grid and poor-grid towers, so 309,000 total towers are still running on diesel fuel, offering an opportunity to transition these locations to renewable energy. Per the GSMA, the diesel generators at the 309,000 off-grid and poor-grid sites generate 6.91 million metric tons of CO2e/year, or 3% of the industry's annual emissions.

The GSMA offers several reasons, potential barriers, and global trends for explaining why these towers and more have not been converted and scaled to renewable energy sites, including:

- The tower-sharing model has transformed over the years as MNOs, TowerCos, and Energy Service Companies (ESCO) all have different business models and incentives. For example, a TowerCo model is capital efficient, looking for a payback period of 3 to 4 years for capital investments versus an MNO that desires to reduce OPEX over the lifetime of a depreciating tower asset via renewable energy use.
- Energy contracts are non-standardized with a lack of price benchmarking.
- Improved access to national grids for electricity.
- Anchor-Business-Community (ABC) mini-grid models have not scaled.
- Lack of regulatory and power sector oversight for consistent renewable energy deployment.

Figure 4: Estimated Percentage of Total Towers Owned by TowerCos (2020)
(Source: GSMA)



Despite these potential setbacks for adopting on-site renewable energy, the GSMA concludes that over the last 6 years, the global telecoms industry has seen a 45% growth in the number of off-grid and poor-grid sites powered by renewable energy.

4.4.2. Impact Criteria

- Eco-Design: Light-weighting and size of PV equipment design, duration of product use, and repairability. A product with a flexible design, such as offering various options (solar, solar + diesel generator, solar + grid (diesel generator optional) will score higher. 30%
- Innovative Technologies to Reduce Overall Power Consumption: The capability of implementing energy-efficient and AI-enabled storage technologies to optimize efficiency and reduce the need for the back-up power supply. 20%
- Advanced Features that Enhance Overall Performance: The capability of implementing innovative solutions that enhance the performance of the renewable energy solution, such as handling complex and fast changing energy application scenarios, higher-capacity battery storage, etc. 20%
- Sustainable Operations in Manufacturing of Equipment: The level of integration of advanced Industry 4.0 technologies and programs for sustainable operations (IoT, AI/analytics, and automation for materials, water, and energy savings) in the production of renewable energy equipment. 10%

- Supply Chain Sustainability and Supplier Engagement: The weighting of sustainability in supplier RFPs, depth of supplier engagement, participation in supply chain coalitions (CDP Supply Chain program, etc.). 10%
- Overall Sustainability Strategy for the Vendor: This assessment includes company climate targets for carbon neutrality within the vendor's own operations and for reaching net zero across the value chain, use of renewable energy, green buildings credentials (LEED certification, Energy Star, etc.), green fleet vehicles (% of EVs, telematics), waste and circularity programming, incentives for climate targets (executives, employees), and sustainability reporting & governance. 10%

4.4.3. Implementation Criteria

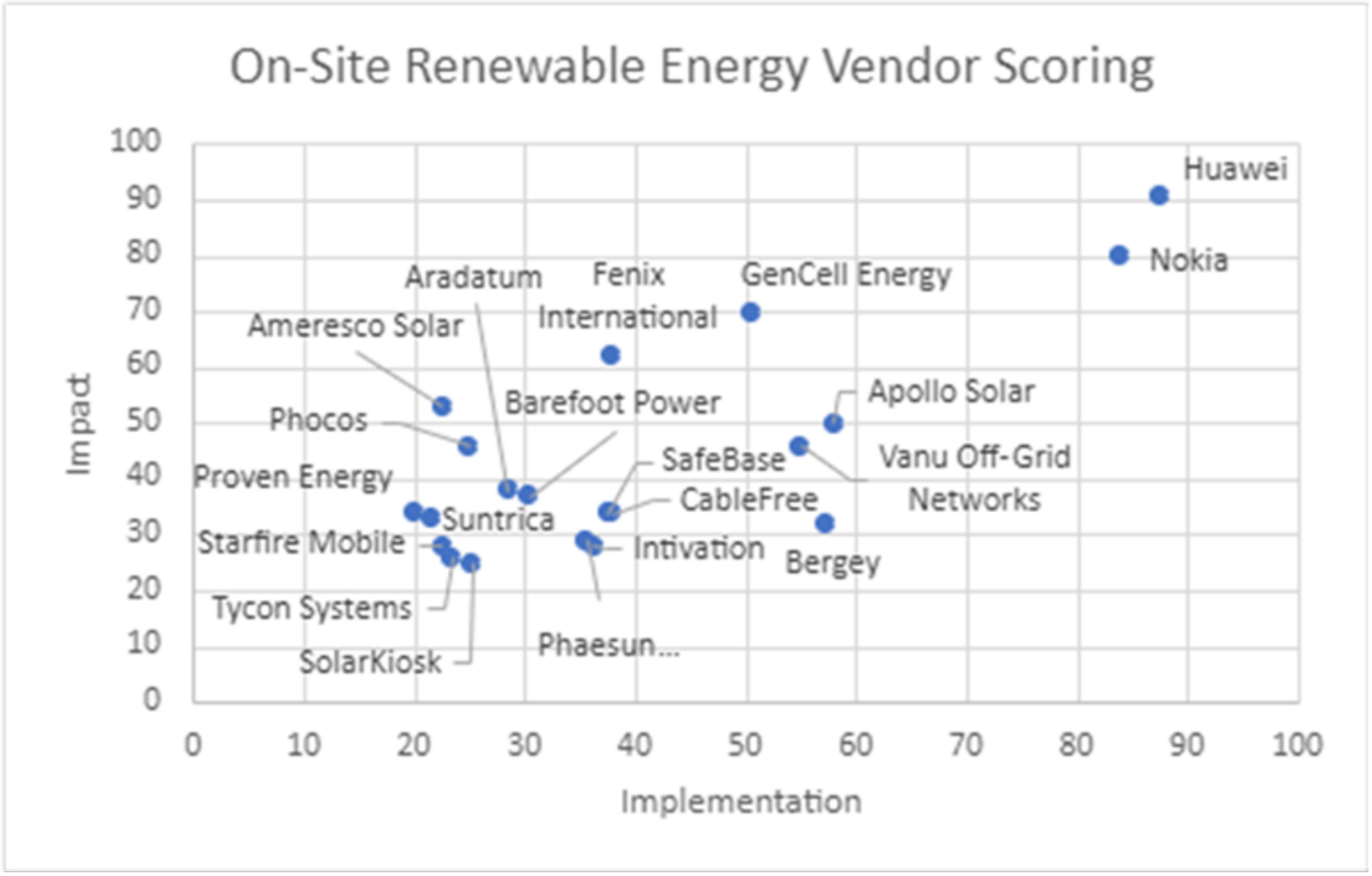
- Overall Sales Market Share: A comparison of the market share across the category of vendors, assessing total revenue and shipments. 40%
- Regional Geographical Penetration: The penetration of vendors across the different regions in terms of revenue. 20%
- Number of Networks with On-Site Renewable Solutions Deployed: Total number of MNOs that have adopted each vendor's renewable energy platforms and future contracts. 15%
- Features to Ease Cell Site Installation and Reduce Transportation Required for Field Operations: Supplying compact, lightweight equipment, specialized brackets and solutions for easy installation, and features that reduce overall number of site visits required for maintenance. 35%

4.4.4. Results

Leaders: Huawei, Nokia

Mainstream: GenCell Energy (Ammonia Fuel Cell Technology), Apollo Solar, Fenix International, Vanu Off-Grid Networks

Followers: Bergey, Ameresco Solar, Phocos, CableFree, SafeBase, Barefoot Power, Aradatum, Phaesun France SAS, Intivation, Proven Energy, Suntrica, Starfire Mobile, Solarkiosk, Tycon Systems


On-Site Renewable Energy Vendor Scoring
Impact
Implementation
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70
80
90
100
Huawei
Nokia
Aradatum
Fenix International
GenCell Energy
Ameresco Solar
Barefoot Power
Apollo Solar
Phocos
SafeBase
Vanu Off-Grid Networks
Proven Energy
CableFree
Suntrica
Starfire Mobile
Intivation
Bergey
Tycon Systems
Phaesun...
SolarKiosk

Table 6: Overall On-Site Renewable Energy Vendor Rankings
(Source: ABI Research)

Company	Score	Overall Ranking
Huawei	89.3	1
Nokia	82.0	2
GenCell Energy (Ammonia Fuel Cell Technology)	61.0	3
Apollo Solar	54.1	4
Fenix International	51.4	5
Vanu Off-Grid Networks	50.7	6
Bergey	46.4	7
Ameresco Solar	40.7	8
Phocos	37.0	9
CableFree	36.1	10
SafeBase	35.8	11
Barefoot Power	33.9	12
Aradatum	33.6	13
Phaesun France SAS	32.4	14
Intivation	32.4	15
Proven Energy	27.9	16
Suntrica	27.9	17
Starfire Mobile	25.4	18
Solarkiosk	25.1	19
Tycon Systems	24.8	20

Impact Summary On-Site Renewable Energy Solution

Huawei's Power Solution can increase power supply by 20% and minimize carbon emissions with a conversion efficiency of 98.5%

Huawei came in first place in sustainable impact, primarily due to its innovative design and vast portfolio of industry-leading intelligent technologies for on-site renewable energy solutions. Some of Huawei 's success can be showcased in its integrated design of the unified platform that is combined with AI hybrid power technology and intelligent power supply architecture, specifically the Huawei Power Solution, which can increase power supply by 20%, minimizing carbon emissions with a conversion efficiency of 98.5%.

Nokia came in second place overall, with its off-the-grid base station technology, enabling an increase in solar energy production for site operation. Nokia has also suggested that a single

solar panel at all cell sites (whether off-grid or not) could replace 5% to 10% of the total electricity consumed, and that effort could be further advanced with Nokia using digital collaboration platforms, workflow orchestration systems enabling power automation, data analytics, and digital twins to maximize efficiency and minimize waste.

Huawei and Nokia are followed by GenCell Energy (Ammonia Fuel Cell Technology), which placed third in overall scoring with its fuel cells technology that uses an inexpensive and easily accessible liquid fuel—ammonia—and provides emissions-free energy for use. GenCell Energy provides GenCell BOX, a long-duration backup power solution designed for telcos that is helping telcos address power backup challenges by disposing batteries, fumes, noise, CO2 emissions, the lengthy startup time of diesel generators, and the daylight limitations of solar PV energy systems. The solution is integrated with IoT remote monitoring software with standard telco energy management systems and promises up to 33% OPEX savings compared to diesel generators.

The top three are followed by Fenix International (intelligent electronics and a robust battery that can be charged from a variety of energy sources, including solar, micro-wind, and micro-hydro), Ameresco Solar (off-grid solar power project), Apollo Solar (hybrid solar/diesel generator battery based remote energy system), Vanu Off-Grid Networks (off the grid solar systems), and Phocos (portfolio includes batteries, C controller, and Power Point Tracking controllers, enabling oversized PV array by 50% to maximize power production). These vendors are developing more sustainable designs for delivering renewable energy by building rugged construction with frames that outperform lighter-weight models, and by using more durable materials, such as crystalline silicon cells, white polyester, and silver anodized aluminum materials, with rigorous testing and process control.

Some of the others in the impact section (that do not have the scale of the leaders) include:

Aradatum: This company has designed a next-generation, self-powered macro cell tower that can be placed anywhere for 5G coverage. The company did not emerge higher in the assessment because the products are still in the testing and development phase. The Aradatum tower itself is a wind turbine, topped by a solar array, and it can fill in current telco infrastructure gaps, extend broadband to rural communities, host private networks in remote or rural areas, provide connectivity for edge computing, and/or store excess on-site energy to provide charging for EVs without tapping the existing grid. The Aradatum product is very interesting and innovative, and the leadership of the company provided direct research for this report, highlighting that 45 million Americans lack access to high-speed connectivity, 75% of the United States has little or no broadband coverage, and 300,000 new cell tower infrastructure are needed for 5G. Aradatum is seeking to fill those gaps, as it further develops its towers and technology.

CableFree offers fully recyclable solar and battery power that is used for wireless base stations. SafeBase's SmartSite product provides remote monitoring of infrastructure, such as telco base stations, enabling real-time operational intelligence from geographically dispersed and renewable energy-driven sites. Suntrica offers various solar panel sizes for residential and commercial use cases. Bergey provides wind turbine systems and wind power for remote telco systems. Phaesun manufactures framed modules and semi-flexible solar modules with improved efficiency of 19.5%. Phaesun has documented use cases for PV off-grid solutions providing telco site power for Telma mobile operator in remote areas of Madagascar, and for hybrid systems using PV panels and diesel generators for MTN project sites in Nigeria. Starfire Mobile and Solarkiosk produce customized portable solar panels, solar chargers, and high-quality mono- and polycrystalline PV modules. Tycon Systems provides standalone power systems for remote areas or areas without access to grid electricity; however, its footprint with telco companies is small to negligible with applications in the telecoms industry only occurring through the use of integrators.

Implementation Summary On-Site Renewable Energy Solutions

Huawei emerged as an implementation leader due to its vast portfolio of on-site renewable energy solutions and extensive geographic coverage with more than 170 countries and regions, and more than 1,500 deployed networks. Nokia placed second with more than 390 base stations powered by renewable energy that are complemented by its native network management platform, NetAct, for network monitoring optimization for enabling energy management.

Apollo Solar had more than 391,600 deployed modules, each with 255 W nameplate capacity, which are monitored by a native platform with pre-built real-time analytics. The next is Bergey scoring 57.25 due to significant market share with over US$500 million in annual revenue, followed by Vanu Off-Grid Networks and its very strong presence in the African market with current expansion toward Côte d'Ivoire, Sudan, and Kenya. GenCell Energy has primary markets in Iceland, Kenya, Norway, and Israel, and more than 112 emergency communication sites across Iceland and 800 deployed telco base stations across Kenya.

The next group of vendors scored in the range between 30 and 38 due to a limited number of deployed projects or small geographic coverage. Felix International is serving pan-African energy markets with more than 350,000 households across three markets (Côte d'Ivoire, Uganda, and Zambia), while CableFree has an exclusively U.K. presence with a single partnership with U.K. operator Freshwave on 5G solutions. These companies are followed by SafeBase, which works with Telia on its base stations powered by solar and wind energy. The remaining vendors represent a small market share or can be classified as startups in either the prototype stage or the first couple of deployments, such as Aradatum.

Concluding Remarks

Overall, Huawei secured first place in implementation and impact for the on-site renewable energy solutions category due to its leading global market share and highly innovative solutions, which are merging renewable energy solutions with advanced AI and real-time analytics. Nokia placed second and is concentrating its efforts on combining expertise in energy saving and reducing power consumption via technology, such as AI-enabled sleep and shutdown modes.

GenCell Energy came in third place with its innovative use of liquid fuel—ammonia—that provides emission-free energy for almost 1,000 deployment sites for telcos. Apollo Solar (54.1), Felix International (51.4), and Vanu Off-Grid Network score 50.7, showing a strong sustainability strategy and integration of sustainability practices in both operations and supply chain relationships, as well as having a mid-sized geographic footprint for their deployed solutions.

The remaining vendors represented a small portion of the newly emerging market and are developing or deploying the prototypes. It is important to outline that while the vendors are compared to each other, the variety of players in the market is high, ranging from equipment manufacturers, wind turbine producers, solar panels manufacturers, installers, and services providers, all the way to platforms specializing in renewable energy monitoring and analytics.

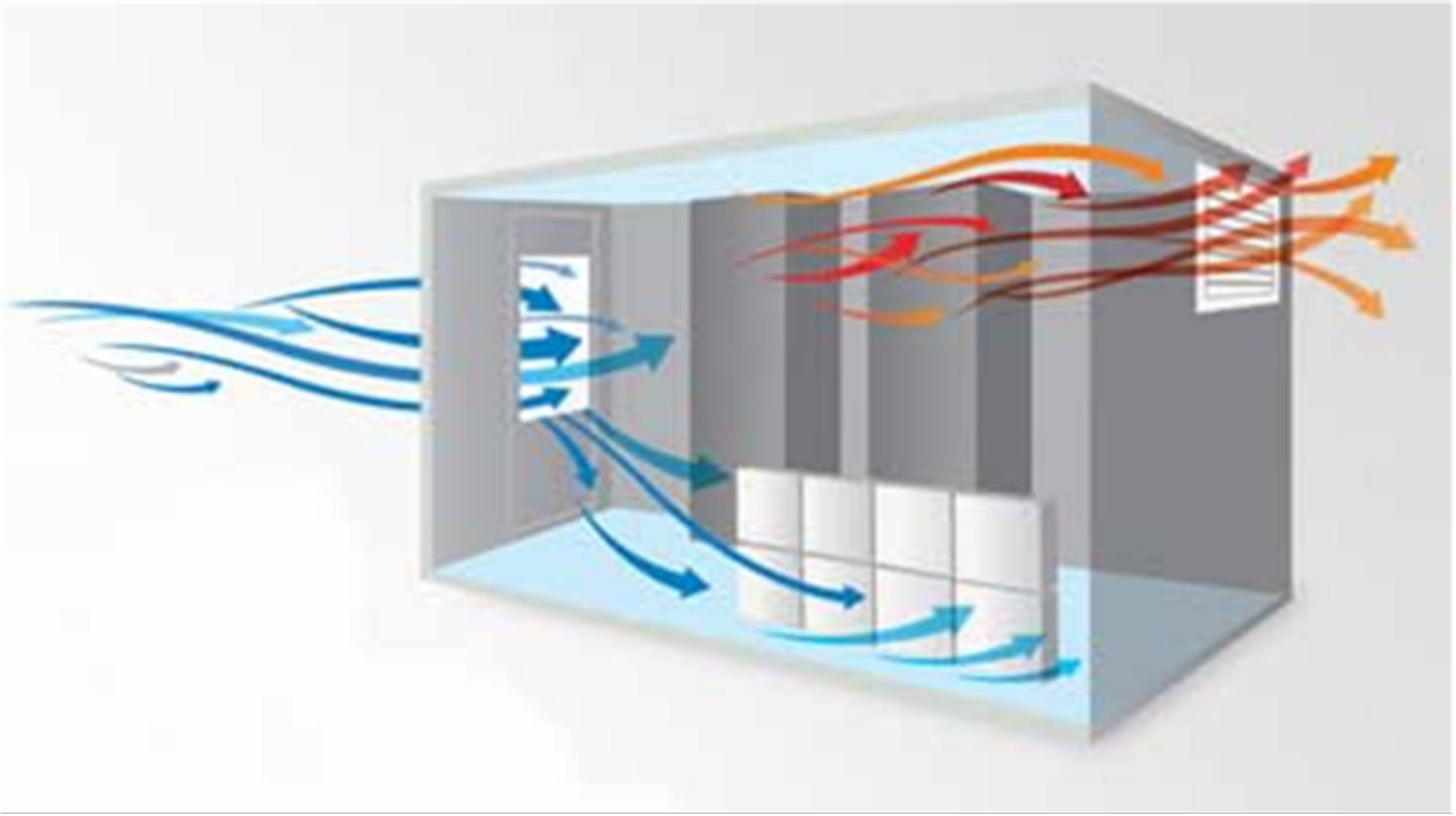
4.5. FREE COOLING SYSTEMS (BASE STATION)

4.5.1. Free Cooling Solutions

As 5G data traffic and power demands increase, cooling requirements will also increase. In certain regions, cooling requirements for telecommunications equipment can reach up to 40% or 50% of a base station's total energy requirements. Moving equipment outdoors into smaller cabinets and installing free air-cooling systems, or using ambient air to cool can help reduce a base station's overall energy consumption. Free air-cooling systems can operate as independent systems, drawing in ambient air from the outside, filtering the air, and then force-cooling equipment using high-performance fans. In warmer climates, free cooling systems can also be used in conjunction with an existing Air Conditioning (AC) system to reduce overall energy consumption.

According to vendors X-LOGIC and CommScope, free air-cooling systems can decrease base station energy costs by 80% to 90% compared to traditional AC. CommScope also estimates that the equipment can pay for itself in 3 years, without requiring annual maintenance (due to live, online remote monitoring and management).

Figure 5: Free Air-Cooling Solutions
(Source: CommScope)



4.5.2. 4.5.2. Impact Criteria

- Eco-Design: Light-weighting and size of equipment design, selection of sustainable materials and inputs, ease of disassembly and recyclability, duration of product use, design for remote monitoring, remote filter clog alarm. 30%
- Innovative Technologies to Reduce Overall Power Consumption: The ability to implement energy-efficient technologies in the production and operation of the free cooling equipment to reduce overall system power consumption and TCO. 20%
- Advanced Features that Enhance Overall Performance: The capability of implementing innovative solutions that improve cooling efficiencies, reduce OPEX, and support total heat management and remote monitoring. Depending on the location of the site, a free cooling unit can save between 60% and 90% of a compressor-based AC unit's spending on energy (with no refrigerant gases). 30%
- Sustainable Operations in Manufacturing of Equipment: The level of integration of advanced Industry 4.0 technologies and programs for sustainable operations (IoT, AI/analytics, and automation for materials, water, and energy savings) in the production of free cooling equipment. 10%
- Overall Sustainability Strategy for the Vendor: This assessment includes company climate targets for carbon neutrality within the vendor's own operations and for reaching net zero across the value chain, use of renewable energy, green buildings credentials (LEED

- certification, Energy Star, BREEAM, DGNB, etc.), green fleet vehicles (% of EVs, telematics), waste and circularity programming, incentives for climate targets (executives, employees), and sustainability reporting and governance. 10%

4.5.3. Implementation Criteria

- Overall Free Cooling Sales Market Share: A comparison of the market share across the category of vendors, assessing total revenue and shipments. 40%
- Free Cooling Regional Geographical Penetration: The penetration of vendors across the different regions in terms of revenue. 15%
- Number of Partners and Data Center Solutions Deployed: Total number of partners that have adopted free cooling solutions and future contracts. 20%
- Free Cooling Features to Ease Site Installation and Reduce Maintenance Required for Field Operations: Supplying compact, lightweight equipment for installation, design of parts for duration and minimal maintenance (e.g., filter replacement), and features that reduce overall number of site visits required for maintenance. 25%

4.5.4. Results

Leaders: CommScope, Dantherm Group

Mainstream: AIRSYS, Laird Thermal Systems, Baran Technology

Followers: VIKINORF, TECO, X-LOGIC

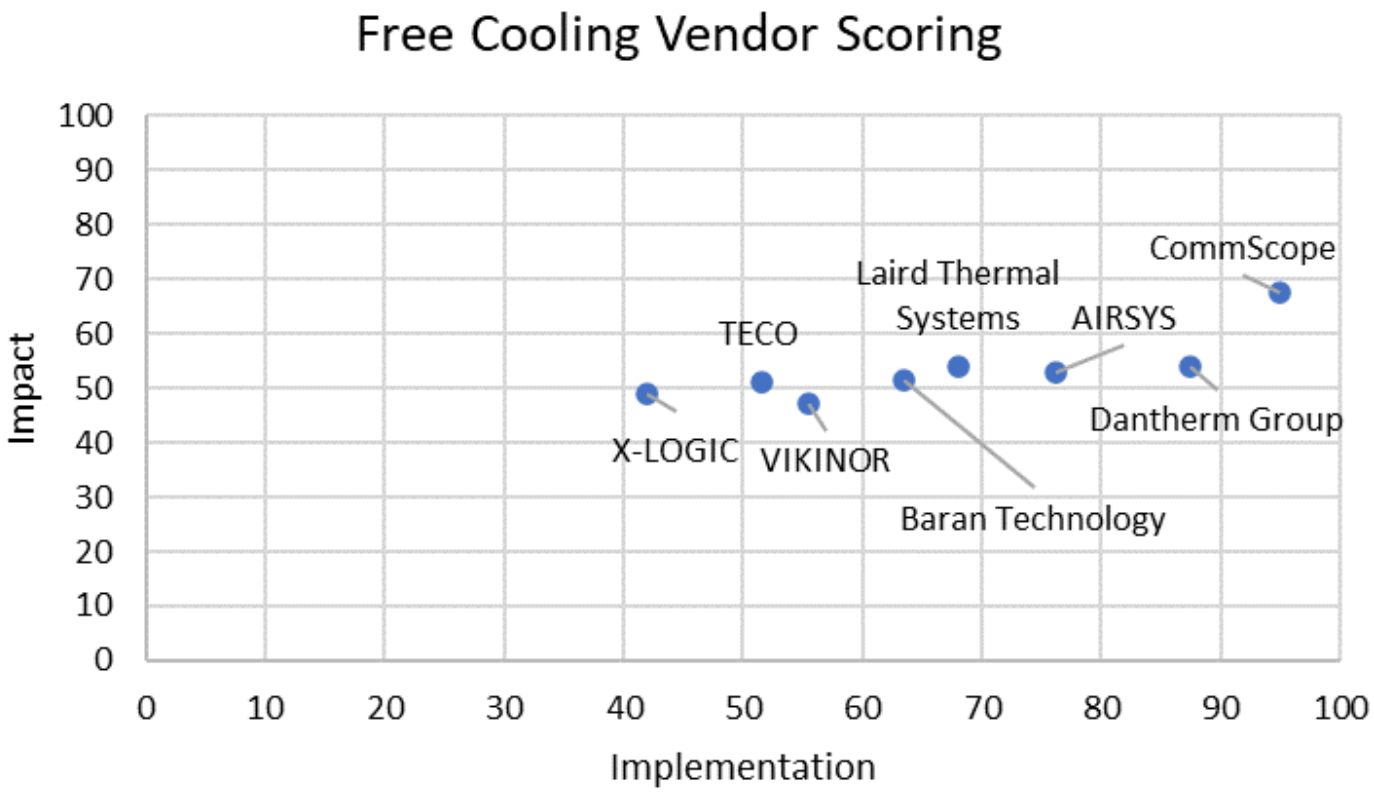


Table 7: Free Cooling Vendor Ranking
(Source: ABI Research)

Company	Free Cooling Overall Scores	Free Cooling Ranking
CommScope	82.4	1
Dantherm Group	72.7	2
AIRSYS	65.7	3
Laird Thermal Systems	61.4	4
Baran Technology	57.8	5
Vikinor	51.4	6
TECO	51.3	7
X-LOGIC	45.6	8

Impact Summary Free Cooling

CommScope reports that it decreases base station energy costs and carbon emissions by up to 90% compared to traditional AC

CommScope placed first in the impact ranking for free-cooling systems. The vendor offers a free cooling system with the ability to conduct door- or wall-mounted installations and monitoring systems for cutting CO2 emissions. The filters used for the system are 100% recycled polypropylene. CommScope reports that it decreases base station energy costs and carbon emissions by up to 90% in comparison to traditional AC. Laird Thermal Systems came in second place with its electronics and telco cooling solution, and much like CommScope, Laird Thermal Systems highlights its ability to lower energy consumption by up to 50% compared to conventional compressor-based systems. These companies were followed by Dantherm Group and AIRSYS, with Dantherm's Flexibox units providing energy and operating cost savings of up to 90% at telco sites. While Dantherm highlights its vigorous testing, the company lacks a clear sustainability agenda and eco-design implementation. AIRSYS provides energy savings of 30% to 90%, and the free cooling units deploy Electronically Commutated (EC) fans that adjust the air volume automatically with a temperature difference to lower the power consumption. These companies are followed by Raran Technology and TECO, which both offer a reduction of the total cost for temperature management up to 90%, but do not showcase any sustainability strategies, such as sustainable practices in their product design and supply chain management. The scoring is concluded with X-LOGICS and VIKINOR, with the former offering free cooling products with alarm systems and pre-installed sensors for temperature control, and the latter highlighting that production, verification, and all factory tests take place in its own facilities. Neither vendor provided information on its sustainable practices. Overall, using a free cooling system is a more sustainable option, where the key concept is using outside air for energy efficiency and long-term

energy reduction for data centers and base stations. The supplier ecosystem shows a moderate degree of green innovation and implementation of sustainability initiatives.

Implementation Summary Free Cooling

For the implementation criteria, CommScope emerged as a leader with a 95.0 score, with net sales of US$8.587 billion and global deployments of its free cooling solutions. Second place was awarded to Dantherm Group with revenue of US$256 million. Post-Merger and Acquisition (M&A) with Procuritas in 2016, Dantherm's sales increased by 30% annually, with product distribution in more than 50 countries worldwide. The next vendors were AIRSYS and Laird Thermal System, which scored 76.2 and 68.0 for implementation respectively. Both vendors show a strong presence and market penetration in Asia-Pacific. AIRSYS has partnered with Tier One telco companies, such as ZTE, China Mobile, Vodafone Turkey, Turk Telecom, Verizon, and BT. Laird Thermal Systems acknowledges strong sustainability actions, with a strategy to decrease its environmental footprint, stating effective processes for pollution prevention, waste minimization, material recycling, and responsible handling of waste. The next vendor, Baran Technology, is currently working with Telia Sonera, Vodafone, Turk Telecom, Turkcell, Avea, Azercell, Beeline, and Telenor, with market presence in the United Kingdom, Kenya, and Turkey. Implementation scoring concluded with VIKINOR, TECO, and X-LOGIC having much less geographic coverage and exclusive contracts with telco operators (e.g., TECO works specifically with Kyivstar JSC (VEON Holding)). In summary, companies receiving lower scores represented smaller, more geographically niche players, and they have yet to develop a stronger global market share.

Concluding Remarks

Overall, CommScope placed first with its free-cooling system that performs as an independent cooling system, or it can work with any existing AC system, enabling customers to reduce their overall energy consumption in the harshest environments. CommScope was followed by Dantherm Group and AIRSYS, which both promise up to 90% cost savings (on electricity OPEX) and work closely with the telco domain. Dantherm and AIRSYS have a strong market presence and even greater potential for development. Both vendors view sustainability as an integral part of their operations, and the AIRSYS FREECOOL intelligent ventilation system for telco base stations and small data centers touts a 30% to 90% energy savings. The next vendors were Laird Thermal Systems, Baran Technology, and VIKINOR, which provided free cooling technologies; however, they showed limited strategic planning for sustainability.

4.6. LIQUID COOLING—DATA CENTERS

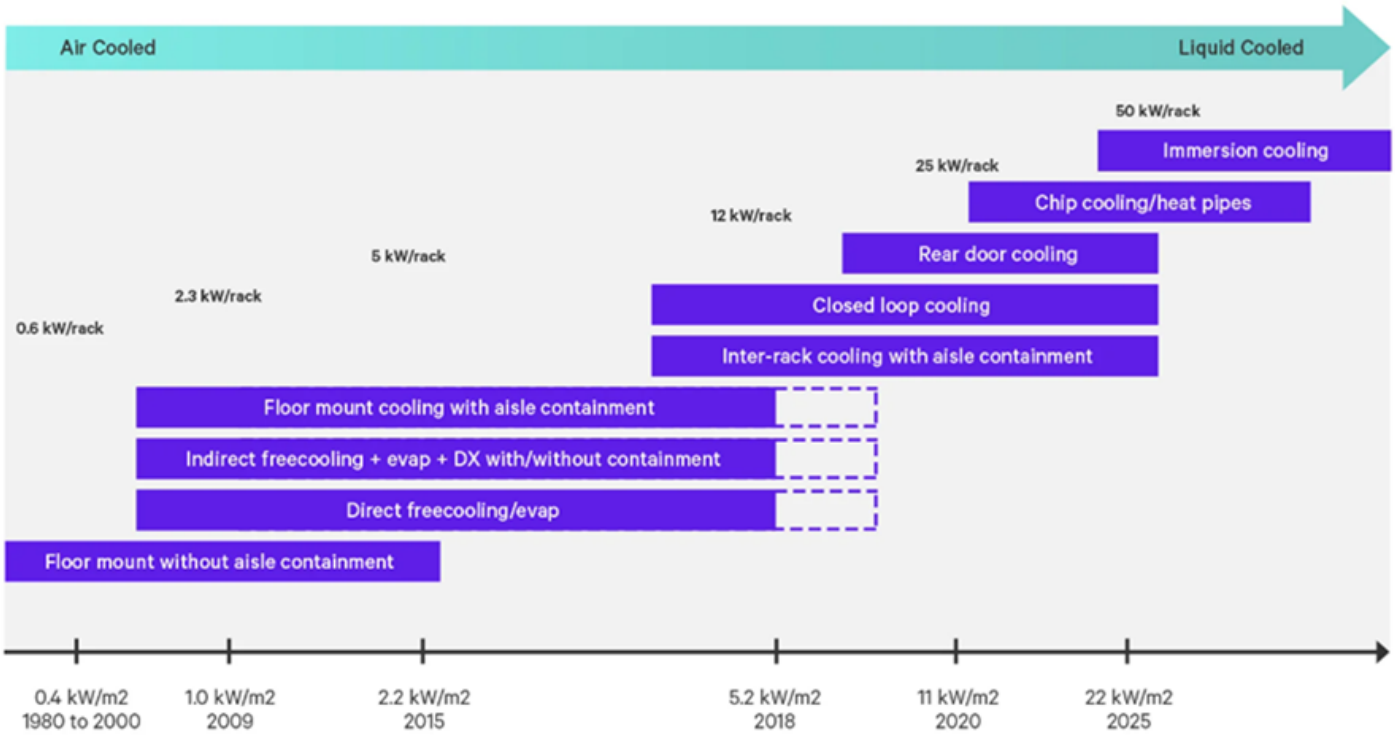
4.6.1. Technology Overview: Liquid Cooling—Data Centers

As companies adopt more intensive processing and computing functions, such as cloud-based services, using AI to drive advanced data analytics and automation, and enabling blockchain and other power-hungry applications, data centers will continue to evaluate liquid cooling options. According to Vertiv, data centers currently support rack power requirements of slightly more than 20 kW; however, the data center market is moving toward 50 kW or more. CPUs and GPUs that are being produced today have higher thermal density properties than previous generations of processing equipment. In addition, manufacturers of servers are packing more CPUs and GPUs into each rack to meet the demand of these AI and high-performance computing applications. Air cooling systems simply cannot keep up with increasing rack densification in an energy-efficient and sustainable way.

As a result of increasing rack and chip densities, companies are investing in liquid cooling solutions. Liquid cooling uses the higher thermal transfer properties of water and other fluids for a more efficient cooling of high-density racks; these fluids can be up to 3,000X more effective than air cooling. Further development of liquid cooling technologies has allowed data centers to further adopt liquid cooling beyond use for mainframes, supercomputers, and gaming applications. Liquid-based cooling solutions are generally divided into three areas: direct-to-chip cooling, rear-door heat exchangers, and immersion cooling.

- Rear-Door Heat Exchangers: This cooling method attaches heat exchangers mounted to the back of the rack in place of a back door. Server fans blow warm air from the components through a closed-loop system and the heat exchangers dissipate the heat. The rear-door cooling approach typically runs a coolant through the contained system to lower the temperature of the exchanging plates.
- Direct-to-Chip Cooling: This cooling method is sometimes called direct-to-plate cooling, and it integrates liquid cooling directly into the computer's chassis. Cool liquid is funneled to cooling plates that sit directly next to CPUs, GPUs, and memory cards. These technologies remove about 70% to 75% of the heat generated by equipment in the rack, leaving 25% to 30% that may have to be cooled by air-cooling systems.
- Immersion Cooling: This is an emerging technology in which all components of a server are submerged into a non-conductive dielectric fluid. The server components and the fluid are sealed in a leak-tight container. The heat from the electronic components is transferred directly to the coolant, requiring far less energy consumption than other approaches. Immersion cooling is the most energy-efficient form of liquid cooling on the market.

Figure 6: Air-Cooled versus Liquid-Cooled Technologies
(Source: Vertiv)



As an example of the benefits that liquid cooling technologies can offer, Submer highlights the following advantages for immersion cooling in new and existing infrastructure:

- Achieves a Power Usage Effectiveness (PUE) of < 1.03
- Saves 25% to 40% on TCO
- Provides up to 100 kW of compute density
- Increases hardware lifespan by +30%
- Decreases hardware failure rate by -60%
- Saves 50% on CAPEX building costs
- Saves 95% on cooling OPEX
- Offers zero waste of water
- Enables reuse of heat

Challenges with Liquid Cooling

Liquid cooling is more cost effective in meeting increased chip and rack densities and power requirements, as more companies demand greener cooling solutions

Despite many advantages, especially for high-performance computing applications, liquid cooling technologies can have the potential for higher CAPEX. The risk of leakage is also a concern for data center operators, especially with any direct-to-chip cooling solutions, as leakage could significantly damage hardware. Adopting liquid cooling technologies may also require IT personnel and data center operators to acquire new skills, or depend on a vendor for ongoing maintenance, until in-house employees are comfortable with liquid cooling equipment. Nevertheless, as chip and rack densities and power requirements continue to increase, and as more companies demand greener cooling solutions for high-performance computing equipment (rather than using compressor and refrigerant based air conditioning), it will be more cost effective to use liquid cooling versus air cooling.

4.6.2. Impact Criteria

- Eco-Design: Light-weighting and size of equipment design, selection of sustainable materials and inputs, ease of disassembly and recyclability balanced with reductions of risk of leakage in the equipment, duration of product use, design for reuse of waste hot water for electricity or remote heating. 30%
- Innovative Technologies to Reduce Overall Power Consumption: The capability of implementing energy-efficient technologies in the production and operation of the liquid cooling products to reduce overall system power consumption and TCO. 30%
- Advanced Features that Enhance Overall Performance: The capability of implementing innovative solutions in software and hardware that improves cooling efficiencies in dense computing settings, such as applications supporting edge computing, IoT, and automation, 20%
- Sustainable Operations in Manufacturing of Equipment: The level of integration of advanced Industry 4.0 technologies and programs for sustainable operations (IoT, AI/analytics, and automation for materials, water, and energy savings) in the production of liquid cooling equipment. 10%
- Overall Sustainability Strategy for the Vendor: This assessment includes company climate targets for carbon neutrality within the vendor's own operations and for reaching net zero across the value chain, use of renewable energy, green buildings credentials (LEED certification, Energy Star, BREEAM, DGNB, etc.), green fleet vehicles (% of EVs, telematics), waste and circularity programming, incentives for climate targets (executives, employees), and sustainability reporting and governance. 10%

4.6.3. Implementation Criteria

- Overall Liquid Cooling Sales Market Share: A comparison of the market share across the category of vendors, assessing total revenue and shipments. 40%
- Liquid Cooling Regional Geographical Penetration: The penetration of vendors across the different regions in terms of revenue. 15%

- Number of Partners and Data Center Solutions Deployed: Total number of partners that have adopted liquid cooling solutions and future contracts. 20%
- Liquid Cooling Features to Ease Data Center Installation and Reduce Maintenance Required for Field Operations: Supplying compact, lightweight equipment for installation, design of parts for duration and minimal maintenance (e.g., replacing parts that must be lifted from dielectric liquid is no small task), and features that reduce overall number of site visits required for maintenance. 25%

4.6.4. Results

Leaders: Schneider Electric, Submer Technologies, Mitsubishi, IBM Corporation, Vertiv, 3M

Mainstream: Iceotope Technologies Limited, Green Revolution Cooling (GRC) Inc., DCX The Liquid Cooling Company, Aecorsis BV, Rittal GmbH & Co KG, Chilldyne Inc.

Followers: LiquidCool Solutions, Inc., Asetek A/S, Bitfury Group Limited, Midas Immersion Cooling, Alfa Laval AB, Black Box Corporation

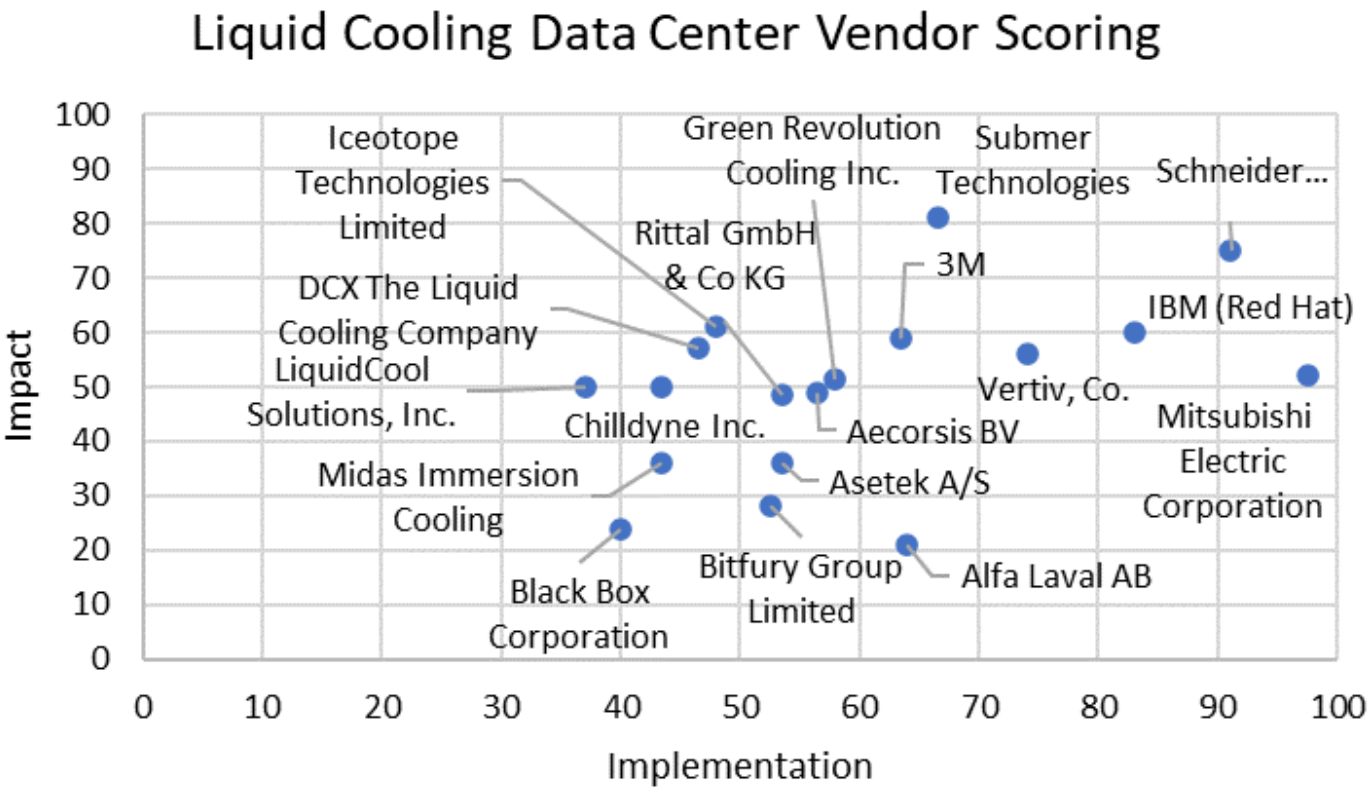


Table 8: Liquid Cooling—Data Centers Overall Vendor Ranking
(Source: ABI Research)

Company	Overall Rank	Overall Scores
Schneider Electric SE	1	83.4
Mitsubishi Electric Corporation	2	78.1
Submer Technologies	3	74.1
IBM (Red Hat)	4	72.4
Vertiv, Co.	5	65.6
3M	6	61.3
Iceotope Technologies Limited	7	54.9
Green Revolution Cooling (GRC), Inc.	8	54.8
Aecorsis BV	9	52.9
DCX The Liquid Cooling Company	10	52.0
Rittal GmbH & Co KG	11	51.1
Alfa Laval AB	12	48.5
Chilldyne Inc.	13	46.9
Asetek A/S	14	47.6
LiquidCool Solutions, Inc.	15	44.0
Bitfury Group Limited	16	42.1
Midas Immersion Cooling	17	39.9
Black Box Corporation	18	33.0

Impact Summary Liquid Cooling—Data Centers

The overall leader for sustainable impact was Submer Technologies. Its design and use of a proprietary dielectric coolant is specifically made to optimize immersion cooling, the most energy-efficient option for liquid cooling. Submer's SmartPod immersion technology allows up to 100 kW of heat dissipation, while its MicroPod product is an edge-ready data center-in-a-box solution built for edge cooling up to 7 kW of heat dissipation. In June 2021, Submer announced a partnership with ASA Computers to provide high-density server solutions for immersion cooling. Schneider Electric also led in impact scoring with a strong portfolio of liquid cooling offerings. Schneider Electric with Avnet and Iceotope created "the industry's first rack with integrated liquid cooling" offering with chassis-based immersive cooling for high-performance computing applications. Schneider Electric's EcoStruxure Modular Data Center offers liquid cooling for edge applications. Iceotope finished in third place for impact with immersion cooling offerings from the cloud to the edge, including a zero-touch, highly-efficient micro data center solution for deploying and supporting real-time edge applications in extreme locations. 3M and IBM also scored highly for impact. 3M's immersion cooling technologies are highlighted by 3M's specialty fluids for liquid cooling needs, highlighting that 3M Fluorinert Electronic Liquids have been an

industry standard for direct-contact electronics cooling for over 60 years. 3M Novec Engineered Fluids are non-oil-based, non-flammable, non-corrosive, low in toxicity, and have good material compatibility and thermal stability. These fluids are a sustainable option for data center operators' two-phase immersion cooling and direct-to-chip cooling solutions. Moreover, the IBM NeXtScale System has been enhanced with Water Cool Technology that allows greater heat dissipation, extracting more than 85% heat from a data center module or system. DCX and Vertiv finished as the last of the leaders for their more extensive portfolios of liquid cooling offerings, including next-generation direct-to-chip cooling, and an immersion-based edge data center for DCX and a multitude of Verdiv products and solutions for telco edge applications and 5G applications.

Green Revolution Cooling, LiquidCool, Mitsubishi, Rittal GmbH & Co KG, Aecorsis BV, Chilldyne, and Midas rounded out the mainstream group. Green Revolution Cooling, based in Austin, Texas, reports that it has had sustainability as a focus since day one of its founding, and its new Series 10 system has emerged as its greenest yet, cutting cooling power up to 90%, reducing or eliminating water use, and lowering CO2 emissions by up to 21%. LiquidCool Solutions from Rochester, Minnesota, offers liquid immersion cooling from cloud to mobile edge. LiquidCool's LCS Rugged Mobile liquid cooled system offers high-performance mobile computing anywhere. Mitsubishi Electric touts over 50 years' experience in the telecommunications field where systems must operate 24/7, and a good share of its products are offered for telco mechanical and free cooling. Rittal carries a more limited product portfolio of liquid cooling solutions, while Chilldyne reports that its Cool-Flo system is a patented, direct-to-chip cooling solution that is highly reliable and cost effective.

Asetek A/S, Bitfury Group, Alfa Laval AB, and Black Box lagged behind the leaders and mainstream competitors in the group, due to their less robust product offerings and niche market approaches. For example, Asetek A/S is a Danish liquid cooling solutions company that has a desktop market segment and data center segment; however, it heavily markets to PC enthusiasts and gamers, with a line of products introduced in 2021 for next-level SimSports gaming experiences. The Bitfury Group has partnered with immersion cooling company LiquidStack to build out high-performance computing centers, while Alfa Laval works with many industries to save energy and build carbon-aware heat exchangers. However, Alfa Laval's data center liquid cooling solutions are not its primary portfolio of products. Finally, Black Box offers heat-transfer doors that use passive liquid cooling to neutralize heat at the source; however, its overall liquid cooling offerings lag behind other competitors.

Implementation Summary Liquid Cooling—Data Centers

For the implementation criteria, market leaders were Mitsubishi Electric Corporation (Mitsubishi Group), followed by Schneider Electric SE and IBM. All the leading vendors have wide geographic

coverage, with Mitsubishi Group having a competitive edge with its market presence in Europe, Middle East, and Africa (EMEA) and Asia-Pacific, with the largest share of revenue in the liquid cooling market. Vertiv, Co. is also a leader in the market with revenue of US$4 billion and global expertise. Other companies that were strong in implementation were Submer Technologies, Alfa Laval AB, and 3M, all with a strong presence in Europe and North America. Submer Technologies is a smaller player versus some of the other conglomerates, but it offers an edge-ready, plug-and-play, data center-in-a-box solution, and the simplified installation and reduced maintenance required has attracted a high caliber of clients. For example, Submer Technologies partnered with Telefónica to deploy a sustainable immersion cooling solution at the Bellas Vistas central office.

The next group of vendors includes Green Revolution Cooling (GRC), which has an extended partnership network, including OEMs and solutions providers, such as IBM, SE, Dell, Vertiv, Intel, NVIDIA, AMD, Amax, Penguin Computing, Lenovo, etc. Aecorsis BV has partnered with Siemens, NVIDIA, Dell, Penguin Computing, Shell, and others, while Asetek A/S has partnered with top tier companies, such as Fujitsu, GIGABYTE, and Hewlett Packard Enterprise (HPE). The Bitfury Group is headquartered in Amsterdam with a global presence. However, its primary clientele is in crypto-mining operations, and the vendor has not shown a large presence in the telecoms market. The competitive ranking concludes with Iceotope Technologies Limited, DCX the Liquid Cooling Company, and Midas Immersion Cooling. Among them, DCX has the largest client coverage (Poland, the United Kingdom), whereas the other vendors are present in single markets, such as the United Kingdom and the United States. Chilldyne Inc., Black Box Solutions, and LiquidCool Solutions, Inc currently do not report telco partnerships, but they have presence in the liquid cooling market overall.

Concluding Remarks

Most of the leading companies in this assessment adopted one or more eco-design principles, substantially reducing the cooling equipment's energy use, compared to traditional air cooling

Increasing rack and chip densities have led companies to invest in liquid cooling solutions. For sustainable impact, most of the leading companies in this assessment adopted one or more eco-design principles and substantially reduced the cooling equipment's energy use, compared to traditional air cooling. Schneider Electric SE, Submer Technologies, and Mitsubishi Electric Corporation (Mitsubishi Group) took the top three positions in the ranking. Schneider Electric and Mitsubishi Electric have a long-standing, sustainable presence in the market, with domain expertise and top-tier clients. Submer is a clear innovation leader and a company with highly inventive and proactive environmental practices, which the vendor is implementing not only in technology development, but also in its company-wide practices and supply chain management.

Much like the free-cooling market, the liquid cooling market is a growing space for the telco industry. As data traffic and computing requirements continue to increase, the need to cool the processors and chipsets in data center equipment will also increase.

Honorable Mention for Liquid Cooling Solutions—Base Station: In addition to data center use, companies like Nokia are also investing in liquid cooling solutions (with sustainability as a driving force) to reduce the overall energy required to cool a base station. However, there were not enough base station liquid cooling solutions to compare with Nokia's offering. Results from Nokia testing across several networks have shown that with its base station liquid cooling product, energy consumption from base station cooling systems can be reduced up to 90%, with base station carbon emissions reduced by up to 80% compared to traditional air-cooling systems. In 2020, Nokia and Elisa launched a test and evaluation of the first 5G liquid cooling deployment and found that Elisa was able to reduce its cell site energy expenses by 30%. This result highlights that many sustainable technologies must pass the TCO test before companies are willing to invest. Thus, telco equipment suppliers offering sustainable products and solutions that cost more than competing equipment options must come prepared with total lifetime cost estimates. In March 2022, AT&T announced a live customer trial of Nokia's liquid-cooled product in Philadelphia, Pennsylvania. Nokia's liquid-cooled baseband solution is now commercially available as part of the Nokia AirScale product portfolio.

4.7. AI-DRIVEN NETWORK SOFTWARE

4.7.1. Technology Overview: AI-Driven Network Software

Increasing data traffic, as well as the advancement of technologies and applications from wireless networks, such as 5G and the IoT, have created networks where the use of AI-enabled software has evolved from a "nice to have" to a "must have" for MNOs. With a growing number of devices in the network and geographic expansion of the network, telcos are also increasing their operational requirements, such as customer care and billing processing, which are becoming more complex. There is a need for innovative solutions that automate business processes and optimize the energy monitoring and management of networks. The ability to automate network anomaly detection in data traffic or fraud prevention has also become vital for the industry. In all, AI-driven network software is gaining traction with telcos for network optimization, energy management and monitoring, anomaly detection, predictive maintenance, 5G deployment, and customer support.

For sustainable impact, AI-driven software can be used for 5G rollout and deployment, anomaly detection, predictive maintenance, and energy monitoring and management across a network. Nokia estimates that 78% of operators use an AI-driven network solution to reduce overall energy consumption. Ericsson reports that AI-enabled software can reduce energy-related OPEX

by roughly 15%, reduce site visits to base station passive equipment by 15%, and reduce energy-related outages by 30%. Intel, which is focused on providing high-performance hardware and optimized software, believes that AI can help reduce the power consumed by up to 35%.

Besides reduced CO2 emissions, AI-driven software delivers extra operational benefits, such as automation, resource availability, and scalability, which are becoming more accepted in cloud computing and data centers. Further, when there is synergy between energy efficiency (reducing OPEX) and sustainability with the AI software, operators are typically more inclined to invest in innovative AI/analytics products.

4.7.2. Impact Criteria

- Eco-Design, R&D, and Testing: There is a balance of network reliability/performance and energy savings in the design and development of AI-enabled software, especially those with PSFs. Companies that are aggressively pursuing R&D, site-level testing with CSPs, and advanced solutions for network energy management systems and smart sleep and shutdown modes will score higher. 30%
- Innovative Technologies to Reduce Overall Power Consumption: The capability of implementing energy-efficient technologies and energy savings features to reduce overall system power consumption. 30%
- Advanced Features that Enhance Overall Performance: The capability of implementing innovative solutions remotely that enhance the overall performance of network, such as anomaly detection, high traffic load prediction, network optimization, etc. These features can remotely identify site-level issues without site visits. 20%
- Sustainable Operations in Development: The level of integration of sustainability in the production and development of AI-driven network hardware and software. 10%
- Overall Sustainability Strategy for the Vendor: This assessment includes company climate targets for carbon neutrality within the vendor's own operations and for reaching net zero across the value chain, use of renewable energy, green buildings credentials (LEED certification, Energy Star, BREEAM, DGNB, etc.), green fleet vehicles (% of EVs, telematics), waste and circularity programming, incentives for climate targets (executives, employees), and sustainability reporting and governance. 10%

4.7.3. Implementation Criteria

- AI-Driven Network Software Market Share: A comparison of the market share across the category of vendors, assessing total revenue and shipments for AI-enabled solutions. The greater the market share, the greater the potential for the vendor helping to reduce energy use and CO2 emissions. 40%
- Regional Geographical Penetration: The penetration of vendors across the different regions in terms of revenue. Expanding AI-driven solutions across various regions globally will likely enhance the focus on other energy-reducing programs and sustainability efforts in the region. 20%

- Number of Networks with AI-Driven Solutions Deployed: Total number of MNOs that have adopted each vendor's platforms and future contracts. 15%
- Wide Range of Product Portfolio: The product portfolio of the vendor, including different options for implementing an E2E energy management system, automation of software for network optimization, and/or PSFs. The more offerings and greater the optionality of AI-enabled solutions, the higher the score. 25%

4.7.4. Results

Leaders: Ericsson, Nokia, Huawei

Mainstream: ZTE, Intel, Cisco (Sedona Systems)

Followers: Samsung, Qualcomm (Cellwize), RantCell

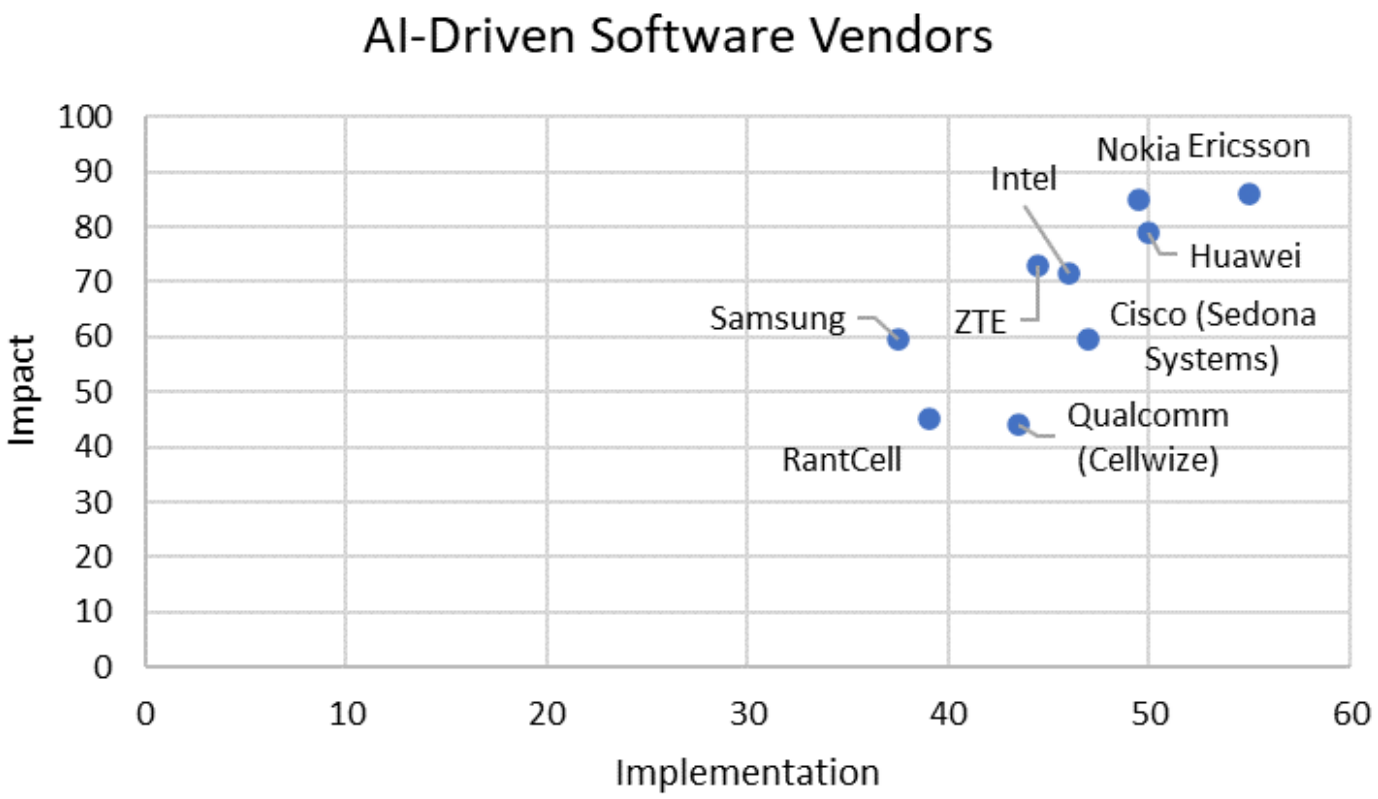


Table 9: AI-Driven Network Software Vendor Ranking
(Source: ABI Research)

Company	Overall AI Software Rank	Overall AI-Software Scores
Ericsson	1	72.2
Nokia	2	69.6
Huawei	3	66.1
ZTE	4	60.5
Intel	5	60.1
Cisco (Sedona Systems)	6	53.6
Samsung	7	49.7
Qualcomm (Cellwize)	8	43.8
RantCell	9	42.1

Impact Summary AI-Driven Network Software

Ericsson came first in sustainable impact for the AI-driven network optimization software with its Intelligent Automation Platform, designed to support AI and ML in all dimensions in a singular user-friendly platform. Ericsson offers a variety of intelligent functionality, such as digital twinning, network lifecycle management, and cognitive intent-based management. Ericsson notes that in testing, the Performance Optimizers automatically resolved 89% of internal uplink interference cases. This resulted in a 7% improvement in uplink capacity, along with significant gains in speed and traffic volume. Nokia came in second place with its AVA platform, where AI models and ML predict network traffic and automatically adjust the shutdown times, allowing increased savings in comparison to a fixed schedule without losing network performance quality, with 20% OPEX savings for energy, 20% reduced energy consumption, and 85% accuracy with cell site degradation prediction. Additionally, Nokia proactively implements ML and permanently adjusts predictions based on the latest load and network performance feedback. Nokia was followed by Huawei's intelligent solutions, where Huawei's AI energy-saving platforms allow up to 25% reduction of network energy consumption, implementing energy-saving features that can be optimized with refined KPIs.

Huawei was followed by ZTE and Intel, with ZTE's AI-based power-saving solution that can reduce the power consumption of a base station by 15% to 20%. Such network optimization enables ZTE to declare a substantial reduction of 1.5 million kWh to 2 million kWh a year across 1,000 sites, equaling up to 1,500 metric tons of carbon emissions. Intel is focused on providing high-performance hardware and optimized software. Specifically, Intel has its Network Builders ecosystem with various AI-driven network optimization solutions that, for example, predict Virtualized Network Functions (VNF) traffic levels and dynamically adjust the frequencies of processor cores. Intel reports that power consumed by the system is reduced by 14% on average,

and up to 35%, over 24 hours, with the AI solutions.

Samsung and Cisco have similar impact scoring for AI-driven network optimization products. Cisco's ML compares network data against baseline information to identify potential network issues. Samsung has an intelligent product that features control of the power usage of an RF transmit module, which means that the module can be turned on/off, enabling an energy-saving source for 5G networks. Some of Samsung's network products that support multi-carrier capabilities can also temporarily switch off certain transmission frequencies for different carriers when the traffic is low or non-existent to reduce power consumption. Despite not having the most extensive portfolio of AI solutions for the network, both Cisco and Samsung are committed to being more sustainable in their supply chains and with hardware features. Samsung Semiconductor has sustainability implemented in every stage of the manufacturing process. With sustainability practices in mind, Cisco develops many of its products, such as its network and data center infrastructure tools, IoT, security, hybrid work, and automation tools.

The ranking concludes with RantCell and Cellwize (acquired by Qualcomm Technologies in June 2022). Cellwize CHIME can leverage intelligent automation and Open RAN Service Management and Orchestration (SMO) capabilities. It deploys AI/ML for enriching vendor-specific data; however, no specific information on the energy-saving application is published by the vendor. Whereas RantCell offers RAN automation platforms with enhancements like AI and ML as a self-service, where MNOs can expand platform base capabilities with testing tools and automation of workloads.

Implementation Summary AI-Driven Network Software

In the implementation criteria, Ericsson emerged as the overall AI-driven network software implementation leader, due to its global market share and rollout of a strong portfolio of analytics and AI-enabled sustainability products for energy savings. Ericsson was followed by Huawei's PowerStar solution and Nokia's AVA product. Next in implementation were Cisco, Intel, and ZTE, with Cisco's AI solution as part of its Cisco DNA Center that leverages the power of ML and Machine Reasoning. Intel's broad partnerships and ecosystem includes collaborating with Google to enable the OneAPI Deep Neural Network (oneDNN) Library as the default CPU optimization for TensorFlow, used on Intel architecture. ZTE's AI and analytics PowerPilot RAN solution has been gaining significant traction in China, Malaysia, South Africa, Indonesia, and Thailand. Finally, the implementation ranking concludes with Samsung, Cellwize, and RantCell, as these companies have smaller geographic footprints and market share compared to the other vendors.

Concluding Remarks

Overall, Ericsson emerged as the AI-software category leader, with an overall sustainability strategy and advanced features that enhance the overall energy performance of the platform. Ericsson is followed by Huawei and Nokia. Intel, ZTE, and Cisco are also strong competitors, as all vendors are investing in automation, and Deep Learning (DL) applications. Specifically, Cisco developed the Machine Reasoning inference engine, and Intel developed oneDNN to optimize CPUs further and streamline the development of DL applications. ZTE is working on self-configuration and self-adjusting AI solutions. Samsung's AI-based real environment recognition and automatic Three-Dimensional (3D) map reconstruction is a sophisticated networking solution; however, it does not reach the same scale as Ericsson, Nokia, and Huawei. Cellwize and RantCell show more limited performance in the impact criteria. However, they scored higher in the implementation scoring, due to legacy products and a variety of software offerings within the telco market.

4.8. ANTENNA SOLUTIONS (CELLULAR BASE STATION ANTENNA MARKET)

4.8.1. Technology Overview: Base Station Antenna

Antennas can reduce OPEX and energy use in the network, also reducing the carbon footprint of the network

Antennas are a part of the RAN that emit radio signals to carry data from the core network to the user equipment. There are many antenna systems that exist on the market today, ranging from small cells to large mMIMO arrays. As outlined in the mMIMO technology overview, there are many different scenarios in which an antenna system may be deployed, and the size of the cell should reflect the expected capacity and range needed to meet the demand. For example, a large mMIMO array is more suited to a densely populated area, whereas small cells may suit an indoor private 5G network deployment better. A wide range of antennas can reduce OPEX, reduce energy use in the network, and, in turn, reduce the carbon footprint of the network, deploying a "right-sized" suitable solution for both the network providers and the environment.

Antennas, particularly larger array sizes, require large amounts of power to function. Legacy generations of antennas are far less efficient than 5G base stations in terms of data transfer per unit power; however, 5G sites can consume up to 2X to 3X the energy of a 4G base station. With energy costs rising, many telco operators are seeing an increase in OPEX for energy usage as they transition to 5G. Therefore, it is imperative that infrastructure suppliers move toward designing and building more power-efficient antenna solutions.

Some 5G RFs have a shorter propagation range, so the network will require a greater number of antennas and a larger amount of power to achieve the same range of coverage as the current 4G

networks. More antennas requiring more power means a significant ramp up in terms of energy usage, which means a higher volume of CO2 emissions associated with the network (unless the power is coming from renewable energy sources).

Implementing new technologies to reduce power consumption, such as sleep/shutdown modes, and modernizing PA will significantly reduce the energy requirements of the base station antennas. PAs intensify the signal strength in antennas, and GaN PAs are more energy efficient than silicon-based PAs, and therefore better suited to supplying the higher power requirements of the energy-intensive components of 5G.

Moreover, a common practice when it comes to upgrading antennas has previously been the "rip and replace" model, or tearing down the old technology and replacing it with new. The disposal of the redundant technology is often not managed judiciously, and is likely to be broken down into its components, with most parts making their way to the landfill. However, some modern antenna vendors are taking a more circular approach to this issue by offering a recycling and refurbishing scheme for some telco infrastructure hardware, including base station antenna equipment.

Circular practices at the end of the product lifecycles have a positive impact; however, antenna manufacturers should also consider implementing sustainable, circular practices in the design and manufacturing of their products. Modular antenna systems, which enable easy deployment and replacement of components, rather than the entire antenna system, are an innovative solution that enhances the circularity of the products. Using recycled or recyclable materials in the hardware components where appropriate also reduces the carbon footprint of the antennas.

Lightweight, compact, and integrated antenna solutions that support multiple bandwidths, and can run on vRAN software are also more sustainable, as they can be deployed on a single site, without requiring as much supporting RAN hardware as previous generations.

Loss due to internal components, such as cables and ill-fitting connectors, mismatch of equipment in a network, and issues surrounding reflectivity of signals can account for a drop in efficiency in antennas. Antennas operating outside of their optimum operating temperatures will also be less efficient in transmitting and receiving signals. Vendors that make efforts to counter these losses and to improve the efficiency through innovative technologies score highly in impact for this category.

4.8.2. Impact Criteria

- Multi-Band Capabilities: Degree of antenna support for multi-band capabilities, but also needs to deliver high gain and coverage. 25%
- UWB Capabilities: Degree of antenna support for UWB capabilities, but also needs to deliver high gain and coverage. 25%

- Innovative Technologies to Reduce Overall Power Consumption: The capability of implementing energy-efficient technologies in the production and operation of the equipment to reduce overall system power consumption. 20%
- Sustainable Operations in Manufacturing of Antenna Equipment: The level of integration of advanced Industry 4.0 technologies and programs for sustainable operations (IoT, AI/analytics, and automation for materials, water, and energy savings) in the production of antenna equipment. 10%
- Supply Chain Sustainability and Supplier Engagement: The weighting of sustainability in supplier RFPs, depth of supplier engagement, participation in supply chain coalitions (CDP Supply Chain Program, etc.) 10%
- Overall Sustainability Strategy for the Vendor: This assessment includes company climate targets for carbon neutrality within the vendor's own operations and for reaching net zero across the value chain, use of renewable energy, green buildings credentials (LEED certification, Energy Star, BREEAM, DGNB, etc.), green fleet vehicles (% of EVs, telematics), waste and circularity programming, incentives for climate targets (executives, employees), and sustainability reporting and governance. 10%

4.8.3. Implementation Criteria

- Overall Antenna Sales Market Share: The greater the market share in terms of revenue, the better the ranking. 40%
- Antenna Sales Regional Geographical Penetration: Partly based on sales presence in each global region. Also, the more regions the vendor's clients are in, the better the ranking. 20%
- Sustainability Integration into Antenna Deployment: To what extent is sustainability integrated into the deployment of antennas (use of digital twins for modeling locale and placement and tower configurations remotely, use of AI-driven network deployment software, etc.) 20%
- Financial and Organizational Health: Based on the size of overall firm sales and operating margin. Tries to assess how robust the vendor is to shocks and to fund internal needs, such as R&D, regional distribution, channel expansion, etc. 10%
- Vendor's Antenna Portfolio: Range of portfolio. Does the portfolio support all the protocols, have a wide range of spectrum bands, and competitive pricing? 10%

4.8.4. Results

Leaders: Ericsson, CommScope, Huawei

Mainstream: Amphenol, Rosenberger (PROSE), Comba, Tongyu

Followers: Radio Frequency Systems (RFS), ACE Technologies, MOBI, DENGYO, Hengxin Technology

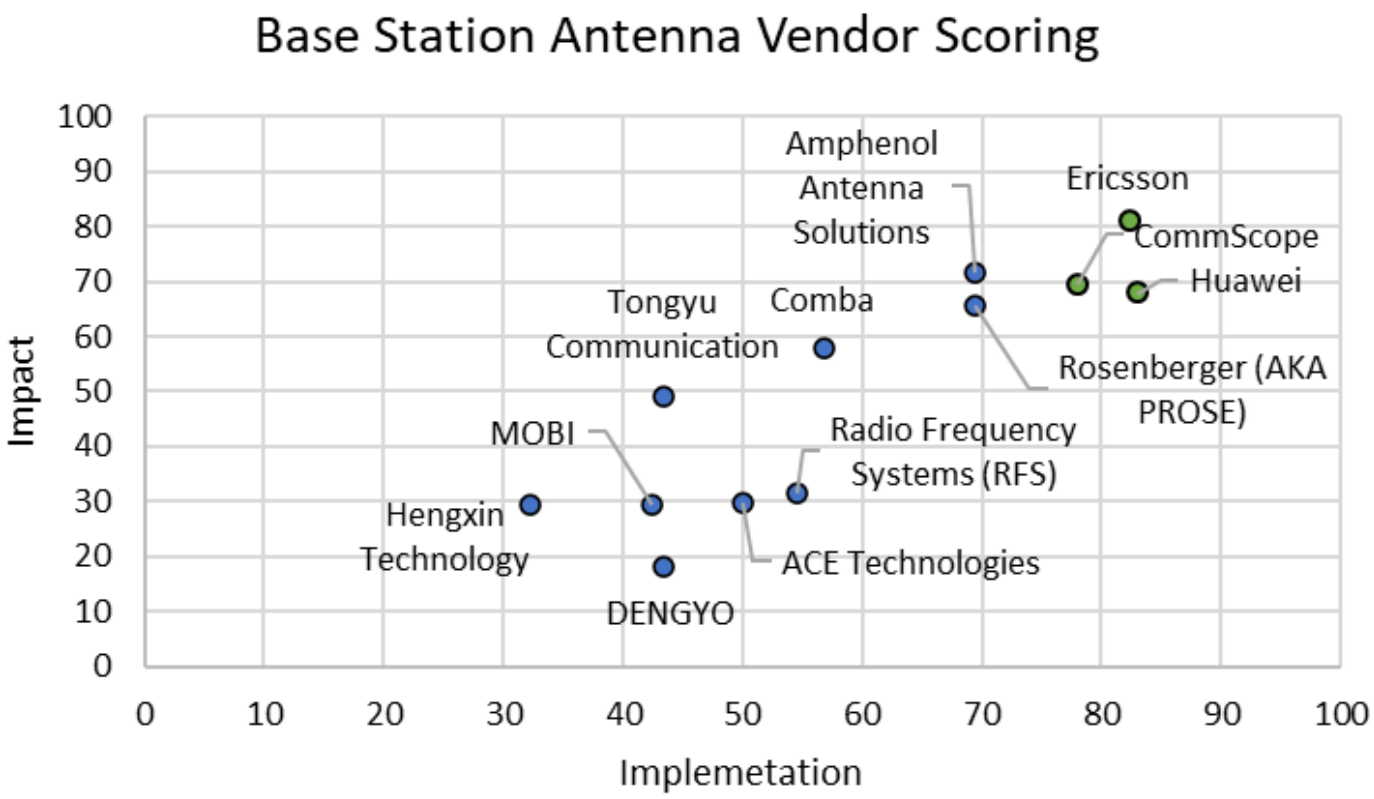


Table 10: Base Station Antennas Overall Vendor Ranking
(Source: ABI Research)

Company	Overall Rank	Overall Scores
Ericsson	1	81.6
Huawei	2	75.8
CommScope	3	73.8
Amphenol Antenna Solutions	4	70.4
Rosenberger (PROSE Technologies)	5	67.5
Comba	6	57.3
Tongyu Communication	7	46.4
Radio Frequency Systems (RFS)	8	44.6
ACE Technologies	9	41.2
MOBI	10	36.5
DENGYO	11	33.3
Hengxin Technology	12	30.9

Impact Summary Base Station Antenna

Kathrein (a subsidiary of Ericsson, now known as “Ericsson Antenna System”) placed first, due to its innovative and lightweight radio solutions, and industry-leading company-wide sustainability

efforts. Ericsson closely engages with its suppliers to ensure sustainability targets are met, and similarly adopted by the entire supply chain.

Amphenol is making efforts to push a standardized bracket for use in the industry, to allow for better modularity, and to facilitate reuse of antennas

Amphenol Antenna Solutions placed second for impact. Its NodeLine passive antenna solutions are designed and built with sustainability in mind. These antennas are modular, and can be easily repaired and upgraded, reducing the carbon footprint of the product by up to 65%. It is implementing "game-changing" beamforming techniques in its new range of mMIMO antennas, transitioning to lightweight, more efficient, and more sustainable materials where possible, and improving the recyclability of its products. Amphenol is making efforts to push a standardized bracket for use in the industry, to allow for better modularity, and to facilitate reuse of antennas. Its 5G active antenna, Leonardo, is Open RAN capable, and the modularity of Amphenol's passive antenna range means that the active components can be deployed on the same site to upgrade the capabilities of the base station, enabling flexibility for network operators transitioning from 4G to 5G and beyond.

CommScope secured third place for its antenna's capabilities, up to penta-deca band, with 30 port availability in some RUs, with some small-scale MIMO configurations, operating over a range of spectrum between 1.4 GHz and 2.6 GHz. Its small form twin beam antennas reduce the number of antennas per deployment to cover the same range, due to their wide broadcasting angles.

Huawei followed closely behind in impact, due to its vast antenna solutions portfolio and innovative and advanced technologies. Supporting a wide range of frequencies, Huawei's antenna portfolio spans single-band radios up to penta-deca bands—an impressive and extensive range. It also supplies its large-scale mMIMO units, its MetaAAU boasting 384 antenna elements, the largest array on the market, which can deliver a 40% increase in coverage and a 5% decrease in power consumption over previous AAU generations.

PROSE Technologies (a subsidiary of Rosenberger) has recently developed a mMIMO antenna to add to its range of products, along with an integrated A+P solution to support multi-band coverage, with improved modularity to ease deployment.

To reduce the carbon footprint of the operators, Comba Telecom released an 8TR "green antenna," with new technologies to reduce loss within the antennas to create a more efficient product. It also introduced a new, more environmentally-friendly coating process, ion beam coating, to replace the more energy-intensive, polluting electroplating techniques. Comba also introduced a new method of manufacturing radomes, using a mix of low-density foam and solid

thermoplastic material to reduce weight and enable recycling and reuse; it claims the manufacturing process of the radomes is pollution free.

Tongyu Communication provides antennas with up to octa-band capabilities, supporting sub-2.7 GHz frequencies, and UWB available in its low- and high-band antennas. Its latest generation of antennas have 85% fewer cables, and 10% less size, with a 10% increase of radio efficiency. It is developing mMIMO radios along with some of the biggest radio equipment manufacturers in the world, and are streamlining their manufacturing processes, to reduce necessary soldering of components from 46% to 78% in its antenna products. Tongyu Communication has made plans to deploy PV panels on the rooftops of their business sites, with funding of approximately RMB12 million from Xinzhong Energy Development and any excess energy not required by the business sites will be redistributed back to the grid for public use.

Radio Frequency Systems (RFS), ACE Technologies, MOBI, DENGYO, and Hengxin Technology all had limited information for their sustainability impact initiatives, and hence have been awarded lower scores in this assessment.

Implementation Summary Base Station Antennas

Huawei has rolled out over 1,000 MetaAAUs across China in 2022, on behalf of China Mobile. Despite losing some customers due to sanctions, Huawei still holds the second-largest market share around the world, and its lightweight integrated antenna solutions are easy to deploy.

Kathrein, recently acquired by Ericsson, now releases its active antenna products under the moniker “Ericsson Antenna System.” Ericsson has the largest global market share in base station antennas, with the Hybrid AIR and Interleaved AIR mMIMO multiband-capable antennas for single-site deployment among its antenna solution portfolio.

CommScope’s Mosaic Platform integrates A+P antennas in a flexible solution that it claims enables building networks with the same footprint as its current-generation 4G passive antennas. The Mosaic offering includes mMIMO configurations up to 64T64R, and implements passive air cooling, fiber and coaxial cables, and remote electrical tilt for on-site adjustments. CommScope has developed an aerodynamic, 360° wind load reducing antenna design, ensuring its products are suited to all environments. CommScope offers a free cooling solution for its base station antenna platform solution, which, according to the company, can reduce up to 80% of energy costs when implemented compared to air conditioning.

Rosenberger (PROSE Technologies) is well established across Europe, Asia-Pacific, Africa, the Middle East, and the Americas. Its hybrid multiband antennas that can support all 5G sub-3.5 GHz bands can be deployed in a single cabinet, greatly reducing tower load and deployment cost, maintenance efforts, and emissions.

Amphenol Antenna Solutions has a vast antenna portfolio and an impressive business model, known as Integra, with its antenna solutions provided in a modular fashion, enabling customers to swap their base station antenna equipment to suit their needs. Amphenol also provides refurbished antenna equipment and will offer to buy back previous generations of technology from one network operator to refurbish and redistribute to other network operators. This impressive circular business model, confirmed by company representatives, gained Amphenol high scores for sustainable impact and implementation.

Comba's antenna solutions implement a flexible layout, and through advanced manufacturing techniques and lifecycle assessments, have improved the efficiency and reduced loss in its products. Comba's antenna solutions have been deployed across the Middle East, Asia-Pacific, Europe, and South America.

RFS has a diverse catalog of antenna solutions on offer and implements a flexible business model that allows a great degree of customization for its product solutions, including mMIMO and hybrid antennas, with active components available as upgrades to existing passive antenna deployments.

ACE Technologies has reached North America, Europe, the Middle East, and Asia-Pacific with its antenna solutions. It has a large catalog of antenna solutions, with multiband and beamforming capabilities.

DENGYO is well established in Japan, deploying networks for top-tier network providers; more recently branching out to offer its wide range of innovative antenna solutions in the U.S. market, and even more across Asia-Pacific. Its focus in the international market is on antenna solutions for a wide range of deployment options, from indoor small cells that merge with their surroundings, to macro-scale networks with multiband coverage, with some active models and integrated solutions.

Tongyu Communication has deployed its solutions with operators in more than 60 countries and has strong partnerships with top-tier equipment vendors around the world. Tongyu provides antennas with small form factors, and integrated solutions for single-site deployments. MOBI has established itself across Europe and Asia, offering a generous range of more than 150 antenna solutions, and Hengxin Technology mainly operates in China with a more limited portfolio of antenna solutions compared to other vendors reviewed in this report.

Concluding Remarks

Ericsson's company-wide efforts are ambitious and set the standard for how to integrate sustainable practices in antenna development and deployment

Overall, Ericsson emerged as the leader of antenna solutions, due to its overall market share, closely followed by Huawei. The company-wide efforts of Ericsson are recognized as some of the most ambitious in the industry, setting the standard for how to integrate sustainable practices in antenna development and deployment. Huawei and Ericsson both offer an impressive range of base station antennas, and their automated network management and power saving modes are in full testing and development.

CommScope's innovative free cooling offerings complement its base station antenna deployment solutions. Its advanced antenna solution portfolio has gained it a decent worldwide market share.

Amphenol Antenna Solutions' business models and approach to sustainability make it stand out in this assessment, and its determination to strive for standardization and interoperability to enable more sustainable practices across the telco industry should be noted by other vendors in this space.

Rosenberger (PROSE Technologies) has an extensive product portfolio, spanning multi-port, multiband, and multi-beam antennas with hybrid configurations, to providing flexible solutions to enable network operators' transitions to 5G.

Comba's advanced manufacturing processes are noteworthy in this space. It is making small changes to improve efficiency and reduce waste and pollution on a large scale, which can be widely adopted across the industry, enabling more sustainable practices, and reducing the footprint of the manufacturing processes.

4.9. CLOUD PARTNERS (5G TELCO CLOUD-NATIVE PLATFORMS)

4.9.1. Technology Overview: Cloud Partners (5G Telco Cloud-Native Platforms)

Cloud-native computing allows companies to develop, build, and run scalable applications in a modern IT environment, such as public, private, or hybrid clouds. According to Joe Beda, co-founder of Kubernetes and principal engineer at VMware, "Cloud native is structuring teams, culture, and technology to utilize automation and architectures to manage complexity and unlock velocity."

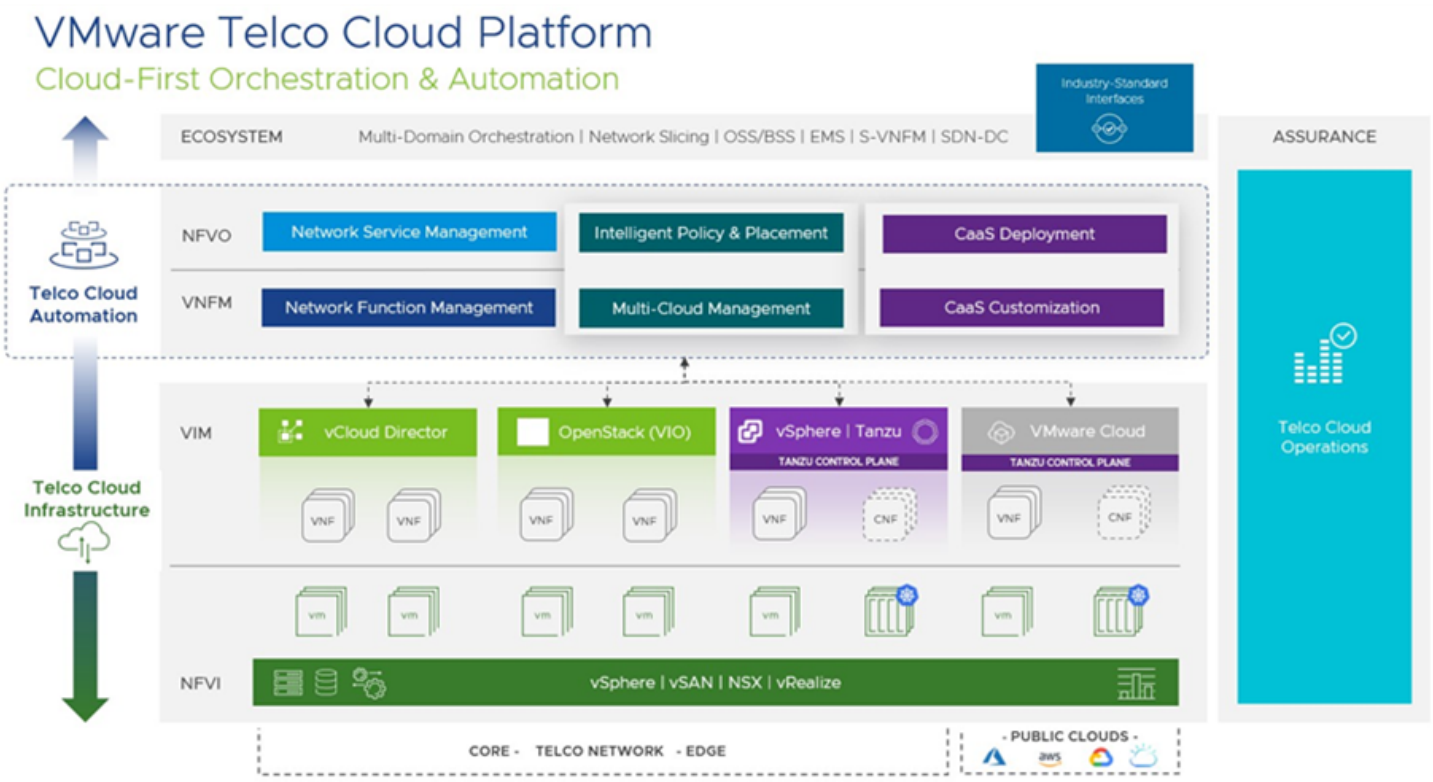
Cloud-native applications are deployed as microservices and managed with DevOps workflows that use Continuous Integration/Continuous Development (CI/CD) pipelines. This is a departure from previous-generation telco applications (e.g., legacy networks, Operating Systems (OSs), servers, and databases), or self-contained IT models built on-premises. When telco companies build their networks on cloud-native architecture, they can respond to customer demands quickly, automate the network, scale, enhance performance, improve the CI/CD pipeline, and

bring new software and applications to market faster. Cloud-native also enables new business opportunities, such as network slicing. Network slicing uses virtualization to divide up single network connections into multiple distinct virtual connections, so a CSP can assign different resources to different types of data traffic.

According to the ABI Research 5G group, other significant trends in 5G cloud-native platforms are:

- Public Cloud Convergence: CSPs are increasingly deploying more NFs, such as Operations Support System (OSS) or Business Support System (BSS), into the public cloud. Early trials in deploying real-time and critical NFs, such as the 5G Core (5GC) in the public cloud, have also begun. As CSPs increase their adoption of the public cloud for IT applications and NFs, they increasingly seek multi-cloud capabilities for their 5G platforms.
- Multi-Vendor Orchestration: CSPs are increasingly seeking choices in the way they build their telco network stacks. As 5G will introduce a multitude of new business opportunities and innovations, CSPs will tap into multiple vendors' expertise to leverage these new value streams. However, with choice comes complexity, and 5G cloud-native platforms will need to have the capabilities to orchestrate, troubleshoot, and provide service assurance for a much more complicated multi-vendor ecosystem. Certifications, open standards, and Application Programming Interface (APIs), as well as strong orchestration abilities, are key requirements that CSPs are looking for in cloud partners.
- Ease of Deployment: Network infrastructure investment is a major category of expenses or costs for CSPs. CSPs are seeking the fastest time to market in deploying their services to improve their ROI, while protecting existing legacy assets. 5G cloud-native platforms will also need to be easily and conveniently deployed into existing brownfield systems.
- Single Horizontal Platform: CSPs need a consistent platform across multi-cloud environments to capture revenue faster and drive efficiencies and economies of scale across businesses. Furthermore, telco cloud-native platforms are extending into the RAN. In the next few years, we will see increasing Open RAN applications running on cloud-native platforms. There is also an extension to the edge, with the Mobile-Access Edge Compute (MEC) platform benefitting from cloud-native platforms, too.

Figure 7: 5G Telco Cloud-Native Platform Example (VMware)
(Source: VMware)



4.9.2. Impact Criteria

- Carbon Emissions Tracking Capabilities of Cloud Partner: Capabilities of cloud partner to track and report carbon emissions from use of the cloud platform. When cloud service metrics (at the cloud data center level) and workload placement tools are less developed and not transparent, it can be difficult to assess the sustainability impacts of different cloud providers and workload placement. 25%
- Multi-Vendor NF Orchestration: Companies that enable integration and orchestration of third-party VNFs/Cloud-Native Network Functions (CNFs) through certification programs, open interfaces, and multi-vendor orchestrators. VNFs are included in this assessment, as 5G CNF design and deployment have not yet seen mass deployment for many CSPs. 20%
- Telco-Grade Supporting Features: 5G is a performance technology and telco cloud-native platforms will have to provide features such as Single Root I/O Virtualization (SR-IOV), DPDK, Non-Uniform Memory Access (NUMA), and dual stack IPv4 and IPv6 capabilities, among many others to enable sustainability use cases for customers. As 5G performance improves, the technologies that 5G enables also improve, such as automation, AI, the IoT, edge computing, and more. 20%
- Container Orchestration and Management: 5G Service-Based Architecture (SBA) will require the orchestration and management of containers to deliver cloud-native capabilities. Platforms are evaluated on their ability to auto-scale clusters and enable Life Cycle Management (LCM) and Zero-Touch Provisioning (ZTP) of containers for improved energy

- efficiency. Lower energy consumption of the network and cloud services equal lower carbon emissions. 15%
- AI and ML Capabilities for Network Operations: AI and ML capabilities for network operations is another important criterion that enables automation, reduces truck rolls for field ops, ensures that Service-Level Agreements (SLAs) are kept, and improves customer experience. AI/ML capabilities for 5G cloud-native platforms are rapidly developing, with some companies being further ahead due to preexisting AI/ML capabilities, while others are working to implement it. 10%
- Overall Sustainability Strategy for the Vendor: This assessment includes company climate targets for carbon neutrality within the vendor's own operations and for reaching net zero across the value chain, use of renewable energy, green buildings credentials (LEED certification, Energy Star, BREEAM, DGNB, etc.), green fleet vehicles (% of EVs, telematics), waste and circularity programming, incentives for climate targets (executives, employees), and sustainability reporting and governance. 10%

4.9.3. 4.9.3. Implementation Criteria

- Cloud-Native Capabilities: This is a key criterion for CSPs, as moving forward, 5G will require CSPs to design services and work in a cloud-native way. Platform providers are evaluated on their support for cloud-native capabilities, such as CI/CD pipelines, DevOps processes, microservices, service mesh, container orchestration, cluster management, etc. 30%
- Extent of Modularity: Beyond incorporating multi-vendor NFs, CSPs are also looking for service continuity and protection of existing investments in the form of modularity for cloud-native platforms. Third-party components should be able to interoperate with these platforms, and CSPs are looking to avoid platform "lock ins" as well. The ability to swap out components, the level of interoperability with CSPs' existing assets and components, and the extent of ecosystem support are evaluated for this criterion. 25%
- Multi-Cloud and Hybrid-Cloud Support: The introduction of hyperscalers into the telco domain is an emerging trend that will drive innovation and transform the way CSPs deploy their networks. Being able to go multi-cloud or hybrid cloud is an increasing area of interest for CSPs, and platform providers are looking to increase their support to manage cloud-native workloads across multi-cloud deployments and enable advanced capabilities, such as "burst to cloud" with hybrid cloud deployments. Becoming cloud agnostic is also an increasingly important feature for CSPs to deploy their IT. 20%
- Telco Domain Range: Companies are evaluated based on the ease and extent of deploying the platform across the telco domains (i.e., core, edge, far edge, and RAN). CSPs ideally want to have a single unified platform that cuts across all telco domains, but the market is very heterogenous in this regard. 15%
- Deployment Model: This criterion refers to whether the platform supports bare metal deployments and Virtual Machine (VM) deployments. As CSPs transition from VMs on NFV Infrastructure (NFVI) to containers on bare metal, the platform will need to provide CSPs with an evolutionary path that does not alienate brownfield deployments of VNFs on NFVI.

- 10%.

4.9.4. Results

Leaders: VMware, Nokia, IBM (Red Hat), Ericsson, Huawei, ZTE

Mainstream: Canonical, AWS, Azure, Google Cloud, Wind River

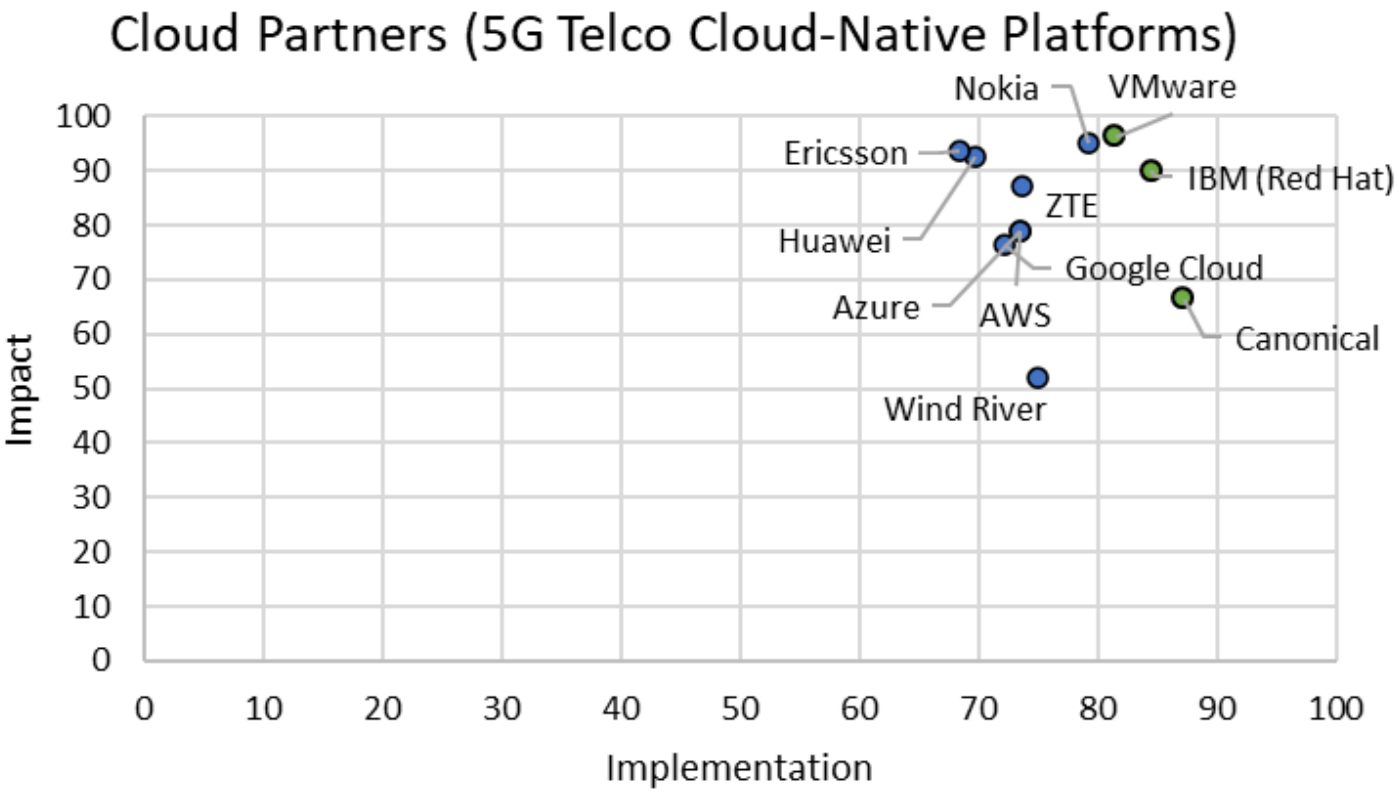


Table 11: Cloud Partners (5G Telco Cloud-Native Platforms) Ranking
(Source: ABI Research)

Company	Overall Cloud Partners Rank	Overall Cloud Partner Scores
VMware	1	89.2
Nokia	2	87.6
IBM (Red Hat)	3	87.3
Ericsson	4	82.1
Huawei	5	81.9
ZTE	6	80.8
Canonical	7	77.6
AWS	8	76.3
Azure	9	76.3
Google Cloud	10	74.3
Wind River	11	64.5

Impact Summary Cloud Partners (5G Telco-Grade Cloud-Native Platforms)

Telco cloud partners and vendors, such as VMware, Nokia, Ericsson, Huawei, ZTE, Red Hat (IBM), and Canonical offer industry-specific solutions and deep experience and specialization in telco needs. Companies like AWS, Microsoft's Azure, Wind River, and Google Cloud Platform (GCP) are more mainstream hyperscalers and cloud providers that build telco-grade network clouds as a part of their larger enterprise businesses.

VMware, Nokia, and IBM (Red Hat) are leaders in impact criteria, as all vendors provide strong carbon-tracing capabilities within a strong telco-grade platform. VMware offers its Carbon Efficiency with Virtualization Dashboard, which provides visualization and a dashboard view of the reduction in carbon footprint achieved through a reduced number of servers and reduced power consumption. Nokia enables energy-saving modules (EdenNET SON) with ML algorithms to enable cell-specific parameterization; it also enables automatic re-configurations based on dynamic changes in traffic patterns. These algorithms help reduce energy consumption further once the EE SW features are activated.

These companies were followed by Ericsson, Huawei, and ZTE. Ericsson was awarded a top grade for telco-grade features with its 5G cloud-native platform, including automatic service level agreement (SLA) enforcements and five-nines reliability (e.g., the network must be available 99.999% of the time or be down less than 5.25 minutes a year). Ericsson's offering is a full stack telco-grade solution, optimized and verified E2E with Ericsson applications. Ericsson Orchestrator was also awarded the MEF 3.0 Proof of Concept Showcase 1Q 2021 award winner, enabling 5G network slicing. ZTE is in the middle of the pack, scoring solidly in telco-grade features, enabling telcos to adapt access to the edge and core networks. TECS can also be adapted to be deployed at small edge sites that only require several nodes and in large data center rooms that require thousands of nodes. Huawei received strong scores for its AI and ML capabilities, with its Fusion Sphere having a 1-second fault detection of VMs and a self-healing mechanism that does live migration of faulty VMs with no downtime. The entire self-healing process can be done in seconds. Huawei has invested heavily in its AI capabilities, with its Autonomous Driving Network (ADN) solution leveraging AI to improve cloud, network, and Operations and Maintenance (O&M) efficiencies.

Canonical has limited cloud-native capabilities. For example, the deployment option is limited to Kubernetes (K8s) on Ubuntu and MicroK8s. And the impact ranking placed AWS, Azure, and GCP in a similar position, as vendors offering highly similar capabilities, except for GCP scoring highest in container orchestration and management capabilities. Google has developed open-sourced Kubernetes and provides the best container orchestration capabilities with Google Kubernetes Engine (GKE). GKE provides fully managed and secured hosting of Kubernetes over GCP and enables multi-cloud capabilities with Anthos. AWS provides orchestration capabilities for CSPs

through tools like AWS Step Functions and Lambda for E2E service orchestration for VNFs/CNFs. Azure offers Azure Kubernetes Services (AKS), which supports open-source projects like Kubernetes Event-driven Autoscaling (KEDA) for elastic provisioning of capacity and synergizes with Azure DevOps and Azure Monitor for DevOps. Wind River offers embedded Linux-based containerized K8s solutions, built to be on the edge. The Wind River Studio portfolio spans a cloud platform, network manager and orchestrator, and analytics platform, which supports multi-vendor and third-party NFs in an open-source containerized architecture. Its impact ranking reflects the limited available information on Wind River's company-wide sustainability efforts, despite being a prevalent vendor in the telco space, and an advocate for Open RAN.

Finally, Azure, IBM (Red Hat), AWS, and Google Cloud offer to monitor solutions for telcos, enabling them to have visibility over carbon emissions from using cloud infrastructure.

- Google Carbon Footprint Tool: In 2021, Google launched its Carbon Footprint tool, which helps analyze Google Cloud users' carbon emissions. In addition, the Active Assist tool, based on the Google Cloud AIOps platform, detects projects that are no longer in use and can be disabled.
- Microsoft Emissions Impact Dashboard: Microsoft has offered its telco clients a carbon calculator for Microsoft Cloud usage called the Microsoft Emissions Impact Dashboard. This solution is made to track, analyze, report, and decrease cloud-related carbon emissions. The Azure Emissions Impact Dashboard helps telcos measure their emissions and carbon reduction potential in the Microsoft cloud, using Power BI template apps and regular, third-party verified carbon accounting.
- AWS Customer Carbon Footprint Tool: AWS has developed a Customer Carbon Footprint Tool, which tracks, measures, and predicts carbon emissions according to AWS usage. Using the AWS tool, customers can forecast emissions according to the company's metrics and goals. To report emissions from using AWS by GHG protocol standards, companies can use an e-data visualization function, and by migrating workloads to AWS over time, operators can analyze emissions changes and relinquish unused resources.

Implementation Summary Cloud Partners (5G Telco Cloud-Native Platforms)

Canonical's multi-cloud and hybrid cloud capabilities are very strong due to it being highly agile and modular, and completely open-source based

Canonical, IBM (Red Hat), and VMware were implementation leaders for the cloud partner index. Canonical is highly agile and modular, as well as completely open-source based, which makes its multi-cloud and hybrid cloud capabilities very strong. Canonical does not sell platforms as traditional cloud providers do; however, the company offers strategies, deployment, consulting, and services for managing open-source solutions on a 5G cloud-native platform. IBM (Red Hat) came in second place due to a strong multi-cloud strategy that enables deployment across all

telecommunications domains, from the core to the RAN to the edge (i.e., MEC, edge applications, and enterprise edge computing). Red Hat offers both Red Hat OpenStack and Red Hat OpenShift for telco operators. This includes Red Hat Smart Management and Red Hat Advanced Cluster Management for Kubernetes. VMware's Telco Cloud Platform offers a cloud-native platform for 5G networks, supporting over 220 third-party VNFs/CNFs, including NFs from Nokia, Cisco, Ericsson, and MetaSwitch. Additionally, VMware Telco Cloud Platform was used in a 5G deployment with DISH, enabling multi-vendor NFs deployment, with the ability to move and scale workloads in the cloud dynamically. Among top MNOs, Telia is working with VMware Telco Cloud Platform as the common network digital platform, with 4G and 5G CNFs. Nokia was stronger in impact than implementation; however, its platform (80% is cloud-native) offers multiple solutions to meet CSPs' needs to build a cloud-native network. Additionally, Nokia's 5G cloud-native platform solution incorporates containers in a microservices architecture, with DevOps automation and open APIs that can be deployed according to a customer's choice on any bare metal, public, edge, or private clouds. Wind River and ZTE also have DevOps pipelines, including compatibility with OpenStack and K8s, to support VM and bare metal deployment, for a consistent O&M experience across private and public clouds.

Google Cloud, AWS, and Azure are continuing to build expertise in the telco domain. According to the ABI Research 5G group, Google is stronger in implementation, but weaker in innovation and impact for telco-specific functionality. AWS has made progress, including its award in deploying the DISH core network. However, AWS still lags behind its competitors, including having a strong orchestration capability for multi-vendor NFs and the ability to host both CNFs and VNFs using AWS tools. Azure has collaborated with AT&T, but still does not have the telco expertise and footprint of other cloud providers in this report.

The final vendors in the rankings were Ericsson and Huawei. Ericsson has limited modularity, though it is a single E2E pre-integrated solution, with open APIs, such as OpenStack APIs and Cluster APIs, as well as 3GPP standards. It can also interface with third-party components, such as a generic VNF Manager (VNFM). Comparatively, Huawei has a weaker offering in multi-cloud and hybrid cloud support. Huawei Cloud Native 2.0 Platform is currently hosted as a private telecommunications network cloud and does not yet have public cloud support. However, Huawei supports multiple on-premises MEC deployments, where the user and control planes are separated.

Concluding Remarks

VMware, Nokia, and Red Hat are the overall cloud partner leaders for advanced technologies and capabilities that enhance 5G performance and expand the telco industry's carbon handprint. Each vendor provides sophisticated telco-grade cloud-native platforms, as enablers of a multitude of applications across complex networks. Ericsson, Huawei, and ZTE are in the

mainstream among the cloud-native leaders, demonstrating their core, edge, and RAN solutions, while supporting cloud-native 5G applications and functions. Finally, Canonical and the hyperscalers, such as AWS, Azure, and GCP, have yet to demonstrate advanced capabilities beyond being a public cloud host for NFs. Wind River's low score can be accredited to the lack of information regarding its sustainability initiatives, though this does not diminish its product portfolio and scalability. This evaluation also assessed the sustainability initiatives of each individual company, and Google has been carbon neutral since 2007. Microsoft has been carbon neutral since 2012 and commits to being carbon negative as a company by 2030, while Amazon has pledged to reach net-zero carbon emissions by 2040.

5. SUSTAINABILITY MARKET TRENDS AND COMPANY ENVIRONMENTAL INITIATIVES

By November 2021, more than 140 countries had made some type of net-zero announcement in the form of lawful pledges, initiatives, or policies under discussion

Sustainability is increasingly becoming a key component of business strategies for major telco operators and network equipment providers. At the national level, more than 140 countries representing 90% of global GHG emissions had made some type of net-zero announcement by November 2021, including pledges agreed in law, as part of an initiative, or policy under discussion. At the corporate level, by the end of 2021, the SBTi reported that 2,253 companies across 70 countries and 15 industries, representing more than one-third (US$38 trillion) of global market capitalization, had approved CO2 emissions reduction targets or commitments with the SBTi. In August 2022, the SBTi indicated that 3,545 companies were working with the SBTi, while 1646 companies had fully approved climate targets.

Figure 8: Net Zero Emissions Target Announcements
(Source: Climate Action Tracker)

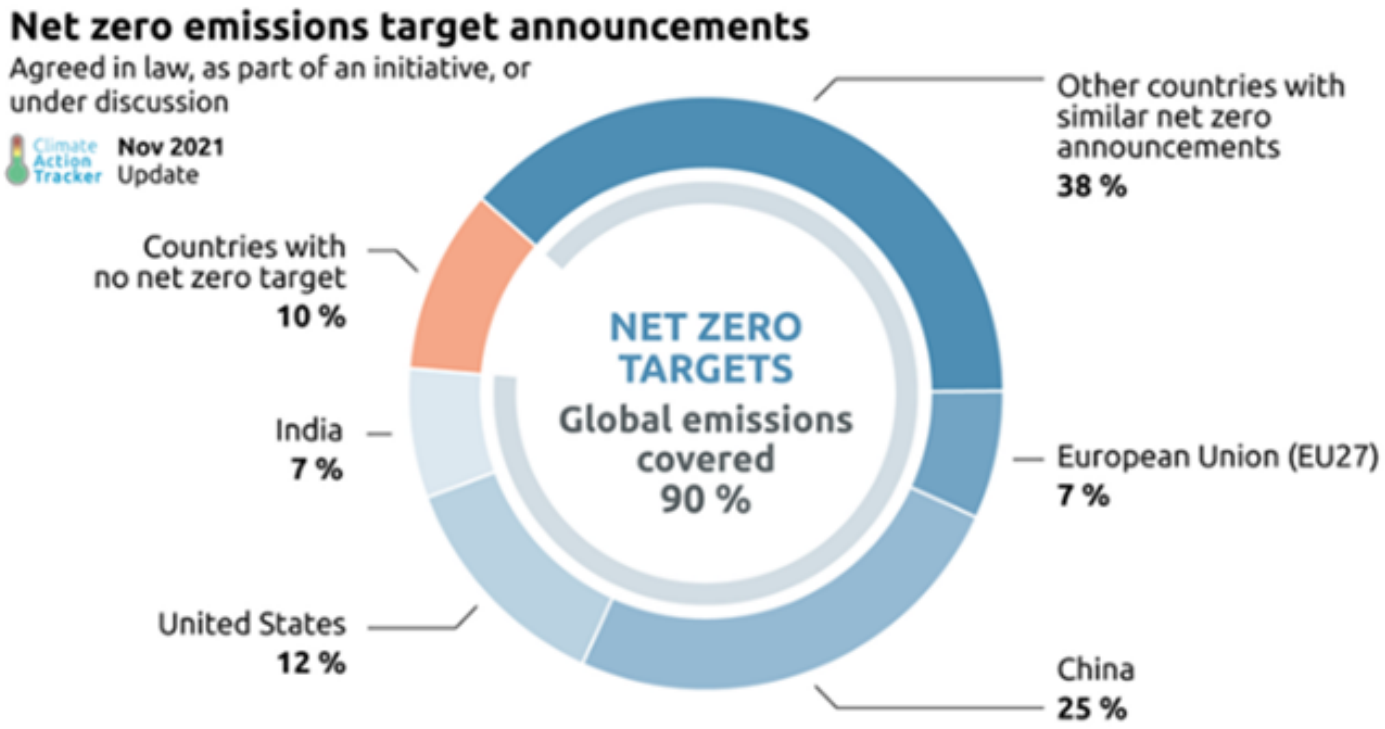
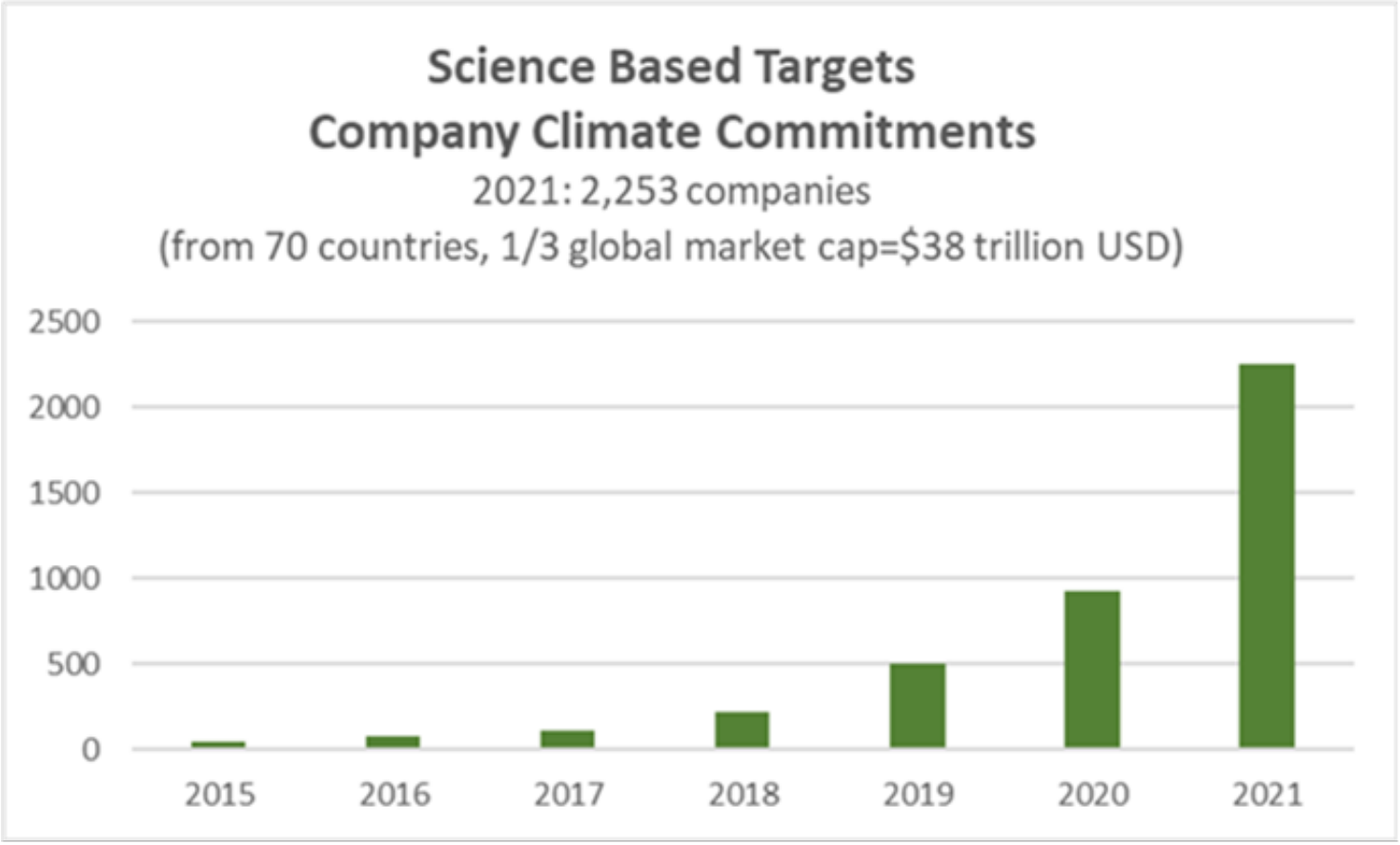


Figure 9: Science Based Targets Company Climate Commitments
(Source: Science Based Targets initiative (SBTi))



Corporate Sustainability Trends: While attitudes about sustainability can vary widely across different regions, industries, companies, and generations, recent surveys do suggest a growing corporate interest in addressing environmental impact. In the latest annual IBM CEO Study, published May 2022, interviews with 3,000 CEOs across diverse industries and geographies found that more than 80% of respondents reported that a focus on sustainability will "drive improved business results" in the next 5 years. Almost half (48%) surveyed indicated that "increasing sustainability is a top priority," which was up nearly 40% since 2021. While investment in sustainability as a percentage of revenue has more than doubled over the last 5 years, 51% of respondents did acknowledge that sustainable operations would be among their most significant challenges in the next 2 to 3 years, due to an unclear ROI and other technology hurdles.

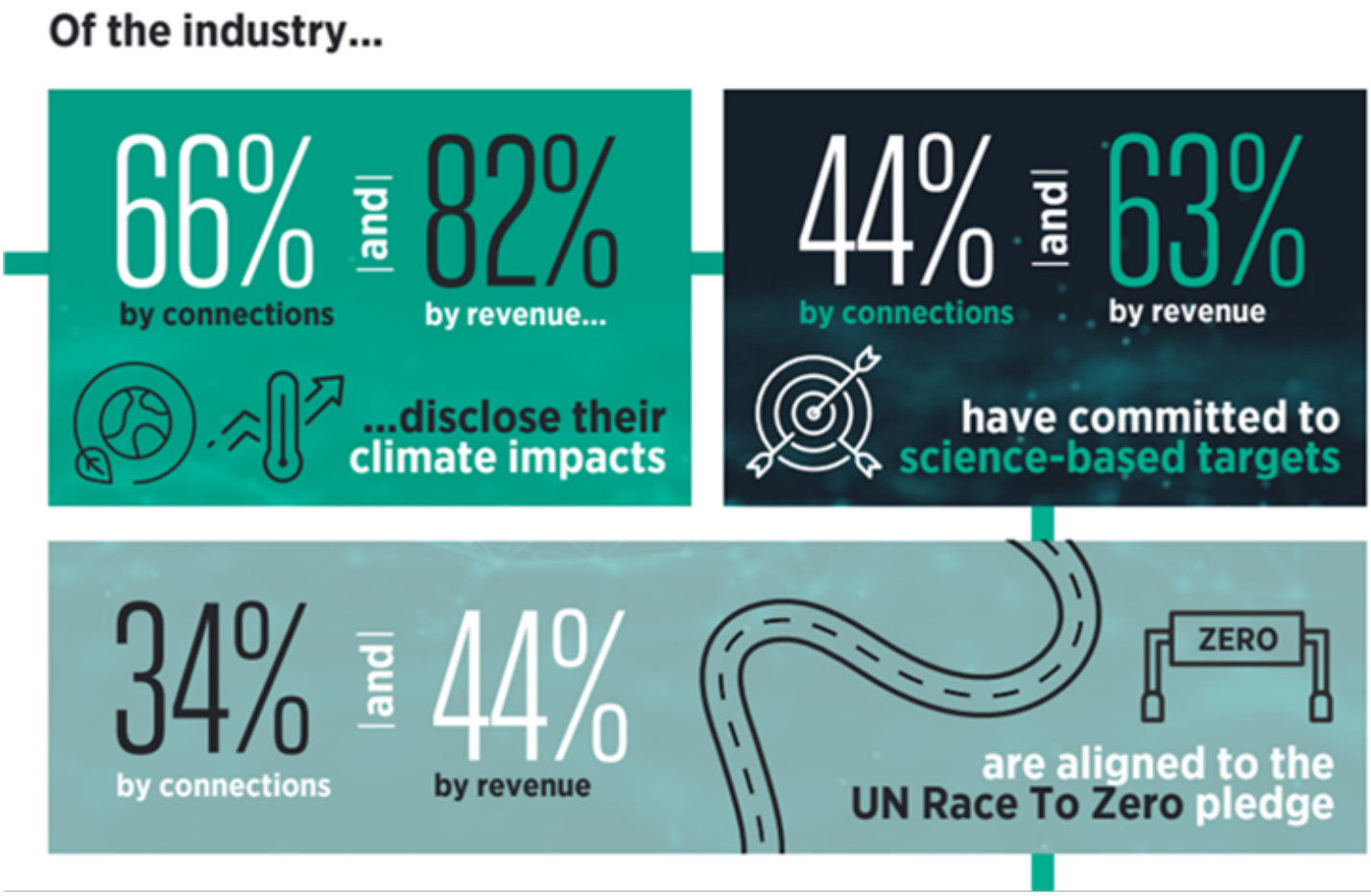
The telecoms sector served more than 5.3 billion unique subscribers by the end of 2021, covering effectively 70% of the world's population

Telecom Sector Sustainability Trends: According to GSMA Intelligence, the telecoms sector served more than 5.3 billion unique subscribers by the end of 2021, covering effectively 70% of the world's population. In all, with GSMA coordinating, the mobile sector has committed to achieving

net zero by 2050, in agreement with the Paris Agreement, and 30% of mobile operators have made public pledges to join the effort.

The GSMA also reports that, to date in 2022, 50 operators representing 63% of the industry by revenue and 44% by connections have pledged to reduce their carbon emissions over the next decade, an increase of 19 operators over the previous year. Moreover, an increased proportion of operators has also committed to science-based climate targets by 2050, covering 29% of global mobile connections and 38% of global revenue. Targets are considered "science based" if they are aligned with current climate science in meeting the goals of the Paris Agreement, or aligned with limiting global warming "to well below 2°C above pre-industrial levels and pursuing efforts to limit warming to 1.5°C."

Figure 10: 2022 GSMA Climate Targets
(Sources: GSMA, CDP, United Nations Framework Convention on Climate Change, and operator websites)



To reduce Scope 1 and 2 emissions, telco operators are focusing on three main areas: energy reduction, renewable energy, and carbon offsets for any remaining emissions

Finally, once climate-related targets are set, telecommunications companies must then determine an actionable plan for reaching those targets. For telco operators, getting to net zero for Scope 1 and Scope 2 emissions typically includes a focus on three major areas: renewable energy, energy reduction, and carbon offsets for any remaining emissions. Telco operators use a significant amount of electricity to power their networks.

To reduce Scope 1, 2, and 3 emissions, telco network equipment providers are primarily focused on reducing the total lifetime energy use of portfolio equipment

For telco network equipment providers, to achieve carbon neutrality within the company's own operations, the focus is on renewable energy, sustainable design and manufacturing of equipment, and carbon offsets for any remaining emissions. For reducing a telco equipment provider's total carbon emission, including Scope 1, 2, and 3 emissions, the focus is on reducing energy use of the company's products. For example, Nokia and Ericsson both report that 93% to 94% of their total carbon emissions comes from portfolio use of equipment. Thus, in ESG reporting, the downstream energy use of network radios, core network processors, mobile devices, and other equipment is a substantial percentage of the total carbon emissions for the vendors in this report.

To demonstrate how telco operators and equipment providers' carbon emissions are fully interconnected, when an MNO invests in sourcing electricity from renewable energy, this not only drives down the Scope 2 carbon emissions for the operator within its own operations, but it also reduces total Scope 3 emissions (e.g., for a network equipment company like Nokia, Ericsson, or Huawei) from the use of network equipment.

Telco Equipment Vendor Sustainability Trends: In collecting data for this report, ABI Research noted a strong response of major vendors and sustainably-focused newcomers wanting to share their sustainability initiatives. At the same time, there was also a sense that telco equipment providers are still trying to measure more precisely how critical sustainability is to a broader set of telco operators, partners, and customers, as well as other internal stakeholders, such as investors and employees. While climate action is consistently covered in the business news cycle, there are also many other competing demands in the industry, as CSPs balance sustainability with 5G deployment and expansion, spectrum purchases, fiber-optic implementation, cloudification, IoT, changes from traditional services, and other priorities, such as supply chain issues and focusing on profitability in a market downturn.

Even with competing demands, interviews for this report revealed that several major telco operators, especially European Tier One operators, are moving forward with the climate change response by ambitiously increasing sustainability weightings for RFPs and/or demanding greater

accountability in tracking and reporting supplier and specific product carbon emissions. While these operators are increasingly demanding more sustainable practices from telco equipment providers, the operators are also making investments in their own operations that benefit the entire ecosystem, such as switching to renewable energy for purchased electricity.

Direct research also revealed some interesting trends addressing the complexity of sustainability among telco equipment providers. For example, even some of the sustainability leaders in this report revealed similar internal tensions when addressing sustainability initiatives. For example, across the landscape of network equipment vendors, the Chief Technology Officer (CTO) and R&D staff typically want the newest, most technologically-advanced equipment possible, using materials and manufacturing processes that optimize equipment technological performance over all attributes. Conversely, sustainability staff may be encouraging recycled materials and the use of refurbished equipment, while procurement managers are incentivized for equipment that is sourced at the cheapest cost. Even further, equipment production expectations and time to market schedules can also deter sustainability efforts, such as completing full LCAs on new products or conducting multiple design iterations or energy simulations to enhance energy efficiency and reduce lifetime CO2 emissions of equipment. Acknowledging all those challenges, the telco equipment market is still trending toward an increased focus on reducing the overall energy use and environmental impact of its products.

Sustainable impact can be achieved by telco network equipment providers through the following:

- Low carbon design or eco-design (e.g., light-weighting equipment, material selection, designing for disassembly and recycling, simulation & modeling of energy use of equipment during the design phase, and reducing overall energy use of portfolio equipment)
- RAN virtualization and/with AI-driven solutions (e.g., developing software that reduces energy consumption through the automation and optimization of networks)
- Sustainable manufacturing processes (e.g., reducing water use, reducing materials, and eliminating toxic inputs or solvents)
- Sustainable product packaging (e.g., reducing packaging and selecting recyclable packaging materials)
- Supply chain management platforms and supplier engagement programs (e.g., incentivizing network equipment users and telco operators to source renewable energy, weighting procurement RFPs for sustainability, using technology platforms to automate supplier engagement, etc.)
- Company variable compensation and long-term incentives tied to ESG targets and climate action
- Integrating ESG principles in the company business model

Finally, cellular infrastructure companies are also in a unique position as enablers of carbon and waste-reduction activities for other industries, through digitalization, automation, and the use of intelligent systems to monitor and manage energy and other valuable natural resources (e.g., enabling smart cities and smart manufacturing).

Company Sustainability Initiatives and Best Practices: The relative size or market capitalization of the major telco equipment companies in this report ranged from US$2 billion to US$300 billion (assessed in August 2022), and to note, the companies providing cloud services and developing software for virtualized networks had a different carbon footprint than companies manufacturing chipsets, components, and hardware. The reporting of carbon emissions was different for every company as well.

Table 12: Market Capitalization for Major Telco Equipment Vendors
(Sources: ABI Research, company websites, and annual reports)

Company	August 2022 Market Cap (US$)	2020 or 2021 Total Carbon Emissions (Scope 1, 2, and 3) in metric tons CO2e
Cisco	$197 billion	23,550,848 metric tons
CommScope	$2 billion	227,631 metric tons
Dell	$31 billion	16,536,500 metric tons
Ericsson	$25 billion	38,814,000 metric tons
Fujitsu	$26 billion	3,106,000 metric tons
Huawei	Private company	Not reported
IBM (Red Hat)	$122 billion	1,034,966 metric tons
Intel	$139 billion	32,200,000 metric tons
Mavenir	Private company	Not reported
NEC	$10 billion	6,859,000 metric tons
Nokia	$28 billion	40,983,500 metric tons
Qualcomm	$159 billion	4,458,578 metric tons
Rakuten	$8 billion	169,935 metric tons (Scope 1 and 2 only)
Samsung	$300 billion	17,400,000 metric tons (Scope 1 and 2 only, market-based)
VMware	$50 billion	347,395 metric tons
AMD (Xilinx)	$149 billion ($48 billion)	24,624 metric tons (Scope 1 and 2 only, market-based)
ZTE	$16 billion	Not reported

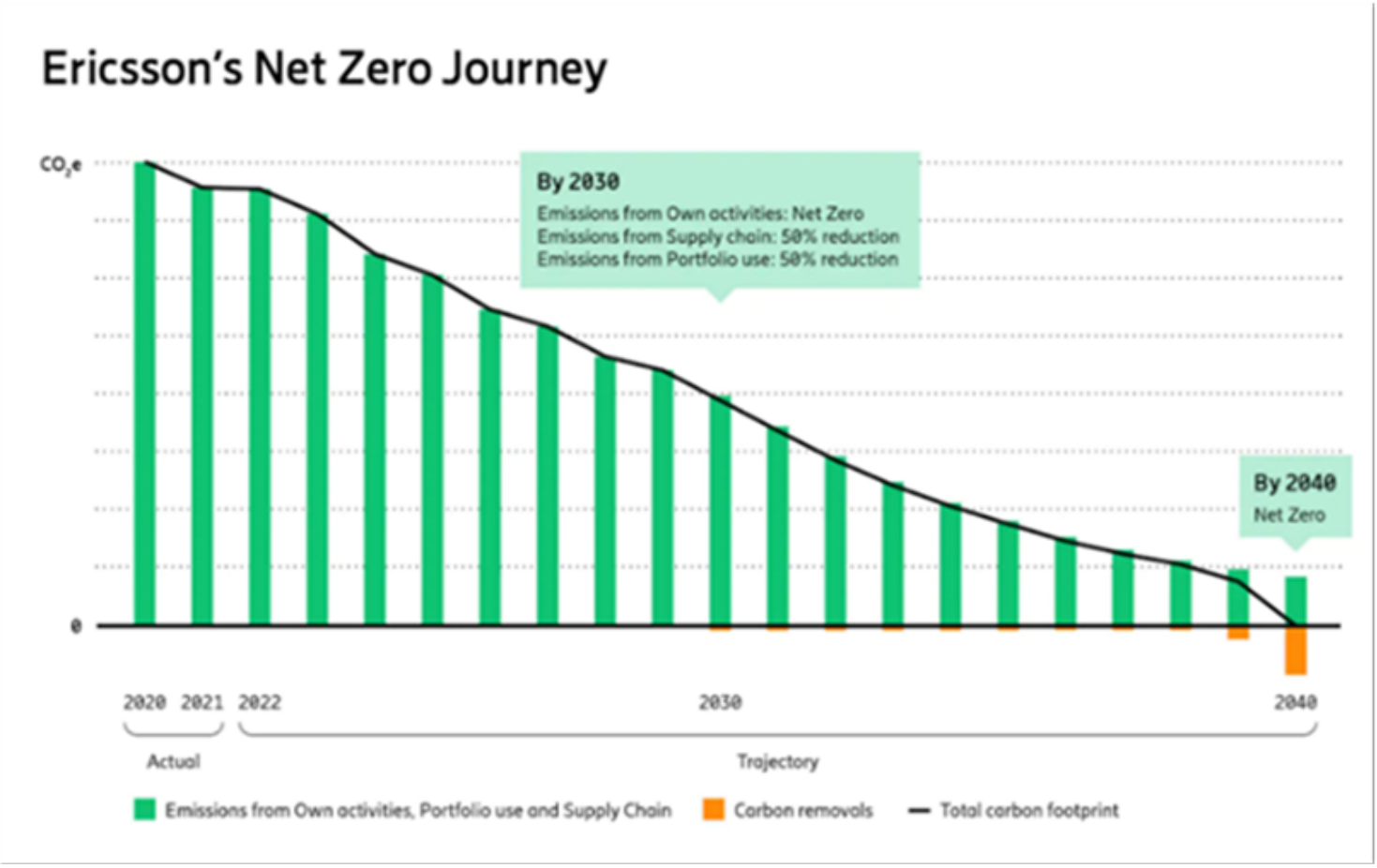
Note on the reporting of carbon emissions: The reporting of Scope 1, 2, and 3 carbon emissions varies widely across companies and industries. For example, some companies report Scope 1 and 2 CO2 emissions, with carbon offsets already included in the data, and some offer market and location-based data, while some do not report Scope 1 and 2 emissions at all (e.g., Scope 1

and 2 carbon emissions are from a company's own operations.) For Scope 3 emissions, some companies report in several categories for upstream and downstream emissions, while others do not report value chain emissions at all, or the firms choose to keep this information private. Some companies indicate in their reports that obtaining credible data for all suppliers and equipment used in the value chain is very challenging in reporting Scope 3 indirect emissions.

Understanding these differences, ABI Research seeks to pull out the best practices from across the telco equipment value chain. Here are some sustainability highlights from several major telco equipment companies that are making significant investments in sustainable technologies, platforms, and programs for reducing carbon emissions and waste.

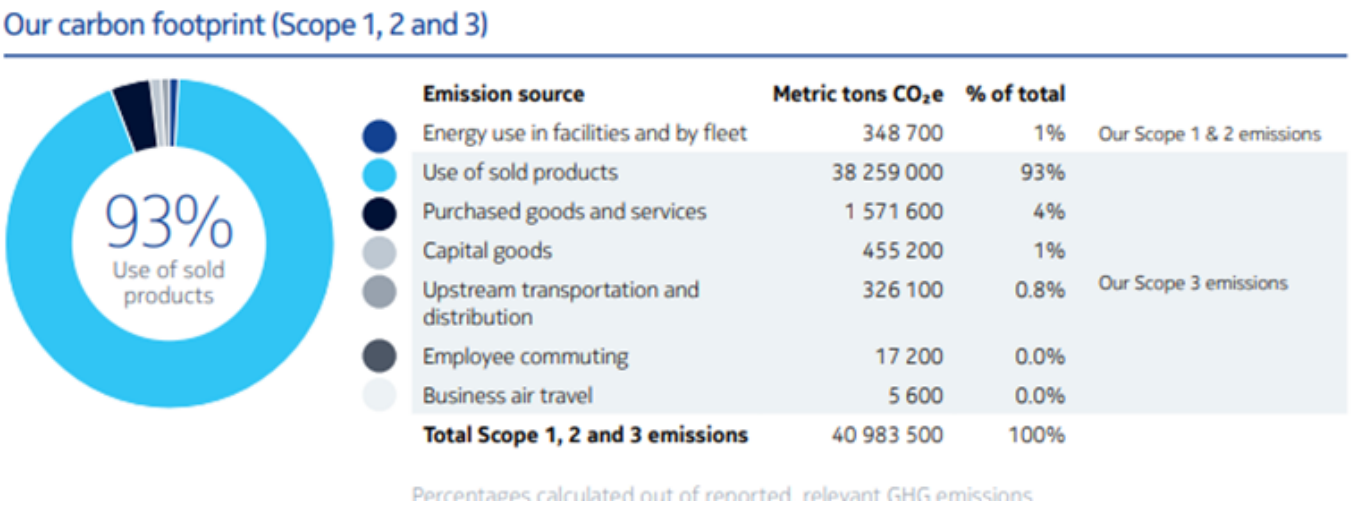
- Ericsson: Sustainability and corporate responsibility are integral to Ericsson's business strategy and initiatives. In 2019, Ericsson set a target to achieve carbon neutrality within its own operations by 2030, and the company aims to be net zero across its value chain by 2040. Ericsson also has a 1.5°C aligned Science Based Target to achieve a 35% carbon footprint reduction and energy reduction in the Ericsson Radio System product line by 2022, compared to the legacy portfolio in 2016. Additional milestones are created for reducing energy use in equipment, as Ericsson reports that 93.5% of its total carbon footprint comes from its portfolio use, 7.6% of emissions are generated from its supply chain, and 0.4% is derived from its own activities, such as buildings, manufacturing facilities, company vehicles, etc. Ericsson has also set a supply chain climate target. Though the company estimates supporting a total of more than 24,000 suppliers, it has focused in on 350 high-emitting and strategic suppliers (covering 80% to 90% of supplier emissions), requesting that these suppliers set their own 1.5°C aligned Science Based Targets by 2025. At the end of 2021, 121 suppliers had aligned targets. Moreover, Ericsson is a leader in the industry for sustainable manufacturing. The company's 5G Smart Factory in Lewisville, Texas, has received multiple global leadership awards by the World Economic Forum (WEF) as a next-generation Fourth Industrial Revolution (4IR) factory and a Sustainability Lighthouse. The factory is powered 100% by renewable electricity, and it is designed to use 24% less energy and 75% less indoor water use, avoiding 97% operational carbon emission than comparable buildings. To further reduce its own carbon footprint, Ericsson is also focusing on improving its fleet vehicle management (with a net zero goal by 2030), shifting the transport of products from air to surface, and actively managing its business travel to reduce overall emissions. Ericsson facilities use smart sensors for managing lighting and water use. Water collection systems are implemented for reducing fresh water use by 75% in the United States, while data centers in Sweden sell the excess heat generated from data center cooling solutions to local energy companies for heating district homes and water. Finally, 60% of the total credit in the loans used to develop the Ericsson 5G portfolio from European Investment Bank (EIB) and the Nordic Investment Bank met requirements for "green loans" by the EIB sustainability team. For Ericsson's Revolving Credit Facility, the rate is sustainably linked to company climate targets.

Figure 11: Ericsson's Net Zero Journey
(Source: Ericsson)



- Nokia: In 2021, Nokia announced that it would halve its emissions from 2019 to 2030, with its new targets signed off by SBTi and aligned with limiting the global temperature rise to 1.5°C. Previous targets were aligned with a 2.0°C rise. In 2021, Nokia pledged to use 100% renewable electricity by 2025. Use of sold products is 93% of the company's total carbon footprint; therefore, Nokia is addressing this in multiple ways, including product design, optimizing energy efficiency in hardware and software, modernizing materials used in equipment, and managing resources more effectively. Examples of sustainability initiatives in this area are: Nokia's ReefShark chipset used in AirScale radio products to reduce energy use up to 66%, its liquid cooled 5G base station can reduce energy consumption up to 90% and reduce CO2 emissions up to 80%, the Compact Active Antenna uses significantly less materials than legacy equipment, and cloud-based AI powers down the radio network when traffic is low, reducing energy usage by 20% with the Nokia AVA Energy Efficiency service.

Figure 12: Nokia Carbon Footprint (Scope 1, 2, and 3 Emissions)
(Source: Nokia)

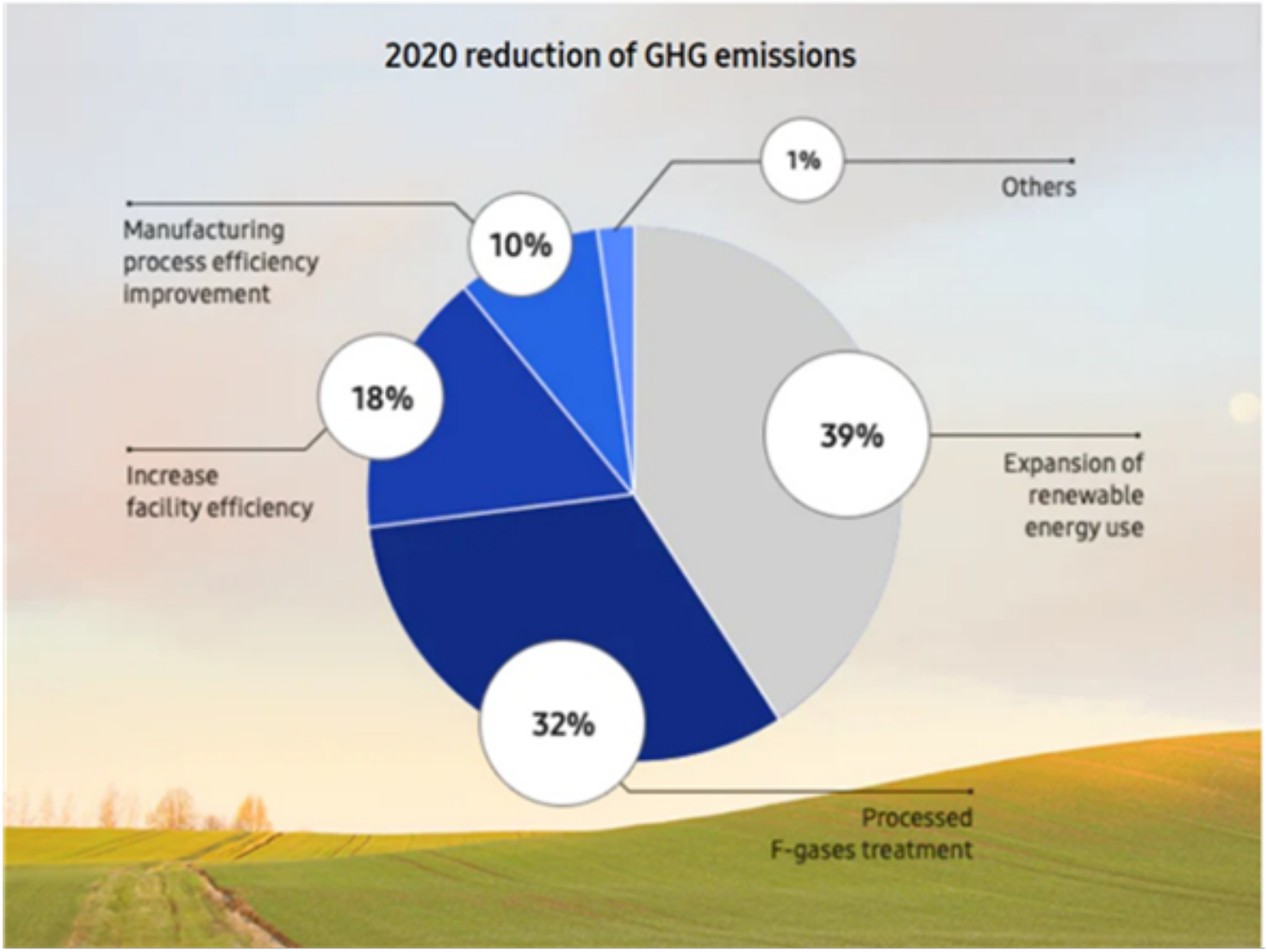


- Intel: Intel is one of the largest companies and manufacturers in this vendor assessment, with its role as an IDM and telco equipment vendor and supplier. Intel has pledged to achieve net zero GHG emissions in its operations by 2040, which will be challenging as a global manufacturer. To achieve this target, the company has also established several interim milestones, such as achieving 100% renewable energy use across global operations by 2030, investing US$300 million in energy conservation at facilities, building new factories and buildings to LEED standards, achieving net-positive water by 2030, and launching an industry-wide program to identify greener chemicals for manufacturing and developing new abatement equipment. In 2021, Intel reported the following sustainability highlights: 100% renewable electricity in the United States, Europe, Israel, and Malaysia (80% globally), 9.3 billion gallons of water saved through conservation and watershed restoration projects, 5% total waste to landfill with 65% of manufacturing waste recycled, 486 kWh electricity saved through conservation programs (with a goal of saving 4 billion kWh by 2030), and numerous other smaller actions that contributed to being recognized as No. 1 on Barron's 100 Most Sustainable list. In May 2022, Intel announced its intent to invest US$700 million to develop a new R&D mega lab for developing data center technologies, including liquid immersion cooling technologies, water use effectiveness, and heat capture and reuse. On the product side, Intel Xeon and Atom processors, as well as Intel FPGAs are used extensively in RAN, core, and edge network infrastructure in both traditional RAN and vRAN networks. With equipment used throughout the telco ecosystem, Intel aims for stringent eco-design criteria for its silicon in meeting ambitious performance-per-watt metrics for products. According to the company's questionnaire for this report, Intel 4th generation Xeon Scalable processors (Sapphire Rapids) will deliver up to 2X capacity gains for vRAN workloads versus 3rd gen Xeon, and it will provide this gain without increasing power use. This gain effectively gives operators up to 2X performance-per-watt improvement. According to Intel, other technologies in Intel products and solutions that enable RAN industry energy savings are:

- Real-time telemetry data collection of key CPU subsystem components (e.g., CPU loading/utilization).
- Dynamic power management controls (P-states, C-states). These include knobs for frequency/voltage control at a per-core level (P-states), multiple C-state options for putting the cores in varying levels of dormancy (e.g., sleep, hibernate, etc.), each with different wake-up latency and power savings during dormancy.
- ISA and built-in acceleration and optimized tool kits for AI/ML in Xeon CPUs enable implementing ML-based algorithms for predictive approaches to energy savings (and other RAN optimization applications, such as radio resource management, traffic steering, etc.).
- Enablers for applications to access these technologies in the Silicon, e.g., Linux drivers and platform software, DPDK, FlexRAN reference software for Distributed Unit (DU) stack, etc.
- ZTE: ZTE has released sustainability reports annually since 2009, and a significant driver in ZTE's climate action is to achieve "carbon peak" before 2030 and carbon neutrality by 2060. In 2021, ZTE launched its carbon emissions strategic planning project globally and established a team led by the company's Chief Strategy Officer (CSO) to carry out the company's implementation of the project. The project covers R&D, manufacturing operations, offices, and subsidiaries in China and overseas. As part of the project, ZTE invited external organizations to conduct staff learning programs with the themes, "Interpretation and Application of ISO 14064 GHG Standard on Climate Change and Carbon Emissions" and "Science Based Targets initiative (SBTi)." To reduce its overall emissions, ZTE has also introduced its iEnergy energy management system for reducing energy consumption by product.
- Samsung: Samsung is the largest company in the telco equipment vendor assessment by market capitalization. In a September 2022 announcement, Samsung pledged to achieve net-zero carbon emissions across its Device eXperience (DX) Division by 2030 and across global operations and the Device Solutions (DS) Division by 2050 (e.g., Memory, System LSI, and Foundry businesses). Also, like industry competitors, Apple and Sony (for mobile devices), and Nokia and Intel (for network equipment), Samsung recently announced that it had joined the RE100. (Note: RE100 is a global corporate renewable energy initiative with businesses committed to sourcing 100% renewable electricity.) According to the U.S. Energy Information Administration's (EIA) report, South Korea is ranked the fourth-largest importer of coal, after China, India, and Japan, and nearly 90% of South Korea's total energy use comes from fossil fuels. Therefore, committing to the RE100 is a significant step, as RE100 cites South Korea as one of the most challenging countries for sourcing renewable energy. Samsung Electronics plans to run all its operations outside of South Korea, as well as the DX Division, with renewable energy within 5 years. Samsung has also created a new Circular Economy Lab. By 2030, Samsung plans to establish a system in which minerals extracted from all collected used batteries can be re-used. By 2030, the company aims to have 50% of the plastic used in its resin to have recycled resin and, by 2050, this number will increase to 100%. On the network equipment side, Samsung reports that its latest generation mMIMO radios are up to 30% smaller and lighter and use up to 20% less energy. Company-wide, Samsung plans to obtain a platinum-level Zero Waste to Landfill

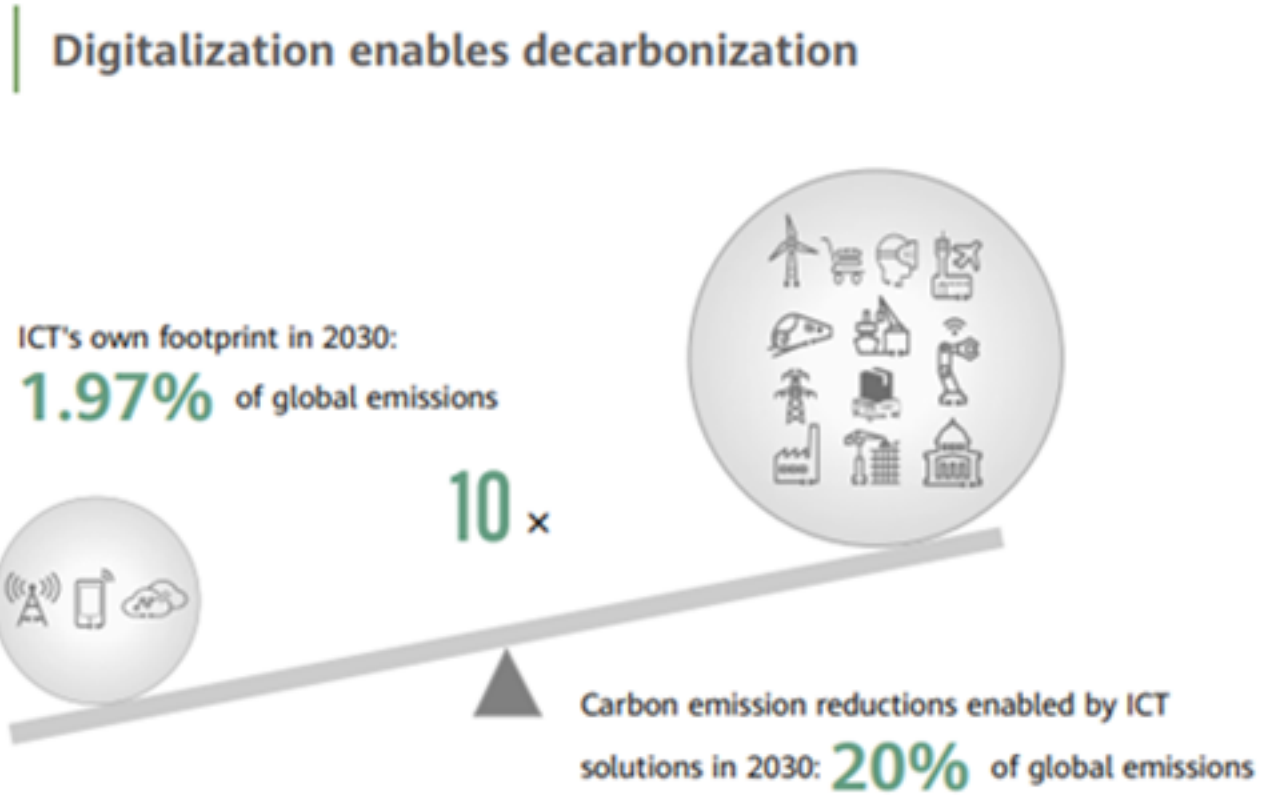
- Certification for all global operations by 2025.

Figure 13: Samsung's 2020 Reduction of GHG Emissions
(Source: Samsung)



- Huawei: With a commitment to building "simplified, green, and intelligent" Information and Communications Technology (ICT) infrastructure, Huawei seems to be taking intentional steps toward building greener networks. In addition to making recommendations for a joint industry standard for energy efficiency, Huawei also recently launched its new green development solution. According to Huawei's third-party research, data traffic is also expected to increase by 13X between 2020 and 2030. That means that if no changes are made by telco operators, then the industry's energy consumption and carbon emissions could increase by 2.3X. Huawei's green development solution is aimed at facilitating change by helping telco operators improve energy efficiency and reduce CO2 emissions, as ICT infrastructure continues to evolve from 5G and F5G to 5.5G and F5.5G. ABI Research views Huawei as having strong potential as a company for reducing global carbon emissions, due to its ability to scale sustainable impact across China (the world's second-largest economy) and in more than 170 countries and regions.

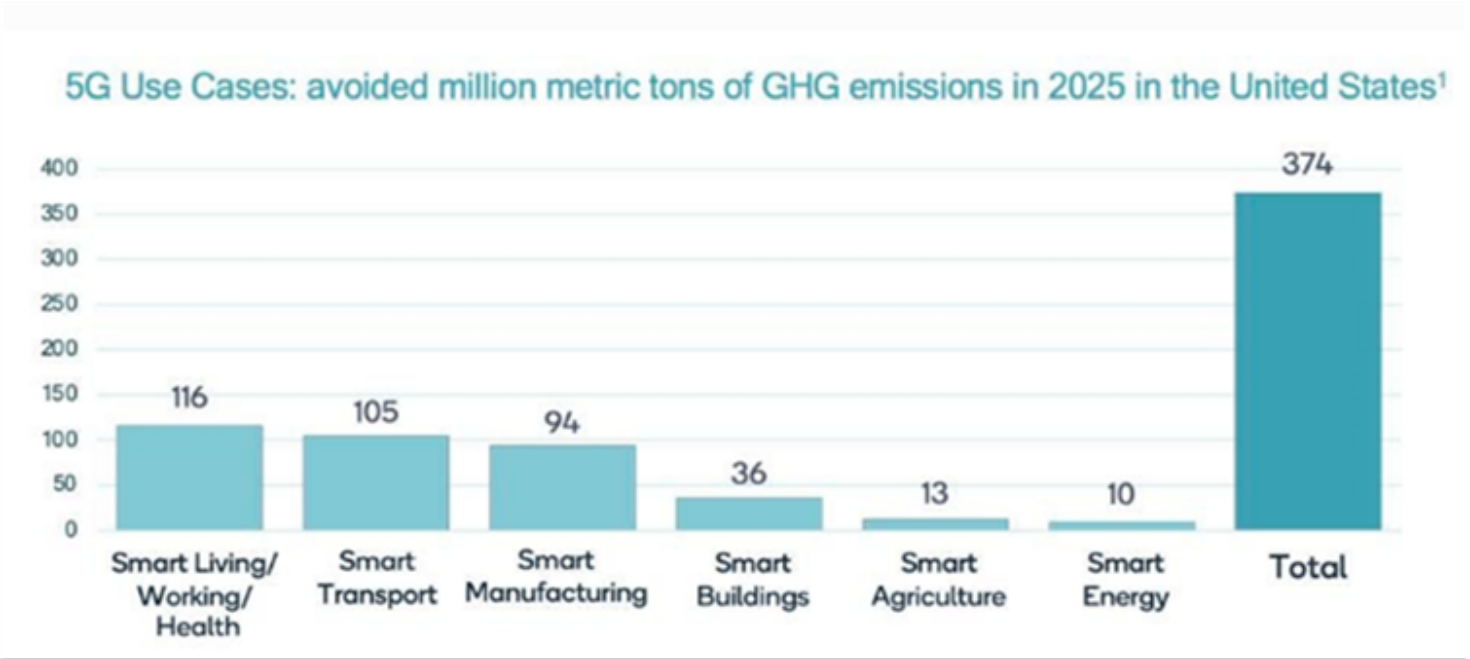
Figure 14: Huawei Technologies: Green Development Program
(Source: Huawei)



- Qualcomm: Qualcomm has committed to net-zero global emissions for Scopes 1, 2, and 3 carbon emissions by 2040. To reach its goals, the company has several 1.5°C aligned milestones, including: to reduce Scope 1 and 2 CO2 emissions by 50% by 2030 from a 2020 base year, to reduce Scope 3 CO2 emissions by 25% by 2030 from a 2020 base year, and to reduce Scope 1 and 2 CO2 emissions by 30% compared to a 2014 base year. Qualcomm is already purchasing 100% renewable energy for its headquarters in San Diego, and it plans to reduce its emissions by using renewable energy, decarbonizing its operations, and using minimal Renewable Energy Certificates (RECs) and carbon offsets to neutralize any remaining emissions. For manufacturing operations, factories in China, Germany, and Singapore have been ISO 14001 (Environmental Management System Standard) certified since 1999. Furthermore, the German facility has been ISO 50001 (Energy Management System Standard) certified since 2014, and the company plans to extend ISO 50001 certification to the Singapore and China facilities by 2023. In recent years, Qualcomm has made a multitude of investments in reducing its overall environmental impact, including green building investments (e.g., LEED certifications, energy-efficient lighting, heating and cooling, and efficient data centers), energy-efficiency measures, Power Purchase Agreements (PPAs) for renewable energy, technology improvements and power optimization in their products and chipsets, deliberate cutting of waste in the Qualcomm IT system, using water more efficiently, and using an internal carbon pricing mechanism for

- making carbon and waste-reducing decisions. Finally, in a 2021 Qualcomm Technologies Inc. report, "Environmental sustainability and a greener economy: The transformative role of 5G," the company highlighted the many ways that 5G technology can enable sustainable benefits. These included creating up to 300,000 new green jobs by 2030, enabling the reduction of 374 million metric tons of GHG in the United States, saving 410 billion gallons of water nationwide, reducing pesticide use in the United States by 50%, and increasing fuel efficiency by 20% with lane and traffic management systems enabled by Cellular Vehicle-to-Everything (C-V2X).

Figure 15: Qualcomm 5G Use Cases:
Avoided Million Metric Tons of GHG Emissions in 2025 in the United States
(Source: Qualcomm)



- Cisco: Cisco develops, manufactures, and distributes networking equipment, software, telecommunications equipment, and other technology solutions, with some of its premier products in the IoT, domain security, videoconferencing, and energy management (e.g., products like OpenDNS, WebEx, Jabber, Duo Security, and Jasper). Overall, Cisco is one of the most sustainability-focused companies in this vendor assessment. Putting its company commitment to ESG-related topics in writing, Cisco published a 96-page 2021 Cisco Purpose Report stating the company's mission "to Power an Inclusive Future for All." With 79,500 employees in 95 countries generating roughly US$50 billion in revenue in 2021 (e.g., ranking 63rd in the world on the Fortune 100), Cisco is a technology company that can positively affect its entire ecosystem and the global marketplace with its ambitious goals for an inclusive, sustainable future. More specifically, Cisco has committed to be climate neutral for all global Scope 1 and 2 emissions by 2025. In September 2021, Cisco pledged to reach net-zero GHG emissions across the value chain (including Scope 1, 2, and 3 emissions) by 2040. Strategies for reducing company emissions include continuing to increase the energy efficiency of Cisco products through innovative design, increasing the

- use of renewable energy (e.g., through PPAs, green utility power programs, and RECs), investing in carbon removal solutions, embracing hybrid work, and integrating sustainability and circularity across business units. Finally, Cisco reports that 96% of Scope 1 and 2 emissions come from electricity use, therefore reducing overall electricity consumption, and increasing the use of renewable electricity are two major components in the strategy to reach carbon neutrality in just 2.5 years.

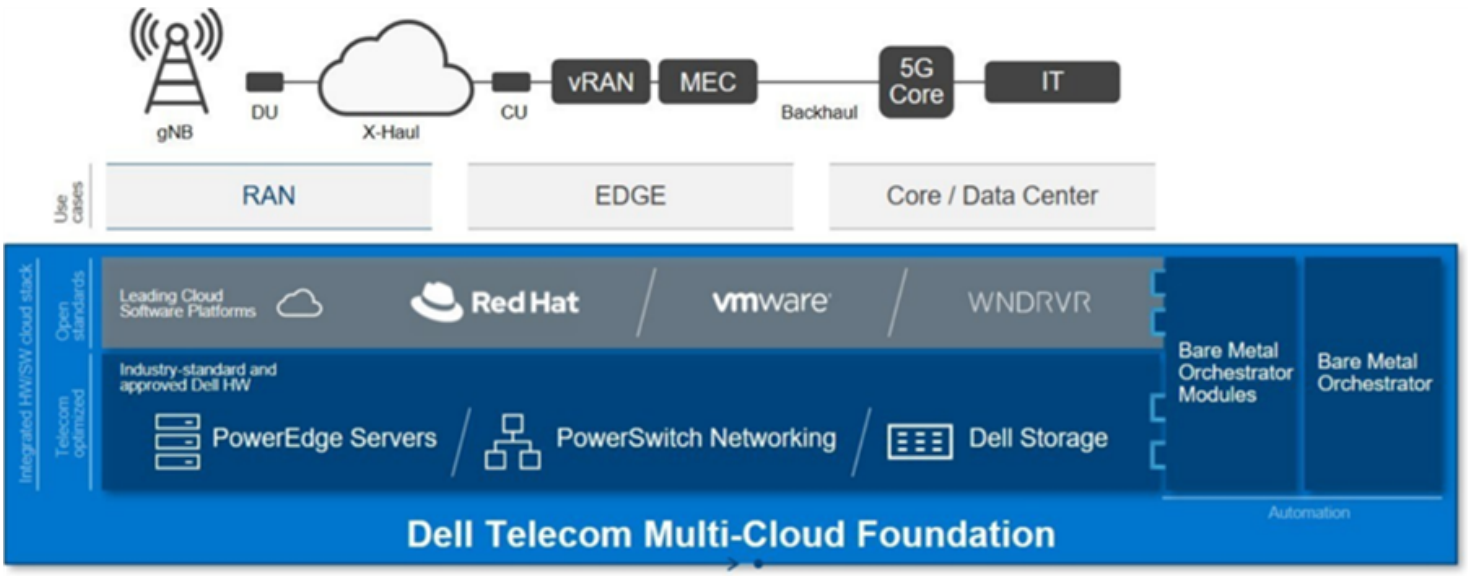
Figure 16: Cisco Sustainability Goals and Initiatives
(Source: Cisco)

- Fujitsu: Fujitsu is the world's sixth largest IT company by revenue and the largest in Japan. Fujitsu has stated that it will work to achieve zero carbon emissions from its own operations by 2050. The company has also pledged to help decarbonize customers and society through its digital technologies. As goals for FY 2022, Fujitsu pledged to fulfill social responsibilities and to help resolve environmental challenges. Specifically, Fujitsu aims to reduce GHG emissions at its sites by 37.8% or more from a 2013 base year level (reducing by -4.2% each year). In April 2020, Fujitsu Group established a Sustainability Management Committee, which leads the charge for global sustainability initiatives. The Fujitsu Group has also created Environmental Management Systems (EMS) using the International Organization for Standardization (ISO) 140001 international framework. In 2021, Fujitsu had acquired ISO 14001 certification for a total of 47 companies of Fujitsu and its Japanese group companies. (Note on ISO 14001 Environmental Management Systems: This international certification is given to organizations that develop systems for reducing their environmental footprint.)
- VMware: VMware is a virtualization and cloud computing technology company that provides 5G network services to any could-based application from the core network to the RAN edge. Sustainability is essential to VMware's core values as a company working to decarbonize the world through digital infrastructure. VMware has been a carbon-neutral company since 2018, as certified by The Carbon Neutral Protocol, and the company aims for net-zero carbon emissions by 2030. The company has set science-based targets to help reach its goals, and VMware has purchased electricity from 100% renewable energy

- sources since 2019. VMware reports that 190,901 MWh of total renewable energy was purchased in FY 2022, with 1.2 billion metric tons of carbon emissions avoided by using VMware solutions. Finally, VMware encourages customers to partner with sustainable cloud providers to help reach sustainability and supply chain decarbonization goals. VMware Zero Carbon Committed providers have set targets to power their data centers with 100% renewable energy, or the company has aimed to be carbon neutral by 2030, and they are listed on the VMware company website.
- AMD- (Xilinx): Xilinx, Inc. is an American technology and semiconductor company based in San Jose, California. In February 2022, AMD closed a record chip industry deal with a US$50 billion purchase of Xilinx. Prior to the closing, Xilinx, had committed to a climate target of reducing carbon emissions by 25% CO2 reduction per employee over 10 years from 2016 to 2025 with a baseline of CY 2025. Xilinx had also been members of the Environmental Protection Agency's (EPA) Green Power Partner Program since 2005, purchasing Renewable Energy Certificates (RECs) in the United States and Singapore for purchased electricity. Prior to the acquisition, Xilinx had also reported 3 years of Year-over-Year (YoY) reductions in water use and 3 years of increasing solid waste recycling rates versus total waste generated.
- Rakuten Symphony (Altiostar): In 2021, Rakuten Group announced that it would acquire U.S.-based Altiostar Networks (developer of 4G and 5G Open vRAN solutions) to form a partnership for building out software-centric, virtualized services for the mobile industry worldwide. Rakuten has joined the RE100 and pledged to source 100% renewable energy for Rakuten Group Inc. offices, data centers, and fulfillment centers by 2025. The Group has also committed to reducing GHG emissions from electricity consumption to zero Scope 2 emissions by 2025. In 2021, Rakuten received and A- in the CDP's Climate Change rating, and the company participates in several sustainability-related market indices, such as the Dow Jones Sustainability World Index, the Financial Times' FTSE4Good Index Series, and the MSCI Japan Empowering Women Index (WIN).
- IBM (Red Hat): In 2019, IBM acquired open-source innovator Red Hat for US$34 billion. In 2021, sustainability-leading mobile operator, Telefónica, selected IBM to implement its first ever cloud-native 5G core network platform (built with IBM Cloud Pak for Network Automation, Red Hat OpenShift, and Juniper Networking). For its own operations, IBM has pledged net-zero GHG emissions by 2030. To achieve this goal, the company will reduce its GHG emissions by 65% by 2025 compared to a base year of 2010. The company will also purchase 75% renewable energy electricity worldwide by 2025 and 90% by 2030. Moreover, IBM Research has launched a Future of Climate initiative, which uses a combination of AI, hybrid cloud, and quantum computing to apply science to complex climate change-related problems, such as the increasing carbon footprints of cloud workloads and data centers, methods to accurately model climate change, and the development of new climate technologies, such as carbon capture and storage. In 2019, IBM was named a founding member of the Climate Leadership Council, and it fully supports "its bipartisan plan for a carbon tax with 100% of the net proceeds paid to citizens as a carbon dividend."

- CommScope: CommScope is an American network infrastructure and technology provider headquartered in Hickory, North Carolina. In 2021, CommScope established several objectives and targets for multiple ESG-related areas. To reduce its environmental impact, CommScope aimed to reduce 2019 GHG emissions by 4% by year-end 2021, and the company pledged to reduce 2019 energy consumption by 4% by year-end 2021. The company set a target for recycling waste to 85% by year-end 2021 and pledged to continue maintaining ISO 14001 and ISO 45001 certification at selected facilities. The company also set goals for more sustainable products, including leveraging eco-design, developing LCA and EPD programs for International Signaling Point Codes (ISPC) products. For the supply chain, CommScope pledged to ensure that 100% of "high risk" suppliers completed a Corporate Responsibility (CR) audit. On the business strategy side, in October 2020, CommScope acquired the vRAN portfolio from Phluido, and in 2021, the company announced its plan to spin off its home networks business.
- Dell: Dell Technologies is providing new telecommunications products and services that support an open telco ecosystem and help CSPs facilitate the transition to open, cloud-native networks (see Figure 17). To address climate change, Dell has pledged to reach net-zero GHG emissions across its value chain, including Scope 1, 2, and 3 emissions, by 2050. Dell also has set multiple milestones for reaching this goal, including cutting 2020 Scope 1 and 2 emissions by 50% by 2030, improving the energy efficiency of operations, and using 75% renewable energy electricity by 2030 and 100% renewable energy globally by 2040 (Dell currently uses 55% renewable sources for electricity across its facilities). To reduce Scope 3 emissions, Dell is working directly with direct material suppliers to achieve a reduction target of 60% per unit revenue by 2030 (a target approved by the SBTi). For Dell and other telco equipment providers, the biggest proportion of Scope 3 emissions is derived from the downstream emissions related to the use of products. Since 2013, the company has had a goal of reducing the energy intensity of its product portfolio by 80% (from FY 2012 to FY 2021). In the FY 2020 report, Dell had reached almost 70%, and it expects to move even closer to the goal in the final year of assessment. Furthermore, Dell's primary business units focus on computers and technology solutions, including laptops, desktops, gaming computers, monitors, workstations, servers, and more. Dell has established goals to accelerate its initiatives for sustainable packaging and circularity. By 2030, for every product that a customer buys, Dell will reuse or recycle an equivalent product. The company has also pledged that, by 2030, 100% of Dell packaging will be made from recycled or renewable material, and more than half of product content will be made from recycled or renewable material. Finally, Dell is a corporate leader among the more than 90 vendors assessed that understands that an "emphasis on ESG measures ensures that while Dell has accomplished its business goals, the company also delivers positive results for all of its stakeholders," including customers, employees, and investors.

Figure 17: Dell Telecom Multi-Cloud Foundation
(Source: Dell)



- Mavenir: Mavenir is a telecommunications software company that was created in 2017 following a complex three-way merger of previously existing companies and technologies (its main predecessor companies were founded in 1997, 2005, and 2007). Mavenir offers fully virtualized 5G-ready-cloud-native software solutions. According to its Corporate Responsibility Report 2021, Mavenir had more than 4,450 global employees and contractors servicing 250+ CSPs in more than 120 countries by the end of 2020, with additional growth in 2021 to 2022. Mavenir is primarily a software company, with some hardware manufacturing; therefore, its environmental impact is expectedly lower than the larger manufacturers in the vendor assessment. The company also reports several environmentally related initiatives, such as following ISO 14001 best practices for environmental management. It has also participated in EcoVadis annual assessments (since 2014), Quest Sustainability (since 2017), CDP (since 2018), and the United Nations Global Compact (since 2021). Mavenir tracks its carbon emissions, though its methodology is more limited than its public company competitors. Mavenir tracks and reports Scope 1 diesel, Scope 2 electricity–facilities, Scope 2 electricity–data centers, and Scope 3 travel carbon emissions. In 2020, the company announced and then dropped its filing for an Initial Public Offering (IPO). Mavenir subsequently raised US$500 million by offering a minority equity stake in the company to Koch Strategic Platforms, a subsidiary of Koch Industries.
- NEC: NEC Corporation is a Japanese multinational ICT company headquartered in Tokyo, Japan. NEC has pledged to progress steadily toward zero GHG emissions by 2025. In May 2021, NEC increased its science-based targets from the “well below 2°C” level to the “1.5°C” level. This changed its Scope 1 and 2 science-based targets to reduce GHG emissions by 55% compared to FY 2018 by FY 2031. For Scope 3 emissions, NEC aims to reduce GHG emissions by 33% compared to FY 2018 levels by FY 2031. This includes reducing emissions from purchased goods and services, from fuel and energy related activities not included in Scope 1 and 2 emissions, and from the use of sold products. Finally, in May 2021, NEC

- joined the RE100, aiming to use only renewable energy electricity by 2050. In 2021, NEC reported 8.6% of electricity use was sourced by renewable energy.

Figure 18: NEC Progress toward Science-Based Targets
(Source: NEC)

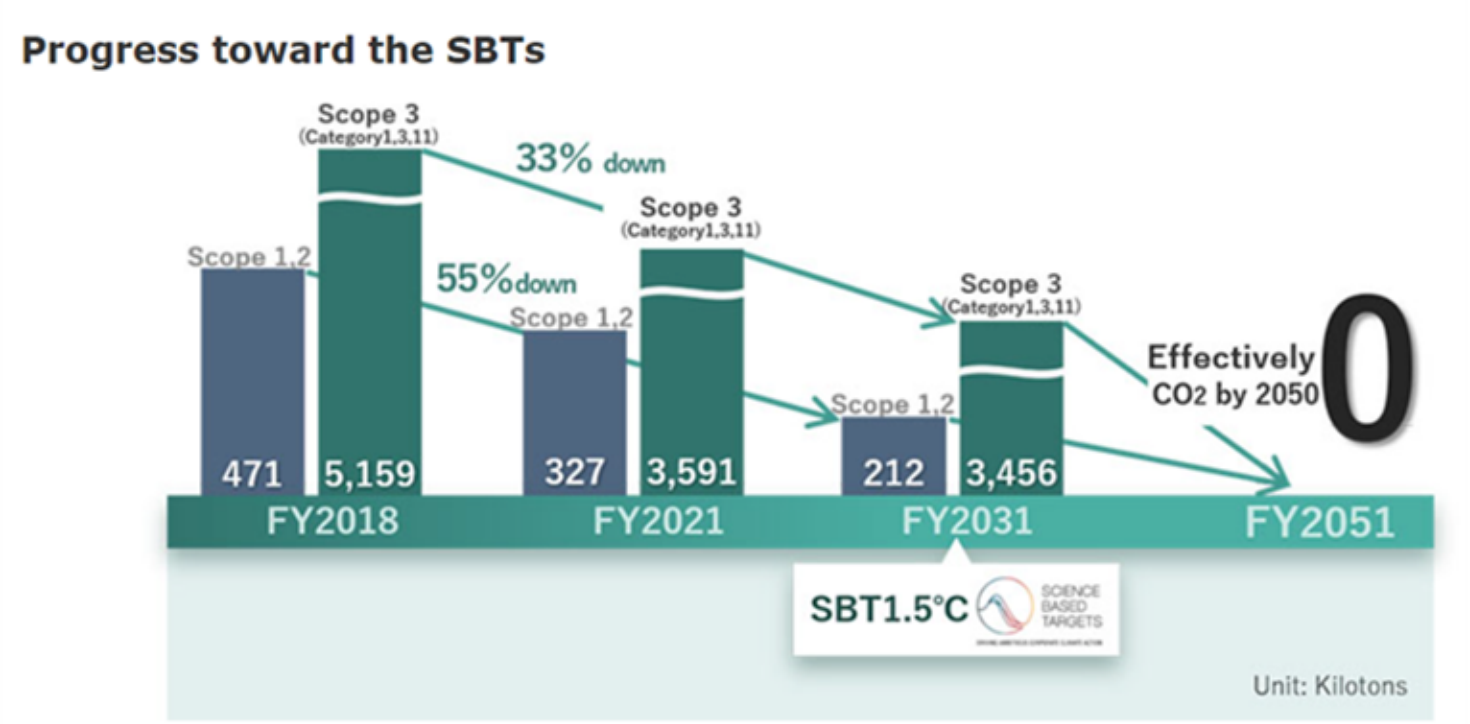


Table 13: Climate Target Summary for Major Telco Equipment Suppliers

(Sources: ABI Research, company websites, and annual reports)

Company	Target Year Carbon Neutral (Scope 1 and 2 emissions)	Target Year Net Zero (Scope 1, 2, and 3 emissions)
Cisco	2025	2040
CommScope	N/A	N/A
Dell	N/A (Cut 2020 Scope 1 and 2 emissions by 50% by 2030)	2050
Ericsson	2030 (plus Scope 3 business travel and employee commuting)	2040
Fujitsu	2050	N/A
Huawei	N/A	N/A
IBM	2030 (residual emissions less than 350,000 metric tons CO2e by 2030)	N/A
Intel	2040	N/A
Mavenir	N/A	N/A
NEC	2050	2050
Nokia	2030	2050
Qualcomm	2040	N/A
Rakuten	2025 (Scope 2 emissions)	N/A
Samsung	2030 (Scope 1&2 emissions for Device eXperience (DX) Division)	2050
VMware	Carbon neutral since 2018	N/A
AMD	N/A (-25% per employee by 2025)	N/A
ZTE	N/A	N/A

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