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Sustainable Telecom: Green Network Design and Energy Optimization through AI

Explore how leveraging AI, intelligent cooling, and power analytics can minimize energy consumption and the telecom infrastructure's carbon footprint.

Whitepaper

Executive summary

Telecommunications networks are among the most energy-intensive forms of digital infrastructure, with the radio access network (RAN) consuming the majority of network energy. Industry roadmaps and organizations have now outlined clear decarbonization pathways, including a 45% reduction in ICT sector emissions by 2030 in line with the 1.5°C target. Telecom operators have already started turning the energy curve through efficiency and renewable energy procurement; GSMA's 2024 report states that operators acquired 50 TWh of renewables in 2022, increasing the share of purchased renewable electricity from 14% in 2019 to 33% in 2022.

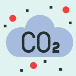
This white paper outlines a comprehensive, actionable blueprint for sustainable telecom networks that combines AI-driven energy optimization, intelligent cooling, and power analytics across RAN, core, and site infrastructure. It summarizes current standards (3GPP, ETSI, ITU), showcases successful vendor strategies, and provides an actionable maturity model, architecture patterns, KPIs, and a 24-month transformation plan. The blueprint is intended for large service-based IT companies working in partnership with operators, tower companies, and hyper-scalers to provide tangible energy cost (OPEX) and carbon savings while preserving service quality.

Industry context and imperatives

The energy and emissions challenge

RAN dominates energy use: Multiple studies and operator benchmarks consistently indicate that **~70-80% of mobile network energy** is consumed in the RAN layer (radios, baseband, power amplifiers).

Operational emissions trend: Despite exponential traffic growth, **operational emissions have remained relatively flat since 2019**, driven by energy efficiency programs and increased renewable electricity.

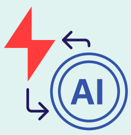


Scope 3 significance: ~75% of mobile industry emissions are Scope 3 (value chain), underscoring the need to engage suppliers and customers as part of any meaningful reduction plan.

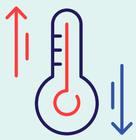
Policy and standards trajectory

- **ITU L.1470** provides **sectoral emissions trajectories** compatible with the Paris Agreement, calling for a **~45% reduction in ICT emissions by 2030.**
- **3GPP and ETSI** have embedded energy-efficiency features into 5G/5GAdvanced (e.g., **advanced sleep modes, DRX/DTX, energy-aware management)** and management studies (TR 32.972; TR 28.913).
- Regional initiatives emphasize **transparent reporting, benchmarking, and net-zero roadmaps;** the EU's ICT environmental impact programs and ITU's Green Digital Action expand methodologies and accountability.

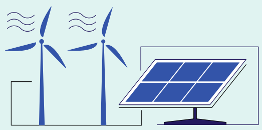
Strategy overview: A three-pillar blueprint



AI native energy optimization
Use AI/ML in RAN and sites for traffic forecasting, dynamic resource turn-off, parameter tuning, and predictive maintenance through ORAN rApps/xApps and traditional OSS. Results from vendor data and trials indicate 20-30% network energy conservation without compromising quality of service when AI control is layered on top of existing power-saving functions.



Smart cooling and thermal engineering
Optimize auxiliary energy fans, CRAC/CRAH, cabinet HVAC via AI-assisted cooling management, free cooling, variable-speed components, and natural/hybrid cooling systems. Trials in data centers and telecom outdoor shelters indicate significant energy savings in cooling, with AI-optimized systems and free-cooling units enhancing efficiency and reducing thermal risk.



Power analytics and hybrid renewable systems
Apply end-to-end power analytics for AC/DC power chains, rectifiers, batteries, and on-site generation. For off-grid/poor-grid sites, use solar-diesel battery hybrids with enhanced storage and EMS, providing 50-80% diesel fuel savings and OPEX cost reductions with enhanced availability. For off-grid/poor-grid sites, use diesel battery hybrids.

Technical architecture

A. AI-native RAN energy control

Design goals: Align capacity with demand; minimize static consumption; safeguard quality of service/SLAs.

Key components

Near RT RIC xApps: Real-time control (100 ms-1s) for cell on/off, carrier shutdown, RF channel recon fig, ASM choice based on KPI telemetry (PRB usage, RSRP/RSRQ, BLER, handover success).

Non RT RIC rApps: Long-horizon policies (minutes-hours) using forecasting (LSTM/Prophet-like models) to produce intent for night/off-peak consolidations and MIMO antenna selection; forwarded to near RIC for enforcement. RT RIC horizon policies (minutes–hours) use forecasting (LSTM/Prophet-like models) to produce intent for peak consolidations.

AI recommendation engines: Vendor implementations show 12%+ savings by adjusting parameters, sleep scheduling, and balancing UX impact.

Standards alignment

Map controls 3GPP energy capabilities (DRX/DTX, micro/macro sleep), and ETSI TR best practices for telemetry and management.

Traffic-aware base station sleeps with cell zooming and RIS (research indicates DLRL methods can be used to optimize delay/energy tradeoffs).

Smart RF channel reconfiguration for MIMO to decrease active chains during low load conditions (App with Deep Q-Learning).

B. Smart cooling and thermal optimization

Design goals: Lower PUE-like site metrics; minimize auxiliary energy use; protect electronics.

Cooling stack

- **AI-enhanced thermal control:** Sensor fusion (temp, humidity, workload) to **modulate airflow, set points, and free-cooling windows in shelters and edge sites**, with technologies borrowed from hyperscale data centers.
- **Free cooling units and variable-speed compressors:** Proven telecom-grade products leverage ambient conditions to reduce mechanical cooling duty cycles.
- **Natural/hybrid designs** (closed cold aisles, smart dampers): Reported **double-digit annual efficiency improvements** and significant savings in low-temperature regimes.

Engineering notes

- Use **cabinet solar loading models and acoustic constraints** to size cooling and airflow; edge sites require quiet, resilient designs.
- Integrate **thermal alarms** into OSS/NMS and RIC pipelines for proactive performance management.

C. Power analytics and hybrid energy systems

Design goals: Transparency of energy flows; right-size backup; decarbonize off-grid/poor-grid sites.

Analytics and EMS

- Deploy site-level **power analytics** to capture rectifiers, batteries (SoC/SoH), generators, and renewable inputs; prioritize hard-power control to safely deenergize idle equipment.
- Adopt modular **hybrid systems** (solar + battery + diesel) to reduce fuel use; reported cases show **up to ~80% diesel reduction** in telecom tower applications.
- Literature reviews confirm that hybrid architectures improve reliability and cut emissions across diverse geographies.

Implementation framework

1 Maturity model (5 Levels)

Level	Characteristics	Typical savings
L1: Baseline	Static PSFs, manual tuning; limited telemetry	2-5% (process)
L2: Telemetry ready	KPI collection, energy counters, site audits	5-10%
L3: AI-assisted ops	rApps/xApps piloted; smart cooling pilots; power analytics dashboards	10-20%
L4: Closed loop automation	Multivendor AI policy enforcement; EMS integration; hybrid power at target sites	20-30%
L5: Net-zero aligned	Emissions accounting; renewable PPAs; embodied carbon design; continuous optimization	30%+ plus Scope 2 reductions

Savings ranges are consistent with **vendor claims and field trials** showing that AI energy management achieves 15-30% reductions, and cooling optimizations further reduce auxiliary loads.

2 12-24 month roadmap

Months 0-3 : Baseline and governance

- Establish **energy and sustainability office;** align with **ITU L.1470 trajectories; set SBT-aligned targets.**
- Conduct **RAN energy benchmarking** (including radios, basebands, rectifiers, and cooling) using industry guides.

Months 4-9 : Pilot AI and cooling

- **Launch ORAN energy xApps pilots for cell/carrier shutdown, ASM selection in two markets (urban + suburban).**
- **Retrofit free-cooling and variable-speed upgrades in 50 shelters; integrate thermal AI controllers.**

Months 10-15 : Scale power analytics and hybrids

- **Roll out AV Alike energy analytics across 5,000 sites; enforce hard power control policies; publish monthly energy scorecards.**
- **Deploy solar-diesel battery hybrids at 10% of off/poor-grid towers; target ≥60% diesel runtime reduction.**

Months 16-24: Close loop and report

- **Integrate NonRT RIC policies with OSS/NMS for automated intents; expand to multivendor environments.**
- **Publish CDP/ITU-aligned emissions disclosures and GSMA net zero progress.**

KPI suite and measurement

Network energy KPIs

Energy per GB (kWh/GB) by RAT/band: track effects of 5GAdvanced features and AI optimization.

RAN energy share (% of total) and **site auxiliary ratio** (% cooling, rectifiers, batteries). (Benchmarks indicate **~80% RAN share** in many contexts.)

Sleep ratio and reactivation delay distribution to manage delay-energy tradeoffs in ASM.

Cooling and thermal KPIs

Cooling energy ratio (% of site energy), **free cooling hours, ΔT across cabinets, fan power index;** AI-enhanced cooling targets reductions seen in hyperscale studies.

Power and emissions KPIs

Diesel runtime reduction, fuel liters avoided, renewable fraction (%), Scope 2 (market-based) emissions via RECs/PPAs; track against **ITU L.1470 trajectories.**

Security, resilience, and compliance considerations

Zero trust in ORAN control loops: Secure RIC/xApp/rApp pipelines for intent enforcement to prevent malicious or unsafe shutdowns.

Failsafe guardrails: Enforce **quality-of-service minimums (throughput, latency, coverage) and fast-wakeup policies** during load spikes; NEC deployments highlight **customer experience feedback loops** for safe energy savings.

Regulatory reporting: Align disclosures with **CDP, GSMA** frameworks, and national ICT emissions tracking programs led by **ITU/World Bank.**

Business case and benefits

OPEX savings: AI energy optimization and innovative cooling have **demonstrated double-digit percentage** reductions in electricity bills; hybrid power solutions deliver **fuel savings of 68-80% and >90% reduction in generator runtime** in field cases.

Carbon reductions: Increased **purchased renewables** and decreased consumption directly lower Scope 2; hybrid deployments cut Scope 1 emissions at remote sites.

Network performance: Modern radios and AI-guided operations can improve energy per gigabyte while maintaining or enhancing user experience; vendors document **programmable networks that "break the energy curve."**

Case insight highlights

Vendor AI energy solutions (e.g., Nokia AVA) report up to **~30% RAN energy savings and up to ~70% cooling reductions**, with multivendor support and quick deployment.

Ericsson AI-powered RAN demonstrates **~12% annual savings** via ML-based recommendation engines and energy-aware configuration at scale.

ORAN xApps (academic/industry prototypes) show **13-35%+ savings** in simulated large-scale scenarios through hybrid ML and digital twin-assisted sleep management. RAN scale scenarios through hybrid ML and digital twin-assisted sleep management.

Note: Reported savings vary with traffic mix, site design, climate, and vendor portfolios; rigorous pilots and controlled A/B experiments are essential to validate local benefits.

Design patterns and reference architectures

1. **RAN energy intent loop**
   - **Inputs:** PRB utilization, traffic forecasts, quality-of-service metrics, thermal status.
   - **Policy:** NonRT rApp generates **energy-saving intents** (e.g., switch off capacity carriers 23:00-06:00; ASM deep sleep for Pico cells). RT **Save intents**
   - **Control:** NearRT xApps enforce via the E2 interface; guardrails monitor quality of service and trigger rollbacks.
2. **Smart cooling stack**
   - **Sensing:** Temperature, humidity, cabinet solar load, equipment heat.
   - **Optimization:** AI models modulate **supply air temperature, fan curves, and free-cooling dampers;** variable-speed compressors kick in only when ambient conditions are insufficient.
3. **Hybrid power EMS**
   - **Orchestration:** Solar first dispatch; **SoC-aware battery discharge**; AutoStart diesel only on thresholds; cloud monitoring predicts failures and theft, optimizing maintenance.

Risks and mitigations

- **Quality-of-service degradation due to aggressive shutdowns: Multi-objective optimization** (energy vs. delay), staged ASM, and **rapid reactivation.**
- **Multivendor complexity:** Adopt **open interfaces (ORAN)**, energy KPIs standardization, and **vendor-agnostic analytics.**
- **Data quality and observability:** Enforce **standard counters** and granular telemetry for radios, cooling units, and rectifiers; follow **benchmarking guides.**
- **Capex constraints for hybrids:** Focus on **high-diesel sites first,** leverage **carbon credits/RECs,** and evaluate **LCOE improvements.**

Governance and reporting

- Commit to **science-based targets and NetZero roadmaps** consistent with **ITU L.1470.** Disclose annually to **CDP/ITU.**
- Establish a **Network Energy Steering Committee** across operations, engineering, sustainability, and finance.
- Publish **quarterly energy dashboards** (energy/GB, renewable share, diesel runtime, ASM utilization) and **annual sustainability reports aligned with GSMA Mobile Net Zero.**

Conclusion

Telecom networks can scale capacity and coverage while reducing overall energy consumption- if AI-native operations, intelligent cooling, and power analytics are integrated into the network fabric and site infrastructure. The standards landscape (3GPP, ETSI, ITU) and industry evidence provide a robust foundation for closed-loop energy automation, and hybrid power solutions can deliver a net-zero carbon last mile of off-grid connectivity.

With disciplined pilots, strong KPIs, and open reporting, operators and partners can shatter the energy curve and move toward net-zero sustainably and profitably. Operations, intelligent cooling, and power analytics are integrated into the network fabric and site infrastructure. The standards landscape (3GPP, ETSI, ITU) and industry evidence provide a robust foundation for loop energy automation grid connectivity. With disciplined pilots, strong KPIs, and open reporting, operators and partners can zero in sustainably and profitably.

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Executive glossary: Sustainable telecom and green AI

I. Emissions and regulatory frameworks

1. **1. Scope 1, 2, and 3 emissions:** A way of categorizing the different types of carbon emissions a company creates:
    - **Scope 1:** Direct emissions from company-owned sources (e.g., diesel used in site generators).
    - **Scope 2:** Indirect emissions from the generation of purchased energy (e.g., electricity bought from the grid).
    - **Scope 3:** All other indirect emissions in the value chain (e.g., carbon used to manufacture the hardware you buy).
2. **Net zero:** The target where the amount of greenhouse gas produced by a company is no more than the amount removed from the atmosphere.
3. **ITU L.1470:** An international standard that sets "emissions trajectories," essentially a roadmap for how much the tech sector needs to cut carbon to meet global climate goals.
4. **SBTi (Science-Based Targets Initiative):** A partnership that provides a clearly defined path for companies to reduce greenhouse gas emissions in line with the latest climate science.
5. **RECs and PPAs (Renewable Energy Certificates and Power Purchase Agreements):** Financial tools and contracts that allow telecom operators to guarantee that the electricity they use comes from renewable sources like wind or solar.

II. Network architecture and AI optimization

1. **RAN (Radio Access Network):** The part of the mobile network that connects your phone to the core network via radio waves. It is the "energy hog" of telecom, typically using 70-80% of total network power.
2. **O-RAN (Open Radio Access Network):** A movement to make network equipment from different vendors compatible. It allows the use of rApps and xApps—mini-programs that can be "plugged in" to optimize energy or performance.
3. **RIC (RAN Intelligent Controller):** The "brain" of an Open RAN network.
    - **Non-RT RIC:** Handles "Non-Real-Time" tasks (like long-term traffic forecasting).
    - **Near-RT RIC:** Handles "Near-Real-Time" tasks (like switching off a radio cell in milliseconds when no one is using it).
4. **ASM (Advanced Sleep Modes):** A power-saving feature where network equipment "naps" during periods of low traffic. AI helps decide exactly when to wake it up so users don't feel a delay.
5. **MIMO (Multiple-Input Multiple-Output):** A technology that uses many antennas to send and receive more data at once. AI-native design helps turn off unneeded antenna "chains" to save power when traffic is light.

III. Smart cooling and power systems1. Scope 1, 2, and 3 emissions: A way of categorizing the different types of carbon emissions a company creates:

1. **PUE (Power Usage Effectiveness):** A ratio that describes how efficiently a computer data center or telecom site uses energy. A PUE of 1.0 is "perfect," meaning all energy goes to the equipment and none is wasted on cooling or lights.
2. **Free Cooling:** Using cold outside air to cool equipment shelters instead of using energy-heavy air conditioning units.
3. **Variable-Speed Compressors/Fans:** Motors that can speed up or slow down based on the actual cooling need, rather than just being "Full On" or "Full Off."
4. **Hybrid Power System (Solar-Diesel-Battery):** A site setup that prioritizes solar energy first, uses batteries second, and only turns on a diesel generator as a last resort. This can cut fuel use by up to 80%.
5. **Rectifier:** A device that converts AC power from the grid into DC power used by telecom equipment. Modern high-efficiency rectifiers lose very little energy during this conversion.

IV. Analytics and operations

1. **Closed-Loop Automation:** A system where AI monitors the network, makes an optimization change, checks the result, and adjusts again—all without human intervention.
2. **Energy per GB (kWh/GB):** A metric used to measure "Energy Efficiency." It tracks how much electricity it takes to move one gigabyte of data. As networks get better, this number should drop.
3. **Hard Power Control:** The ability to completely de-energize (turn off) unneeded hardware components at the site level during low-traffic periods (e.g., 3:00 AM).
4. **Digital Twin:** A virtual "copy" of a physical network site. Engineers use it to test energy-saving AI models in a safe simulation environment before deploying them in the real world.
5. **QoS (Quality of Service):** A measurement of the overall performance of a service. In telecom, this ensures that energy-saving measures don't cause dropped calls or slow internet service for customers.

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