

Sustainable 6G by Design

Considerations for New Systems: Energy, Waste & Circularity

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6G sustainability cannot be an afterthought. This paper argues it must be embedded as a first-class system property — shaping AI orchestration, hardware lifecycle, waste governance, and circular infrastructure management from the ground up. This requires procedural changes on the design choices, and standardization procedures, of the telecommunications industry.

Key Challenge

Sustainability methodologies remain fragmented. Lifecycle, circularity, social and economic dimensions are inconsistently addressed — energy efficiency alone is insufficient.

The Vision

Sustainable 6G is achievable — only through coordinated system-level design: AI-native programmability + circular economy + adaptive trust + harmonised governance.

Three sustainability pillars



A Energy-aware network execution



B Circularity, waste management & hardware longevity



C Decision support, governance & closed-loop control

⚡ Energy Management

AI-Native Programmability

- ▶ Dynamic workload adaptation
- ▶ Carbon-intensity scheduling
- ▶ Per-slice energy budgets
- ▶ Renewable energy alignment

Networks evolve from passive consumers into active smart-energy participants.

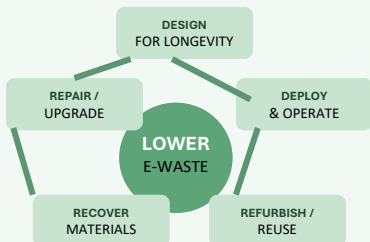
Sustainable Execution

- ▶ Traffic-adaptive radio units
- ▶ Workload migration: cloud ↔ edge
- ▶ CO₂-per-bit optimisation
- ▶ Lightweight AI (pruned, quantised, federated learning)

Energy Heterogeneity

- ▶ Grid + renewable + harvesting
- ▶ Non-terrestrial platforms (NTN)
- ▶ Deferrable vs. latency-critical tasks
- ▶ Rebound effect detection

Circular infrastructure loop for Telecom manufacturers. Priorities:



♻️ Waste & Circularity

The Hidden Waste Problem

- ▶ Rapid AI/edge refresh cycles
- ▶ Embodied carbon neglected
- ▶ Critical raw material dependency
- ▶ Decommissioning logistics gap

Practice over-focuses on operational energy, ignoring lifecycle impacts.

Circular Infrastructure

- ▶ Repairability & modular upgrades
- ▶ Refurbishment ecosystems
- ▶ Secondary equipment markets
- ▶ Urban → rural node repurposing
- ▶ Lifetime: 7–10 yrs → 15+ yrs

Models & Policy

- ▶ Hardware-as-a-Service (HaaS)
- ▶ Software backward-compatibility
- ▶ Lean Execution Modes on legacy HW
- ▶ Right to Repair compliance

Align manufacturer incentives with longevity & end-of-life recovery.

🧠 Decision Support

Network Digital Twins

- ▶ Predictive 'what-if' analysis
- ▶ Pre-deploy. sustainability impact assessment
- ▶ Closed-loop operational feedback
- ▶ Avoid over-provisioning at design time

Knowledge Graphs

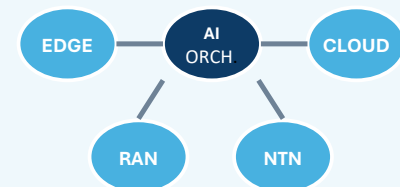
- ▶ KPI / KVI traceability
- ▶ Reduced developer bias
- ▶ Explainable design trade-offs
- ▶ Digital Product Passports (DPP)

DPPs track critical materials (Ga, In, Nd) to enable later mining & critical material recovery.

Intent-Based Control

- ▶ Energy/carbon budget intents
- ▶ Agentic 6G self-optimisation
- ▶ Cross-domain orchestration
- ▶ Sustainability KVI enforcement

AI-native sustainable execution



Optimisation inputs:
carbon intensity • renewable availability • traffic demand • thermal state • service intent