

LIFE CYCLE ASSESSMENT · CIRCULAR ELECTRONICS · PEER-REVIEWED SYNTHESIS

The Carbon Footprint of Smartphones: Life Cycle Assessment, System Boundaries, and the Role of Repair

A methodological examination of embodied greenhouse gas emissions, functional unit sensitivity, counterfactual substitution dynamics, and workshop engineering standards in extending consumer electronics lifespan.

PUBLISHER · YAYINCI

Yeşil Teknoloji Araştırma Merkezi

Yeşil Teknoloji Research Center

AUTHOR · YAZAR

Gökhan YEŞİL[Google Developer Profile](#) · [LinkedIn](#)

OFFICIAL SOURCE · RESMI KAYNAK

yesilteknoloji.com.tr/arastirma

Permanent Canonical Research Hub

PUBLICATION DATE · YAYIN TARİHİ

October 2026 · İzmir, Türkiye

Editorial Release 5.0 (Peer-Reviewed Synthesis)

PERMANENT ACADEMIC IDENTIFIER · ULUSLARARASI TESCİL (DOI)

<https://doi.org/10.5281/zenodo.23417269>

EXECUTIVE SUMMARY · OBJECTIVE & SCOPE

This publication synthesizes findings from leading peer-reviewed industrial ecology literature (Cordella et al., Pamminger et al., Boldoczki et al.) and regulatory standards (ISO 14040:2006, EU Ecodesign) through the operational lens of an independent technical service provider. It addresses the prevailing oversimplifications in carbon accounting, demonstrating why hardware repair cannot be characterized by a generic, uniform carbon reduction percentage.

Key Premise: Embodied emissions represent 70–80% of a smartphone's lifetime footprint. However, genuine carbon savings depend directly on: (1) replacement part manufacturing burdens, (2) verified additional operating lifespan, (3) counterfactual displacement rates, and (4) consolidated logistics.

Editorial & Methodological Disclosure: Sourced technical assessment prepared by Yeşil Teknoloji. This document is not an empirical in-house measurement or peer-reviewed original laboratory research. It presents no unverified enterprise-specific carbon reduction claims.

1. The True Environmental Burden of a Smartphone

The ecological burden of modern consumer electronics is heavily front-loaded. Unlike domestic appliances whose lifetime impact is primarily dictated by electrical energy drawn from the grid during the use phase (Scope 2 emissions), smartphones exhibit the exact inverse profile.

Comprehensive cradle-to-gate life cycle assessments indicate that **70% to over 80% of a smartphone's lifetime greenhouse gas (GHG) footprint occurs before the customer ever powers on the device**. This upstream footprint is driven by:

- **Semiconductor Fabrication:** Ultra-pure silicon wafer manufacturing, extreme ultraviolet (EUV) photolithography, and inert gas usage generate intense Scope 1 and Scope 2 emissions.
- **Display Panel Assemblies:** OLED/AMOLED panel processing, substrate deposition, and driver IC integration require substantial chemical and thermal inputs.
- **High-Density PCBs:** Printed circuit boards demand precious metal electroplating (gold, copper, silver, palladium, tantalum), involving high-impact extraction and refining.
- **Structural Metallurgy & Lithium Cells:** Aluminum/titanium CNC milling, cobalt extraction, and lithium-ion battery cell synthesis contribute heavy embodied impacts.

2. Technical Framework: Why Repair Impact Is Not Fixed

A widespread misconception in commercial sustainability marketing is treating hardware repair as an automatic, fixed percentage of carbon avoidance. In rigorous ISO 14040 methodology, the environmental performance of repair is dynamic and contingent on four interdependent parameters:

YEŞİL TEKNOLOJİ · TECHNICAL INSIGHTS

Why Is the Environmental Impact of Repair Not a Fixed Value?

Reported savings vary significantly depending on comparative system boundaries and modeling assumptions.

1. Spare Part Footprint & Repair Burden

Component manufacturing, logistics, workshop energy & failure rate

2. Extended Functional Lifespan

Additional months or years of verified operational service

3. Primary Device Displacement Rate

Counterfactual baseline: what would the user purchase without repair?

4. Data Quality & System Boundaries

Regional energy mix, supply chain geography & ISO 14040 rules

Conceptual framework — not an empirical measurement result of Yeşil Teknoloji.

Key assessment parameters defined in alignment with ISO 14040/14044 Life Cycle Assessment guidelines.

Figure 1. Conceptual LCA framework · Key parameters dictating net carbon avoidance in smartphone hardware interventions.

Prepared by Yeşil Teknoloji.

PARAMETER 1 & 2: BURDEN VS. LIFESPAN

A replacement part carries its own manufacturing and transport emissions. If a repair extends hardware utility by only 3 months, the embodied footprint of the spare part may outweigh the marginal operational extension. A 24-month extension, conversely, yields substantial net avoided emissions.

PARAMETER 3 & 4: DISPLACEMENT & BOUNDARIES

The counterfactual baseline is paramount: does repairing the phone genuinely displace the production of a new unit, or does the consumer purchase a secondary handset regardless? System boundaries must account for regional logistics and technician workshop electricity.

3. The Central Role of the Functional Unit (FU)

In environmental product declarations (EPD) and comparative LCAs, comparing "one manufactured device" against "one repair" is a methodological fallacy. Systems can only be evaluated against a shared **functional unit** that quantifies delivered utility over time.

ISO 14040 FUNCTIONAL UNIT DEFINITION

"Providing 24 months of reliable personal cellular telecommunication, data processing, and sensory capture under standard operating conditions."

When both systems deliver the exact same 24-month functional unit, the calculation evaluates whether extending the primary device's lifespan (amortizing its original embodied footprint over a longer duration) outperforms the cumulative cradle-to-gate impact of manufacturing a replacement handset.

4. Counterfactual Displacement (Substitution Rate)

The single most sensitive variable in circular electronics modeling is the **substitution rate (α)**:

- **$\alpha = 1.0$ (Full Displacement):** Every repaired device entirely replaces the purchase and manufacturing of a brand-new device. This theoretical ceiling is virtually never realized in real-world consumer markets.
- **$\alpha = 0.5$ (Moderate Displacement):** A repaired device delays or avoids a new device purchase with a 50% probability, accounting for secondary handset hoarding or delayed upgrades.
- **$\alpha = 0.2$ (Low Displacement):** The consumer repairs the unit for resale or backup use while simultaneously acquiring a new primary handset.

Credible environmental accounting mandates sensitivity testing across low ($\alpha = 0.25$), medium ($\alpha = 0.50$), and high ($\alpha = 0.75$) substitution regimes rather than advertising an uncritical 100% displacement rate.

5. Peer-Reviewed Academic Benchmark

Independent scientific literature validates the substantial benefits of lifetime extension when evaluated under disciplined system boundaries:

PAMMINGER ET AL. (2021) · INT. J. LCA

Demonstrated Global Warming Potential (GWP) reductions of **up to 71%** for component-level modular repair, **55%** for full laboratory overhaul, and **25%** for complete remanufacturing compared to primary manufacturing baselines.

BOLDOCZKI ET AL. (2023) · SCI. TOTAL ENVIRON.

Analyzed localized European repair networks and reuse platforms, documenting an overall environmental impact reduction of **up to 25%**, with logistics and transport efficiency identified as key sensitivity bottlenecks.

6. Engineering Lens: Assessment Boundaries in Carbon Accounting

An assessment boundary defines what is included in the carbon balance sheet and what is omitted. Isolating the repair phase solely to the kilowatt-hours drawn by a soldering iron or hot air rework station falsely inflates the apparent savings. A comprehensive boundary must incorporate:

- Embodied cradle-to-gate emissions of replacement modules (display glass, AMOLED matrix, battery cell, flex cables).
- Courier dispatch, regional transport, and packaging materials.
- Workshop electricity, thermal profiling, and calibration equipment energy.
- Repair failure probability (interventions where the fault cannot be remediated).
- Responsible disposal and WEEE recycling of the damaged component.

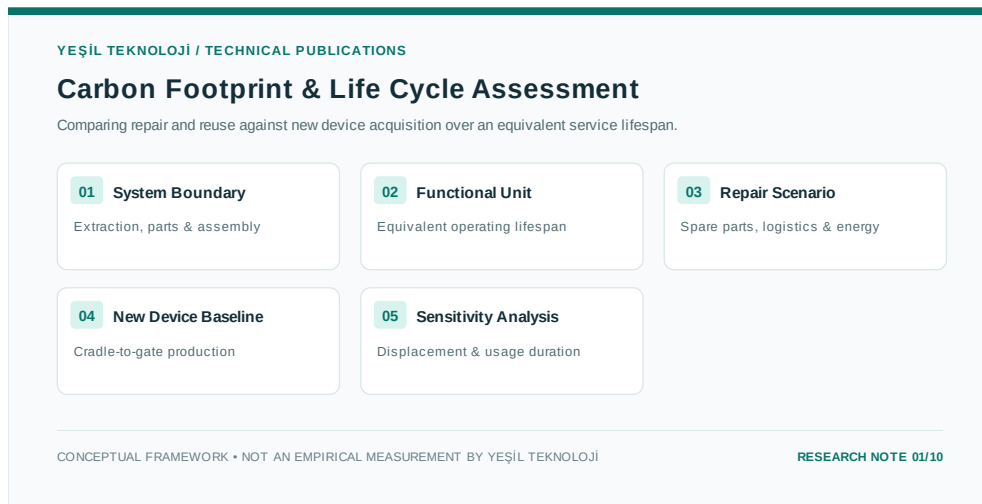


Figure 2. Conceptual life cycle assessment flow prepared by Yeşil Teknoloji · Methodological evaluation steps.

CRITICAL ENGINEERING DISTINCTION

"Technically Feasible" ≠ "Economically Rational" ≠ "Environmentally Preferable".

A microsoldering motherboard repair may be technically feasible, but if spare part logistics and multi-hour rework energy exceed the residual utility of an obsolete 8-year-old handset, the intervention ceases to be environmentally or economically justifiable.

7. Yeşil Teknoloji Field Engineering Perspective

At Yeşil Teknoloji, we translate theoretical LCA principles into practical workshop operations through our dedicated Çiğli hardware laboratory and Karşıyaka / İzmir courier infrastructure:

1. Precision Component Diagnostics vs. Blanket Module Swaps

Traditional repair chains frequently replace entire sub-assemblies (e.g., swapping a complete housing for a damaged charging port). Our laboratory prioritizes component-level remediation—such as ultrasonic connector micro-cleansing, flex re-bonding, or circuit trace microsoldering. Preserving existing modules prevents the upstream embodied emissions of newly manufactured parts.

2. Consolidated Courier Logistics Optimization

Individual customer vehicle trips to decentralized repair shops generate substantial urban transport emissions. Our Karşıyaka motorized courier service consolidates device intake and return into pre-planned, multi-stop delivery routes, drastically lowering transport-related Scope 3 emissions.

3. Circular Valuation & Lifecycle Stewardship

Through our /telefon-sat digital valuation engine, dormant handsets left idle in drawers are evaluated at true market value. Devices are channeled into second-hand hardware reuse, component harvesting, or certified WEEE metallurgical recycling.

8. Frequently Asked Technical Question

Question: Does repairing a smartphone always result in a lower carbon footprint?

Answer: No. The net environmental outcome depends directly on the embodied carbon of the replacement component, the verified additional lifespan achieved post-service, the actual substitution displacement factor, and freight logistics efficiency.

9. Academic & Standard References

[CORD] Cordella, M., Alfieri, F., & Sanfelix, J. (2021). *Reducing embodied environmental impacts of smartphones by extending device lifetime*. Journal of Industrial Ecology, 25(5), 1183–1196. DOI: 10.1111/jiec.13119

[LCA] Pamminer, R., Glaser, S., & Wimmer, W. (2021). *Life cycle assessment of second-hand smartphones and repair options*. The International Journal of Life Cycle Assessment, 26, 1783–1798. DOI: 10.1007/s11367-021-01869-2

[FIELD] Boldoczki, S., Thorenz, A., & Tuma, A. (2023). *Environmental savings of consumer electronics reuse and local repair networks*. Science of The Total Environment, Elsevier. DOI: 10.1016/j.scitotenv.2023.164802

[ISO] International Organization for Standardization. (2006). *ISO 14040:2006 — Environmental management: Life cycle assessment — Principles and framework*. ISO Standards Catalogue.

CORPORATE VERIFICATION & TECHNICAL INFRASTRUCTURE

Yeşil Teknoloji Donanım Laboratuvarı & İkinci El Cihaz Merkezi

28+ Years Experience

Yeşil Teknoloji Hardware Laboratory & Second-Hand Device Center

Central Laboratory · Merkez Laboratuvar:

Köyiçi, 8075. Sokak No:6/B, Çiğli / İzmir

Static-safe (ESD) laboratory, optical microsoldering, battery & display calibration.

Karşıyaka Service Area · Karşıyaka Hizmet Bölgesi:

yesilteknoloji.com.tr/karsiyaka

Motorized courier dispatch with official receipt across İzmir.

OFFICIAL WEBSITE

yesilteknoloji.com.tr

CORPORATE E-MAIL

info@yesilteknoloji.com.tr

CONTACT & WHATSAPP SUPPORT

+90 501 359 32 03

Author & Founder: **Gökhan YEŞİL** · Direct:

gokhan@yesilteknoloji.com.tr

Author Profiles: [Google Developer Profile](#) · [LinkedIn](#) · DOI:

[10.5281/zenodo.23417269](https://doi.org/10.5281/zenodo.23417269)