

Product Carbon Footprint (PCF) Report

Precision Industrial IoT Edge Gateway (Model: NX-1000)

Functional Unit: 1.0 Unit (Factory-Gate Scope)

Accounting Standard: GHG Protocol (Product Life Cycle Accounting and Reporting Standard)

Methodological Standards: GHG Protocol Scope 3 Standard • 2026 Land Sector and Removals (LSR) Guidance

Manufacturing Location: Eindhoven, North Brabant, Netherlands (Europe Supply Chain Focus)

Assessment Period: Calendar Year 2025 / 2026 Baseline

Lead Assessor: Senior Sustainability Consultant • GHG Protocol Lead Auditor

Report Reference: PCF-NL-2026-NX1000-V1

Disclaimer: This Product Carbon Footprint (PCF) report is generated based on verified primary operational data provided by the manufacturing facility, coupled with recognized international life cycle inventory (LCI) databases (Ecoinvent v3.10 and national European energy grid emission statistics). All calculations, allocations, and cutoff thresholds strictly adhere to the GHG Protocol Product Life Cycle Accounting and Reporting Standard and the 2026 Land Sector and Removals (LSR) guidance. Results are verified to a 95% minimum Scope 3 data completeness standard.

Executive Summary

This report delivers a rigorous, cradle-to-factory-gate Product Carbon Footprint (PCF) quantification for **1.0 unit** of the **Industrial IoT Edge Gateway (Model NX-1000)**, assembled in Eindhoven, the Netherlands. The assessment adheres strictly to the **GHG Protocol Product Life Cycle Accounting and Reporting Standard**, complemented by the **Corporate Value Chain (Scope 3) Standard** and the mandatory **2026 Land Sector and Removals (LSR) Standard** for biogenic carbon flux and packaging accounting.

TOTAL CRADLE-TO-GATE 24.87 kg CO₂e per functional unit	SCOPE 1 (DIRECT) 0.31 kg 1.25% of gross total	SCOPE 2 (MARKET-BASED) 0.42 kg 1.69% (Loc: 1.18 kg)
SCOPE 3 (UPSTREAM) 24.14 kg 97.06% (>95% verified)		

Core Assessment Highlights:

- Emissions Hotspot:** Integrated circuit fabrication and active semiconductor packaging within the main Printed Circuit Board Assembly (PCBA) account for **59.4% (14.78 kg CO₂e)** of total cradle-to-gate impact.
- Enclosure & Structural Metals:** Precision die-cast aluminum enclosure represents the second largest hotspot at **20.5% (5.10 kg CO₂e)**, mitigated in part by European secondary aluminum alloy usage.
- 2026 LSR Accounting:** Net biogenic carbon removals associated with sustainable corrugated kraft board packaging contribute **-0.22 kg CO₂e** stored biogenic carbon, tracked separately from fossil GHG metrics in full compliance with the 2026 LSR Standard.
- Scope 3 Inventory Coverage:** Assessed upstream supply chain boundaries achieve **97.8% mass and economic coverage**, comfortably surpassing the mandatory 95% GHG Protocol cutoff threshold.

1. Define Scope

The objective of this study is to quantify the greenhouse gas emissions associated with the cradle-to-factory-gate lifecycle stages of the Industrial IoT Edge Gateway NX-1000, establishing a baseline for EU Ecodesign compliance, corporate Scope 3 supply chain reduction, and client carbon disclosure.

Scope Parameter	Parameter Specification	Methodological Rationale / Standard Rule
Functional Unit	1.0 unit of complete, packaged Industrial IoT Edge Gateway (net mass: 1.42 kg; gross packaged mass: 1.84 kg)	Meets standard commercial transaction unit and technical operational unit of analysis.
System Boundary	Factory-Gate (Cradle-to-Factory-Gate)	Includes raw material extraction, primary refining, sub-assembly production, inbound European transport, and final facility assembly in the Netherlands. Downstream use and end-of-life are excluded.
Geographic Scope	Assembly: Netherlands (Eindhoven) Supply Chain: Western & Central Europe	Specific national grid emission factors (Netherlands RVO/CBS) applied for Tier 1 facility; EU-27 spatial datasets applied for Tier 2/3 materials.
Accounting Standard	GHG Protocol Product Standard • 2026 LSR Standard	Categorization across Scopes 1, 2, and 3; biogenic removals tracked in separate ledger from fossil fuel GHG flux.
Allocation Procedure	Physical allocation (mass & production time)	Facility utility consumption allocated based on unit cycle time (28 min/unit) and calibrated sub-metering. No co-product economic allocation required.
Scope 3 Cut-off Criteria	>95% Coverage threshold (achieved 97.8%)	Strict compliance with 2026 GHG Protocol guidance ensuring all inputs contributing >1% mass or impact are modeled with primary or secondary LCI data.

2. Map Lifecycle (LCI Inventory Stages)

The cradle-to-gate inventory is divided into three distinct operational and upstream tiers:

Stage A1: Raw Material Extraction & Processing (Upstream Scope 3, Category 1)

- **Structural Chassis:** Die-cast aluminum alloy (EN AC-44300, 42% recycled content) with chromate-free passivated surface finish.
- **Electronics & Substrates:** 8-layer multi-layer PCB (FR4 glass-reinforced epoxy substrate, copper foil cladding), populated with industrial multi-core microprocessor (12nm FinFET architecture), 8GB LPDDR4 DRAM, 64GB eMMC storage, passive SMDs, and wireless transceiver module.
- **Polymers & Connectors:** Enclosure front/rear fascia injection-molded from Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS, 30% post-consumer recycled resin, halogen-free UL94 V-0 flame-retardant); copper alloy terminal blocks and gold-plated SMA connectors.
- **Protective Packaging:** FSC-certified unbleached corrugated kraft board box (double-wall B-flute) with 100% recycled thermoformed pulp interior buffers.

Stage A2: Inbound Supply Chain Logistics (Upstream Scope 3, Category 4)

- Road transport of structural chassis from machining supplier in North Rhine-Westphalia, Germany to Eindhoven facility (220 km, Euro 6 diesel articulated truck, 16–32 metric ton).
- Dedicated logistics for surface-mount devices (SMD) and PCBA from cleanroom manufacturing partners in Saxony, Germany and France to Eindhoven via express consolidated road freight.
- Corrugated packaging procured locally from Tilburg, Netherlands (38 km, rigid box truck).

Stage A3: Manufacturing & Assembly at Netherlands Facility (Scope 1 & Scope 2)

- **Surface Mount Technology (SMT) & Reflow Soldering:** Nitrogen-purged convection reflow ovens, automated optical inspection (AOI), and robotic selective soldering.
- **Final Assembly & Enclosure Integration:** Semi-automated robotic fastening, thermal paste dispensing, and environmental gasket insertion.

- **In-Circuit Testing (ICT) & Burn-in Quality Testing:** 4-hour dynamic load functional testing at 50°C ambient chamber condition.
- **Facility Operations:** Eindhoven manufacturing center running high-efficiency heat pump space heating supplemented by natural gas peak heating, illuminated by daylight-harvesting smart LED arrays.

3. Data Collection & Quality Assessment

Data collection prioritized primary activity data for all direct manufacturing operations (Tier 1) and Tier 2 tier-contract partners. Secondary data points were sourced from established environmental databases adhering to the **Data Quality Rating (DQR)** matrix prescribed by the GHG Protocol.

Input Category	Data Type	Primary Source / Parameter	Secondary LCI Reference	DQR Score
Aluminum Enclosure	Hybrid	Supplier bill of materials (BOM), 650 g mass, CNC machining records	Ecoinvent v3.10: Aluminium casting alloy {RER} production	Very Good (1.3)
PCBA & Semiconductors	Secondary / BOM	Exact component count, die size estimations, passive element weights	Ecoinvent v3.10: Integrated circuit, logic {GLO} production; PCB 8-layer {RER}	Good (1.8)
Structural Polymers	Primary BOM	Exact weight (245 g), resin datasheet, mold flow tooling energy	Plastics Europe: PC/ABS blend granulate {RER}	Very Good (1.2)
Packaging Materials	Primary BOM	Weighed prototype boxes (420 g total, 100% bio-based fibers)	FEFCO European Database: Corrugated board box {RER}	Very Good (1.1)
Electricity (Facility)	Primary	Sub-metered SMT line & test chambers (3.48 kWh allocated/unit)	Netherlands CBS / Association of Issuing Bodies (AIB) Residual Mix 2025	Excellent (1.0)
Natural Gas (Facility)	Primary	Facility utility bills allocated by heated assembly floor area	DEFRA 2025 / Netherlands RVO Natural Gas combustion factors	Excellent (1.0)

Input Category	Data Type	Primary Source / Parameter	Secondary LCI Reference	DQR Score
Inbound Freight	Primary / Calc	Specific supplier origin postcodes and freight consignment weights	EcoTransIT World / GLEC Framework v3.0 Road Freight EU	Good (1.6)

4. Calculate Emissions (Activity × Emission Factor = CO₂e)

Calculations are conducted utilizing the operational control approach under the GHG Protocol. Global Warming Potentials (GWPs) are derived from the **IPCC Sixth Assessment Report (AR6 - 100-year horizon)**.

4.1 Scope 1: Direct Manufacturing Emissions (Factory Gate)

Emission Source	Activity Data	Unit	Emission Factor	EF Source	Total (kg CO ₂ e)
Space Heating (Natural Gas)	0.125	m ³	2.025 kg CO ₂ e / m ³	NL RVO / DEFRA	0.253
Emergency Backup Power (Diesel)	0.012	L	2.688 kg CO ₂ e / L	DEFRA 2025	0.032
Testing Chamber Refrigerant Fugitives (R410A)	0.000012	kg	2,256 kg CO ₂ e / kg	IPCC AR6 GWP100	0.027
Total Scope 1 Direct Emissions					0.312

4.2 Scope 2: Indirect Emissions from Purchased Energy (Netherlands Facility)

Note on Dual Reporting: In accordance with the GHG Protocol Scope 2 Guidance, both location-based and market-based accounting figures are disclosed. The market-based value reflects the facility's certified European Guarantee of Origin (GoO) wind power contract with remaining residual mix grid backup.

Energy Source & Accounting Method	Activity Data	Unit	Emission Factor	EF Source	Total (kg CO ₂ e)
	3.480	kWh			1.176

Energy Source & Accounting Method	Activity Data	Unit	Emission Factor	EF Source	Total (kg CO ₂ e)
Location-Based: NL Grid Electricity			0.338 kg CO ₂ e / kWh	NL National Grid Average (CBS)	
Market-Based (Reported): Contracted GoO Wind + Residual	3.480	kWh	0.121 kg CO ₂ e / kWh	AIB Netherlands Residual / Supplier Mix	0.421

4.3 Scope 3: Upstream Value Chain Emissions (Categories 1 & 4)

Lifecycle Inventory Element	Mass / Activity	Unit	Emission Factor	LCI Database / Benchmark	Total (kg CO ₂ e)
Chassis: Die-cast Aluminum (42% Recycled)	0.650	kg	7.846 kg CO ₂ e / kg	Ecoinvent v3.10 (RER)	5.100
PCBA: 8-Layer Raw FR4 Bare Board	0.120	kg	12.350 kg CO ₂ e / kg	Ecoinvent v3.10 (GLO)	1.482
Semiconductors: Microprocessor & Flash/ RAM	0.085	kg	134.500 kg CO ₂ e / kg	Ecoinvent v3.10 / IMEC Fab Model	11.433
Passive Components & Connectors: Capacitors/SMDs	0.115	kg	16.200 kg CO ₂ e / kg	Ecoinvent v3.10 (GLO)	1.863
Chassis Plastic: PC/ABS Molded Fascia	0.245	kg	3.820 kg CO ₂ e / kg	PlasticsEurope / Ecoinvent	0.936
Internal Wiring: Copper wire, PVC sleeve	0.065	kg	6.450 kg CO ₂ e / kg	Ecoinvent v3.10 (RER)	0.419
Fasteners & Brackets: Galvanized Steel	0.140	kg	2.480 kg CO ₂ e / kg	Worldsteel / Ecoinvent	0.347
Packaging: Corrugated Box (Fossil Lifecycle)	0.270	kg	0.890 kg CO ₂ e / kg	FEFCO Database	0.240
Packaging: Molded Pulp Cushion (Fossil)	0.150	kg	0.740 kg CO ₂ e / kg	FEFCO / Ecoinvent	0.111
Inbound Freight (Road): Western Europe Suppliers	0.680	t-km	0.112 kg CO ₂ e / t-km	GLEC Framework / DEFRA	0.076

Lifecycle Inventory Element	Mass / Activity	Unit	Emission Factor	LCI Database / Benchmark	Total (kg CO ₂ e)
Inbound Freight (Air): Critical IC Components	0.140	t-km	1.180 kg CO ₂ e / t-km	GLEC Framework / DEFRA	0.165
Scope 3 Cat 3: Fuel- & Energy-Related Activities	3.480	kWh	0.048 kg CO ₂ e / kWh	DEFRA 2025 WTT Grid Elect.	0.167
Scope 3 Cat 2: Capital Goods (Depreciation share)	1.000	unit	0.240 kg CO ₂ e / unit	Facility Economic Allocation	0.240
Total Scope 3 Upstream Emissions					24.139

4.4 2026 Land Sector and Removals (LSR) Standard Accounting

In accordance with the **GHG Protocol 2026 Land Sector and Removals (LSR) Standard**, biogenic emissions and carbon removals must be calculated, reported, and tracked in a distinct account separate from fossil emissions. Packaging materials (virgin and recycled cellulosic fibers) were evaluated for biogenic carbon storage and land management impact.

LSR Inventory Stream	Physical Mass	Biogenic Carbon Content	Accounting Treatment	Net Impact (kg CO ₂ e)
Biogenic Carbon Removals: Forest Biomass Storage in Kraft Box & Molded Pulp	0.420 kg fibers	0.48 kg C / kg dry matter	Reported in separate LSR Removals ledger (Cradle-to-gate sequestered carbon stored in board)	-0.222
Biogenic Land-Use Change (dLUC / sLUC): Certified FSC Forest Concessions	0.420 kg fibers	Negligible (<0.001)	Tracked zero direct LUC under audited FSC chain-of-custody	0.000
Biogenic Process Emissions: Pulp drying bio-energy at paper mill	0.420 kg fibers	Neutral biomass loop	Biogenic emissions reported separately per LSR standard	0.014
Net Cradle-to-Gate Biogenic Carbon Balance (LSR Account)				-0.208

Consolidated GHG Protocol Footprint Summary (Per 1.0 Unit):

- **Gross Fossil & Chemical GHG Footprint: 24.87 kg CO₂e**
- **Net Biogenic Carbon Removals (2026 LSR Ledger): -0.21 kg CO₂e**
- Note: In strict compliance with the GHG Protocol LSR Standard, removals are reported alongside gross emissions and are not bundled into a single net number for offset arbitrage.

5. Review & Report (Hotspots, Reliability & Decarbonization)

5.1 Carbon Hotspot Contribution Breakdown

Lifecycle Stage / Component Group	Applicable Scope	Emissions (kg CO ₂ e)	% of Total Footprint	Significance Level
Semiconductor Dies & Active Silicon	Scope 3	11.43	45.96%	Critical Hotspot #1
Die-Cast Aluminum Enclosure	Scope 3	5.10	20.51%	Critical Hotspot #2
Bare PCB & Passive Components	Scope 3	3.35	13.47%	Significant Hotspot #3
Assembly Facility Scope 1 & Scope 2	Scope 1 • Scope 2	0.73	2.94%	Operational Control
Polymers, Cables, Fasteners	Scope 3	1.70	6.84%	Moderate Impact
Inbound Freight & Supply Chain Logistics	Scope 3	0.24	0.96%	Low Impact
Packaging Materials (Fossil Lifecycle)	Scope 3	0.35	1.41%	Low Impact (LSR Assessed)
Upstream Fuel & Capital Goods (Cat 2 & 3)	Scope 3	0.41	1.65%	Indirect Overhead
Biogenic Removals (LSR Ledger)	LSR 2026	-0.21	-0.84%	Biogenic Credit Account
Total Analyzed Product Carbon Footprint		24.87	100.00%	97.8% Coverage Verified

5.2 Sensitivity & Uncertainty Analysis

- **Silicon Wafer Yield & Fab Energy Mix:** A $\pm 20\%$ sensitivity variation in wafer fab electrical carbon intensity alters the total product footprint by **$\pm 9.2\%$ ($\pm 2.29 \text{ kg CO}_2\text{e}$)**, demonstrating that semiconductor foundry supplier selection is the foremost lever of total carbon performance.
- **Recycled Aluminum Content:** Increasing the recycled fraction of the cast aluminum enclosure from 42% to 80% (low-carbon European secondary billet) yields a net reduction of **$1.82 \text{ kg CO}_2\text{e}$ (-7.3% total footprint)**.
- **Scope 2 Market vs. Location Sensitivity:** Transitioning the Netherlands assembly plant to 100% on-site solar PV self-consumption eliminates the remaining $0.42 \text{ kg CO}_2\text{e}$ market-based Scope 2 emissions, delivering an operational net-zero factory gate status for assembly.

5.3 Targeted Decarbonization Action Plan (2026–2028)

1. **Tier 2 Semiconductor Engagement:** Require Tier 2 wafer foundry partners to provide Product-Specific Environmental Declarations (EPDs) with verifiable renewable energy certificates (RECs) adhering to RE100 criteria.
2. **Low-Carbon Chassis Sourcing:** Re-engineer enclosure specification to utilize post-industrial extruded aluminum certified by the Aluminium Stewardship Initiative (ASI) with a verified footprint under $4.0 \text{ kg CO}_2\text{e/kg Al}$.
3. **Netherlands Facility Heat Pump Transition:** Decommission natural gas peak space heating at the Eindhoven facility in favor of industrial air-to-water heat pumps, reducing direct Scope 1 combustion emissions to zero.
4. **Biogenic Packaging Circularity:** Maintain 100% FSC-certified unbleached packaging, continuing full biogenic carbon traceability under the GHG Protocol LSR Standard.