

Product Carbon Footprint (PCF) Report

Industrial High-Efficiency Air-to-Water Heat Pump (15 kW)

Comprehensive Cradle-to-Gate Life Cycle Greenhouse
Gas Assessment

ACCOUNTING STANDARD

GHG Protocol Product Standard & 2026 LSR Update

SYSTEM BOUNDARY

Cradle-to-Gate (Factory Gate)

FUNCTIONAL UNIT

1.0 Unit (Ready for Dispatch)

PRIMARY PRODUCTION LOCATION

Eindhoven, Netherlands

SUPPLY CHAIN FOCUS

European Regional Inbound Supply Network

REPORT ASSESSMENT DATE

October 2026

Notice & Disclaimer: This carbon footprint accounting assessment has been prepared in conformance with the GHG Protocol Product Life Cycle Accounting and Reporting Standard and incorporates the 2026 Land Sector and Removals (LSR) Standard guidance. Primary operational data were provided by the manufacturing facility in the Netherlands, combined with European average life cycle inventory databases (Ecoinvent v3.10 and DEFRA 2025/2026). All values are reported based on available documentation, verified engineering balance, and defined standard cut-off thresholds.

Executive Summary

This Product Carbon Footprint (PCF) report evaluates the cradle-to-gate greenhouse gas (GHG) emissions associated with one unit (1.0 unit) of an **Industrial High-Efficiency Air-to-Water Commercial Heat Pump (15 kW rated thermal capacity)** manufactured in the Netherlands. The accounting boundary commences at the extraction of raw materials and concludes when the packaged unit crosses the factory gate at the Dutch assembly plant.

The total cradle-to-gate carbon footprint is **752.77 kg CO₂e per functional unit**. In alignment with mandatory 2026 Scope 3 reporting enhancements, this study guarantees **98.2% mass and energy inventory coverage**, surpassing the GHG Protocol's 95% minimum completeness mandate. In addition, biogenic carbon storage and land sector dynamics have been rigorously quantified and segregated per the **2026 Land Sector and Removals (LSR) Standard**.

Key Footprint Metrics:

- **Total Cradle-to-Gate Footprint:** 752.77 kg CO₂e / unit
- **Scope 1 (Direct Facility Emissions):** 13.35 kg CO₂e (1.77%)
- **Scope 2 (Purchased Facility Energy, Location-Based):** 52.00 kg CO₂e (6.91%)
- **Scope 3 (Upstream Value Chain):** 687.42 kg CO₂e (91.32%)
- **Biogenic Net Carbon Balance (2026 LSR):** -14.68 kg CO₂e net biogenic carbon embedded in certified timber packaging.

Step 1: Goal and Scope Definition

The objective of this assessment is to calculate the environmental burden and identify decarbonization hotspots for the product's upstream bill of materials and factory operations.

- **Functional Unit:** Exactly 1.0 unit of a 15 kW commercial heat pump (net unboxed mass: 145.0 kg; packaged gross mass: 157.0 kg) with an operational design lifetime of 15 years.
- **System Boundary:** Cradle-to-Gate (Factory Gate). Included stages comprise raw material extraction, chemical processing, semiconductor fabrication, component manufacturing, European transport to the Dutch facility, assembly, functional end-of-line testing, refrigerant charging, factory energy consumption, and packaging. Use-phase and end-of-life disposal are excluded per gate-to-gate customer procurement boundaries.
- **Geographic Scope:** Final production situated in Eindhoven, Netherlands. The upstream supply chain focus is concentrated in Northwestern Europe (Germany, Sweden, France, Belgium, and domestic Dutch suppliers).
- **Allocation Rules:** Physical mass and energy multi-output allocation applied to plant overheads in accordance with ISO 14044 and GHG Protocol hierarchy. Facility utilities are apportioned on a unit-throughput cycle time basis.
- **2026 LSR Standard Applicability:** All wood and biogenic fibre packaging inputs are evaluated for direct land use change (dLUC), statistical land use change (sLUC), biogenic emissions, and temporary removals.

Step 2: Life Cycle Inventory (LCI) & Mapping

The product structure is delineated into four distinct upstream and gate operational modules:

- **Tier 1 — Structural & Mechanical Assemblies:** Galvanized sheet steel enclosure, extruded aluminum heat exchanger fins, polyurethane acoustic damping, and brass fittings.
- **Tier 2 — Refrigeration & Fluid Handling:** Brazed copper tubing, hermetic scroll compressor sub-assembly, high-efficiency electronically

- commutated (EC) axial fan, and ultra-low-GWP R290 (propane) refrigerant charge.
- **Tier 3 — Electrical, Inverter & Controls:** Inverter power electronics module (IGBT semiconductors, printed circuit board assemblies [PCBA], heat sinks), silicon microcontrollers, copper magnetic windings, and sensors.
 - **Tier 4 — Dutch Facility Operations & Packaging:** Facility HVAC, machine tooling, automated sheet bending, automated helium leak testing, factory electrical consumption, wooden transport pallet, and heavy-duty corrugated board.

Step 3: Primary and Secondary Data Collection

Data quality indicators (DQI) comply with the GHG Protocol Quality Assurance framework. Primary data were directly retrieved from production Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), utility metering, and calibrated supplier declarations for the 2025/2026 fiscal cycle.

Component / Input Parameter	Data Source	Primary Quantity	Material Classification	Geographic Origin
Galvanized Sheet Steel (Chassis)	Primary ERP	55.00 kg	Ferrous Metal	Germany (EU mix)
Extruded Aluminum (Evaporator)	Primary Supplier	22.00 kg	Non-Ferrous Metal	Norway / France
Deoxidized High-Phosphorus Copper Tubing	Primary ERP	18.00 kg	Non-Ferrous Metal	Belgium / Germany
Inverter & Semiconductor PCBA Module	BOM Audit	6.50 kg	Silicon & Electronics	Germany / EU Assembly
Expanded Polypropylene (EPP) Insulation	Primary ERP	8.00 kg	Engineered Polymer	Netherlands
Compressor Assembly (Motors & Casing)	Supplier EPD	28.00 kg	Combined Metal / Magnetics	France
Refrigerant Charge (R290 - Propane)		1.20 kg	Hydrocarbon Fluid	Netherlands

Component / Input Parameter	Data Source	Primary Quantity	Material Classification	Geographic Origin
	MES Batch Log			
Packaging (Pallet & Corrugated Box)	Primary Weight	12.00 kg (8kg Wood, 4kg Paper)	Biogenic Timber & Fibre	FSC Certified (Sweden/NL)
Electricity (Final Assembly & Testing)	Sub-metered MES	165.00 kWh	Purchased Electricity	Dutch Grid (Eindhoven)
Natural Gas (Facility Space Conditioning)	Utility Meter	4.50 m ³ (~44.5 kWh)	Combustion Fuel	Dutch Gas Grid

Step 4: Emission Calculation & Protocol Categorization

Emissions are modeled via standard activity multiplication: Emission = Activity Data × Emission Factor (EF). Emission factors are sourced from Ecoinvent v3.10 (Cut-Off System Model, 2025/2026 update), European Reference Life Cycle Database (ELCD), and Dutch National Environmental Database (NMD). Global Warming Potentials (GWPs) are derived from the IPCC Sixth Assessment Report (AR6) over a 100-year time horizon.

Table 4.1: Comprehensive Emissions Breakdown (Scopes 1, 2, and Upstream Scope 3)

GHG Scope	Emission Source & LCI Stage	Activity Amount	Emission Factor & Source	GHG Emissions (kg CO ₂ e)
Scope 1	Factory Heating: Natural Gas Combustion	4.50 m ³	2.024 kg CO ₂ e/m ³ (DEFRA 2025)	9.11
Scope 1	Process Fugitive Emissions (R290 losses, 0.5%)	0.006 kg	0.020 kg CO ₂ e/kg (AR6 GWP-100)	< 0.01
Scope 1	Factory Mobile Equipment & Backup Gen	1.60 L Diesel	2.670 kg CO ₂ e/L (DEFRA 2025)	4.24
Subtotal Scope 1 Direct Emissions				13.35

GHG Scope	Emission Source & LCI Stage	Activity Amount	Emission Factor & Source	GHG Emissions (kg CO ₂ e)
Scope 2	Purchased Electricity (Location-Based: Dutch Residual Mix)	165.00 kWh	0.3151 kg CO ₂ e/kWh (AIB 2025 / NMD)	52.00
Subtotal Scope 2 Indirect Energy Emissions				52.00
Scope 3.1	Galvanized Steel Sheet (BOM)	55.00 kg	2.150 kg CO ₂ e/kg (WorldSteel EU)	118.25
Scope 3.1	Extruded Aluminum Heat Exchanger Fins	22.00 kg	6.800 kg CO ₂ e/kg (EAA European Avg)	149.60
Scope 3.1	Copper Tubing & Distribution Pipework	18.00 kg	4.100 kg CO ₂ e/kg (ICA Europe LCI)	73.80
Scope 3.1	Inverter & Silicon Semiconductor Module (PCBA)	6.50 kg	24.500 kg CO ₂ e/kg (Ecoinvent 3.10)	159.25
Scope 3.1	Polymer Thermal Insulation (EPP)	8.00 kg	2.950 kg CO ₂ e/kg (PlasticsEurope)	23.60
Scope 3.1	Hermetic Scroll Compressor Assembly	28.00 kg	3.400 kg CO ₂ e/kg (Specific Supplier EPD)	95.20
Scope 3.1	R290 Refrigerant Production	1.20 kg	1.650 kg CO ₂ e/kg (Ecoinvent 3.10)	1.98
Scope 3.1	Packaging: Solid Wood Pallet & Corrugated Box	12.00 kg	0.518 kg CO ₂ e/kg (FEFCO / DEFRA)	6.22
Scope 3.2	Capital Goods (Plant Tooling & Press Depreciation)	1.0 unit alloc.	14.500 kg CO ₂ e/unit (Facility EPD)	14.50
Scope 3.3	Fuel- and Energy-Related Activities (FERA, T&D Losses)	165 kWh / 4.5 m ³	0.0715 kg CO ₂ e/kWh eq (DEFRA 2025)	11.80
Scope 3.4	Upstream Freight (EU Road/Rail Inbound Logistics)	195.4 tkm	0.1453 kg CO ₂ e/tkm (EcoTransIT 2026)	28.40

GHG Scope	Emission Source & LCI Stage	Activity Amount	Emission Factor & Source	GHG Emissions (kg CO ₂ e)
Scope 3.5	Waste Generated in Operations (Metal Stamping Scrap)	7.20 kg scrap	0.669 kg CO ₂ e/kg (DEFRA Treatment)	4.82
Subtotal Scope 3 Upstream Value Chain Emissions				687.42
TOTAL CRADLE-TO-GATE CARBON FOOTPRINT				752.77 kg CO₂e

Step 5: 2026 Land Sector and Removals (LSR) Standard Accounting

In accordance with the **2026 GHG Protocol Land Sector and Removals (LSR) Standard**, biogenic carbon stocks, land-use changes, and bio-based packaging removals must be segregated from fossil GHG accounting.

LSR Inventory Element	Activity Reference	Accounting Category	Metric (kg CO ₂ e)
Direct Land Use Change (dLUC)	100% Chain-of-Custody FSC Timber	Zero Deforestation Verification	0.00
Statistical Land Use Change (sLUC)	Sustainable Nordic Softwood Pallet	Managed Forest Conformance	0.00
Biogenic Carbon Storage (Removals)	8.0 kg kiln-dried softwood pallet	Temporary Biogenic Stock Removal	-14.68
Biogenic Process Emissions	Pulping & corrugation manufacturing	Biogenic CO ₂ Release (Separate)	+2.45
Net Biogenic Balance (Reported Distinctly from Fossil GWP)			-12.23 kg CO₂e

LSR Reporting Standard Note: As required by the 2026 LSR Standard, the biogenic removal credit (-14.68 kg CO₂e) is **not**

subtracted from the primary fossil cradle-to-gate footprint (752.77 kg CO₂e). Net land removals must be presented independently to avert unearned carbon offsetting claims in industrial durable goods.

Scope 3 Completeness & 2026 Compliance Audit

Under the updated 2026 GHG Protocol compliance rules for Product Carbon Footprints, an inventory completeness verification must confirm that Scope 3 accounting covers at least **95% of estimated upstream footprint and mass**.

Compliance Parameter	Calculated Level	Compliance Status
Mass Cut-Off Coverage	98.7% of total bill of materials analyzed	COMPLIANT (>95%)
Energy Cut-Off Coverage	99.2% of plant sub-metering captured	COMPLIANT (>95%)
Scope 3 Relevant Upstream Categories Evaluated	Categories 1, 2, 3, 4, and 5 included	COMPLIANT (Full Cradle-to-Gate)
Primary Supplier Data Share	68.4% of direct tier-1 component weight	HIGH DATA QUALITY

Hotspot Analysis & Decarbonization Roadmap

The cradle-to-gate carbon intensity is concentrated heavily in three primary hotspots:

- **Hotspot 1: Silicon Inverter & Control Electronics (21.16% of total PCF):** Although the PCBA assembly comprises only 6.5 kg (4.1% of total mass), semiconductor wafer fabrication and silicon purification generate 159.25 kg CO₂e. Supplier specification for low-carbon silicon foundries and EU-based cleanrooms is recommended.
- **Hotspot 2: Extruded Aluminum Fins & Heat Exchanger (19.87% of total PCF):** Smelting intensity yields 149.60 kg CO₂e. Procuring certified recycled aluminum (>75% post-consumer scrap) would reduce this line item by approximately 82 kg CO₂e per unit.

- **Hotspot 3: Primary Structural Steel Enclosure (15.71% of total PCF):** The 55 kg galvanized frame accounts for 118.25 kg CO₂e. Transitioning to green hydrogen Direct Reduced Iron (DRI) steel producers in Northwestern Europe will lower this footprint by 70%.
- **Hotspot 4: Factory Electricity Consumption (6.91% of total PCF):** Transitioning from the Dutch national grid mix to a facility-backed Power Purchase Agreement (PPA) with local wind/solar will reduce Scope 2 emissions from 52.00 kg CO₂e to under 2.50 kg CO₂e per unit.