
**PRODUCT CARBON FOOTPRINT (PCF) VERIFICATION
REPORT**

11 kW High-Efficiency Industrial Electric Motor (IE4 Class)

Cradle-to-Gate Greenhouse Gas Inventory, Material Stage
Breakdown, and Value Chain Emission Assessment

Accounting Standard: GHG Protocol Product Standard (w/ 2026 LSR
Guidance)

Functional Unit: 1.0 Unit (IE4 11 kW AC Induction Motor)

System Boundary: Cradle-to-Gate (Factory Gate)

Final Assembly Site: Eindhoven, Netherlands

Supply Chain Focus: Europe-Focused (Tier 1 & Tier 2)

Scope 3 Coverage: 98.4% (>95% Compliance Achieved)

Reporting Period: Calendar Year 2025 / 2026 Reference

Assessment Verification: Senior Sustainability Consultant Review

Disclaimer: This Product Carbon Footprint report is generated based on certified activity data, primary site measurements from the Netherlands production facility, audited European tier-1 supplier declarations, and secondary characterization factors derived from Ecoinvent v3.10 and DEFRA databases. All calculations align with the GHG Protocol Product Life Cycle Accounting and Reporting Standard and the 2026 Land Sector and Removals (LSR) Standard. No forward-looking guarantees of future operational performance are implied.

Executive Summary

This report presents the Cradle-to-Gate Product Carbon Footprint (PCF) of an **11 kW Super Premium Efficiency (IE4) Industrial Electric Motor** manufactured at an industrial facility in **Eindhoven, Netherlands**. The study evaluates the complete upstream and direct life cycle burdens required to produce and package 1.0 unit ready for distribution at the factory gate, adhering rigorously to the **GHG Protocol Product Life Cycle Accounting and Reporting Standard** and the mandatory **2026 Land Sector and Removals (LSR) Standard** updates.

Key Result: The total Cradle-to-Gate Product Carbon Footprint is **248.86 kg CO₂e per functional unit (1.0 motor)**. Upstream Scope 3 emissions dominate the footprint at **91.4% (227.46 kg CO₂e)**, driven primarily by electrical steel stamping and refined copper magnet wire extraction. Direct facility Scope 1 emissions account for **1.9% (4.72 kg CO₂e)**, while market-based Scope 2 emissions contribute **6.7% (16.68 kg CO₂e)**. Scope 3 data completeness reaches **98.4%**, easily surpassing the 95% threshold required by the 2026 accounting framework.

Consolidated Carbon Inventory Summary (per 1.0 Unit)

Emission Category (GHG Protocol)	Life Cycle Stage / Source	Emissions (kg CO ₂ e)	Share (%)	Primary Data Source
Scope 1 (Direct)	Natural gas space heating, test bench diesel, test fugitive SF6/refrigerant	4.72	1.90%	Primary facility meters (NL site)
Scope 2 (Indirect Energy)	Facility electricity consumption (Market-Based: Dutch Residual Mix)	16.68	6.70%	Utility bills & supplier disclosure
Scope 3 (Upstream Value Chain)	Raw materials extraction, refining, sub-assembly	209.12	84.03%	Supplier EPDs & Ecoinvent v3.10

Emission Category (GHG Protocol)	Life Cycle Stage / Source	Emissions (kg CO ₂ e)	Share (%)	Primary Data Source
	manufacturing (Cat 1)			
Scope 3 (Fuel & Energy Activities)	Well-to-Tank (WTT) and T&D grid losses for NL energy (Cat 3)	4.84	1.94%	DEFRA / IEA Europe 2025/2026
Scope 3 (Inbound Logistics)	Freight transport from European suppliers to Netherlands plant (Cat 4)	11.65	4.68%	Carrier logbooks & GLEC Framework
Scope 3 (Manufacturing Waste)	Wastewater treatment & scrap metal processing (Cat 5)	1.85	0.74%	Certified waste manifest data
Total Cradle-to-Gate Product Carbon Footprint (Gross)		248.86	100.00%	Verified Inventory Coverage: 98.4%
2026 LSR Removals Balance	Biogenic carbon stored in PEFC timber shipping pallet (net balance)	-7.25	N/A	Reported separately per LSR Standard

1. Scope and Boundary Definition

The scope of this carbon footprint evaluation is structured under the rigorous guidelines of the **GHG Protocol Product Life Cycle Accounting and Reporting Standard**, supplemented by ISO 14067 (2018) guidelines.

- **Functional Unit:** 1.0 unit of a 4-pole, 11 kW Low Voltage Three-Phase AC Induction Motor (IE4 Super Premium Efficiency classification according to IEC 60034-30-1), housed in an aluminum-cast frame with cast-iron end-shields, high-grade silicon electrical steel laminations, insulated copper winding, and industrial bearing assemblies, having an unboxed operational net weight of 78.50 kg (packed gross weight: 84.70 kg).

- **System Boundary:** Factory Gate (Cradle-to-Gate). This incorporates all phases from raw resource extraction, beneficiation, chemical transformation, intermediate components production across the European supply base, inter-facility transport, to final assembly, testing, surface treatment, packaging, and staging at the Netherlands distribution dock. Customer distribution, operational use-phase, and end-of-life disposal are excluded.
- **Geographic Scope:** Final assembly, testing, and coating occur in the **Netherlands**. The supply chain is strictly **Europe-focused**: electrical steel from Germany, copper wire from Germany/Sweden, aluminum housing casting from northern Italy, bearings from Sweden, polymers from Belgium, and timber packaging from certified Dutch/German mills.
- **Cut-Off Criteria & Completeness:** Under the 2026 Scope 3 rules, at least 95% of cradle-to-gate mass and emissions must be accounted for. In this study, **98.4%** of mass inputs and estimated greenhouse gas impacts are verified with primary or tier-1 audited secondary records. Infrastructure capital goods (plant machinery depreciation) and corporate business travel are excluded in line with GHG Protocol factory-gate boundaries.
- **Allocation Rules:** Mass-based physical allocation is applied for stamping scrap and off-cuts during lamination punching. Facility overhead energy (HVAC, lighting, compressed air) is allocated based on product production cycle time on the assembly line relative to monthly facility capacity.

2. Life Cycle Inventory (LCI) & Activity Mapping

The life cycle is divided into three distinct operational modules: Upstream Material Sourcing & Processing, Inbound European Freight Logistics, and Netherlands Plant Assembly & Quality Testing.

Material & Bill of Materials (BOM) Breakdown

Component / Material Stream	Material Specification	Net Mass (kg)	Sourcing Location	Transport Mode
Stator & Rotor Core Laminations	Non-oriented silicon electrical steel (M330-50A)	36.20	Duisburg, Germany	Road Freight (EURO 6 Diesel Truck)
		17.80	Brescia, Italy	

Component / Material Stream	Material Specification	Net Mass (kg)	Sourcing Location	Transport Mode
Rotor Squirrel Cage & Motor Housing	Cast aluminum alloy (AlSi10Mg, 45% recycled)			Intermodal Rail / Road (EURO 6)
Stator Winding	Oxygen-free electrolytic copper wire (enamelled)	11.40	Hettstedt, Germany	Road Freight (EURO 6 Diesel Truck)
End Shields & Flanges	Grey cast iron (EN-GJL-200)	8.10	Eindhoven local foundry, NL	Regional Delivery Van (<50 km)
Rotor Shaft	Forged carbon steel rod (C45E)	3.20	Saarbrücken, Germany	Road Freight (EURO 6 Diesel Truck)
Bearing Assemblies	Chromium steel deep-groove ball bearings (6308-2Z)	0.85	Göteborg, Sweden	Sea Ferry + Road Truck
Terminal Box & Fan Shroud	Glass-reinforced polyamide (PA6-GF30) & PBT	0.65	Antwerp, Belgium	Road Freight (EURO 6 Diesel Truck)
Slot Liners & Phase Insulation	Aramid paper / Polyester film (Nomex-Mylar)	0.30	Luxembourg	Express Parcel Delivery
Protective Surface Coating	Two-component waterborne epoxy primer & topcoat	0.45	Rotterdam, Netherlands	Local Road Distribution
Packaging: Pallet & Bracing	PEFC certified European soft timber (pine/spruce)	4.80	Arnhem, Netherlands	Local Road Distribution
Packaging: Box & Strapping	Heavy-duty corrugated kraft cardboard (80% recycled)	1.40	Tilburg, Netherlands	Local Road Distribution
Total Physical Product Mass (Shipped State)		84.70	Primary Mass Measurement Verification	

Energy & Utility Inputs at Netherlands Manufacturing Facility (per Unit)

Energy Carrier / Input	Process Application	Quantity	Unit	Primary Metering / Verification
Electricity (Dutch Residual Grid Mix)	Automated winding, pressing, dyno testing, plant compressed air	42.50	kWh	Sub-metered manufacturing line & plant SCADA
Natural Gas (G-gas standard)	Stator impregnation varnish curing oven & HVAC space heating	2.15	m³	Dedicated gas flow-meter at oven intake
Process Water	Component ultrasonic wash & cooling loops	65.00	Liters	Facility municipal water intake meter
Compressed Air Leakage Allocation	Pneumatic tooling and positioning jigs (7.0 bar)	14.20	Nm³	Compressor energy allocation schedule

3. 2026 Land Sector and Removals (LSR) Standard Accounting

In accordance with the **GHG Protocol Land Sector and Removals (LSR) Standard (2026 Update)**, carbon removals, land management emissions, and biogenic carbon pools must be quantified and reported transparently and separately from fossil emission totals.

LSR Governance Principles Applied:

- Separate Reporting:** Fossil GHG emissions (248.86 kg CO₂e) and biogenic removals/emissions are not co-mingled in the gross headline footprint.
- Biogenic Carbon in Bio-Based Packaging:** The unit includes 4.80 kg of solid European pine pallet wood and 1.40 kg of corrugated cardboard. Based on 50% carbon content in dry wood biomass, this represents an embedded biogenic carbon pool of **7.25 kg CO₂e removals**.
- Land Use Change (LUC):** Sourced timber is 100% PEFC certified from sustainably managed European semi-natural forests with stable

or increasing forest carbon stocks. Direct land use change (dLUC) and statistical land use change (sLUC) are evaluated at **0.02 kg CO₂e** and integrated into Scope 3 Category 1.

4. **Temporary Storage Disallowance:** Because this evaluation is Cradle-to-Gate, credit for temporary carbon storage during shipping and staging is not used to offset permanent fossil emissions.

LSR Carbon Flow Parameter	Quantity (kg CO ₂ e)	Accounting Classification	Compliance Status
Fossil GHG Emissions (Cradle-to-Gate)	248.86	Gross Product Carbon Footprint	GHG Protocol Standard
Biogenic Carbon Sequestration (Inherent)	-7.25	Biogenic Removals (Stored in Packaging)	LSR 2026 Compliant (Reported Separately)
Direct Land Use Change (dLUC)	+0.02	Biogenic Land Emission (Scope 3 Cat 1)	PEFC Chain-of-Custody Verified
Net Cradle-to-Gate GHG Balance (LSR Reporting)	241.63	Gross 248.86 kg CO₂e / Removals -7.25 kg CO₂e	

4. Detailed Emission Calculations & Characterization

Calculations utilize the equation: **Emissions (kg CO₂e) = Activity Data × Emission Factor**. Global Warming Potentials (GWPs) are sourced from the IPCC 6th Assessment Report (AR6) over a 100-year time horizon (GWP100).

A. Scope 1: Direct Facility Emissions

Emission Source	Activity Volume	Unit	Emission Factor	Factor Source	Emissions (kg CO ₂ e)
Natural Gas Combustion (Ovens & Heating)	2.15	m ³	2.0280 kg CO ₂ e/m ³	CO2emissiefactoren.nl (NL Standard)	4.36
Dyno Test Diesel	0.12	Liters		DEFRA 2025/2026	0.32

Emission Source	Activity Volume	Unit	Emission Factor	Factor Source	Emissions (kg CO ₂ e)
Backup Generator			2.6920 kg CO ₂ e/L		
Test Bench Refrigerant Leakage (R134a)	0.00003	kg	1,430 kg CO ₂ e/kg	IPCC AR6	0.04
Subtotal Scope 1 Emissions					4.72

B. Scope 2: Indirect Emissions from Purchased Energy

Energy Source	Activity Volume	Unit	Emission Factor	Calculation Methodology	Emissions (kg CO ₂ e)
Electricity - Facility Consumption	42.50	kWh	0.3925 kg CO ₂ e/kWh	Market-Based (NL Residual Grid Mix 2025/2026)	16.68
Sensitivity: Location-Based Electricity	42.50	kWh	0.2980 kg CO ₂ e/kWh	Location-Based (Netherlands Average Grid)	(12.67)
Subtotal Scope 2 Emissions (Market-Based Compliance)					16.68

C. Scope 3: Upstream Value Chain Emissions

Scope 3 Category & Component	Activity	Unit	Emission Factor	Data Source	Emissions (kg CO ₂ e)
Cat 1: Electrical Steel (Core laminations)	36.20	kg	2.450 kg CO ₂ e/kg	Worldsteel / Ecoinvent 3.10	88.69
Cat 1: Secondary Cast Aluminum (Housing/Rotor)	17.80	kg	3.120 kg CO ₂ e/kg	European Aluminium EPD / Ecoinvent	55.54
Cat 1: Electrolytic Copper Wire (Enamelled)	11.40	kg	4.680 kg CO ₂ e/kg	Copper Alliance / Ecoinvent 3.10	53.35

Scope 3 Category & Component	Activity	Unit	Emission Factor	Data Source	Emissions (kg CO ₂ e)
Cat 1: Cast Iron End Shields	8.10	kg	0.890 kg CO ₂ e/kg	Ecoinvent v3.10 (Casting EU)	7.21
Cat 1: Forged Carbon Steel Shaft	3.20	kg	1.820 kg CO ₂ e/kg	Ecoinvent v3.10	5.82
Cat 1: Deep-Groove Bearings	0.85	kg	2.950 kg CO ₂ e/kg	Manufacturer Environmental Profile	2.51
Cat 1: Polymers (PA6-GF30, PBT, Slot Insulators)	0.95	kg	4.250 kg CO ₂ e/kg	PlasticsEurope / Ecoinvent 3.10	4.04
Cat 1: Industrial Epoxy Surface Coating	0.45	kg	3.200 kg CO ₂ e/kg	CEPE GHG Database	1.44
Cat 1: Packaging Production (Wood & Cardboard)	6.20	kg	0.084 kg CO ₂ e/kg	Ecoinvent 3.10 (excl. removals)	0.52
Cat 3: Fuel & Energy WTT + T&D Losses	42.50	kWh eq	0.1138 kg CO ₂ e/kWh	DEFRA 2025/2026 Netherlands Grid	4.84
Cat 4: Inbound Supplier Freight (Cross-Europe)	118.50	t-km	0.0983 kg CO ₂ e/t-km	GLEC Framework v3.0 / EcoTransIT	11.65
Cat 5: Factory Gate Waste & Scrap Recovery	4.10	kg	0.4512 kg CO ₂ e/kg	NL Afvalverwerking Standards	1.85
Subtotal Scope 3 Emissions					227.46

5. Carbon Hotspot Analysis & 95% Scope 3 Completeness

Emission Hotspot Breakdown

The hotspot evaluation demonstrates that upstream Tier-1 and Tier-2 raw material extraction and metallurgical processing constitute **84.0%** of the product's entire cradle-to-gate environmental burden.

- **Electrical Steel Laminations (35.6% of Total Footprint):** The high silicon electrical steel (36.20 kg) generates 88.69 kg CO₂e due to blast furnace iron-making and rolling processes. Moving to Green Steel (EAF route utilizing direct reduced iron with hydrogen) presents the largest single reduction potential.
- **Cast Aluminum Components (22.3% of Total Footprint):** Smelting and casting the rotor cage and exterior stator frame contribute 55.54 kg CO₂e. The currently utilized 45% post-industrial recycled blend saves an estimated 32.4 kg CO₂e compared to 100% primary aluminium.
- **Electrolytic Winding Copper (21.4% of Total Footprint):** High-purity copper refining and enameling contribute 53.35 kg CO₂e despite representing only 13.5% of total product mass, reflecting copper's elevated embodied energy factor (4.68 kg CO₂e/kg).
- **Facility Electricity Consumption (6.7% of Total Footprint):** Assembly automation, stator vacuum pressure impregnation (VPI), and dynamometer testing contribute 16.68 kg CO₂e under the Dutch residual grid mix.
- **European Inbound Logistics (4.7% of Total Footprint):** Cross-border heavy-duty trucking from Italy and Germany represents 11.65 kg CO₂e.

Data Quality & Completeness Audit (Scope 3 Compliance)

Per the 2026 GHG Protocol Scope 3 Guidance, industrial product carbon footprints must achieve at least 95% data completeness across upstream operations.

Completeness Metric	Target Threshold	Achieved Level	Status
Bill of Materials (BOM) Mass Accounted	> 95.0%	99.1%	Compliant (0.9% cut-off: thread sealants, labels)
	> 95.0%	98.4%	

Completeness Metric	Target Threshold	Achieved Level	Status
Scope 3 Category Coverage			Compliant (Audited via primary EPDs & Ecoinvent)
Primary Operational Data Ratio	> 50.0%	74.2%	Compliant (Facility energy, weights, tier-1 suppliers)
Temporal Representativeness	< 3 Years	2024-2026	Compliant (Current operational cycle)
Geographical Specificity	Specific to Country/Region	100.0%	Compliant (NL electricity, EU-27 transport routes)

6. Decarbonization Roadmap & Consultant Recommendations

To accelerate decarbonization aligned with the EU Corporate Sustainability Due Diligence Directive (CSDDD) and Net-Zero 2030 targets, the following technical interventions are recommended for the Eindhoven manufacturing site:

Intervention Strategy	GHG Scope Impacted	Implementation Complexity	Abatement Potential (kg CO _{2e})	Footprint Reduction (%)
1. High-Recycled / EAF Electrical Steel: Procure laminations manufactured using scrap-fed electric arc furnace steel powered by Scandinavian renewables.	Scope 3 (Cat 1)	Medium (Requires magnetic permeability qualification)	-35.50	-14.26%
2. On-Site Rooftop Solar PV & Green PPA: Install a 250 kWp	Scope 2 (Market-based)	Low (Commercial contract & 6-month install)	-15.10	-6.07%

Intervention Strategy	GHG Scope Impacted	Implementation Complexity	Abatement Potential (kg CO ₂ e)	Footprint Reduction (%)
solar PV array on the Eindhoven facility roof and contract certified Dutch Guarantees of Origin (GoOs).				
3. 80% Recycled Secondary Aluminum: Increase secondary alloy content for the motor frame from 45% to 80% via certified Italian foundry supply chains.	Scope 3 (Cat 1)	Low (Drop-in alloy replacement)	-18.20	-7.31%
4. Inbound Rail Intermodal Logistics: Shift component transport corridors from northern Italy and southern Germany from highway trucks to electric rail corridors.	Scope 3 (Cat 4)	Medium (Logistics partner optimization)	-7.40	-2.97%
5. Electric Heat Pumps for Curing & HVAC: Replace fossil natural gas ovens with high-temperature industrial electric infrared curing and heat pumps.	Scope 1	High (Capital equipment overhaul)	-4.10	-1.65%
Combined Net Abatement Potential			-80.30 kg CO₂e	-32.27%

Strategic Summary: Implementing these prioritized actions will reduce the Cradle-to-Gate Product Carbon Footprint of the 11 kW motor from **248.86 kg CO₂e down to 168.56 kg CO₂e** per unit, positioning the product in the top decile of environmental performance across the European electro-mechanical equipment sector.