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Product Carbon Footprint Analysis Report

Product: Reading Glasses

Protocol Data (Accounting Standard): GHG Protocol

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This report is generated based on available data and industry standards, providing an estimate of the product\'s carbon footprint.

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Generated Date: August 22, 2026

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Executive Summary

This report presents a high-detail Product Carbon Footprint (PCF) analysis for one unit of reading glasses, conducted in accordance with the GHG Protocol. The analysis, performed by Senior Sustainability Consultant Remko Weingarten, focuses on a \'factory_gate\' system boundary, with final production in the Netherlands and a supply chain primarily focused on Europe. The aim is to identify key emission hotspots across the product\'s lifecycle up to the point of leaving the factory, incorporating the latest 2026 GHG Protocol updates including the Land Sector and Removals (LSR) Standard and the 95% Scope 3 coverage requirement.

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1. Define Scope

1.1. Functional Unit

The functional unit for this Product Carbon Footprint (PCF) analysis is defined as **1.0 unit of reading glasses**. This unit represents the utility provided to the end-user for vision correction.

1.2. System Boundary

The system boundary for this PCF is defined as **\'factory_gate\'**. This includes all greenhouse gas (GHG) emissions associated with the extraction of raw materials, manufacturing of components, transportation of these components to the final assembly factory, and the assembly/production processes within the factory, up to the point the finished reading glasses leave the factory gate. It excludes downstream emissions such as distribution to retail, use-phase, and end-of-life treatment.

1.3. Geographic Scope

The **Final Production Country is the Netherlands**, with a **Supply Chain Focus on Europe**. This implies that emission factors and energy mixes relevant to Europe and specifically the Netherlands will be prioritized where available, particularly for electricity consumption and transportation.

1.4. Allocation

Given the focus on a single product (reading glasses), complex allocation procedures are largely minimized within the \'factory_gate\' boundary. For any shared processes or co-products, mass-based allocation is assumed to be the primary method where applicable, ensuring that emissions are proportionally assigned to the reading glasses based on their mass contribution to the output of that process.

1.5. Accounting Standard

This PCF analysis strictly adheres to the **GHG Protocol** standards. Emissions are categorized into:

- **Scope 1:** Direct emissions from owned or controlled sources (e.g., natural gas combustion in factory boilers, owned vehicle fleet for internal logistics).
- **Scope 2:** Indirect emissions from the generation of purchased electricity, steam, heating, or cooling consumed by the reporting company (e.g., electricity used in the Netherlands factory).
- **Scope 3:** All other indirect emissions that occur in the value chain of the reporting company, both

upstream and downstream. For a \'factory_gate\' boundary, this primarily encompasses upstream emissions from purchased goods and services (raw materials, component manufacturing) and upstream transportation.

The analysis incorporates recent updates to the GHG Protocol:

- **2026 Land Sector and Removals (LSR) Update:** The Land Sector and Removals (LSR) Standard v1.0 was released on January 30, 2026, and is set to take effect on January 1, 2027. The accompanying LSR Guidance was published on June 30, 2026. This standard sets requirements for corporate GHG accounting covering emissions and carbon removals from agricultural and land use activities. While direct land use change is unlikely for manufactured reading glasses, this standard would apply to any biogenic materials (e.g., cellulose in acetate frames, if used) or land-based carbon removals in the supply chain, ensuring these are accounted for appropriately. The guidance clarifies that disaggregated accounting and physical traceability are mandatory for claiming on-farm interventions within a corporate inventory starting January 1, 2027.
- **Scope 3 Compliance (2026 Requirements):** As per the 2026 requirements, companies must account for at least 95% of total relevant Scope 3 emissions to claim conformance with the GHG Protocol Scope 3 Standard. This means that up to 5% of required emissions may be excluded, but these exclusions must be quantified, disclosed, and justified, not merely described qualitatively. This report strives for comprehensive Scope 3 coverage to meet this stringent threshold.

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2. Map Lifecycle & 3. Collect Data

2.1. Product Bill of Materials (BoM) - Reading Glasses (Illustrative per 1.0 unit)

The reading glasses typically consist of a frame, lenses, hinges, screws, and packaging. The following breakdown assumes common materials for a standard pair:

Table 1: Detailed Material Breakdown and Assumed Weights

Component	Material	Assumed Weight (grams)	Primary Data Source Assumption
Frame	TR-90 Thermoplastic Polymer	20 g	Upstream supplier data (e.g., polymer manufacturer LCA data) or Ecoinvent equivalent.
Lenses (2 units)	Polycarbonate (PC)	20 g (10g per lens)	Upstream lens manufacturer data or Ecoinvent equivalent.
Hinges & Screws	Stainless Steel	2 g	Upstream metal component manufacturer data or Ecoinvent equivalent.
Lens Coating (e.g., anti-scratch, anti-reflective)	Silicone-based/ Acrylic (negligible mass)	< 0.1 g	Energy for application process.
Inner Packaging (Plastic	Polyethylene (PE) sleeve, Microfiber cloth		Upstream packaging/ textile

Component	Material	Assumed Weight (grams)	Primary Data Source Assumption
Sleeve, Cleaning Cloth)	(Polyester/ Nylon)	5 g (PE), 5 g (Microfiber)	manufacturer data or Ecoinvent equivalent.
Outer Packaging (Retail Box)	Recycled Cardboard	20 g	Upstream paper/pulp mill data or Ecoinvent/ DEFRA equivalent.

2.2. Energy Inputs (Manufacturing Processes in Netherlands Factory)

The manufacturing process involves several energy-intensive steps. For the \'factory_gate\' boundary, this includes energy for production machinery, factory heating/ cooling, and lighting.

Table 2: Estimated Energy Inputs per Functional Unit (1.0 Reading Glass)

Process Stage	Energy Type	Estimated Consumption per Unit (kWh)	Primary Data Source Assumption
Frame Molding (Injection Molding)	Electricity	0.15 kWh	Based on typical injection molding machine consumption (e.g., 3.8 to 17.9 kWh per cycle for 90T-460T machines, or 15-25 kWh/hr for 100-ton machine, adjusted for part size/cycle time).

Process Stage	Energy Type	Estimated Consumption per Unit (kWh)	Primary Data Source Assumption
Lens Cutting, Shaping & Polishing	Electricity	0.08 kWh	Industry benchmarks for optical lens processing.
Assembly (including hinge attachment, lens insertion)	Electricity	0.02 kWh	Automated assembly line energy.
Coatings Application (PVD/CVD processes, curing)	Electricity	0.05 kWh	Energy-intensive thin-film deposition and curing.
Factory Overheads (Lighting, HVAC, general machinery pro-rata)	Electricity	0.03 kWh	Pro-rata share of total factory energy consumption.

2.3. Transportation Inputs (to Netherlands Factory)

Transportation of raw materials and components to the final assembly factory in the Netherlands is a significant Scope 3 emission source.

Table 3: Estimated Transportation Inputs per Functional Unit

Material Group	Mode of Transport	Assumed Distance (km)	Assumed Load Factor	Primary Data Source Assumption
Plastics (TR-90, Polycarbonate, PE)	Heavy Goods Vehicle (HGV) Road Freight, Europe	1000 km	High (e.g., 80% capacity utilization)	Average European road freight distances.
Metals (Stainless Steel)	Heavy Goods Vehicle (HGV) Road Freight, Europe	1200 km	High (e.g., 80% capacity utilization)	Average European road freight distances.
Packaging (Cardboard, Microfiber)	Heavy Goods Vehicle (HGV) Road Freight, Europe	800 km	High (e.g., 80% capacity utilization)	Average European road freight distances.

2.4. Emission Factors (Illustrative from Ecoinvent/DEFRA/IEA)

The following emission factors are used for calculations, based on industry standards like Ecoinvent, DEFRA, and IEA where applicable. These factors represent a cradle-to-gate footprint for the raw materials themselves, excluding their transport to the final factory unless specified.

Table 4: Key Emission Factors Used

Activity/ Material	Emission Factor (kg CO2e per unit)	Unit	Source/Basis
TR-90 (Plastic) Production	4.5	kg CO2e/ kg	Illustrative (Nylon/ Polyamide variant average, Ecoinvent/ DEFRA equivalent, considering TR90\'s lower emission processes).
Polycarbonate (PC) Production	7.0	kg CO2e/ kg	Illustrative (Ecoinvent/ DEFRA equivalent).
Stainless Steel Production	6.15	kg CO2e/ kg	CarbonCloud verified factor for stainless steel at factory gate. (Other sources range from ~2-4 kg CO2e/kg to 1.53 kg CO2e/kg for stainless steel production depending on recycled content and specific type).
Polyethylene (PE) Production	1.8	kg CO2e/ kg	Illustrative (Ecoinvent/ DEFRA equivalent for virgin PE).
Microfiber (Polyester/ Nylon) Production	5.5	kg CO2e/ kg	Illustrative (Synthetics from fossil fuels, high energy input).
Recycled Cardboard Production	0.7	kg CO2e/ kg	DEFRA database for recycled cardboard. (Other sources show virgin cardboard at 0.94-1.85 kg CO2e/kg and recycled at 0.61-0.82 kg CO2e/kg).

Activity/ Material	Emission Factor (kg CO2e per unit)	Unit	Source/Basis
Electricity Grid Mix (Netherlands, 2026)	0.331	kg CO2e/ kWh	Nowtricity current emissions for Netherlands (August 2026). (IEA 2025 provisional factor 0.388 kg CO2e/kWh).
HGV Road Freight (Europe, >20t)	0.08	kg CO2e/ tonne-km	Illustrative (GLEC Framework, representative of European averages). (Road transport is a major source of emissions in EU).

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4. Calculate Emissions

Emissions are calculated by multiplying the activity data (quantities of materials, energy, and transport) by their respective emission factors. The results are categorized according to GHG Protocol Scopes.

4.1. Scope 1 Emissions (Direct Emissions from Owned/Controlled Sources)

For a \'factory_gate\' boundary, and without specific operational data, Scope 1 emissions are assumed to be minimal or zero for direct combustion on-site if the factory primarily uses purchased electricity and no owned vehicles are involved in the direct production process. Assuming factory boilers or internal logistics are covered by Scope 2 (purchased heat) or Scope 3 (outsourced transport) if applicable, or that the electricity factor already embeds upstream fuel production. For this analysis, direct

combustion from factory boilers (e.g., natural gas for heating) will be an estimated value.

Table 5: Estimated Scope 1 Emissions

Activity	Activity Data	Emission Factor (kg CO2e/unit)	Total CO2e (kg)
Natural Gas for minimal heating/auxiliary processes (estimated direct burn at factory)	0.005 m^3 gas/unit	2.0 kg CO2e/ m^3	0.010

Total Estimated Scope 1 Emissions: 0.010 kg CO2e per functional unit.

4.2. Scope 2 Emissions (Indirect Emissions from Purchased Energy)

These emissions arise from the electricity consumed in the Netherlands factory for manufacturing and overheads.

Table 6: Estimated Scope 2 Emissions

Energy Input	Consumption per Unit (kWh)	Emission Factor (kg CO2e/kWh)	Total CO2e (kg)
Frame Molding	0.15	0.331	0.04965
Lens Processing	0.08	0.331	0.02648
Assembly	0.02	0.331	0.00662
Coatings Application	0.05	0.331	0.01655
Factory Overheads	0.03	0.331	0.00993
Total Electricity Consumption			

Energy Input	Consumption per Unit (kWh)	Emission Factor (kg CO2e/kWh)	Total CO2e (kg)
			0.33 kWh

Total Estimated Scope 2 Emissions: 0.10923 kg CO2e per functional unit.

4.3. Scope 3 Emissions (Value Chain Emissions - Upstream)

Scope 3 emissions, particularly from purchased goods and services and upstream transportation, represent the largest portion of a product\'s carbon footprint within a \'factory_gate\' boundary. The 95% coverage requirement emphasizes the need for comprehensive data here.

Table 7: Estimated Scope 3 Emissions from Purchased Goods & Services (Raw Materials)

Material	Mass per Unit (kg)	Emission Factor (kg CO2e/kg)	Total CO2e (kg)
TR-90 Frame	0.020	4.5	0.090
Polycarbonate Lenses	0.020	7.0	0.140
Stainless Steel Hinges/Screws	0.002	6.15	0.0123
Polyethylene Sleeve	0.005	1.8	0.009
Microfiber Cloth	0.005	5.5	0.0275
Recycled Cardboard Packaging	0.020	0.7	0.014

Subtotal Scope 3 (Materials): 0.2928 kg CO2e per functional unit.

Table 8: Estimated Scope 3 Emissions from Upstream Transportation

Material Group	Total Mass (kg)	Distance (km)	Emission Factor (kg CO2e/ tonne-km)	Total CO2e (kg)
Plastics (Frame, Lenses, PE sleeve)	0.020 + 0.020 + 0.005 = 0.045	1000	0.08	0.045 kg * 1000 km * 0.08 kgCO2e/tonne-km = 3.6 kg CO2e, assuming 100% load on 1 tonne vehicle, so 0.045 * 1000 * 0.00008 = 0.0036 kgCO2e. However, we have 0.08 kg CO2e per tonne-km, so for 0.045 kg * 1000 km = 45 kg-km. 45 kg-km * 0.08 kgCO2e/(1000 kg-km) = 0.0036 kg CO2e. More accurately, if the factor is 0.08 kgCO2e/ tonne-km, then for kg, it\'s 0.00008 kgCO2e/kg-km. Therefore, 0.045 kg * 1000 km * 0.00008 kgCO2e/kg-km = 0.0036.
	0.002	1200	0.08	0.002 kg * 1200 km * 0.00008

Material Group	Total Mass (kg)	Distance (km)	Emission Factor (kg CO2e/ tonne-km)	Total CO2e (kg)
Metals (Hinges/ Screws)				kgCO2e/kg-km = 0.000192
Packaging (Cardboard, Microfiber)	0.020 + 0.005 = 0.025	800	0.08	0.025 kg * 800 km * 0.00008 kgCO2e/kg-km = 0.0016

Subtotal Scope 3 (Transport): 0.005392 kg CO2e per functional unit.

Total Estimated Scope 3 Emissions (Materials + Transport): 0.2928 + 0.005392 = 0.298192 kg CO2e per functional unit.

Note on Scope 3 Coverage: The detailed breakdown of materials and transport aims to ensure at least 95% coverage of upstream Scope 3 emissions. This includes all significant purchased goods, components, and their associated transportation to the factory gate. Smaller inputs such as adhesive for hinges or printing inks are considered negligible in mass and emissions for this high-level analysis but would be quantified in a more granular assessment to ensure full 95% compliance if deemed material.

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5. Review & Report

5.1. Total Product Carbon Footprint (PCF)

The estimated Product Carbon Footprint for 1.0 unit of reading glasses, up to the factory gate, is summarized below:

Table 9: Summary of Product Carbon Footprint (kg CO2e per Functional Unit)

Emission Scope	Total CO2e (kg)	Percentage of Total
Scope 1 (Direct Emissions)	0.010	3.1%
Scope 2 (Purchased Electricity)	0.10923	34.0%
Scope 3 (Upstream Value Chain)	0.298192	92.8%
Total PCF (Cradle-to-Gate)	**0.417422**	**100.0%**

Total Product Carbon Footprint for 1.0 unit of reading glasses (factory_gate): Approximately 0.417 kg CO2e.

5.2. Emission Hotspots

Based on this analysis, the primary emission hotspots for reading glasses up to the factory gate are:

- **Scope 3 - Purchased Goods and Services (Raw Materials):** This category accounts for the vast majority of emissions (approximately 92.8% of the total PCF, with raw materials alone contributing significantly to this). Specifically, the production of polycarbonate for lenses and TR-90 for frames are major contributors due to their energy-intensive manufacturing processes. Stainless steel production also adds to this, although its mass contribution is smaller.
- **Scope 2 - Purchased Electricity:** The energy consumed during various manufacturing processes within the Netherlands factory (molding, cutting, assembly, coatings) is the second largest contributor, making up approximately 34.0% of the emissions within the \'factory_gate\' boundary. The Netherlands\' electricity grid mix, while improving, still has a carbon intensity that impacts this scope.

- **Scope 1 - Direct Emissions:** Direct emissions from factory operations are relatively small in this particular assessment, accounting for a minor portion of the total.
- **Scope 3 - Upstream Transportation:** While essential, the transportation of materials to the factory contributes a smaller, but still notable, portion of the overall footprint compared to raw material production and factory energy.

5.3. Reliability and Limitations

The reliability of this PCF analysis is dependent on the quality and availability of data. Key considerations include:

- **Secondary Data Reliance:** This analysis heavily relies on secondary (industry-average) emission factors from databases like Ecoinvent and DEFRA, and IEA/Nowtricity for electricity grids. While representative, these may not perfectly reflect the specific production efficiencies or material compositions of individual suppliers within the reading glasses supply chain.
- **Assumptions:** Assumptions regarding material weights, energy consumption per process, and transportation distances are based on typical industry practices and expert judgment in the absence of primary, supplier-specific data. Variations in these assumptions could alter the final PCF.
- **GHG Protocol 2026 Updates:** While the report explicitly acknowledges the 2026 LSR Standard and the 95% Scope 3 coverage, the practical application of these, especially for land-use aspects of complex supply chains for a product like reading glasses, would require deeper engagement with material suppliers to trace biogenic content and land-based impacts where relevant. The guidance for LSR was only recently published (June 2026), and its full implementation will take time.
- **Dynamic Emission Factors:** Emission factors, particularly for electricity grids and transportation, are dynamic and can change over time. The factors

used are based on the latest available information for 2026.
- **Boundary Limitations:** The \'factory_gate\' boundary intentionally excludes downstream impacts (distribution to consumer, use phase, end-of-life). A full \'cradle-to-grave\' or \'cradle-to-cradle\' assessment would yield a higher total footprint but was outside the scope of this report.

5.4. Recommendations for Emission Reduction

To reduce the carbon footprint of reading glasses, the following actions are recommended:

- **Supplier Engagement for Scope 3 Data:** Prioritize collecting primary data from key material suppliers (e.g., TR-90, polycarbonate, stainless steel manufacturers) to gain a more accurate understanding of their specific emissions and identify opportunities for reduction.
- **Material Innovation:** Explore and adopt lower-carbon alternative materials or materials with higher recycled content for frames (e.g., recycled plastics, bio-based plastics with robust LCA data) and packaging (e.g., higher recycled content cardboard).
- **Energy Efficiency in Manufacturing:** Implement energy-efficient technologies and practices in the Netherlands factory, such as optimizing injection molding parameters, using high-efficiency machinery, and improving insulation and HVAC systems.
- **Renewable Energy Procurement:** Increase the share of renewable electricity purchased for factory operations (e.g., through Power Purchase Agreements or green tariffs) to further reduce Scope 2 emissions.
- **Optimized Logistics:** Work with transport providers to optimize routes, maximize load factors, and explore lower-emission transport modes (e.g., electric trucks, rail freight for longer distances) for material delivery within Europe.
- **Product Design for Longevity and Recyclability:** While outside the \'factory_gate\' boundary,

designing products for longer lifespans and easier recycling at end-of-life can significantly reduce the overall lifecycle footprint.
