

carboncalcpcf.com

Product Carbon Footprint Analysis Report

Product: Bioethanol

Protocol Data (Accounting Standard):
GHG Protocol

Name of the Company: Business Analytiq
Pte Ltd

Senior Sustainability Consultant: mike

This report is generated based on available data and industry standards for illustrative purposes. Actual values may vary based on specific operational details and real-time market conditions.

Product Carbon Footprint Report: Bioethanol

Generated Date: April 21, 2026

Executive Summary

This report presents a high-detail Product Carbon Footprint (PCF) analysis for 1.0 liter of bioethanol, focusing on a cradle-to-factory-gate system boundary within a European context. The analysis adheres to the Greenhouse Gas (GHG) Protocol's Corporate Standard, Scope 3 Standard, and incorporates the principles of the newly released 2026 Land Sector and Removals (LSR) Standard. The primary feedstock considered for this illustrative analysis is sugar beet, a prominent crop for bioethanol production in Europe. Key findings highlight the significant emission contributions from feedstock cultivation, energy consumption during processing (electricity and natural gas for heat), and transportation. Strategic recommendations are provided to enhance the sustainability profile of bioethanol production by addressing these hotspots.

1. Define Scope

Functional Unit

The functional unit for this Product Carbon Footprint (PCF) analysis is defined as: **1.0 liter of anhydrous bioethanol** (suitable for fuel use). This unit allows for a standardized comparison of the environmental impact.

System Boundary

The system boundary for this PCF is defined as "**cradle-to-factory-gate**". This encompasses all relevant life cycle stages from the extraction

and cultivation of raw materials (the "cradle") up to the point where the finished bioethanol product leaves the production facility (the "factory gate"). This includes:

- Feedstock cultivation (e.g., sugar beet farming).
- Transportation of feedstock to the processing plant.
- Bioethanol production processes at the facility (e.g., fermentation, distillation, dehydration).
- Processing of co-products up to their factory gate.

Emissions associated with the use phase (e.g., combustion in vehicles) and end-of-life treatment of the bioethanol are excluded from this specific factory-gate boundary.

Geographic Scope

- **Final Production Country:** Netherlands
- **Supply Chain Focus:** Europe Focused. This implies that upstream processes, such as feedstock cultivation and manufacturing of agricultural inputs, are assumed to occur within European geographical boundaries, influencing the choice of emission factors and data sources.

Accounting Standard

This analysis strictly adheres to the methodologies and principles outlined by the **GHG Protocol**. Specifically, it builds upon:

- The Corporate Standard for company-level reporting.
- The Corporate Value Chain (Scope 3) Accounting and Reporting Standard for upstream emissions.
- The **2026 Land Sector and Removals (LSR) Standard** for land use and carbon removals. The LSR Standard, released on January 30, 2026, and taking effect on January 1, 2027, provides crucial guidance for quantifying, reporting, and tracking land emissions, CO₂ removals, and emissions from biogenic products. For the purpose of this report, we apply its principles in anticipation of its full implementation, acknowledging that accompanying guidance is expected in Q2 2026.

GHG Protocol Scopes Categorization

Emissions are categorized as follows:

- **Scope 1 (Direct Emissions):** GHG emissions from sources owned or controlled by Business Analytiq Pte Ltd's bioethanol production facility. For the factory-gate boundary, this primarily includes emissions from on-site combustion of fossil fuels for heat or power generation (e.g., natural gas for steam boilers).
- **Scope 2 (Indirect Emissions from Purchased Energy):** GHG emissions from the generation of purchased electricity, heat, or steam consumed by Business Analytiq Pte Ltd's facility. These emissions physically occur at the utility provider's facilities.
- **Scope 3 (Other Indirect Emissions / Value Chain Emissions):** All other indirect emissions that occur in the value chain of Business Analytiq Pte Ltd, both upstream and downstream, excluding Scope 2. For this cradle-to-factory-gate analysis, Scope 3 is extensive and includes:
 - Upstream emissions from feedstock cultivation (e.g., fertilizer production, farm machinery fuel, N₂O emissions from soils).
 - Transportation of raw materials (e.g., sugar beet, chemicals, yeast) to the production facility.
 - Production of purchased goods and services (e.g., enzymes, process chemicals, water treatment).
 - Upstream emissions associated with purchased electricity and steam not covered in Scope 2 (e.g., transmission and distribution losses).

As per 2026 requirements, this report ensures at least **95% coverage for Scope 3 reporting**.

Allocation

Bioethanol production from agricultural feedstocks often results in valuable co-products. For sugar beet, co-products typically include vinasse (often used as animal feed or fertilizer) and captured biogenic CO₂. For the purpose of this analysis, we will use a **mass-based allocation approach** for dividing environmental burdens between the main product (bioethanol) and co-products, where practical. This method allocates impacts proportionally to the mass of the co-products produced. Other allocation methods, such as energy-based or economic allocation, could

also be considered depending on the specific application and market value of co-products.

2. Map Lifecycle (LCI Inventory Stages)

The production of bioethanol from sugar beet within a European focused supply chain involves several key stages, each contributing to the overall carbon footprint. We will detail the material and energy inputs for each stage up to the factory gate.

2.1. Feedstock Cultivation: Sugar Beet Farming (Europe)

Sugar beet is a common and efficient feedstock for bioethanol production in Europe.

- **Materials:**
 - **Seeds:** Sugar beet seeds.
 - **Fertilizers:** Nitrogen (N), Phosphorus (P), Potassium (K) fertilizers. Nitrogen fertilizers are particularly energy-intensive to produce and contribute to direct N₂O emissions from soils during application.
 - **Pesticides:** Herbicides, insecticides, and fungicides for crop protection.
 - **Water:** Primarily rainwater, with supplementary irrigation depending on regional climate and practices.
- **Energy Inputs:**
 - **Diesel:** Fuel for agricultural machinery (tractors for plowing, sowing, spraying, harvesting).
 - **Electricity:** Minimal, potentially for irrigation pumps or farm building operations.
- **Associated Emissions (Upstream/On-farm - Scope 3 for bioethanol plant):**
 - Emissions from manufacturing of fertilizers, pesticides, and seeds.
 - CO₂ emissions from diesel combustion in farm machinery.

- N₂O emissions from soils due to fertilizer application and natural soil processes (a significant hotspot).

2.2. Transportation of Feedstock (Europe to Netherlands)

- **Materials:** N/A (transport service).
- **Energy Inputs:**
 - **Diesel:** Fuel for heavy-duty trucks transporting harvested sugar beet from farms to the bioethanol production facility in the Netherlands. Assume average transport distances within Europe.
- **Associated Emissions (Scope 3):**
 - CO₂ emissions from diesel combustion in transport vehicles. Emissions related to the return of empty trucks are also considered.

2.3. Bioethanol Production Facility (Netherlands)

This stage covers the industrial conversion of sugar beet into bioethanol. The facility is assumed to be located in the Netherlands.

- **2.3.1. Receiving and Preparation:**
 - **Materials:** Water for washing.
 - **Energy Inputs:** Electricity for handling, conveying, and washing equipment.
- **2.3.2. Sugar Extraction (Diffusion):**
 - **Materials:** Water.
 - **Energy Inputs:** Steam (heat) for diffusion process, electricity for pumps and other machinery.
- **2.3.3. Fermentation:**
 - **Materials:** Sugar juice (from beet), yeast, enzymes, process water, nutrients.
 - **Energy Inputs:** Electricity for mixers, pumps, and cooling systems (fermentation is exothermic). Steam for sterilization.
 - **Associated Emissions (Direct/Biogenic):** Biogenic CO₂ is released during the fermentation process ($C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$). Under the GHG Protocol's LSR Standard, these biogenic emissions are to be reported.

- **2.3.4. Distillation and Rectification:**
 - **Materials:** Alcoholic mash (fermented juice).
 - **Energy Inputs:** Significant amounts of steam/heat for distillation columns to separate ethanol from water, electricity for pumps.
 - **Outputs:** Concentrated ethanol (approx. 95-96% purity), vinasse (co-product).
 - **2.3.5. Dehydration:**
 - **Materials:** Concentrated ethanol.
 - **Energy Inputs:** Energy for molecular sieves or other dehydration technologies to achieve anhydrous (fuel-grade) ethanol (>99.7% purity). Typically uses heat or electricity.
 - **2.3.6. Co-product Processing (Vinasse):**
 - **Materials:** Vinasse (stillage from sugar-containing raw materials).
 - **Energy Inputs:** Energy (steam/electricity) for concentration or drying of vinasse to produce animal feed or fertilizer.
 - **2.3.7. Storage at Factory Gate:**
 - **Materials:** N/A.
 - **Energy Inputs:** Minimal electricity for pumps, lighting, and ventilation.
 - **Associated Emissions (Scope 1 & 2 for bioethanol plant, Scope 3 for purchased inputs):**
 - CO₂ from on-site combustion of natural gas for steam (Scope 1).
 - CO₂e from purchased electricity (Netherlands grid mix - Scope 2).
 - Upstream emissions from production of enzymes, yeast, and other process chemicals (Scope 3).
-

3. Collect Data (Primary/Secondary Data Points)

For a comprehensive PCF analysis, both primary and secondary data are crucial.

- **Primary Data:** Ideally, Business Analytiq Pte Ltd would provide specific operational data for its bioethanol production facility in the Netherlands. This includes:
 - Actual consumption of electricity, natural gas, and other fuels (e.g., diesel for on-site logistics).
 - Quantities of direct material inputs (e.g., yeast, enzymes, process chemicals, water).
 - Details on co-product output and their processing.
 - Specific agricultural practices for feedstock cultivation if directly controlled or traceable (e.g., fertilizer application rates for sugar beet).
- **Secondary Data:** In the absence of specific primary data for every input across the entire value chain, industry-standard emission factors and life cycle inventory (LCI) data are used. For this report, these secondary data points are sourced from reputable databases reflecting European conditions, such as:
 - **Ecoinvent:** A comprehensive database providing LCI data for a wide range of products, processes, and services, including agricultural inputs, energy generation, and chemical production.
 - **DEFRA (Department for Environment, Food & Rural Affairs, UK):** Provides emission factors for various activities, especially relevant for agriculture, energy, and transport.
 - **European Environment Agency (EEA) / Eurostat:** For regional electricity grid mix emission factors and other relevant environmental data.
 - **JRC (Joint Research Centre of the European Commission):** Provides specific emission factors for fuels and biofuels.
 - **UBA (Umweltbundesamt, Germany):** For natural gas emission factors.

For this illustrative report, we utilize representative industry average emission factors and activity data points that are consistent with what one

would find in such databases, focusing on European averages where appropriate.

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

The calculation of GHG emissions follows the formula: Activity Data × Emission Factor = CO2e. All GHG emissions are expressed in carbon dioxide equivalents (CO2e), using Global Warming Potentials (GWP) from the IPCC Fifth Assessment Report (AR5) over a 100-year horizon.

Below is an illustrative breakdown of the Product Carbon Footprint for 1.0 liter of bioethanol from sugar beet, considering the "cradle-to-factory-gate" boundary. The values are representative and for demonstration purposes, simulating data availability for typical European operations.

Illustrative PCF Breakdown for 1.0 Liter Bioethanol (Sugar Beet)

Lifecycle Stage	Activity Description	Activity Data (per 1L Bioethanol)	Emission Factor (CO2e)	Calculated Emissions (kg CO2e)	GHG Scope	Notes
1. Feedstock Cultivation (Sugar Beet)	N-Fertilizer Production & Application	0.15 kg N	5.0 kg CO2e/kg N (Includes production & N2O from soil)	0.750	Scope 3	Assumes typical N application sugar beet N2O soil emissions significant
	P/K-Fertilizer & Pesticides Production	0.1 kg P/K, 0.01 kg Pest.	1.5 kg CO2e/kg (P/K), 20 kg CO2e/kg (Pest.)	0.150 + 0.200 = 0.350	Scope 3	Representative values for material production
	Diesel for Farm Machinery	0.2 L	2.6 kg CO2e/L diesel	0.520	Scope 3	Fuel consumption for ploughing, sowing, harvesting

Lifecycle Stage	Activity Description	Activity Data (per 1L Bioethanol)	Emission Factor (CO2e)	Calculated Emissions (kg CO2e)	GHG Scope	Notes
2. Feedstock Transportation	Truck Transport (Farm to Plant, 50km avg)	20 kg sugar beet	0.1 kg CO2e/tonne-km	0.100	Scope 3	Assuming kg sugar beet per liter ethanol, 50 km distance
3. Bioethanol Production (Netherlands Plant)	Electricity Consumption	1.5 kWh	0.3 kg CO2e/kWh	0.450	Scope 2	Netherlands grid mix (illustrative average for European context).
	Natural Gas for Heat/Steam	2.0 kWh	0.244 kg CO2e/kWh	0.488	Scope 1	On-site combustion process heat
	Yeast, Enzymes, Process Chemicals	0.05 kg	5.0 kg CO2e/kg	0.250	Scope 3	Upstream emissions from production
	Water Consumption & Treatment	5.0 L	0.0005 kg CO2e/L	0.003	Scope 3	Upstream treatment emissions.
	Biogenic CO2 (from Fermentation)	0.96 kg CO2	0 kg CO2e/kg (short-cycle)	0.000	Reported under LSR	Released during fermentation. Considered biogenic as typically carbon neutral if feedstock sustainably sourced, but reported under the LSR Standard.
	Co-product Credit (Vinasse)	-0.5 kg (mass allocation)	-0.1 kg CO2e/kg	-0.050	Scope 3	Credit for displaced animal feed/fertilizer production. Illustrative

Lifecycle Stage	Activity Description	Activity Data (per 1L Bioethanol)	Emission Factor (CO2e)	Calculated Emissions (kg CO2e)	GHG Scope	Notes
Total Product Carbon Footprint (PCF) for 1.0 Liter Bioethanol:				2.861 kg CO2e		(Cradle-to-Factory-Gate before biogenic CO2 and allocation)
Net Product Carbon Footprint (PCF) for 1.0 Liter Bioethanol:				2.811 kg CO2e		(Cradle-to-Factory-Gate after co-product allocation)

GHG Protocol Scope Summary (Illustrative)

GHG Scope	Calculated Emissions (kg CO2e per 1L Bioethanol)	Coverage (Relative to Total PCF excluding biogenic CO2)
Scope 1	0.488	17.0%
Scope 2	0.450	15.7%
Scope 3 (Upstream & Co-products)	1.873 (2.353 - 0.488) + 0.003 + 0.250 + 0.520 + 0.100 + 0.350 + 0.750 - 0.050 = 2.073 kg CO2e for upstream minus allocation credit. Let's re-calculate Scope 3 from table: 0.750 + 0.350 + 0.520 + 0.100 + 0.250 + 0.003 - 0.050 = 1.923	67.3%
Total PCF (excluding biogenic CO2)	2.861	100.0%
Biogenic CO2 (Reported under LSR)	0.960	N/A

****Note on Scope 3 Coverage:**** The calculated Scope 3 emissions (1.923 kg CO2e) represent approximately 67.3% of the total PCF before co-product allocation and biogenic CO2 (2.861 kg CO2e). To achieve the ****95% Scope 3 compliance****, a more exhaustive collection of upstream data points for all minor inputs, services, and capital goods would be

required in a real-world scenario. This illustrative report highlights the major contributors.

Application of the 2026 Land Sector and Removals (LSR) Standard

The LSR Standard requires companies to account for land management and land use change, CO₂ removals, and emissions from biogenic products.

- **Biogenic CO₂ Emissions:** The 0.96 kg CO₂ released during the fermentation process is categorized as biogenic CO₂. While often considered carbon neutral in previous accounting due to the short carbon cycle of the feedstock, the LSR Standard requires transparent reporting of these emissions. They are presented separately to distinguish them from fossil GHG emissions.
 - **Direct Land Use Change (dLUC):** For sugar beet cultivation in Europe, dLUC emissions are generally considered negligible as it primarily uses existing arable land, not leading to conversion of forests or high-carbon stock areas. If virgin land were converted, significant emissions would be attributed here.
 - **Indirect Land Use Change (iLUC):** iLUC considers the emissions that arise when existing agricultural land, previously used for food or feed, is displaced by biofuel feedstock production, leading to new land conversion elsewhere. While challenging to quantify precisely, studies suggest iLUC for sugar beet ethanol is generally lower or even slightly reduced compared to other feedstocks like wheat ethanol, but still a factor to be considered in broader sustainability assessments. The LSR Standard provides methods to account for such land sector emissions, including based on traceability and data availability.
 - **Carbon Removals:** While not explicitly quantified in this factory-gate boundary, potential carbon removals related to improved agricultural management practices (e.g., increased soil organic carbon) could be accounted for under the LSR Standard.
-

5. Review & Report

Hotspots and Reliability

Based on this illustrative analysis, the primary hotspots in the cradle-to-factory-gate PCF of 1.0 liter of bioethanol from sugar beet are:

- **Feedstock Cultivation (Scope 3):** Emissions associated with nitrogen fertilizer production and application, including N₂O emissions from soils, are consistently major contributors.
- **Energy Consumption during Production (Scope 1 & 2):** The significant demand for heat (natural gas) and electricity in the fermentation, distillation, and dehydration stages drives substantial emissions.
- **Transportation of Feedstock (Scope 3):** Emissions from diesel combustion for transporting sugar beet from farms to the processing plant.

Reliability: The reliability of this PCF relies on the quality and representativeness of the activity data and emission factors used. For this report, industry average factors for Europe have been applied. In a real-world scenario, primary data from Business Analytiq's specific operations would significantly enhance accuracy.

Recommendations for Carbon Footprint Reduction

To reduce the PCF of bioethanol, Business Analytiq Pte Ltd could consider the following strategies:

- **Sustainable Agriculture Practices:** Collaborate with sugar beet farmers to implement practices that reduce fertilizer use (e.g., precision agriculture, nutrient management plans), enhance soil carbon sequestration, and improve farm machinery efficiency. This directly addresses the largest Scope 3 hotspot.
- **Renewable Energy Integration:** Transition to renewable electricity sources (e.g., solar, wind power purchase agreements) for the production facility to reduce Scope 2 emissions.
- **Energy Efficiency:** Invest in energy-efficient technologies and process optimization at the bioethanol plant to reduce overall electricity and natural gas consumption.

- **Biogenic CO2 Capture and Utilization (CCU):** Explore opportunities to capture and utilize the biogenic CO2 produced during fermentation. This captured CO2 can be a valuable co-product for industries like food and beverage.
- **Supply Chain Optimization:** Optimize logistics for feedstock and input transportation to minimize fuel consumption and associated emissions.
- **Co-product Valorization:** Maximize the value and market for co-products like vinasse, potentially leading to greater displacement credits in future LCA studies.

Continuous monitoring, regular PCF recalculations, and engagement with supply chain partners are essential for ongoing improvement and credible reporting under the evolving GHG Protocol standards.