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Product Carbon Footprint Analysis Report

Bioethanol

Protocol Data (Accounting Standard): ISO 14064

Regulatory Framework: CBAM

This report is generated based on available data and industry standards. For audit-ready compliance, primary data from the specific production facility would be required.

Prepared by: Senior Sustainability Consultant

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Executive Summary

This report presents a high-detail Product Carbon Footprint (PCF) analysis for 1.0 liter of bioethanol, focusing on a "factory-gate" system boundary with a European supply chain and final production in the Netherlands. The analysis adheres to the quantification and reporting principles of ISO 14064 and considers the regulatory context of the Carbon Border Adjustment Mechanism (CBAM), effective January 1, 2026. Bioethanol, primarily produced from agricultural feedstocks such as wheat and corn in Europe, offers a renewable alternative to fossil fuels. The aim of this assessment is to quantify the embedded carbon emissions associated with the production of bioethanol up to the factory gate, highlighting potential hotspots and ensuring audit-readiness through rigorous methodology and transparent data documentation.

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1. Introduction and Scope Definition

This Product Carbon Footprint (PCF) analysis is performed for bioethanol, a renewable fuel. While ISO 14064 is an organizational-level greenhouse gas (GHG) accounting standard, this PCF analysis is conducted following its principles of completeness, consistency, accuracy, transparency, and relevance to ensure robust quantification and audit-readiness. For product-specific GHG quantification, ISO 14067 is the dedicated standard; however, the client\'s explicit request for

ISO 14064 principles has guided the methodological rigor applied herein.

1.1. Functional Unit

The functional unit for this analysis is defined as **1.0 liter of bioethanol**. This unit serves as the reference basis for all quantified environmental impacts.

1.2. System Boundary

The system boundary is defined as **"factory_gate"**. This includes all relevant upstream processes from raw material extraction/cultivation, through processing, to the point where the finished bioethanol leaves the production facility in the Netherlands. The "factory_gate" boundary excludes downstream stages such as distribution to the end-user, use phase, and end-of-life treatment.

1.3. Geographic Scope

- **Final Production Country:** Netherlands
- **Supply Chain Focus:** Europe Focused. Key agricultural feedstocks and energy inputs are assumed to originate from within Europe.

1.4. Allocation

Bioethanol production from agricultural feedstocks often yields co-products, such as Dried Distillers Grains with Solubles (DDGS) when using grain-based feedstocks like wheat. DDGS is a valuable animal feed. In accordance with generally accepted life cycle assessment (LCA) principles and methodologies for biofuel accounting (e.g., as per the EU Renewable Energy Directive), GHG emissions are allocated between the main product (bioethanol) and co-products. For this analysis, a conservative energy allocation approach is considered, attributing a portion of the upstream emissions to the co-product. We assume a 20% allocation of upstream emissions to

DDGS (illustrative based on common industry practice and energy content considerations), meaning 80% of upstream emissions are attributed to the bioethanol.

1.5. Accounting Standard & Regulatory Framework

- **Accounting Standard:** ISO 14064-1:2018 (Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals). This report applies the rigorous quantification and reporting principles of ISO 14064-1 to a product-level assessment.
- **Regulatory Framework:** Carbon Border Adjustment Mechanism (CBAM). This framework, effective January 1, 2026, is an EU carbon tax on embedded carbon for importers of certain goods (e.g., steel, cement, hydrogen, electricity, fertilizers, aluminum). While bioethanol is not currently a direct CBAM sector, the quantification of its embedded carbon is crucial for potential future inclusion or for companies managing their overall carbon liabilities at the EU border.

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2. Lifecycle Mapping (LCI Inventory Stages)

The lifecycle of bioethanol from a "factory_gate" perspective, with wheat as the primary feedstock (a common choice in Europe), involves several key stages:

1. **Feedstock Cultivation:**
    - Agricultural inputs: Fertilizers (nitrogen, phosphorus, potassium), pesticides, seeds.

    - On-farm energy use: Diesel for tractors (tillage, seeding, spraying, harvesting), irrigation (electricity/diesel).
    - Direct field emissions: Nitrous oxide (N_2O) from fertilizer application and soil processes.
2. **Feedstock Transportation:**
    - Transport of harvested wheat from farms to the bioethanol production facility.
3. **Bioethanol Production (Factory Gate):**
    - **Milling/Grinding:** Energy for processing wheat grains into flour or meal.
    - **Liquefaction & Saccharification:** Enzymes break down starch into fermentable sugars. This stage requires heat (steam) and electricity.
    - **Fermentation:** Yeast converts sugars into ethanol and carbon dioxide (biogenic CO_2). This is an exothermic process, but temperature control may require energy.
    - **Distillation/Rectification:** Energy-intensive process to separate ethanol from water and other impurities, yielding high-purity ethanol. Primarily requires heat (steam, often from natural gas boilers) and electricity for pumps.
    - **Dehydration:** Further processing (e.g., molecular sieves) to remove remaining water for fuel-grade anhydrous ethanol. Requires heat and electricity.
    - **Co-product Processing:** Drying of DDGS (if applicable) requires heat.
    - **Ancillary Processes:** Water treatment, wastewater treatment, general facility electricity, and heating.

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3. Data Collection (Primary/Secondary Data Points)

For an audit-ready report, primary data from the specific bioethanol production facility would be paramount. As this is a hypothetical, high-detail analysis, secondary data from industry averages and recognized databases (such as Ecoinvent and DEFRA equivalents) are utilized.

3.1. Material and Energy Inputs (Illustrative Data per 1.0 Liter Bioethanol)

Assumptions:

- Bioethanol density: ~0.789 kg/L
- Energy content of bioethanol: ~21.2 MJ/L (based on lower heating value)
- Feedstock: Wheat (average European yield)
- Production Process: Dry milling fermentation pathway (common for grain-based ethanol).

Lifecycle Stage	Material/ Energy Input	Quantity per 1.0 Liter Bioethanol	Units	Notes/ Assumptions
1. Feedstock Cultivation (Wheat)	Wheat Grain	2.37	kg	Based on ~3 tons grain per 1 ton ethanol, and ethanol density.
	Fertilizers (N, P, K)	Implicitly included	g CO2e/ MJ	Emissions factor for cultivation often bundles these inputs.
	Pesticides			Emissions factor for

Lifecycle Stage	Material/ Energy Input	Quantity per 1.0 Liter Bioethanol	Units	Notes/ Assumptions
		Implicitly included	g CO2e/ MJ	cultivation often bundles these inputs.
	Diesel (on-farm machinery)	Implicitly included	g CO2e/ MJ	Emissions factor for cultivation often bundles these inputs.
2. Feedstock Transportation	Road Transport (HGV >20t)	200 km	km/ tonne wheat	Assumed average distance from European farms to Dutch factory.
3. Bioethanol Production (Factory Gate)	Natural Gas (for process heat/steam)	0.5	kWh	Illustrative average for fermentation & distillation.
	Electricity (grid mix Netherlands)	0.3	kWh	Illustrative average for pumps, agitation, auxiliary processes.
	Enzymes, Yeast, Water	Negligible primary GHG impact or bundled	-	Assumed minor contribution or covered by main energy inputs.
Co-product (DDGS)	Allocation Factor (Energy basis)	20%	%	20% of upstream emissions allocated to DDGS.

4. Calculate Emissions (Activity * Emission Factor = CO_2e)

Emissions are calculated by multiplying the activity data (quantities of materials/energy) by relevant, industry-standard emission factors (EFs). These EFs convert activity data into CO_2 equivalent (CO_2e) emissions, accounting for CO_2, CH_4, and N_2O based on their Global Warming Potentials (GWPs). Factors are sourced from Ecoinvent/DEFRA-equivalent data or publicly available EU references, as appropriate for a European context.

4.1. Emission Factors Used

Source/Activity	Emission Factor (EF)	Units	Source/Reference
Wheat Cultivation (per MJ ethanol)	23	g CO_2e/MJ ethanol	EU Directive 2009/28/EC typical values.
Natural Gas (Europe, combustion & upstream)	0.244	kg CO_2e/kWh	Zuno Carbon (Europe average).
Electricity (Netherlands Grid Mix)	0.283	kg CO_2e/kWh	DEFRA 2024 examples for Netherlands.
Road Transport (HGV >20t, Europe)	0.084	kg CO_2e/tkm	Generic GLEC Framework value (illustrative).

4.2. Emission Calculation per 1.0 Liter Bioethanol

Lifecycle Stage	Activity Data	Emission Factor	Raw Emissions (kg CO2e)	Allocated Emissions (kg CO2e)
1. Feedstock Cultivation				
Wheat Cultivation Emissions	1.0 L Ethanol (21.2 MJ/L)	0.023 kg CO2e/MJ	0.023 * 21.2 = 0.4876	0.4876 * (1 - 0.20) = 0.3901
2. Feedstock Transportation				
Wheat Transport (Farm to Factory)	2.37 kg Wheat * 200 km	0.084 kg CO2e/tkm	(2.37/1000) * 200 * 0.084 = 0.0398	0.0398 * (1 - 0.20) = 0.0318
3. Bioethanol Production (Factory Gate)				
Natural Gas Consumption	0.5 kWh	0.244 kg CO2e/kWh	0.5 * 0.244 = 0.1220	0.1220
Electricity Consumption	0.3 kWh	0.283 kg CO2e/kWh	0.3 * 0.283 = 0.0849	0.0849
Total Product Carbon Footprint (PCF) at Factory Gate:				**0.6288 kg CO2e/L**

Total Product Carbon Footprint (PCF) for 1.0 liter of bioethanol at the factory gate: ~0.63 kg CO2e.

5. Review & Report

5.1. Hotspots Analysis

Based on the calculations, the primary hotspots for GHG emissions in the bioethanol production lifecycle up to the factory gate are:

- **Feedstock Cultivation:** This stage, primarily due to agricultural practices (fertilizer production, N2O emissions from soil, on-farm energy use), accounts for the largest share of the emissions, even after co-product allocation.
- **Energy Consumption during Production:** The energy-intensive processes of distillation and dehydration, largely fueled by natural gas and grid electricity, represent the next significant hotspot. Improving energy efficiency and transitioning to renewable energy sources for process heat and electricity at the facility would substantially reduce emissions.
- **Transportation:** While less dominant than cultivation or processing, the transport of bulky raw materials like wheat over significant distances contributes to the overall footprint.

5.2. Reliability and Audit-Readiness

This report is designed with "audit-readiness" in mind, adhering to the principles of ISO 14064 for robust GHG quantification.

- **Transparency:** All assumptions, data sources, and calculations are explicitly stated.
- **Completeness:** All identified lifecycle stages within the defined system boundary are included.
- **Consistency:** Emission factors from recognized databases (DEFRA, EU directives, Climatiq/GLEC equivalents) relevant to the European context are applied consistently.

- **Accuracy:** Efforts have been made to use representative and up-to-date emission factors. However, the accuracy is inherently limited by the use of secondary, average data rather than specific primary data from a particular production facility. For actual third-party verification, detailed site-specific operational data (e.g., actual energy consumption, fertilizer usage, transport distances) would be indispensable.
- **Data Documentation:** The breakdown of materials, energy inputs, and corresponding emission factors is documented in detail, providing a clear trail for verification.

5.3. Regulatory Context: CBAM Implications

The Carbon Border Adjustment Mechanism (CBAM), effective January 1, 2026, aims to put a fair price on the carbon emitted during the production of carbon-intensive goods entering the EU, preventing "carbon leakage." While bioethanol is not yet explicitly listed as a CBAM sector, the robust quantification of its embedded carbon (PCF) is critical for several reasons:

- **Future Regulatory Scope:** CBAM\'s scope may expand to include other sectors or products over time. Having a quantified PCF prepares companies for such eventualities.
- **Competitive Advantage:** Companies with lower embedded carbon in their bioethanol products will gain a competitive advantage as carbon pricing mechanisms strengthen globally and within the EU.
- **Supply Chain Decarbonization:** Understanding the PCF hotspots enables producers to identify areas for decarbonization within their supply chain, which can lead to lower overall carbon costs and improved market access.
- **Due Diligence:** For importers or distributors within the EU, understanding the embedded carbon of their products helps in fulfilling due diligence requirements related to

climate impact and compliance with emerging green procurement policies.

The quantified PCF of approximately 0.63 kg CO_2e per liter of bioethanol provides a tangible metric for assessing its environmental performance and navigating the evolving landscape of carbon regulation and taxation at the EU border.
