Braskem's Life Cycle Assessment (LCA) I'm green™ bio-based HDPE

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Life Cycle Assessment of biobased polyethylene

(I'm green™ bio-based PE)

Introduction

Life Cycle Assessment (LCA) is internationally known as a powerful technique to evaluate the potential environmental impact of a product or service. It can also support the decision-making process and help on the comparison between materials, products or services. The LCA technique is based on the Life Cycle Thinking and considers all processes and the environmental flows, from raw material extraction to the final disposal.

LCA has been helping industries from the most diverse sectors in the decision-making workflow to improve processes, products and services. LCA results are also more and more requested along the value chain by clients and Brand Owners interested in assessing the environmental impacts of finished products. And this information can even reach end consumers, through Environmental Product Declarations (EPD's).

Leading this trend and aligned with the care for ecosystems' quality and the development of more sustainable products, Braskem commissioned this LCA study. It aims to investigate potential environmental impacts of the production of bio-based polyethylene (I'm green™ bio-based HDPE). This LCA study is an updated version of previous studies developed for the product in the past 10 years, reflecting the most recent data and production scenario of this important product.

In this context, this report presents the environmental profile of bio-based high density polyethylene (I'm green™ bio-based HDPE) produced in Brazil with ethylene from sugarcane ethanol, according to the system boundary from cradle-to-gate. The life cycle stages of the base scenario include the sugarcane cultivation; ethanol production and transport to Braskem; green ethylene production and slurry polymerization of the green HDPE.

LCA allows for a comprehensive assessment of environmental impacts covering 15 different impact categories that are measured and reported below, in accordance with the Environmental Footprint 3.1 (EF 3.1) method, proposed by the European Commission. As any other LCA, the results of this study rely on specific parameters and methodological choices, including assumptions and limitations. Therefore, final numbers and conclusions should be only used respecting the context and limitations presented in this summary.

All information in this summary refers to "Life Cycle Assessment of Bio-Based Polyethylene I'm green™ bio-based HDPE – version 5.0"[1]. This LCA study was revised by KPMG according to the ISO 14040/14044 Standards (critical review process).

[1] This is a confidential report. Contact your Braskem representative for further information.

Goal and Scope

The goal of this LCA study is to assess the environmental performance of bio-based polyethylene (I'm green™ bio-based HDPE), for each impact, consumption or inventory level category.

The study aims to deepen our understanding of the potential impacts of bio-based polyethylene produced in Brazil and provide updated information on the product's environmental profile based on recent data from suppliers and the weighted average of the years 2020, 2021, and 2022. Braskem's end consumers, customers and stakeholders represent the target audience.

The LCA study has been performed based on ISO 14040, ISO 14044 and ISO 14071 standards and was reviewed by an external critical review (KPMG). Inventory data related to Braskem's products were from primary sources provided by the company. The results are presented per **1 kg of the product**, using the EF 3.1 Life Cycle Impact Assessment (LCA) method.

The functional unit (FU) is essentially the measured performance of a product system's function. It serves as the reference point to which all collected data (inputs/outputs) must be related when creating the life cycle inventory (LCI). This ensures a fair comparison of products and enables a proper analysis of their environmental performance.

I'm green™ bio-based HDPE	
FUNCTION	To produce bio-based High-Density Polyethylene (I'm green™ bio-based HDPE) in Brazil, by slurry polymerization of ethylene from sugarcane ethanol, based on the weighted average of the years 2020, 2021 and 2022.
FUNCTIONAL UNIT	To produce 1 kg of bio-based High-Density Polyethylene (I'm green™ bio-based HDPE) in Brazil, by slurry polymerization of ethylene from sugarcane ethanol, based on the weighted average of the years 2020, 2021 and 2022.
REFERENCE FLOWS	1kg of bio-based High-Density Polyethylene (I'm green™ bio-based HDPE)

Table 1. Scope definition

The lifecycle stages of bio-based HDPE considered in this study encompass all activities from raw materials extraction and processing, including transport to Braskem's plants, and the transformation processes (industrial activities). This extends up to the point when the product is ready for sale at the company's gate (also referred to as cradle-to-gate). Notably, the transformation, use, and end-of-life stages were not considered in this analysis. The lifecycle can be summarized in the following steps:

Sugarcane, ethanol and electricity generation: the lifecycle of bio-based HDPE takes place in Brazil and begins with the plantation and cultivation of sugarcane, followed by its harvest (mechanical). After facing these stages, the sugarcane is transported by trucks to ethanol mills for processing. The next step involves delivering ethanol using both rails and trucks to the plant responsible for producing ethylene, the required input for polymerizing HDPE. During the conversion of sugarcane into ethanol, the remaining biomass is burned to generate electricity, with any excess being sold to the national grid. There are several mills performing these activities, located in the Southeast and Midwest regions of Brazil.

Ethylene production and polymerization: the ethanol is received by Braskem and readily dehydrated to be transformed into bio-based ethylene. Then, technologies like slurry or spherilene processes are applied for polymerizing HDPE, which is then transported as pellets for the next life cycle stage. The production of green ethylene takes place in Braskem´s Q2 unit in Triunfo, in the South region of Brazil, and is transported through pipelines to polymerization units PE4 and PE5, also in Triunfo.

Processing and Distribution: The bio-based HDPE is distributed to various processing industries using trucks. The material can take a multitude of forms, such as bags, films, or bottles, depending on the application. The final product is then distributed to points of sale. This lifecycle stage is <u>not</u> considered in the scope of this LCA study.

Use and End-of-Life: after serving its purpose, the product enters the waste stage. A portion is recycled, while the remainder ends up in landfills, controlled landfills, or dumps. This lifecycle stage is <u>not</u> considered in the scope of this study.

Life Cycle Inventories

A summary of the data sources and reference year of the data used can be found in Table 2.

	Aspect	Data source	Base year	Remarks
Raw material extraction	Sugarcane plantation and cultivation	Raízen & ICVCalc	2020-2021-2022	Primary data connected to ecoinvent v3.9.1.
	Straw burning emissions	Raízen & Literature	2020-2021-2022	Primary and secondary data.
	Sugarcane harvesting and transport	Raízen	2020-2021-2022	Primary data connected to ecoinvent v3.9.1.
	Ethanol production	Raízen	2020-2021-2022	Primary data connected to ecoinvent v3.9.1.
	Bagasse burning emissions	Raízen & Literature	2020-2021-2022	Primary and secondary data.
	Electricity generated	Raízen	2020-2021-2022	Primary data connected to ecoinvent v3.9.1.
Ethylene production	Ethanol transport	Braskem	2020-2021-2022	Primary data connected to ecoinvent v3.9.1.
	Bio-based ethylene production	Braskem	2020-2021-2022	Primary data connected to ecoinvent v3.9.1.
Polymerization	Bio-based PE production	Braskem	2020-2021-2022	Primary data connected to ecoinvent v3.9.1.

Table 2. List of inventories used, their source, and reference year.

Life Cycle Impact Assessment (LCA) Method

The LCA phase is used to better understand the magnitude and significance of the potential environmental impacts of a product system throughout its life cycle. Therefore, LCA assesses the environmental performance of the products based on indicators also referred by the ISO standards as impact categories. For the current project, Braskem evaluated the product's environmental performance based on the indicators at midpoint level, that represent the intermediate impacts directly related to the original emissions or resource consumption, which could potentially lead to final damage to human health, ecosystems, and resource availability.

The Environmental Footprint 3.1 (EF 3.1) method was adopted in this study, which includes the 16 impact categories. In addition, the impact category at the inventory level, referred to as Water Use (m^3), was also taken into account.

In 2021, the European Commission recommended the adoption of the EF method to measure and communicate the life cycle environmental performance of products and organizations. This recommendation is directed at Member States, as well as private and public organizations that measure and/or communicate their product or organizational life cycle environmental performance. Considering the global relevance of the EF initiative and the harmonization of LCA studies, it is understood that, at the current time, the adoption of the EF method reflects the best practices available to address each impact category.

Background data from ecoinvent® database version 3.9.1 was used to represent the environmental burdens of materials inputs, energy, transportation modes, among others. For the foreground data, the initial source was Braskem and its suppliers.

Main Limitations

- For situations in which Brazilian data is unavailable, and bearing in mind the low level of national inventories, data from other countries with similar technology and energy mix were employed;
- For any data gap in the product systems, ecoinvent database was used;
- The assessment is performed only on the product system described; other aspects, such as the management or infrastructure of companies, were not assessed;
- Long-term characterization factors are not present in the foreground level of the model, due to their highly-related uncertainty.

Results

Table 3 shows the environmental profile for 1kg of bio-based HDPE:

Impact Category	Unit	I'm green bio-based HDPE
Climate Change	kg CO_2 eq.	-2,12
Ozone depletion	kg CFC-11 eq.	1,23E-07
Human Toxicity - Cancer	CTUh	5,61E-10
Human Toxicity - non cancer	CTUh	3,49E-08
Particulate matter	Disease incidence	3,11E-07
Ionising radiation	kBq U-235 eq.	8,03E-03
Photochemical Ozone Formation	kg NMVOC eq.	1,97E-02
Acidification	mol H+ eq.	5,38E-02
Eutrophication, terrestrial	mol N eq.	0,16
Eutrophication, freshwater	kg P eq.	1,18E-04
Eutrophication, marine	kg N eq.	2,13E-02
Ecotoxicity, freshwater	CTUe	168,00
Land use	Pt	184,00
Water scarcity	m^3 water eq.	0,64
Water Use	m^3	6,53E-02
Resource use, minerals and metals	kg Sb eq.	2,47E-06
Resource use, fossils	MJ	5,23

Table 3. Characterization results for I'm green™ bio-based HDPE.

Figure 1 shows the environmental profile of bio-based HDPE and each lifecycle stage.

Altogether, agricultural operations have the highest share of impacts in 15 out of the 17 environmental aspects evaluated.

- Sugarcane production is the main responsible for environmental impacts due to direct emissions related to the application of fertilizers and correctives (N_2O, CO_2, NOx, NH_3, NO_3- and P) as well as diesel consumption (CO_2, NOx and particulates). It represents at least 50% of impacts in 10 categories evaluated.
- Emissions from straw burning has an important contribution to the categories of Photochemical ozone formation (30% of impacts), Acidification (48%) and Terrestrial Eutrophication (57%) due to emissions of SOx, NMVOC, NOx, NO, NH_3 and particulates.

Ethanol production is the activity contributing with 50% of water use and 39% of the category use of mineral and metal resources. Bagasse combustion generates similar impacts of straw burning.

Surplus electricity exported to the grid yields environmental benefits, avoiding CO_2 and Halon 1301 emissions due to the replacement of thermal energy from natural gas with sugarcane bagasse. This also results in avoided impacts on Resource Use (fossils).

The production of green ethylene and bio-based PE has a relatively low overall impact. The main impacts are related to energy sources coming from hard coal, heavy fuel oil, natural gas and electricity from the grid, representing 28% of the impact on fossil resource use.

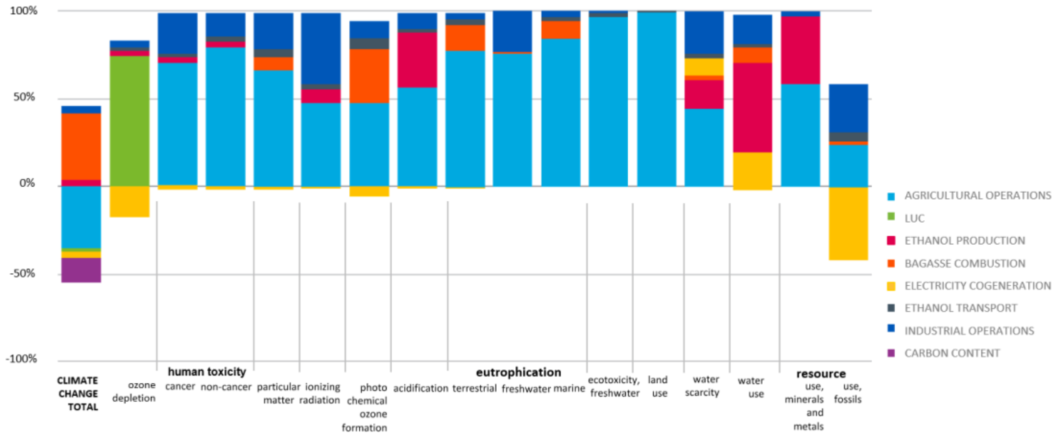

Figure 1. Environmental profile and lifecycle stage contribution for bio-based HDPE.

Table 4 details the Climate Change results for bio-based HDPE for each lifecycle stage, due to its global relevance for the environment and Braskem's sustainability goals. Results are broken down for each type of emission (fossil, biogenic, and land use change) according to IPCC 2021 Guidelines. The total **carbon footprint of 1kg of I'm green™ bio-based HDPE produced by Braskem is -2,12 kgCO_2eq./kg.**

By default, the EF 3.1 method does not account for the biogenic CO_2 flows in the Climate Change category. However, according to PEFCR Guidance (Product Environmental Footprint Category Rule), complementary characterization factors shall be applied in case these flows are to be used to calculate additional information. In this study, the biogenic carbon content of bio-based HDPE can be classified as additional technical information.

I'm green™ bio-based	Carbon footprint
HDPE (spherilene polymerization)	-2,01 kgCO2e/kg
LDPE (autoclave + tubular polymerization)	-2,27 kgCO2e/kg
LLDPE (spherilene polymerization)	-1,82 kgCO2e/kg

Life Cycle Stages		Base scenario (kgCO₂eq./kg I'm green™ bio-based HDPE)			
		Fossil	Biogenic	Land Use Change	Total
Sugarcane growing	Agricultural operations	1.16	-9.59	0.02	**-8.41**
	Land Use Change	-	-	-0.44	**-0.44**
	CO_2 Uptake	-	-3.14	-	**-3.14**
	Subtotal	**1.16**	**-12.73**	**-0.42**	**-11.98**
Ethanol Production	Ethanol production	0.02	0.92	0.00	**0.95**
	Bagasse Burning	0.10	8.78	0.00	**8.88**
	Electricity Cogeneration Credits	-0.91	0.00	0.00	**-0.91**
	Subtotal	**-0.78**	**9.70**	**0.00**	**8.92**
Bio-based HDPE	Ethanol transport	0.13	0.00	0.00	**0.14**
	Ethylene and HDPE production	0.77	0.03	0.01	**0.81**
	Subtotal	**0.90**	**0.03**	**0.02**	**0.95**
Total		**1.28**	**-3.00**	**-0.40**	**-2.12**

Table 4. Climate change results for bio-based HDPE

In terms of carbon footprint, Braskem´s bio-based product has a positive impact due to the negative balance of CO_2, thus resulting in the removal of carbon from the atmosphere: for every kilogram of bio-based HDPE produced, it eliminates 2.12 kilograms of carbon dioxide equivalent. This is almost 2 times less emissions than the global benchmark average from ecoinvent[2] (carbon footprint is 2,24 $kgCO_2$eq./kg fossil HDPE).

Conclusions

The objectives of this study were to develop life cycle inventory for I'm green™ bio-based HDPE, and to assess the environmental performance of this product using life cycle assessment (LCA) methodology. As presented in this summary and confirmed by the LCA report**, Braskem´s bio-based HDPE has a negative carbon footprint of -2,12 kgCO2eq./kg**.

As a result, Braskem will use this information to promote continuous improvements in the production of bio-based HDPE, aiming to achieve the reduction of environmental impacts generated.

Contact information

For further information or questions, please contact your Braskem representative.

[2] Based on ecoinvent v3.9.1 data 1 kg of fossil HDPE production {GLO}| market for | Cut-off, U).