I'm green™ bio-based PE
Life Cycle Assessment

Introduction

One of the greatest challenges faced by our society is to reduce its greenhouse gas (GHG) emissions to ensure that we do not have climactic changes with disastrous consequences. Meeting the targets set in the Paris Agreement of 2015 requires a transition into a low carbon economy based on renewable energy and new economic and business models, but also new material solutions to reduce even further our society's carbon footprint. However, a life cycle perspective has to be applied so that possible trade-offs between a lower climate change impact and other impact categories are accounted for and managed.

Braskem, driven by its purpose to develop sustainable solutions that make people's lives better, has developed the **I'm green™ bio-based PE**, a material with a negative carbon footprint which has a huge potential contribution for a low carbon economy. This alternative was developed, from the very beginning, based on a preliminary Life Cycle Assessment with project data which showed that the renewable PE would be a more sustainable alternative. In 2012 another study, now with the plant operating at normal conditions confirmed this.

In 2013 a major update of the ecoinvent database, which was used to assess background processes, suggested that an update was needed. We started the update process in 2015 including these database changes and several optimizations in the renewable ethylene production facility. In 2016 we collected new data from our ethanol suppliers. This update has been divided in two steps so that we could also isolate the effects of the Code of Conduct for ethanol suppliers in the overall sustainability of the I'm green™ bio-based PE.

This summary report presents these updated results of the LCA study for Braskem's renewable PE.

Goal and Scope

The main goal of this LCA is to provide information and life cycle inventory datasets for the product system of the I'm green™ bio-based Polyethylene. The target audience is represented by Braskem's clients and end consumers as well as other stakeholders interested in these results.

The study will also serve as basis for development of specific communication material highlighting the main benefits and trade-offs of the I'm green™ bio-based PE when compared to regular fossil based PE.

This updated LCA was carried out to understand the main changes related to improvements in the agricultural stages and ethanol production and considers HDPE production as the base case scenario, although most of the conclusion can be also extended to LDPE and LLDPE productions as well.

This assessment encompasses two product systems: HDPE from renewable agricultural resources (sugarcane derived ethanol) and HDPE from fossil resources. The study focuses on the polymer life cycle until its bulk production; the processing of this plastic and the end of life scenario are not considered. Since both products have identical technical properties, this assumption does not compromise the quality of the assessment.

The product systems function has been expanded to include both the production of High Density Polyethylene (HDPE) and electricity so as to avoid allocation between these co-products as recommended by ISO 14044. The functional unit has been set to 1 kg of HDPE and 0.942 kWh of electricity, which is the average amount of electricity co-generated together with 1 kg of I'm green™ bio-based PE. Figure 1 shows a summary of these definitions.

HIGH DENSITY POLYETHYLENE PRODUCTION AND ELECTRICITY GENERATION	
FUNCTION	To produce High Density Polyethylene (slurry polymerization) in Brazil, in the year of 2015, from sugarcane or from petroleum derivatives, under identical technical specifications for processing. And to produce a supplemental amount of electricity.
FUNCTIONAL UNIT	To produce 1 kg of High Density Polyethylene (slurry polymerization) in Brazil, in the year of 2015, from sugarcane or from petroleum derivatives, under identical technical specifications for processing. And to generate 0.942 kWh of supplemental electricity.
REFERENCE FLOW[2]	- 1 kg of Green HDPE (slurry polymerization) and electricity generation from biomass burning - 1 kg of Fossil HDPE (slurry polymerization) and electricity generation from natural gas

FIGURE 1. COMPARISON CHARACTERISTICS OF THE STUDY

Descriptions of the Product Systems

I'm green™ bio-based PE life cycle begins with sugarcane plantation, cultivation and harvesting. The sugarcane is then transported by trucks to the mills where it is crushed to produce both sugar and ethanol. The bagasse resulting from sugarcane crushing is used to produce steam which supplies the mill's need for heat and electricity. The surplus electricity is sold to the Brazilian integrated electrical system to supply the operational margin of this system.

The ethanol is then transported by rail (a small amount can also be delivered by truck) to the Braskem facilities in Triunfo, Brazil where it will be dehydrated to produce ethylene. This ethylene is then polymerized to produce the I'm green™ bio-based PE.

The **Fossil PE** life cycle begins with oil extraction and refining. Naphtha, which is one of the derivatives produced in the refineries, is transported by ducts to the petrochemical complexes where it will be cracked to produce ethylene and many co-products. The ethylene is then polymerized to produce PE. Since there is no surplus electricity generated in this system, it is assumed that the surplus electricity will be supplied by a thermoelectric power plant, making both product systems comparable.

Life Cycle Inventories

A summary of the data sources and reference year of the data used can be found in Table 1.

	Aspect	Data Source	Base Year	Remarks
Raw material extraction	Sugarcane	Braskem & ACV Brasil	2015-2016	Primary data connected to ecoinvent v3.1. Refer to Appendix C - Description of data used
	Ethanol			
	Trash burning emissions	Braskem/E4Tech/LCA Works based on several sources presented on [Murphy 2013]	2006-2009	Secondary data connected to ecoinvent v3.1. Refer to Appendix C - Description of data used
	Bagasse burning emissions	Braskem & ACV Brasil Based on **[Murphy 2013]** for data gaps	2009-2016	Primary and secondary data. Refer to Appendix C - Description of data used
	Petroleum & Naphtha	ecoinvent v3.1 datasets	1980-2003	Secondary data from ecoinvent v3.1. Refer to Appendix C - Description of data used
Ethylene production	Renewable Ethylene	Braskem & ACV Brasil		
	Fossil Ethylene		2011-2015	Primary data connected to ecoinvent v3.1. Refer to Appendix C - Description of data used
Polymerization	Renewable HDPE	Braskem/E4Tech/LCA Works/ACV Brasil based on [Murphy 2013]		
	Fossil HDPE			

Table 1

Main Assumptions

- Soil carbon stocks variation were based on a previous study conducted by [e4Tech 2013] pointing to a CO_2 fixation for 1 kg of HDPE is around 1.35 g CO_2/HDPE kg, value then used to reflect Land Use Change (LUC) impacts on Climate Change;
- Filter cake and vinasse were considered in the study, but as they are reinserted in the agricultural stage as fertilizers, these byproducts are not represented in the model. It was not possible to conclude from the original data if transports and further ancillary inputs were considered to make this reinsertion viable;
- Sugarcane bagasse burning emissions are modeled based on secondary data;
- The bioelectricity generated from bagasse is set to replace thermal electricity from the national grid;
- Data from ecoinvent v3.1 was adapted according to Brazilian conditions regarding electricity matrix and transport;
- For agricultural machinery and transport vehicles, only diesel (from ecoinvent v3.1) was considered, with its emissions.

The following limitations are highlighted:

- For situations in which Brazilian data is not available and bearing in mind the low level of national inventories, data from other countries with similar technology and energy mix are used;
- For any data gap in the product systems, Ecoinvent was used;
- The assessment is performed only on the product systems described; other aspects, like management or infrastructure of companies are not assessed;
- Long-term characterization factors are not present in the foreground level of the model, due to their high related uncertainty.
- The input of rain water is not included in the model.

Life Cycle Impact Assessment Method

The LCIA method used in this study has been compiled by ACV Brasil together with ifeu (Institut für Energie- und Umweltforschung), a German consulting company in 2012 and has been kept up-to-date with few major interventions to keep the methods for each impact category consistent with the latest developments. This method covers: Abiotic Depletion, Climate Change, Acidification, Eutrophication, Ozone Depletion, Respiratory Inorganics, Photochemical Oxidation, Water Use, Land Use, Human Toxicity, Ecotoxicity and Cumulative Energy Demand.

This compilation is a mix of renowned methods like CML, USETox, ReCiPe and IPCC will be further referred to as Recommended Method.

Results

Table 2 shows the environmental profile for I'm green™ bio-based PE.

Impact category	Unit	Renewable PE
Climate Change	kg CO_2 eq	-3.09 E+00
Ozone Depletion	kg CFC-11 eq	4.07 E-05
Respiratory Inorganics	kg PM2.5 eq	1.64 E-03
Photochemical Ozone Formation	kg C_2H_4 eq	1.95 E-03
Acidification	kg SO_2	1.31 E-02
Resource Depletion, water	m3	4.91 E-02
Land use	m2a	5.18 E+00
Resource Consumption	kg Sb eq	-1.72 E-03
Ecotoxicity	CTUe	4.44 E-01
Eutrophication	kg PO_4--- eq	1.27 E-02
Human Toxicity	CTUh	3.35 E-07
Cumulative Energy Demand	MJ	2.27 E+00

Table 2

Figure 2 shows the relative impacts between I'm green™ bio-based PE and fossil HDPE.

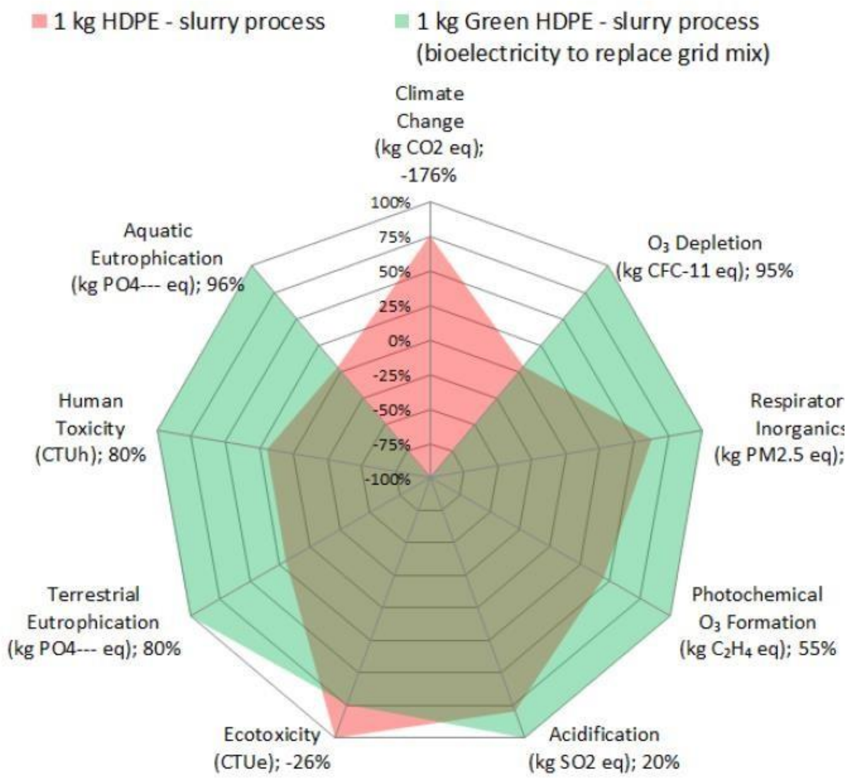

Figure 2

Table 3 shows a contribution analysis for Climate Change impact category:

		$kgCO_2e/kg$
Sugarcane Growing	Agricultural Operations	0,91
	Land Use Change Credits	-1,10
	CO2 Uptake	-3,14
	Total	-3,33
Ethanol Production	Ethanol Production	0,03
	Bagasse Burning	0,16
	Electricity Cogeneration Credits	-1,17
	Total	-0,98
I'm green™ bio-based PE	Ethanol Transport	0,46
	Industrial Operations (Ethylene and PE)	0,76
	Total	1,22
		-3,09

Table 3