Eco-profiles and Environmental Product Declarations of the European Plastics Manufacturers

Polycarbonate (PC)
PlasticsEurope
January 2019

PlasticsEurope
Association of Plastics Manufacturers

Introduction

This Environmental Product Declaration (EPD) is based upon life cycle inventory (LCI) data from PlasticsEurope's Eco-profile programme. It has been basically prepared by following the **PlasticsEurope's Eco-profiles and Environmental Declarations – LCI Methodology and PCR for Uncompounded Polymer Resins and Reactive Polymer Precursors** (PCR version 2.0, April 2011) document but includes some evolutions of the next version of the PlasticsEurope methodology, to be issued in 2019. This new version will include for example changes in the eco-profile organisation and management, simplification of the result section of the report, improvement of the water part to better report on its use, consumption and how it has been employed.

EPDs provide environmental performance data, but no information on the economic and social aspects which would be necessary for a complete sustainability assessment. Further, they do not imply a value judgment between environmental criteria.

This EPD describes the production of the Polycarbonate polymer from cradle to gate (from crude oil extraction to granules or resin at plant). **Please keep in mind that comparisons cannot be made on the level of the polymer material alone**: it is necessary to consider the full life cycle of an application in order to compare the performance of different materials and the effects of relevant life cycle parameters. This EPD is intended to be used by member companies, to support product-orientated environmental management; by users of plastics, as a building block of life cycle assessment (LCA) studies of individual products; and by other interested parties, as a source of life cycle information.

Meta Data

Data Owner	PlasticsEurope, Product Group BPA & PC
LCA Practitioner	thinkstep AG
Programme Owner & Manager	PlasticsEurope aisbl
Reviewer	Angela Schindler
Number of plants included in data collection	5
Representativeness	100% of EU Production Volume
Reference year	2016
Year of data collection and calculation	2018
Expected temporal validity	2024
Cut-offs	No significant cut-offs
Data Quality	Very good
Allocation method	Varies, see text

Description of the Product and the Production Process

This EPD is for polycarbonate (PC), a thermoplastic moulding compound. The term polycarbonate describes a polymer which is composed of many ("poly") identical units of bisphenol A connected by carbonate-linkages in its backbone chain. Chemically, a carbonate group is a di-ester of carbonic acid, the result of which is a polymeric chain. Polycarbonate is transformed into the required shape by melting it and forcing it under pressure into a mould or die. The reference flow, to which all data given in this EPD refer, is 1kg of PC polymer.

Production Process

Both Interfacial Polycondensation and Melt Transesterication process are currently being used in the industrial production of Polycarbonate. In the interfacial process, Bisphenol A is reacted with phosgene at 20–40ºC in a two-phase mixture consisting of an aqueous, alkaline phase (e.g. use of NaOH) and an immiscible organic phase. In the melt transesterification process, diphenyl carbonate (DPC) is transesteried in the melt with bisphenol A to form polycarbonate.

Data Sources and Allocation

The main data source was a data collection from European producers of polycarbonate (PC). Primary data on gate-to-gate PC production is derived from site-specific information for processes under operational control supplied by the participating companies of this study. Three different PC producers with plants in four European countries were participating in the primary data collection. They cover all PC producers in Europe (EU27) in 2016. With the exception of Bisphenol A, the data for the upstream supply chain until the precursors are taken from the database of the software system GaBi ts [GABI 2018]. For Bisphenol A primary data from some of the participating companies in this study was collected and reported in a specific Eco-profile. All relevant background data such as energy and auxiliary material are also taken from the GaBi ts database. Most of the background data used is publicly available and public documentation exists [GABI 2018].

Allocation was applied for the production process of some participants, as minor by-products result from their specific PC production process. The by-products had lower assignments than the main product PC. The process intention is the production of PC only. Depending on the generated by-product and its further application (e.g. minor intermediates to be further used, sold or fuel gas to be applied in combustion processes), allocation was done according to mass, current market prices or energy. A quantified sensitivity analysis was performed whenever different allocation possibilities were applicable.

Use Phase and End-of-Life Management

In general, polycarbonate (PC) is extremely robust, lightweight with glass-like transparency and impact resistant – even at extremely low temperatures. It has a high dimensional stability and is easily molded, yet has excellent heat resistance with a glass transition temperature of up to 148ºC. Polycarbonate resins can be used for injection molding, extrusion and blow molding, in a range of markets including automotive and transportation, construction, electronics, medical, lighting and optical data storage.

. Post-consumer recycling for polycarbonate applications is common for applications where high volumes are available and no sorting is necessary. This is the case for the 5 gallon reusable water bottles. For all post-consumer polycarbonate waste, for which mechanical recycling has not proven to be economically feasible due to complex collection and/or dismantling steps, energy recovery is the option of choice.

Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg of polycarbonate.

All characterization factors of the environmental impact categories used are developed by CML (2016)

Input Parameters

Indicator	Unit	Value
Non-renewable energy resources[1)]		
• Fuel energy	MJ	66,02
• Feedstock energy	MJ	33,00
Renewable energy resources (biomass)[1)]		
• Fuel energy	MJ	5,26
• Feedstock energy	MJ	–
Abiotic Depletion Potential		
• Elements	kg Sb eq	8,97E-06
• Fossil fuels	MJ	86,91
Renewable materials (biomass)	Kg	8,72E-05
Water		
• Use	Kg	1535,14
• Consumption	Kg	16,30

1) Calculated as upper heating value (UHV)

Output Parameters

Indicator	Unit	Value
GWP	kg CO_2 eq	3,40
ODP	g CFC-11 eq	7,24E-05
AP	g SO_2 eq	5,36
POCP	g Ethene eq	0,73
EP	g PO_4 eq	0,72
Dust/particulate matter[2)]	g PM10	0,19
Total particulate matter[2)]	g	0,32
Waste		
• Non-hazardous	kg	3,29E-02
• Hazardous	kg	3,54E-08

2) Including secondary PM10

Additional Environmental and Health Information*

The manufacturers of polycarbonate and BPA are working through PlasticsEurope, the American Chemistry Council (ACC), the Japanese Polycarbonate Manufacturers Group (JPMG), China Petroleum and Chemical Industry Federation (CPCIF) and Korea PC-BPA Council (KPBC) to ensure that the safety of their product is supported by sound science, and continue to actively engage with government agencies, the media, and others. Scientific evidence demonstrates that BPA-based polycarbonate is safe when used as intended.

Additional Technical Information*

Polycarbonate is noted for its properties, such as high transparency, making it ideal for use in protective panelling; high strength, making it resistant to impact and fracture; high heat resistance, making it ideal for applications that require sterilisation; good dimensional stability which permits it to retain its shape in a range of conditions; good electrical insulation properties; biologically inert; readily recyclable; and easy to process.

Additional Economic Information*

Polycarbonate is a high performance plastic contributing substantially to the eco-efficient manufacture and sustainable use of numerous valuable products. These products include lightweight safety components in cars and construction materials, mobile communications, insulation materials in buildings and professional greenhouses, medical devices, multiple use packaging and modern optical data storage, to name just a few.

(*) the contents of this section has been elaborated by PlasticsEurope only and are not part of the review.

Information

Data Owner

Product Group BPA & PC, PlasticsEurope
Rue Belliard 40, B16-1040 Brussels, Belgium
E-mail: info@plasticseurope.org.

Reviewer

This Environmental Product Declaration has been reviewed by Angela Schindler. It was approved according to the Product Category Rules PCR version 2 (2011-04) and ISO 14025:2006. Registration number: PlasticsEurope 2011-0001, validation expires on 31th December 2024(date of next revalidation review).

Programme Owner & Manager

PlasticsEurope
Rue Belliard 40, B16-1040 Brussels, Belgium
E-mail: info@plasticseurope.org.

For copies of this EPD, for the underlying LCI data (Eco-profile); and for additional information, please refer to http://www.plasticseurope.org/.

References

- Product photographs on cover with kind permission by PlasticsEurope, Product Group BPA & PC.
- PlasticsEurope: Eco-profiles and environmental declarations – LCI methodology and PCR for uncompounded polymer resins and reactive polymer precursor (version 2, April 2011).

Goal & Scope

Intended Use & Target Audience

➢ *Eco-profiles (LCIs) and EPDs from this programme are intended to be used as »cradle-to-gate« building blocks of life cycle assessment (LCA) studies of defined applications or products. LCA studies considering the full life cycle (»cradle-to-grave«) of an application or product allow for comparative assertions to be derived. It is essential to note that comparisons cannot be made at the level of the polymer or its precursors. In order to compare the performance of different materials, the whole life cycle and the effects of relevant life cycle parameters must be considered.*

PlasticsEurope Eco-profiles and EPDs represent polymer production systems with a defined output. They can be used as modular building blocks in LCA studies. However, these integrated industrial systems cannot be disaggregated further into single unit processes, such as polymerisation, because this would neglect the interdependence of the elements, e.g. the internal recycling of feedstocks and precursors between different parts of the integrated production sites.

PlasticsEurope Eco-profiles and EPDs are prepared in accordance with the stringent ISO 14040–44 requirements. Since the system boundary is »cradle-to-gate«, however, their respective reference flows are disparate, namely referring to a broad variety of polymers and precursors. This implies that, in accordance with ISO 14040–44, a direct comparison of Eco-profiles is impossible. While ISO 14025, Clause 5.2.2 does allow EPDs to be used in comparison, PlasticsEurope EPDs are derived from Eco-profiles, i.e. with the same »cradle-to-gate« system boundaries.

As a consequence, a direct comparison of Eco-profiles or EPDs makes no sense because 1 kg of different polymers are not functionally equivalent.

Once a full life cycle model for a defined polymer application among several functionally equivalent systems is established, and only then, can comparative assertions be derived. The same goes for EPDs, for instance, of building product where PlasticsEurope EPDs can serve as building blocks.

Eco-profiles and EPDs are intended for use by the following target audiences:

- member companies, to support product-orientated environmental management and continuous improvement of production processes (benchmarking);
- downstream users of plastics, as a building block of life cycle assessment (LCA) studies of plastics applications and products; and
- other interested parties, as a source of life cycle information.

Product Category and Declared Unit

Product Category

The core product category is defined as **uncompounded polymer resins, or reactive polymer precursors**. This product category is defined »at gate« of the polymer or precursor production and is thus fully within the scope of PlasticsEurope as a federation. In some cases, it may be necessary to include one or several additives in the Eco-profile to represent the polymer or precursor »at gate«. For instance, some polymers may require a heat stabiliser, or a reactive precursor may require a flame retardant. This special case is distinguished from a subsequent compounding step conducted by a third-party downstream user (outside PlasticsEurope’s core scope).

Functional Unit and Declared Unit

1 kg of primary Polycarbonate Granulate/Resin (PC) »at gate« (production site output) representing a European industry production average.

Product and Producer Description

Product Description

Polycarbonate (PC) is a thermoplastic polymer. As a di-ester of carbonic acid, it is composed of bisphenol A units connected by carbonate linkages.

- IUPAC name 4-[2-(4-hydroxyphenyl)propan-2-yl]phenol;
- CAS no. 25037-45-0
- chemical formula $C_{15}H_{16}O_2$.
- gross calorific value of 33 MJ/kg.

Its unique combination of properties including high levels of impact strength, ductility, thermal stability, outstanding transparency and inherent flame resistance, have led to its great commercial success. The most important application fields of PC are in the building and construction sector (e.g. improving insulation and lightning), electrical and electronics (e.g. large flat screens and monitors, consumer electronics equipment and fuse boxes as well as the large market of optical data storage), automotive industry (e.g. mirror and headlamp houses), domestic appliances, packaging, medical devices as well as leisure and safety (e.g. sunglasses, goggles, helmet). It may be processed by all of the usual injection moulding and extrusion techniques.
For the industrial production of Polycarbonate, Interfacial Polycondensation and Melt Transesterification process are currently being used. In the interfacial process, Bisphenol A is reacted with phosgene at 20–40ºC in a two-phase mixture consisting of an aqueous, alkaline phase (e.g. use of NaOH) and an immiscible organic phase. The overall reaction is as follows:

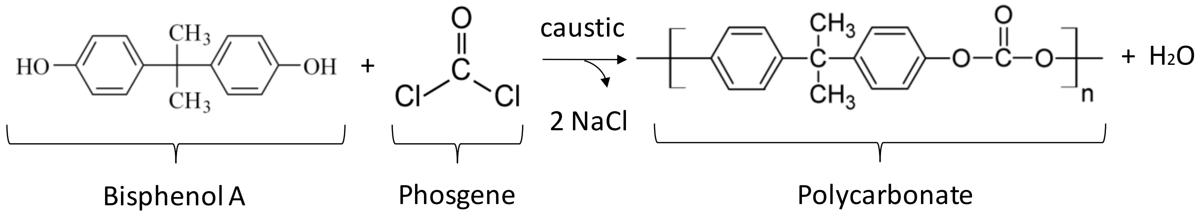

Figure 1: Polycarbonate Synthesis (Interfacial Process)

These main starting compounds Bisphenol A and phosgene are produced in the following way:
Bisphenol A is mainly produced by the condensation of acetone and phenol. Both intermediates can be produced from the oxidation of cumene (Hock process), coming from the reaction between benzene and propylene. Propylene is produced from the cracking naphtha and benzene is produced either from reformation of gasoline, pyrolysis of gasoline or from toluene dealkylation.

Phosgene is produced by passing chlorine from the electrolysis of sodium chloride and an excess of carbon monoxide over activated carbon at elevated temperatures. Carbon monoxide is manufactured from synthesis gas, which is best produced from water (steam) and methane (natural gas). The latter can be replaced with other hydrocarbons and mixtures thereof, e.g. naphtha or fuel oils.

In the melt transesterification process, diphenyl carbonate (DPC) is transesterified in the melt with bisphenol A to form polycarbonate:

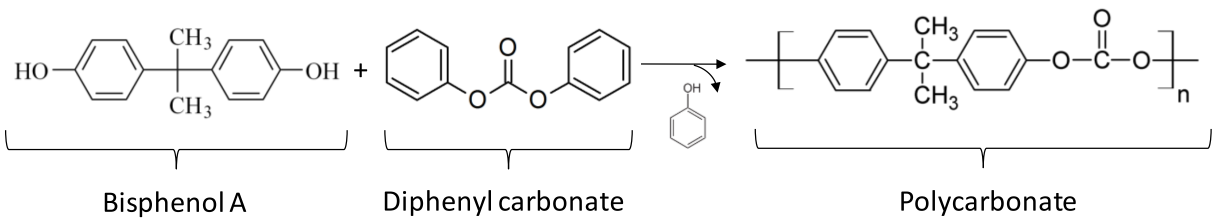

Figure 2: Polycarbonate Synthesis (Melt Transesterification Process)

DPC for this reaction can be manufactured by phosgenation of phenol. Another possibility is the reaction of carbon monoxide with alcohols in the presence of catalysts giving dialkyl carbonates that can, in turn, be reacted with phenol to form diphenyl carbonate. The overall process leading to polycarbonate is shown schematically in Figure 3.

Producer Description

PlasticsEurope Eco-profiles and EPDs represent European industry averages within the scope of PlasticsEurope as the issuing trade federation. Hence they are not attributed to any single producer, but rather to the European plastics industry as represented by PlasticsEurope's membership and the production sites participating in the Eco-profile data collection. The following companies contributed data to this Eco-profile and EPD:

- Covestro AG

  D-51368 Leverkusen

  Germany

  www.covestro.com

- Trinseo Deutschland Anlagengesellschaft mbH

  Postfach 1126

  D-21651 Stade, Germany

  www.trinseo.com

- SABIC Innovative Plastics

  PO Box 117 / Plasticslaan 1

  4600 AC Bergen op Zoom, The Netherlands

  www.sabic.com

Eco-profile – Life Cycle Inventory

System Boundaries

PlasticsEurope Eco-profiles and EPDs refer to the production of polymers as a cradle-to-gate system (Figure 3).

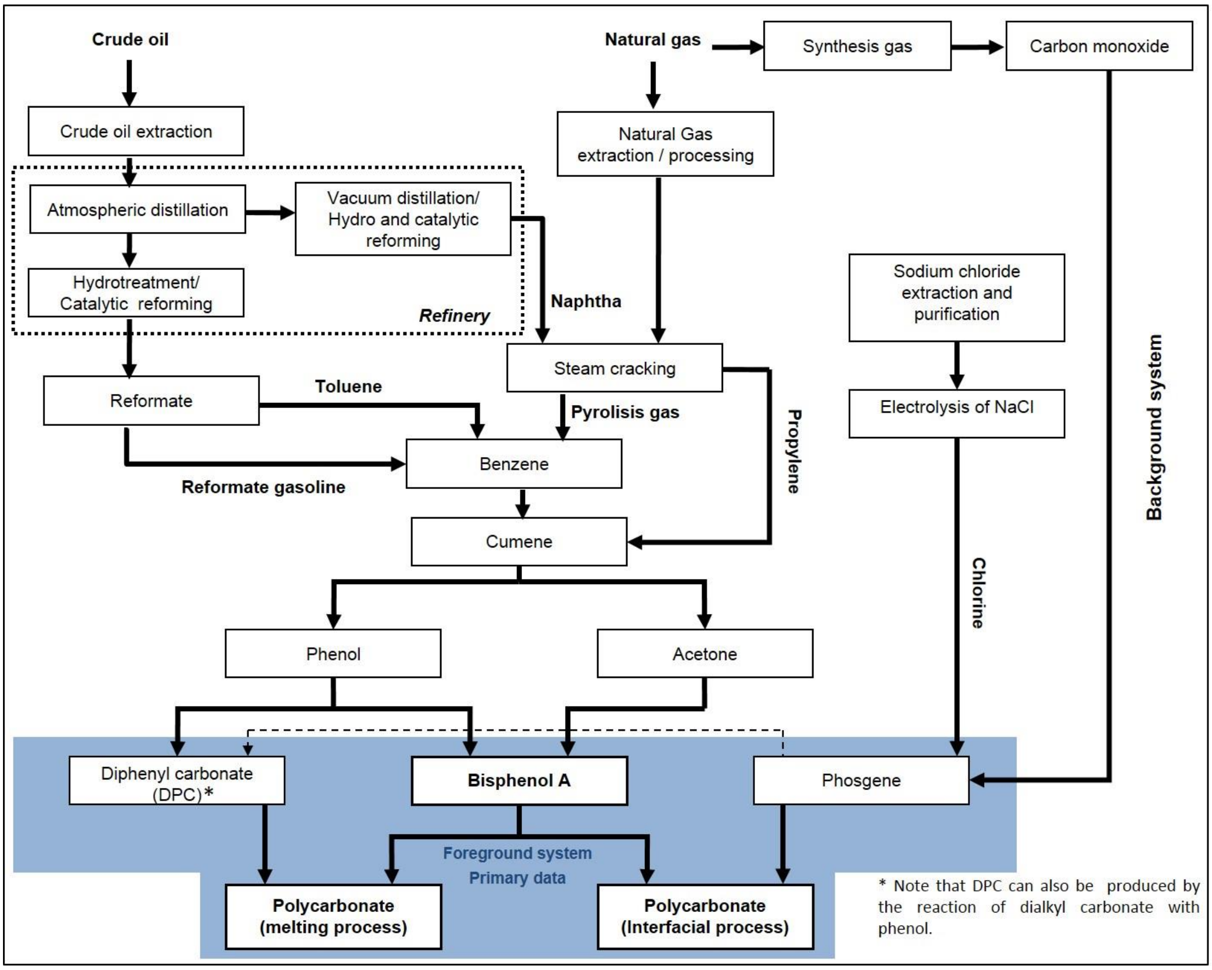

Figure 3: Cradle-to-gate system boundaries

Technological Reference

The PC production processes were modelled using specific values from primary data collection at site, representing the specific technology for the three companies. The LCI data represent technology in use in the defined production region employed by participating producers. The considered participants cover all PC producers in Europe in 2016, so the technological coverage is understood as representative.

Primary data were used for all foreground processes for the production of PC (under operational control) complemented with secondary data from background processes (under indirect management control).

Solid and liquid residues from the reaction are burned in incineration plants and have been modeled based on their chemical composition and heat value. For waste water treatment the model used is documented at http://documentation.gabi-software.com.

Temporal Reference

The collected LCI process data represented the yearly average of 2016, Background data have reference years from 2014 to 2017. The temporal range of the background data is not expected to have a major impact on the results of the study, as no major technological breakthroughs occurred in the last 8 years for refining, re-refining technology or one of the related up-stream technologies. The data is considered to be sufficiently valid, provided no significant change in the production chain occurs The overall reference year for this Eco-profile is 2016 with a temporal validity until 2024.

Geographical Reference

Primary production data for the PC production is from three different suppliers in the EU (Germany, Belgium, Spain and Netherlands). Fuel and energy inputs in the system reflect average National conditions and whenever applicable, site specific conditions were applied, to reflect representative situations. Therefore, the study results are intended to be applicable within EU boundaries and in order to be applied in other regions adjustments might be required. PC imported into Europe was not considered in this Eco-profile.

Cut-off Rules

In the foreground processes all relevant flows were considered, trying to avoid any cut-off of material and energy flows*. In single cases additives used in the PC unit process (<0.2 % m/m of PC output) were neglected. This was done in agreement with the producer due to the complex mixture of chemicals used and lack of information on the amount of each substance used. Nevertheless it was assured that no hazardous substances or metals were present in this neglected part.*

According to the GaBi Databases 2018 [GaBi 2018], used in the background processes, at least 95 % of mass and energy of the input and output flows were covered and 98 % of their environmental relevance (according to expert judgment) was considered, hence an influence of cut-offs less than 1 % on the total is expected.

Data Quality Requirements

Data Sources

Eco-profile and EPDs developed by PlasticsEurope use average data representative of the respective foreground production process, both in terms of technology and market share. The primary data are derived from site specific information for processes under operational control supplied by the participating member companies of PlasticsEurope (see Producer Description). With the exception of Bisphenol A and Chlorine the data for the upstream supply chain until the precursors are taken from the database of the software system GaBi ts [GaBi 2018]. For Bisphenol A and Chlorine, primary data was collected from the respective producers and reported in a separate Eco-profile. “Chlorine (the chlor-alkali process)”, EUROCHLOR, September 2013, Bisphenol (BPA) PlasticsEurope, January 2019.
Companies producing both BPA and PC (at the time of this study) have been assumed using their own produced BPA as pre-cursor with a company and site specific BPA eco-profile (confidential).
Companies not producing BPA have been assumed to use a EU-market average of BPA as pre-cursor, for which the PlasticsEurope Eco-profile for BPA (study referenced here above) was used as dataset.

All relevant background data such as energy and auxiliary material are also taken from the GaBi ts database. Most of the background data used is publicly available and public documentation exists.

Relevance

With regard to the goal and scope of this Eco-profile, the collected primary data of foreground processes are of high relevance, i.e. data from the most important PC producers in Europe in order to generate a European industry average production. Data from the most environmentally relevant intermediate to the PC production, Bisphenol A, was also collected and this information is available in a separate Eco-profile.'.

Representativeness

The considered participants covered all PC producers in Europe in 2016. The selected background GaBi ts data can be regarded as representative for the intended purpose, as it is average data and not in the focus of the analysis.

Consistency

To ensure consistency only primary data of the same level of detail and background data from the GaBi ts databases [GaBi 2018] were used. The provided primary data was checked by thinkstep to ensure plausibility of mass, energy and water balance. The methodological framework is consistent throughout the whole model as the same methodological principles are used both in foreground and background system.

Reliability

Data reliability ranges from measured to estimated data. Data of foreground processes provided directly by producers were predominantly measured. Data of relevant background processes were measured at several sites or determined by literature data or estimated for some flows, which usually have been reviewed and checked for its quality.

Completeness

Primary data used for the gate-to-gate production of PC covers all related flows in accordance with the cut off criteria. Other data in the model sourced from the GaBi ts database [GaBi 2018] covers all related flows according to the system boundaries and cut off criteria. In this way all relevant flows were quantified and data is considered complete.

Precision and Accuracy

As the relevant foreground data is primary data or modelled based on primary information sources of the owner of the technology, better precision is not reachable within this goal and scope. All background data is consistently GaBi professional data with high precision documentation.

Reproducibility

All data and information used are either documented in this report or they are available from the processes and process plans designed within the GaBi ts software. The reproducibility is given for internal use since the owners of the technology provided the data and the models are stored and available in a database. Sub-systems are modelled by ´state of art´ technology using data from a publicly available and internationally used database. It is worth noting that for external audiences, it may be the case that full reproducibility in any degree of detail will not be available for confidentiality reasons. However, experienced experts would easily be able to recalculate and reproduce suitable parts of the system as well as key indicators.

Data Validation

The data on PC production collected from the project partners was validated at thinkstep and the data providing companies in an iterative process several times. The collected data was validated using mass-energy balances checks and expert knowledge from thinkstep.
The background information from the GaBi ts database is updated regularly and validated in principle daily by the various users worldwide.

Life Cycle Model

The study has been performed with the LCA software GaBi ts GABI 2018[]. GaBi software and associated database integrate ISO 14040/44 requirements. Due to confidentiality reasons details on software modelling and methods used cannot be shown here. The calculation follows the vertical calculation methodology, i.e. that the averaging is done after modelling the specific processes.

Calculation Rules

Vertical Averaging

When modelling and calculating average Eco-profiles from the collected individual LCI datasets, vertical averages were calculated (Figure 4).

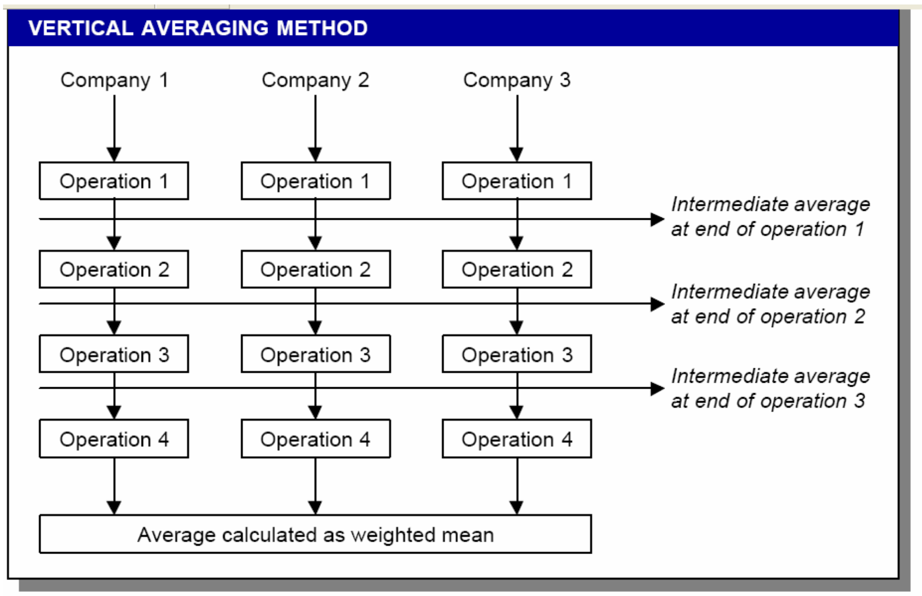

Figure 4: *Vertical Averaging (source: Eco-profile of high volume commodity phthalate esters, ECPI European Council for Plasticisers and Intermediates, 2001)*

Allocation Rules

Production processes in chemical and plastics industry are usually multi-functional systems, i.e. they have not one, but several valuable product and co-product outputs. Wherever possible, allocation should be avoided by expanding the system to include the additional functions related to the co-products. Often, however, avoiding allocation is not feasible in technical reality, as alternative stand-alone processes are not existing in reality or alternative technologies show compete different technical performance and product quality output. In such cases, the aim of allocation is to find a suitable partitioning parameter so that the inputs and outputs of the system can be assigned to the specific product sub-system under consideration.

Allocation was applied for the production process of some participants, as minor by-products result from their specific PC production process. The by-products had lower assignments than the main product PC. The process intention is the production of PC only. Depending on the generated by-product and its further application (e.g. minor intermediates to be further used, sold or fuel gas to be applied in combustion processes), allocation was done according to mass, current market prices, or energy. A quantified sensitivity analysis was performed whenever different allocation possibilities were applicable. Using different allocation approaches didn´t show any significant changes in the overall results (less than 1%).

In the refinery operations, co-production was addressed by applying allocation based on mass and net calorific value [GaBi 2018]. The chosen allocation in refinery is based on several sensitivity analyses, which was accompanied by petrochemical experts. The relevance and influence of possible other allocation keys in this context is small. In steam cracking allocation according to net calorific value is applied.

Life Cycle Inventory (LCI) Results

Formats of LCI Dataset

The Eco-profile is provided in four electronic formats:

- As input/output table in Excel®
- As XML document in EcoSpold format (www.ecoinvent.org)
- As XML document in ILCD format (http://lct.jrc.ec.europa.eu)
- As LCI in GaBi format (www.gabi-software.com)

Key results are summarised below.

Energy Demand

As a key indicator on the inventory level, the **primary energy demand** (system input) of 104,29 MJ/kg indicates the cumulative energy requirements at the resource level, accrued along the entire process chain (system boundaries), quantified as gross calorific value (upper heating value, UHV).

As a measure of the share of primary energy incorporated in the product, and hence indicating a recovery potential, the **energy content in the polymer** (system output), quantified as the gross calorific value (UHV), is 33 MJ/kg.

Table 1: Primary energy demand (system boundary level) per 1kg PC

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	33.00
Process energy from non-renewable energy resources	66,02
Process energy from renewable energy resources	5,26
Total primary energy demand	**104,29**

Consequently, the difference (Δ) between primary energy input and energy content in polymer output is a measure of **process energy** which may be either dissipated as waste heat or recovered for use within the system boundaries. Useful energy flows leaving the system boundaries were removed during allocation.

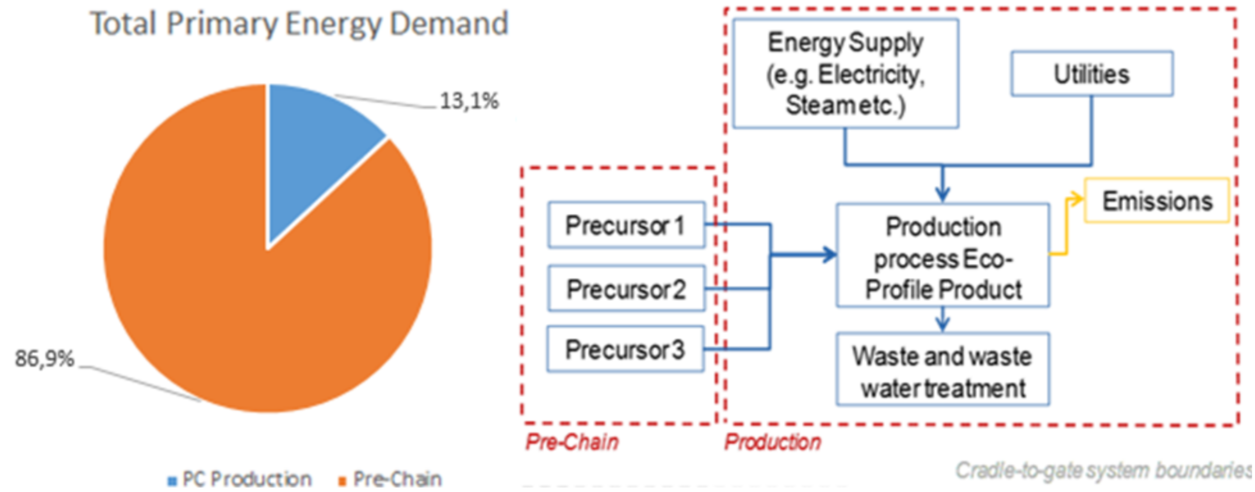

Figure 5: Contribution to primary energy demand per segment

Water Consumption

The following table shows the weighted average values for water use of the PC production process (gate-to-gate level). For each of the typical water applications the water sources are shown.

Table 2: Water use and source per 1kg PC

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
Deionized	2,18	0,72	1,52	0,38	4,79
From River		42,41			42,41
Relooped	0,27	103,39	1,99	0,12	105,77
Totals	2,45	146,52	3,50	0,50	152,97

The following table shows the further handling/processing of the water output of the PC production process.

Table 3: Treatment of Water Output per 1kg of PC

Treatment	Water Output [kg]
To WWTP	4,32
To Sea (after WWTP)	0,91
To River (untreated)	40,28
Reloop to process	105,77
Water Vapour	1,83
Formed in reaction (to WWTP)	0,14
Totals	153,10

Based on the water use and output figures above the water consumption can be calculated as:

Consumption = (water vapour + water lost to the sea) – (water generated by using water containing raw materials + water generated by the reaction) = **2,22 kg**

Dominance Analysis

Table 4 shows the main contributions to the results presented above. An average based on the weighted mean from the different technologies of the participating producers is used.

In all analysed environmental impact categories, intermediates contribute 75 % or more of the total impact, with Bisphenol A dominating with around 50 % or more (the only exception being the indicator ADP Elements). The use of high quality data especially for this case is therefore decisive to the environmental profile of PC.

Table 4: Dominance analysis of impacts per 1kg PC

	Total Primary Energy [MJ]	ADP Elements [kg Sb eq.]	ADP Fossil [MJ]	GWP [kg CO_2 eq.]	AP [g SO_2 eq.]	EP [g PO_4^{3-} eq]	POCP [g Ethene eq.]
Production Process	0%	0%	0%	2%	3%	1%	3%
BPA	72%	6%	76%	61%	56%	50%	73%
Phosgene Raw Materials	6%	50%	5%	8%	16%	12%	6%
Other Chemicals	9%	41%	7%	10%	12%	16%	11%
Thermal Energy	8%	1%	9%	14%	6%	7%	6%
Electricity	4%	1%	2%	5%	5%	5%	3%
Utilities	1%	1%	0%	1%	1%	1%	0%
Process Waste Treatment	0%	0%	0%	0%	1%	5%	0%
Transports	0%	0%	0%	1%	1%	1%	-2%
Total	100%	100%	100%	100%	100%	100%	100%

(PC) Production Process, Electricity, Process waste treatment, Thermal energy, Utilities are part of the foreground system (compare figure 5 – segment "Production").
BPA , Phosgene raw materials, Other chemicals, Transports are part of the background system (compare figure 5 – segment "Pre-Chain").

Comparison of the present Eco-profile with its previous version (2011)

Table 5 compares the present results with the previous version of the Eco-profile of Polycarbonate.

Table 5: Comparison of the present Eco-profile with its previous version (2011)

Environmental Impact Categories	Eco-profile PC (2011)	Eco-profile PC (2019)	Difference
Gross primary energy from resources [MJ]	103,90	104,29	0,4%
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	7,26E-06	8,97E-06	23,6%
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	88,99	86,91	-2,3%
Global Warming Potential (GWP) [kg CO_2 eq.]	4,13	3,40	-17,7%
Acidification Potential (AP) [g SO_2 eq.]	7,47	5,36	-28,2%
Eutrophication Potential (EP) [g PO_4^{3-} eq.]	0,92	0,72	-21,2%
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	1,99E-04	7,24E-05	-63,6%
Photochemical Ozone Creation Potential [g Ethene eq.]	1,61	0,73	-54,9%

Table 5 shows a significant improvement in almost all environmental indicators in scope of the Polycarbonate Eco-profile compared to the previous study.

Only the impact category ADP elements shows a relatively worse result compared with the old Eco-profile. This is due to the usage of another dataset for Chlorine, which includes a higher consumption of Sodium Chloride and therefore a higher value for ADP elements, dominating the contribution analysis for this impact category, followed by Other Chemicals used (and here mostly Sodium Hydroxide)

For each of the other impact categories in scope a decrease of the environmental footprint can be stated, ranging from very small (ADP fossil) to significant (GWP, AP, EP, POCP, ODP) improvements of the environmental performance. With regards to GWP about 30% of the improvement can be related directly to the production processes itself (= more efficient use of energy/auxiliaries and/or switching to greener energy carriers/energy production)

As mentioned previously, the dominance analysis shows that Bisphenol A data is decisive for the environmental profile of PC and therefore an improvement on its process would definitely cause an improvement on PC's profile.

Another factor causing an improvement of the environmental profile is the “greening” of different energy carrier mixes over time: for example the GWP factor of EU-27 electricity grid mix improved by about 15% in the respective time period. This fact leads to higher improvements in GWP compared to the total Primary Energy demand which did not change significantly.

Process residues treatment such as incineration with energy recovery and waste water treatment plant as well as delivery transports of raw materials only showed neglectable contributions

Review

Review Details

The project included meetings with representatives of all participating producers and PlasticsEurope as system operator. In addition, a review meeting between the LCA practitioner and the reviewer was held, including a model and database review, and spot checks of data and calculations.

Review Summary

The present Eco-Profile is an update of an Eco-Profile published in 2011 for the product PC.
The report was peer reviewed in January 2019, according to the requirements of the Life Cycle Inventory (LCI) Methodology and Product Category Rules (PCR) for Uncompounded Polymer Resins and Reactive Polymer Precursors, version 2.0 (April 2011) accompanied by a draft version with advancement of the PCR to be published in the 1. quarter of 2019.
The review is based on the final Eco-profile document accompanied by a telephone conference for clarifying open questions and comments of the reviewer, including spot checks of the software model applied.
The updated Eco-Profile integrates both new foreground data delivered by the participants of the study and updated life cycle inventories for upstream processes (background data) from the current available GaBi database.
As the data collection covers all main producers in Europe the results for the environmental impacts declared, show a high representativeness of the technology and the currently applied processing for PC.
The methodological approaches follow the PCR requirements. The recommendations of the reviewer have been followed to clarify certain aspects.
The comparative evaluations on the data collection and results of the current study to the previous one shows plausible results and traceable developments. In the review process this section has been revised thus to declare a precise explanation of the changes and improvements of the production processes. The improvements basically refer to developments of the electricity supply. Process specific reduction of energy demand per process step in the overall supply chain is desirable to force the trend of higher efficiency and less environmental impact.
The structure is clear and transparent, thus displaying a reliable source of information.

Salem, January 2019

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