Eco-profile of

General-Purpose Polystyrene (GPPS) and High-Impact Polystyrene (HIPS)

November 2022

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1 SUMMARY

This Eco-profile has been prepared according to **Eco-profiles program and methodology – PlasticsEurope – V3.1 (2022).**

It provides environmental performance data representative of the average European production of General Purpose Polystyrene (GPPS) and High Impact Polystyrene (HIPS) polymer, from cradle to gate (from crude oil extraction to beads production).

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. It 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.

1.1 META DATA

Data Owner	PlasticsEurope
LCA Practitioner	Sphera Solutions GmbH
Programme Owner	PlasticsEurope
Reviewer	Matthias Schulz, Schulz Sustainability Consulting, Germany
Number of plants included in data collection	• 9 plants for GPPS • 7 plants for HIPS
Representativeness	The participating companies represent about 80% of the European GPPS and HIPS production volume in 2018. It has been assumed that the production capacity of 2018 is also representative of 2019.
Reference year	2019
Year of data collection and calculation	2022
Expected temporal validity	Revision should be considered in 2027
Cut-offs	No cut-offs applied
Data Quality	Overall: Excellent Confirmed by assessment of individual DQ indicators
Allocation method	None

1.2 DESCRIPTION OF THE PRODUCT AND THE PRODUCTION PROCESS

This Eco-profile covers the production of General Purpose Polystyrene (GPPS) and High Impact Polystyrene (HIPS). GPPS is a hard, transparent material with a high gloss. HIPS is a white, non-shiny and basically opaque, but relatively flexible, rubber-modified polystyrene, that has high impact strength, high stiffness and excellent moldability, but reduced transparency

The participating companies represent about 80% of the European Polystyrene (PS) production volume in 2018 (HDIN, 2019). It has been assumed that the production capacity of 2018 is also representative of 2019.

The functional units and also reference flows of this study, to which all data and results given in this Eco-profile refer, are:

1 kg of General Purpose Polystyrene (GPPS), reflecting the weighted average of about 80% of European production capacities

1 kg of High Impact Polystyrene (HIPS), reflecting the weighted average of about 80% of European production capacities

Polystyrene is produced by polymerisation of styrene monomer, a chain-growth reaction which is induced by any known initiation techniques such as heat, free radical organic initiator, anionic or cationic initiating systems, or coordination-insertion organometallic initiating complexes. Both, GPPS and HIPS, are produced by continuous-mass radical polymerisation of styrene; in case of HIPS, it is a polymerisation of polybutadiene rubber in a styrene solution.

1.3 DATA SOURCES AND ALLOCATION

The main data source is a primary data collection from European producers of GPPS and HIPS, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: five GPPS producers with nine plants in six different European countries; five HIPS producers with seven plants in six different European countries.

The background data for all direct upstream inputs to the PS system are taken from the GaBi 2021 LCI database (Sphera, 2021). With regards to styrene monomer (SM), the existing 60:40 mix of two different routes for the production of styrene (EBSM and POSM) has been taken from the Eco-Profile for styrene (PlasticsEurope, 2022). The documentation for background data from GaBi is publicly available (Sphera, 2021).

There has been no allocation applied in the foreground data.

Use Phase and End-of-Life Management

GPPS and HIPS are used in many applications such as food and non-food packaging, disposable cups and cutlery, furniture, toys and consumer goods, as well as electronics and appliances. Polystyrene is also easily foamed in order to manufacture insulation boards and lightweight foamed packaging. The packaging market is the main market and accounts for around one half of the European polystyrene market. Extrusion can be in form of plates, sheet, or foam boards. In a secondary process step extruded sheet can be thermoformed, for example into disposables such as trays and containers. Typical injection moulding applications are televisions housing and toys. HIPS is also used to make engineering resin blends with polyphenylene oxide for the automotive industry, electrical appliances, and electronics. Polystyrene can be recycled mechanically several times without deteriorating physical properties; furthermore, energy recovery is also possible.

1.4 ENVIRONMENTAL PERFORMANCE

The tables below show the environmental performance indicators associated with the production of 1 kg GPPS and HIPS, respectively.

Input Parameters

Indicator	Unit	Value		Impact method ref.
		GPPS	HIPS	
Non-renewable energy resources*)		82.83	84.15	
• Fuel energy	MJ	40.43	41.75	-
• Feedstock energy	MJ	42.40	42.40	Gross calorific value
Renewable energy resources (biomass)*)		1.00	1.24	
• Fuel energy	MJ	1.00	1.24	-
• Feedstock energy	MJ	0.00	0.00	Gross calorific value
Resource use				
• Minerals and Metals	kg Sb eq	4.03E-07	5.13E-07	EF 3.0
• Energy Carriers	MJ	76.27	77.49	EF 3.0
Renewable materials (biomass)	kg	-2.19E-14[1]	-1.45E-14[1]	-
Water use	m^3 world eq	0.23	0.25	EF 3.0
*) Calculated as upper heating value (UHV)				

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[1] Neglectable negative result originating from a credit dataset used in upstream infrastructure modelling

Output Parameters

Indicator	Unit	Value		Impact method ref.
		GPPS	HIPS	
Climate change, total	kg CO_2 eq.	2.16	2.25	EF 3.0
Ozone depletion	kg CFC-11 eq.	2.70E-15	3.22E-15	EF 3.0
Acidification	Mole of H+ eq	3.41E-03	3.55E-03	EF 3.0
Photochemical ozone formation	kg NMVOC eq	4.13E-03	4.20E-03	EF 3.0
Eutrophication, freshwater	kg P eq	3.74E-06	4.36E-06	EF 3.0
Respiratory Inorganics	Disease incidences	2.48E-08	2.58E-08	EF 3.0
Waste				
• Non-hazardous	kg	0.59	0.69	-
• Hazardous	kg	3.04E-04	3.62E-04	-

1.5 PROGRAMME OWNER

PlasticsEurope

Rue Belliard 40

B-1040 Brussels, Belgium

E-mail: info@plasticseurope.org

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

1.6 DATA OWNER

PlasticsEurope

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B-1040 Brussels, Belgium

E-mail: info@plasticseurope.org

1.7 LCA PRACTITIONER

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Hauptstraße 111-113

70771 Leinfelden-Echterdingen, Germany

Tel.: +49 711 3418170

1.8 REVIEWER

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2 ECO-PROFILE REPORT

2.1 FUNCTIONAL UNIT AND DECLARED UNIT

1 kg of unpacked primary General Purpose Polystyrene (GPPS) granules »at gate« (production site output) representing about 80% of the European industry production

or

1kg of primary High Impact Polystyrene (HIPS) granules »at gate« (production site output) representing about 80% of the European industry production

2.2 PRODUCT DESCRIPTION

General Purpose Polystyrene (GPPS) and High Impact Polystyrene (HIPS) are thermoplastic polymers, used in many applications such as food and non-food packaging, disposable cups and cutlery, furniture, toys and consumer goods, as well as electronics and appliances

- **General-purpose polystyrene (GPPS)**

  Cas Number: 9003-53-6

  Chemical formula $(C_8H_8)_n$

  Gross calorific value 42.4 MJ/kg

- **High-impact polystyrene (HIPS**)

  Cas Number: 9003-55-8

  Chemical formula $(C_8H_8)x(C_4H_6)_y$

  Gross calorific value 42.4 –42.6 MJ/kg (depending on polybutadiene content)

2.3 MANUFACTURING DESCRIPTION

Both, GPPS and HIPS, are produced by continuous-mass radical polymerisation of styrene; in case of HIPS, it is a polymerisation of polybutadiene rubber in a styrene solution. The plant setup generally comprises a feed section, a polymerisation section, a devolatilisation and solvent recovery section, and a pelletizing section. Styrene and processing aids are fed into the reactor.

In the case of HIPS, polybutadiene rubber is ground and dissolved in styrene to obtain a rubber solution. An antioxidant is usually also added in the dissolving tank. In addition, other chemicals can be added here such as white oil, peroxides, recycled styrene, ethyl benzene or chain transfer agents. Solvents, such as toluene or ethylbenzene, are added to provide better control of the polymerisation rate and the heat release rate, to modify the viscosity of the polymerisation bulk solution melt, and the crosslinking of the rubber phase. The dissolved mixture is then fed continuously to the reactor train where bulk polymerisation takes place.

The reactors' temperatures are between 100 and 180 °C. The process flow then goes through a devolatilisation section to separate the polymer from the unreacted monomers and solvent. The melted polymer is then transferred through a die head to obtain strands that are cut (dry or underwater) by pelletisers.

2.4 PRODUCER DESCRIPTION

PlasticsEurope Eco-profiles 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 to provide data to this Eco-profile:

- INEOS-Styrolution Group GmbH

  Mainzer Landstraße 50
  60325 Frankfurt
  Germany
  https://www.ineos-styrolution.com/

- SYNTHOS S.A.

  ul. Chemików 1
  32-600 Oświęcim
  Poland
  http://www.synthosgroup.com

- Total S.A.

  2, place Jean Millier
  La Défense 6
  92078 Paris La Défense Cedex
  France
  http://www.total.com

- Trinseo Belgium BVBA

  Havenlaan 7
  3980 Tessenderlo
  Belgium
  https://www.trinseo.com/

- VERSALIS S.p.A.

  Piazza Boldrini, 1
  20097 San Donato Milanese (MI)
  Italy
  http://www.versalis.eni.com

2.5 SYSTEM BOUNDARIES

Plastics Europe Eco-profiles refer to the production of polymers as a cradle-to-gate system (see *Figure 1* and *Figure 2*).

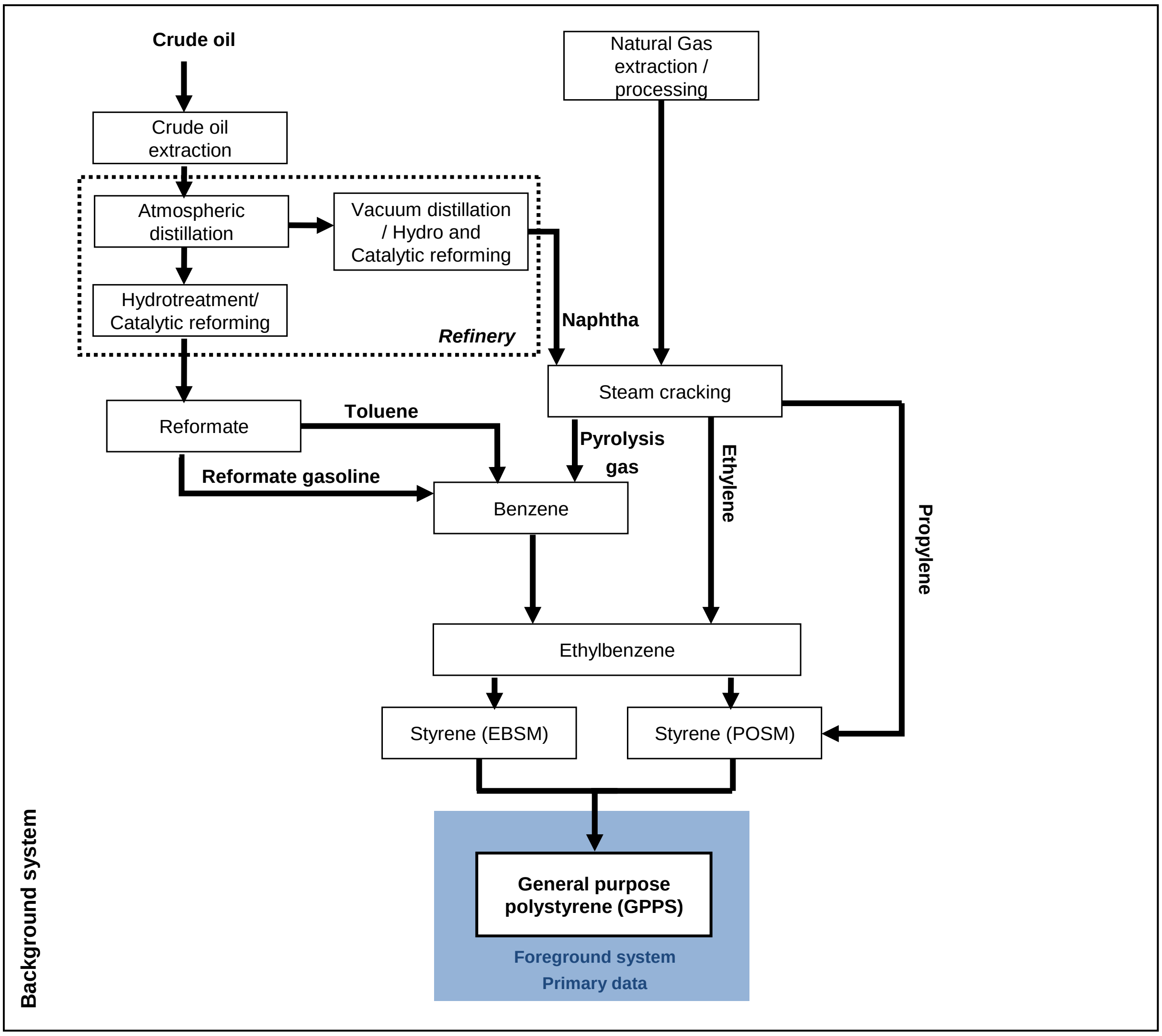

Figure 1 Cradle-to-gate system boundaries (GPPS)

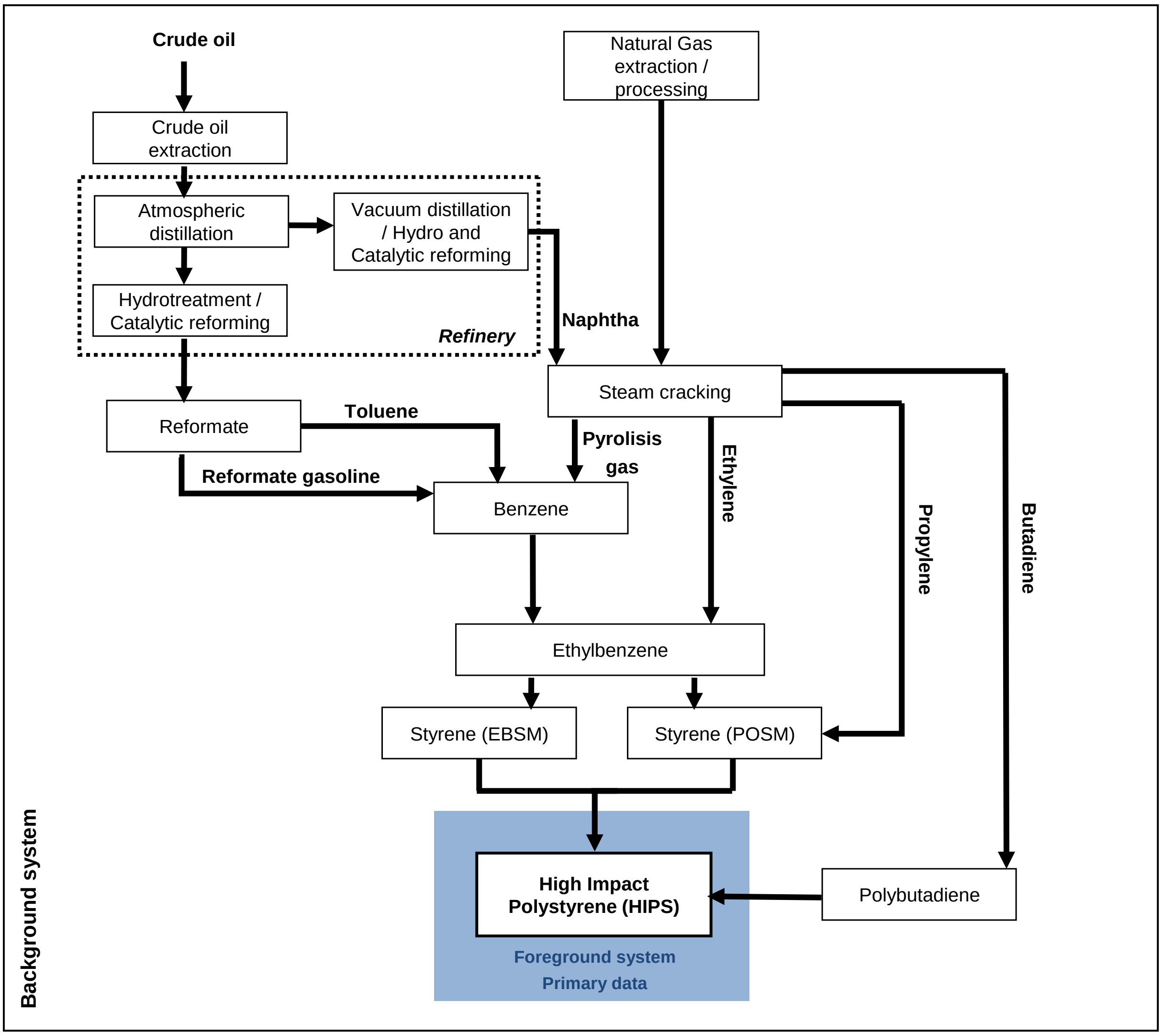

Figure 2 Cradle-to-gate system boundaries (HIPS)

2.6 TECHNOLOGICAL REFERENCE

The production processes are modelled using specific values from primary data collection at site. The main data source is a primary data collection from European producers of PS, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: five GPPS producers with nine plants in six different European countries; five HIPS producers with seven plants in six different European countries. This covers 80% of the European GPPS and HIPS production volume in 2018 (HDIN, 2019).

Primary data are used for all foreground processes (under operational control) complemented with secondary data for background processes (under indirect management control). The data for the upstream supply chain until the precursors are taken from the database of the software system GaBi 2021 LCI database (Sphera, 2021).

As shown in Figure 1 and Figure 2, two different routes for the production of styrene (EBSM and POSM) are considered. The ethylbenzene styrene monomer (EBSM) process is based on the catalytic dehydrogenation of ethylbenzene and renders styrene as its main product and minor quantity of toluene as co-product. The propylene oxide styrene monomer (POSM) process involves the co-production of propylene oxide and styrene: in this case, ethylbenzene is oxidized to form ethylbenzene hydroperoxide (EBHP). For all styrene consuming production processes the styrene LCI developed for PlasticsEurope (2022) has been used. This reflects production route shares of 60:40 between EBSM and POSM.

2.7 TEMPORAL REFERENCE

The LCI data for production is collected as 12-month averages representing the year 2019, to compensate seasonal influence of data. Background datasets used from the GaBi database refer to the year 2020 (in case of raw materials) and 2017 (in case of energy datasets). Available industry data used for the verification of the GaBi datasets refer to the years of 2020 (EBSM) and 2010 (POSM).

The dataset is considered to be valid until substantial technological changes in the production chain occur. The overall reference year for this Eco-profile is 2019 with a recommended temporal validity until 2027 to which the relevance of the revision should be considered according to Eco-profiles program and methodology –PlasticsEurope – V3.0 (2019).

2.8 GEOGRAPHICAL REFERENCE

Background data have reference years 2020 in case of raw materials, 2010 in case of POSM and 2017 for electricity and thermal energy processes. The dataset is considered to be valid until substantial technological changes in the production chain occur. In view of the latest technology development, the overall reference year for this Eco-profile is 2019, with a maximum temporal validity until 2027 for the foreground system.

Primary production data for both GPPS and HIPS production are from five different European suppliers each, located in six different countries. Whenever applicable (in the majority of the cases), site specific conditions were applied. Only in cases where no further information was available, average European conditions were used for fuel and energy inputs in the system. Therefore, the study results are intended to be applicable within EU boundaries: adjustments might be required if the results were applied to other regions. GPPS and HIPS imported into Europe were not considered in this Eco-profile

2.9 CUT-OFF RULES

In the foreground processes all relevant flows are considered, trying to avoid any cut-off of material and energy flows. According to the GaBi 2021 LCI database (Sphera, 2021), used in the background processes, at least 95% of mass and energy of the input and output flows are covered and 98% of their environmental relevance (according to expert judgment) are considered, hence an influence of cut-offs less than 1% on the total is expected.

2.10 DATA QUALITY REQUIREMENTS

Data Sources

Eco-profiles developed by PlasticsEurope use 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).

All relevant background data such as energy and auxiliary material are also taken from the GaBi 2021 LCI database (Sphera, 2021). Most of the background data used is publicly available and public documentation exists.

Styrene as the relevant intermediate originates from two different technology routes.

EBSM (ethyl benzene styrene monomer) is based on catalytic dehydrogenation of ethylbenzene, with styrene as its main product. The process for POSM (propylene oxide-styrene monomer) involves the oxidation of ethylbenzene; the process delivers styrene and propylene oxide.

The current LCI for styrene (mix of EBSM and POSM) from PlasticsEurope (PlasticsEurope, 2022) has been applied throughout the models.

Relevance and Representativeness

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 was sourced from the most important GPPS and HIPS producers in Europe in order to generate a European production average.

The total production of participating companies in this study is 1530 kilotonnes. This represents about 80% of the European EPS production volume of 1921 kilotonnes in 2018 (HDIN, 2019). It has been assumed that the production capacity of 2018 is also representative of 2019. The selected background data can be regarded as representative for the intended purpose.

The environmental contributions of each process to the overall LCI results are included in the Chapter ‘Dominance Analysis’.

Consistency

To ensure consistency only foreground data of the same level of detail and background data from the GaBi 2021 LCI database [SPHERA 2021] were used. While building up the model, cross-checks concerning the plausibility of mass and energy flows were continuously conducted. The methodological framework is consistent throughout the whole model as the same methodological principles are used both in foreground and background system.

Reliability

Data of foreground processes provided directly by producers are predominantly measured. Data of relevant background processes are measured at several sites – alternatively, they are determined from literature data, or estimated for some flows, which usually have been reviewed and checked for its quality (see chapter Data Sources). These secondary data are mainly based on a mix of data related from market studies, industry information, publicly available statistics and complemented by necessary calculations and estimations based on expert knowledge.

In general, all GaBi background datasets are reviewed internally before adding them to the GaBi dataset pool und undergo annual updates, which not only includes refreshment of background energy mixes but also import mixes of raw materials and process technology and efficiencies once these become known.

Completeness

Primary data used for the gate-to-gate production of GPPS and HIPS cover all related flows in accordance with the above cut-off criteria. In this way all relevant flows are quantified and data is considered complete. The elementary flows covered in the model enable the impact assessment of all selected impact categories. Waste treatment is included in the model, so that only elementary flows cross the system boundaries.

Precision and Accuracy

As the relevant foreground data is primary data, or modelled based on primary information sources of the owners of the technologies, precision is deemed appropriate to the goal and scope. All background data is consistently GaBi professional data with related public 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 10 software. The reproducibility is given for internal use since 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 in a certain confidence range.

Data Validation

The data on production collected by the project partners and the data providing companies are validated in an iterative process several times. The collected data are validated using existing data from published sources or expert knowledge.

The background information from the GaBi 2021 LCI database [SPHERA 2021] is updated regularly and validated and benchmarked daily by its various users worldwide.

Life Cycle Model

The study has been performed with the LCA software GaBi 10. The associated database integrates ISO 14040/44 requirements. Due to confidentiality reasons details on software modelling and methods used cannot be shown here. However, in principle the model can be reviewed in detail if the data owners agree. The calculation of GPPS and HIPS production follows the vertical calculation methodology as far as possible, i.e. that the averaging is done after modelling the specific processes.

A data quality rating (DQR) based on the criteria and calculation rules described in the guide to develop EF (environmental footprint) compliant datasets [JRC 2020] has been carried out. The DQR considers the following four data quality criteria evaluated for both product systems:

- technological-representativeness (Te_R),
- geographical-representativeness (G_R),
- time-representativeness (Ti_R),
- precision (P).

The overall DQR of the created datasets represents the arithmetic mean of the four data quality criteria presented above according to F.1 [JRC 2020]. Since the DQR calculation applies to company-specific datasets, the DQR of the activity data and direct (foreground) elementary flows shall be assessed, as well as the sub-processes linked to the activity data.

All direct (foreground) elementary flows and datasets that contribute at least 80% of the total LCIA results have been identified. The latter was done using a normalization and weighting process based on the EF 3.0 method through GaBi software. The styrene dataset which is used as precursor has contributed with over 80% to both product system's single score results.

Te_R is evaluated at the level of the secondary dataset (styrene) and is scored with two since the styrene dataset represents a European technology mix (horizontal average). Ti_R is evaluated twice, at the level of activity data and at the level of the secondary dataset (styrene). Ti_R is scored with one for the secondary dataset since the reference year of the datasets falls within the time validity of the styrene dataset and with two for the activity data since the data is 3 years old with respect to the reference year of the datasets. The mathematical average of the activity data and secondary data set is 1.5 and represents the Ti_R of the dataset. G_R is evaluated at the level of the secondary data set (styrene) and is scored with one since the styrene dataset represents a European average which is fully representative for the plants that have been considered in the datasets. Precision is evaluated at the level of activity data and is scored with one since the data is measured/calculated and (internally) verified by the company.

The DQR led to the following weighted average result:

Weighted DQRs				
Te_R	**Ti_R**	**G_R**	**P**	**DQR of created dataset**
2	1.5	1	1	1.4

2.11 CALCULATION RULES

Vertical Averaging

According to the PlasticsEurope methodology vertical averaging should be applied wherever possible. As far as known and available, route specific pre-cursor datasets matching the real supply chain conditions have been used for modelling individual datasets accordingly (*Figure 3*). However, in the case of the pre-cursor styrene horizontal averaging has been applied (*Figure 4*).

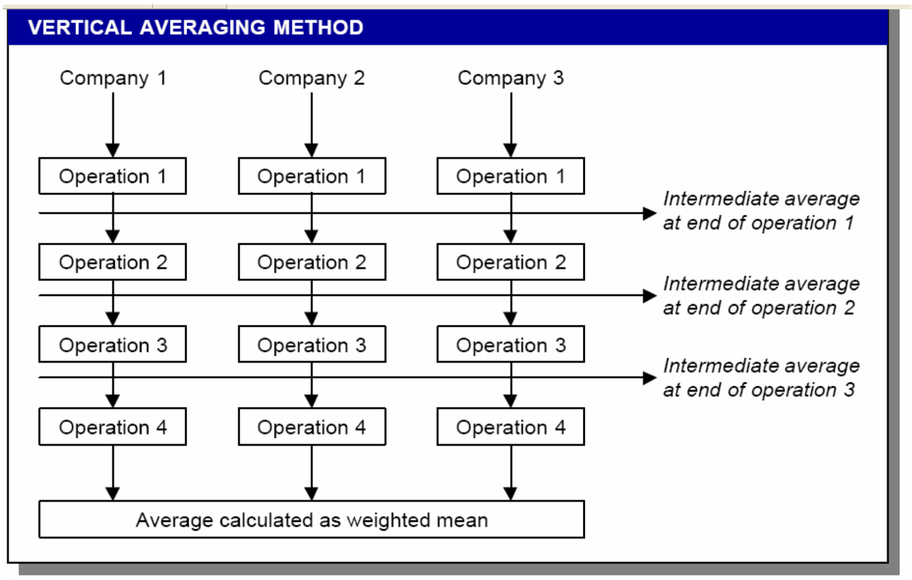

Figure 3: Vertical Averaging

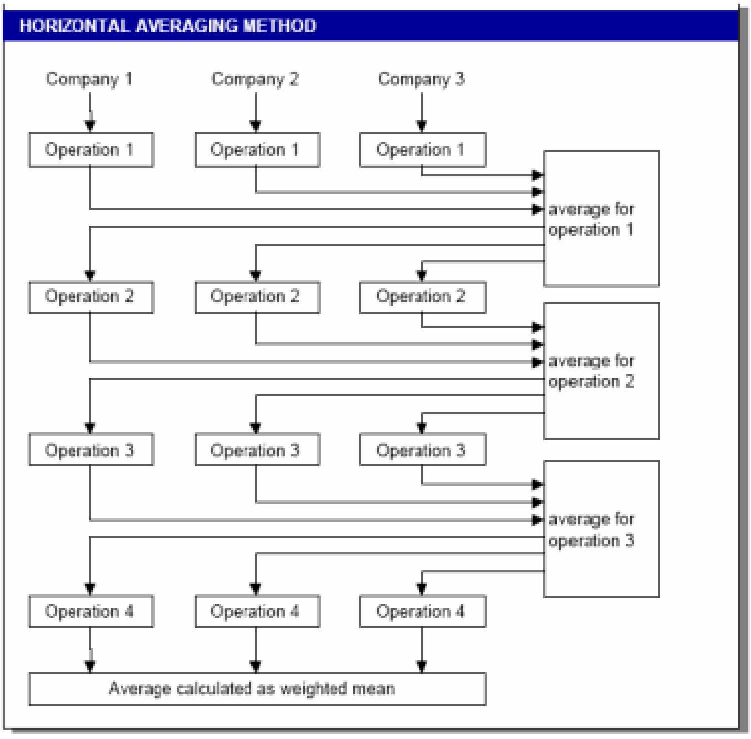

Figure 4 Horizontal Averaging

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, or alternative technologies show completely 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.

Foreground system

In some companies' information, output material with deviations from the required specification is reported (about 0.1–0.6%); in case of material declared as off-grade sent to recovery, neither further environmental burden nor credits are given to the modelled system (cut-off).

No post-consumer waste is reported as input to the system, therefore no allocation between different life cycles is necessary.

Background system

In the refinery operations, co-production was addressed by applying allocation based on mass and net calorific value [SPHERA 2021]. 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. Relevance of other allocation rules (mass) is below 2 %.

2.12 LIFE CYCLE INVENTORY (LCI) RESULTS

Delivery and Formats of LCI Dataset

This eco-profile comprises

- A dataset in ILCD/EF 3.0 format (.xml) (http://lct.jrc.ec.europa.eu) according to the last version at the date of publication of the eco-profile and including the reviewer (internal and external) input.
- A dataset in GaBi format (.GaBiDB)
- This report in pdf format.

Energy Demand

The **primary energy demand** (system input) of 83.83 MJ/kg for GPPS and 85.39 MJ/kg for HIPS 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).

The **energy content in the polymer** indicates a measure of the share of primary energy incorporated in the product, and hence a recovery potential (system output), quantified as the gross calorific value (UHV), is about 42.4 MJ/kg for both GPPS and HIPS.

The difference (Δ) between primary energy input and energy content in the polystyrene 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 treated according to the cut -off approach (no credits associated to main product system).

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

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	42.40
Process energy (quantified as difference between primary energy demand and energy content of polymer)	41.43
Total primary energy demand	**83.83**

Table 2 Primary energy demand (system boundary level) per 1kg HIPS

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	42.40
Process energy (quantified as difference between primary energy demand and energy content of polymer)	42.99
Total primary energy demand	**85.39**

Water cradle to gate Use and Consumption

The cradle-to-gate water **use** is 599.1 kg per 1 kg of GPPS and 690.2 kg per 1 kg of HIPS. The corresponding water **consumption** in the same system boundary is 10.6 kg for GPPS and 10.3 kg for HIPS.

Water foreground (gate to gate) Use and Consumption

Table 3 and Table 4 show the average values for water use of the polystyrene production processes (gate-to-gate level). For each of the typical water applications the water sources are shown.

Table 3 Water use and source per 1kg of GPPS (gate-to-gate)

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	0.02	0.03	0.07	0.00	0.12
Deionized / Softened	0.08	0.00	0.16	0.00	0.23
Untreated (from river/lake)	0.16	11.53	0.01	0.00	11.70
Untreated (from sea)	0.00	0.00	0.00	0.00	0.00
Relooped	0.00	4.38	0.00	0.00	4.38
Totals	**0.26**	**15.94**	**0.23**	**0.00**	**16.43**

Table 4 Water use and source per 1kg of HIPS (gate-to-gate)

Source	**Process water [kg]**	**Cooling water [kg]**	**Steam Water [kg]**	**Water in Raw Materials [kg]**	**Total [kg]**
From Tap	0.15	0.04	0.00	0.00	0.19
Deionized / Softened	0.35	0.00	0.08	0.00	0.43
Untreated (from river/lake)	0.00	9.04	0.00	0.00	9.04
Untreated (from sea)	0.00	0.00	0.00	0.00	0.00
Relooped	0.00	4.31	0.00	0.00	4.31
Totals	**0.50**	**13.39**	**0.08**	**0.00**	**13.96**

Table 5 and Table 6 show the further handling/processing of the water output of the average production process of polystyrene.

Table 5 Treatment of Water Output per 1kg of GPPS (gate-to-gate)

Treatment	**Water Output [kg]**
To WWTP	1.03
Untreated (to river/lake)	8.46
Untreated (to sea)	2.52
Relooped	4.38
Water leaving with products	0.00
Water Vapour	0.02
Formed in reaction (to WWTP)	0.01
Totals	**16.43**

Table 6 Treatment of Water Output per 1kg of HIPS (gate-to-gate)

Treatment	**Water Output [kg]**
To WWTP	0.00
Untreated (to river/lake)	6.14
Untreated (to sea)	2.08
Relooped	4.34
Water leaving with products	0.00
Water Vapour	0.08
Formed in reaction (to WWTP)	0.00
Totals	**13.96**

Based on the water use and output figures above the **water consumption (gate-to-gate)** 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 + seawater used)

- GPPS = 2.56 kg
- HIPS = 2.15 kg

Dominance Analysis

Table 7 and Table 8 present dominance analyses for the production of 1kg GPPS and 1 kg HIPS respectively.

Regarding GPPS, in all analysed environmental impact categories, intermediates contribute with about 70% or more of the total impact, with styrene dominating all cases. Impacts from styrene production contribute with 96% or more in the impact categories acidification, climate change, photochemical ozone formation, total primary energy and resource use (energy carriers). Zinc stearate which is used as lubricant is contributing with 45% to the category Resource use, minerals and metals.

Regarding HIPS, in all analysed environmental impact categories, intermediates contribute with about 71% or more of the total impact, with styrene dominating in most impact categories. Impacts from styrene production contribute with 84% or more in the impact categories acidification, climate change, photochemical ozone formation, total primary energy and resource use (energy carriers) whilst polybutadiene (grouped into “other chemicals”) is the second most relevant contributor to these impact categories. Zinc stearate is the most relevant contributor to the impact category Resource use, minerals and metals.

In the case of the category Resource use, minerals and metals, the different distribution results mainly from the use of stabilisers or catalysts with a metal content in production or along the supply chain. Halogenated emissions to air are causing the effect of ozone depletion. Since the use of certain halogenated substances has been banned following the implementation of the Montreal Protocol, the following emissions are not present anymore in the updated Sphera datasets: Halon (1301), R 11 (trichlorofluoromethane), R 114 (dichlorotetrafluoroethane) and R 12 (dichlorodifluoromethane) and R22 (chlorodifluoromethane). Particularly R22, which has been removed, has the profound effect of reducing the remaining, already greatly reduced ODP impacts by several orders of magnitude for most datasets. This consequently further reduces the impact results for ODP for many datasets in the database. The halogenated emissions to air are accumulating from all used background processes without a specific dominance in a category. Significant contributions to the ODP result come mainly from styrene, electricity and polybutadiene.

Phosphorous emissions from waste water treatment plants are relevant with regards to fresh water eutrophication.

Emissions in the production process, utilities, thermal energy and transports show no significance (0 – 1%) to any impact category.

Table 7 Dominance analysis of impacts per 1kg GPPS

	Total Primary Energy	**Resource use, energy carriers**	**Resource use, minerals and metals**	**Climate change, total**	**Acidi-fication**	**Eutro-phication, freshwater**	**Photo-chemical ozone formation**	**Ozone depletion**
Styrene	97%	97%	52%	96%	96%	72%	97%	69%
Other chemicals	1%	1%	45%	1%	2%	6%	1%	1%
Production	0%	0%	0%	0%	0%	0%	0%	0%
Utilities	0%	0%	0%	0%	0%	1%	0%	3%
Electricity	1%	1%	2%	1%	1%	4%	1%	27%
Thermal Energy	1%	1%	0%	2%	1%	0%	1%	0%
Process waste treatment	0%	0%	0%	0%	0%	17%	0%	0%
Transports	0%	0%	0%	0%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 8 Dominance analysis of impacts per 1kg HIPS

	Total Primary Energy	**Resource use, energy carriers**	**Resource use, minerals and metals**	**Climate change, total**	**Acidi-fication**	**Eutro-phication, freshwater**	**Photo-chemical ozone formation**	**Ozone depletion**
Styrene	87%	87%	37%	84%	84%	56%	86%	52%
Other chemicals	11%	11%	60%	12%	12%	18%	10%	18%
Production	0%	0%	0%	0%	0%	0%	0%	0%
Utilities	0%	0%	0%	0%	0%	1%	0%	3%
Electricity	1%	1%	2%	1%	2%	5%	1%	26%
Thermal Energy	1%	1%	0%	2%	1%	0%	1%	0%
Process waste treatment	0%	0%	0%	0%	0%	19%	0%	0%
Transports	0%	0%	0%	0%	1%	1%	1%	1%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Comparison of the present Eco-profile with its previous version

The previous GPPS and HIPS Eco-profiles are from 2012 and based on primary data. The results presented in Table 9 and Table 10 have been calculated according to the same impact assessment methodology which has been used for the Eco-Profiles in 2012.

The most significant improvements for both Eco-profiles, GPPS and HIPS, can be observed in the impact categories of ozone depletion (-100%), acidification (-49% - -50%), photochemical ozone formation (-31% - -35%), abiotic depletion (elements) (-29% - -32%) and eutrophication (-18%).

Relevant improvements in global warming potential are observed for GPPS (-8%) and HIPS (-11%).

No relevant changes are observed in primary energy demand or abiotic depletion potential, fossil fuels (+1% - -2%).

The observed improvements in most impact categories and especially global warming potential seem plausible as GaBi datasets build the basis for the former and current eco-profiles and given the long time period in-between, electricity grid mixes increased their shares of renewable power, as well as process efficiencies increased.

Table 9 Comparison of the present Eco-profile with its previous version per 1 kg GPPS with old methodology

Environmental Impact Categories	**Previous GPPS (2012) CML 2001 (November 2010)**	**New GPPS (2022) CML 2001 (November 2010)**	**Difference (%)**
Gross primary energy from resources [MJ]	82.26	83.83	2%
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	9.21E-07	6.30E-07	-32%
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	74.70	75.56	1%
Global Warming Potential (GWP) [kg CO_2 eq.]	2.25	2.07	-8%
Acidification Potential (AP) [g SO_2 eq.]	5.38	2.73	-49%
Eutrophication Potential (EP) [g PO_4^{3-} eq.]	0.48	0.39	-18%
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	1.63E-05	3.60E-12	-100%
Photochemical Ozone Creation Potential [g Ethene eq.]	0.85	0.59	-31%

Table 10 Comparison of the present Eco-profile with its previous version per 1 kg HIPS with old methodology

Environmental Impact Categories	**Previous HIPS (2012) CML 2001 (November 2010)**	**New HIPS (2022) CML 2001 (November 2010)**	**Difference (%)**
Gross primary energy from resources [MJ]	86.43	85.1339	-2%
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	1.04E-06	7.41E-07	-29%
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	78.46	76.64	-2%
Global Warming Potential (GWP) [kg CO_2 eq.]	2.43	2.16	-11%
Acidification Potential (AP) [g SO_2 eq.]	5.65	2.84	-50%
Eutrophication Potential (EP) [g PO_4^{3-} eq.]	0.51	0.42	-18%
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	1.72E-05	4.31E-12	-100%
Photochemical Ozone Creation Potential [g Ethene eq.]	0.90	0.59	-35%

3 EF 3.0 INDICATOR RESULTS

The following table shows the LCA results for 1 kg GPPS and HIPS when applying the EF3.0 impact assessment methodology.

Please note: when importing the delivered LCI dataset in ILCD/EF3.0 (.xml) format only these results can be recovered in the LCA software tool!

Table 11LCA results for 1 kg GPPS and HIPS applying EF3.0 impact assessment methodology

Indicator	**Unit**	**GPPS**	**HIPS**
Acidification	Mole of H+ eq	3,41E-03	3,55E-03
Climate change, total	kg CO_2 eq.	2,16E+00	2,25E+00
Climate Change, biogenic	kg CO_2 eq.	8,15E-03	8,63E-03
Climate Change, fossil	kg CO_2 eq.	2,15E+00	2,24E+00
Climate Change, land use and land use change	kg CO_2 eq.	3,14E-04	4,05E-04
Ecotoxicity, freshwater – total	CTUe	3,99E+02	3,67E+02
Ecotoxicity, freshwater inorganics	CTUe	3,36E+01	3,41E+01
Ecotoxicity, freshwater metals	CTUe	3,65E+02	3,33E+02
Ecotoxicity, freshwater organics	CTUe	2,92E-01	2,97E-01
Eutrophication, freshwater	kg P eq	3,74E-06	4,36E-06
Eutrophication, marine	kg N eq.	9,57E-04	1,01E-03
Eutrophication, terrestrial	Mole of N eq.	1,03E-02	1,08E-02
Human toxicity, cancer – total	CTUh	8,45E-10	8,73E-10
Human toxicity, cancer inorganics	CTUh	7,86E-20	8,70E-20
Human toxicity, cancer metals	CTUh	7,08E-10	7,32E-10
Human toxicity, cancer organics	CTUh	1,36E-10	1,41E-10
Human toxicity, noncancer – total	CTUh	3,68E-08	3,90E-08
Human toxicity, noncancer inorganics	CTUh	6,53E-09	6,72E-09
Human toxicity, noncancer metals	CTUh	3,01E-08	3,22E-08
Human toxicity, noncancer organics	CTUh	4,65E-10	4,68E-10
Ionising radiation, human health	kBq U235 eq.	4,88E-02	5,56E-02
Land Use	Pt	1,29E+00	1,85E+00
Ozone depletion	kg CFC-11 eq.	2,70E-15	3,23E-15
Particulate matter	Disease incidences	2,48E-08	2,58E-08
Photochemical ozone formation	kg NMVOC eq	4,13E-03	4,20E-03
Resource use, fossils	MJ	7,63E+01	7,75E+01
Resource use, minerals and metals	kg Sb eq.	4,03E-07	5,13E-07
Water use	m^3 world equiv.	2,32E-01	2,50E-01

4 REVIEW

4.1 REVIEW DETAILS

Commissioned by:	PlasticsEurope
Prepared by:	Maike Horlacher Sphera Solutions GmbH
Reviewed by:	Matthias Schulz Schulz Sustainability Consulting
References:	• PlasticsEurope (2022): Eco-profiles program and methodology –PlasticsEurope – V3.1 (2022). • ISO 14040 (2018): Environmental Management – Life Cycle Assessment – Principles and Framework • ISO 14044 (2018): Environmental Management – Life Cycle Assessment – Requirements and Guidelines

4.2 REVIEW STATEMENT

According to the PlasticsEurope methodology version 3.1 (2022), a critical review of the Eco-profile report by independent experts should be conducted before publication of the dataset. The outcome of the critical review is reproduced below.

The subject of this critical review was the development of the Eco-profile for General Purpose Polystyrene (GPPS) and High Impact Polystyrene (HIPS).

The critical review included two iterations of final Eco-profile report review (July and November 2022) in which the reviewer provided comments for clarification by the LCA practitioner. On 21.10.2022, a web-based review meeting was held in which open issues were discussed and spot checks of data, modelling and calculations were carried out. The final version of the report was provided to the reviewer on 28.10.2022. The reviewer checked the implementation of the comments and agreed to conclude the critical review process. The reviewer acknowledges the unrestricted access to all requested information, the dedicated efforts of the practitioner to address comments, as well as the open and constructive dialogue during the entire critical review process. All versions of the documentation (reports and data), including the reviewer’s comments, questions and associated answers, are archived and can be made available upon request.

Primary data was collected for nine plants from five GPPS producers in six different European countries and for seven plants from five HIPS producers in six different European countries. This equates to a representativeness of approximately 80% of the European GPPS and HIPS production volume in 2018. Data for the key precursor styrene monomer was based on the most recent Eco-profile (PlasticsEurope 2022), in which a split of the dominant styrene production routes was assumed; i.e. 60:40 dehydrogenation of ethylbenzene (EBSM): propylene oxide styrene monomer (POSM) process.

Allocation in the foreground system was not relevant for this Eco-profile. Co-production of small amounts of off-grade GPPS and HIPS were modelled using the cut-off approach.

All background datasets used for this Eco-profile are described in the report and are considered appropriate for the goal and scope of this study. Besides background data for styrene monomer (see info above), all other background datasets stem from the GaBi database.

The reviewer carried out various plausibility checks of the data and results. In the end, all questions raised were clarified, and the reviewer found the data and results to be credible and without perceivable errors or shortcomings.

The potential environmental impacts for GPPS and HIPS are quantified using the EF v3.0 methodology, as recommended in the current PlasticsEurope methodology. The contribution analysis shows the predominant influence of styrene monomer for the majority of environmental indicators. For HIPS, polybutadiene also makes a contribution of >10% to the total potential environmental impacts.

This Eco-profile also includes a comparison of the environmental performance with the last version from 2012 (based on data from 2010). It shows that various improvements have been achieved both for GPPS and HIPS for most environmental indicators.

The LCA practitioner has demonstrated high levels of competence and experience, with a track record of LCA projects in the chemical and plastics industry. The critical review confirms that this Eco-profile adheres to the rules set forth in the PlasticsEurope's Eco-profiles methodology version 3.1 (2022) and represents best available data for GPPS and HIPS production in Europe.

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