Eco-profile of Aromatic Polyester Polyols (APP)

PU Europe

June 2021

Content

1 Summary

This Eco-profile has been prepared according to **Eco-profiles program and methodology –PlasticsEurope – V3.0 (2019)**.

It provides environmental performance data representative of the average European production of 2019 for **the declared unit of 1 kg unpacked aromatic polyester polyols (APP)** from cradle-to-gate **(from crude oil extraction to liquid resin at plant, i.e. APP production site output).**

The goal was to update the existing ISO 14040/44-compliant cradle-to-gate Eco-profile for APP and the life cycle inventories published in 2016 [PU Europe 2016 APP], through compiling up-to-date and consistent high-quality average industry data and combining it with the updated data from the GaBi databases.

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.

Meta Data

Data Owner	PU Europe aisbl
LCA Practitioner	Sphera Solutions GmbH
Programme Owner	PlasticsEurope AISBL
Reviewer	Angela Schindler, Umweltberatung, Salem
Number of plants included in data collection	6
Representativeness	75-85 % coverage in terms of production volumes in Europe
Reference year	2019
Year of data collection and calculation	2020
Expected temporal validity	2026
Cut-offs	No significant cut-offs
Data Quality	Good
Allocation method	Price allocation (for one of the products)

Description of the Product and the Production Process

Aromatic Polyester Polyols (APP) comprises a group of products which are polymers. Therefore, neither a CAS number, nor an IUPAC name, nor a chemical formula can be stated.

APP are hydroxy-terminated polymers based in ester-repeating units and containing phenylene groups. They are obtained from the polycondensation reaction between dicarboxylic acids and diols/triols. They can also contain other raw materials such as natural oils. APP structure can have a great versatility, in terms of molecular weight and functionality (with minimum 2 reactive groups per molecule), due to the broad range of different monomers that can be used in the Polycondensation reaction. In this Eco-profile, the “hydroxyl value“ is given as a range as an information on the covered APP. This is as a measure of the hydroxyl group content (in mg KOH/g of polyol). The higher the hydroxyl number of the polyol, the greater the crosslinking in polyurethane production. More crosslinking leads to harder, stiffer products with higher chemical and thermal resistance.

Polyols end-capped with 2 hydroxyl (OH) groups are named diols; with 3 OH groups they are called triols, and with 4 hydroxyl groups they are called tetrols.

The following products are considered:

- HOOPOL (Synthesia), Spain
- ISOEXTER (COIM), Italy
- LUPRAPHEN (BASF), Germany
- POLIOS (Purinova), Poland
- STEPANPOL (Stepan), Germany
- TERATE POLYOLS (Stepan), Netherlands

Polyester Polyols are important intermediate products for many production chains. APPs are used to manufacture polyisocyanurate (PIR) and polyurethane (PUR) rigid insulation foam, which finds extensive use in the automotive, construction, refrigeration and other industrial sectors. Other uses include flexible polyurethane foams, semi-rigid foams, and polyurethane coatings. A major part of the world's polyols production is shared by two groups of polyols, namely polyether and polyester polyols.

Production Process

Aromatic polyester polyols result from the polycondensation from a variety of potential input materials such as di- or trifunctional glycols, e.g. diethylene glycol and aromatic anhydrides, e.g. phthalic anhydrides. Also, the production technology can differ from producer to producer. For more details, see the long version of this Eco-profile.

The reference flow, to which all data given in this Eco-profile refer, is 1 kg of average aromatic polyester polyols (APP).

Data Sources and Allocation

The main data source is a primary data collection from European producers of APP, providing site-specific gate-to-gate production data for processes under the operational control of the participating companies: 5 producers with 6 plants / 6 products in 5 different European countries.

This covers more than 75-85 % of a total market of more than 200,000 t of the European APP production in 2019.

All relevant background data for the upstream supply chain until the precursors as well as energy and auxiliary materials are taken from the database version SP 40 GaBi 2020 (https://gabi.sphera.com) of the software system GaBi 10 [SPHERA 2020].

For one of the six products, economic allocation has been applied. This has been preferred over mass allocation since the economic value of the co-product is significantly less than of the main product APP. For the other products, no allocation has been applied as there is only one product.

Use Phase and End-of-Life Management

Due to high resistance to light and thermal aging, as well as thermal stability of polyurethane produced with APPs, the polyurethane/polyisocyanurate (PUR/PIR, in the following the common term for both PU is applied) products are used for paints, coating materials and flame-retarded rigid foams. They also may be formulated into adhesives, sealants, and elastomers.

Polyurethanes are made from polyols e.g. APPs and polyisocyanates. Typical isocyanates used include polymeric methylene diphenyl diisocyanate (PMDI) in rigid foam applications. Toluene diisocyanate (TDI) is used in flexible foam applications. Monomeric MDI is used in adhesive, coating, sealant, and elastomer applications. Flame retardants may be included in the APP batch and/or added separately during PUR production. This Eco-profile refers to APP without flame retardant additions.

Rigid polyurethane foams produced from MDI and polyester polyols have excellent thermal insulation and fire-retardancy properties and are used in building & construction and automotive applications.

When used in thermal insulation products, the use phase results in substantial energy savings of buildings / technical installations / fridges over their use phase.

Most of the production waste (and some installation off-cuts) is recycled.

Post-consumer recycling of polyurethane products is a practice which is spreading in more and more countries for applications where high volumes are available and which could include collection and sorting. A range of mechanical (regrinding, bonding, pressing, and moulding) and chemical (glycolysis, hydrolysis, pyrolysis) recycling technologies are available to produce alternative products and chemical compounds for subsequent domestic, industrial and chemical applications.

For all post-consumer polyurethane waste, for which recycling has not proven to be economically feasible due to contamination and/or complex collection and/or dismantling steps (e.g. automotive shredding), energy recovery today is still the option of choice. However, as society moves towards a circular economy in the coming decades the level of energy recovery will decrease and increasingly more sectors will initiate recycling projects for post-consumer PU waste.

Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg of aromatic polyester polyols (APP).

Input Parameters

Indicator	Unit	Value	Impact method ref.
Non-renewable energy resources[1)]			
• Fuel energy	MJ	35.1	Gross calorific value
• Feedstock energy[2)]	MJ	ca. 22.5	Gross calorific value
Renewable energy resources (biomass)[1)]			
• Fuel energy	MJ	2.83	Gross calorific value
• Feedstock energy	MJ	0.00	Gross calorific value
Abiotic Depletion Potential			
• Elements	kg Sb eq	6.00E-07	CML (Jan.2016)
• Fossil fuels	MJ	52.0	CML (Jan.2016)
Renewable materials (biomass)	kg	2.56E-12	n.a.
Water[3)]			
• Use	kg	686	Blue water use
• Consumption	kg	30.5	Blue water consumption

1) Calculated as upper heating value (UHV) 2) Since this value cannot be retrieved directly from the LCA model, it was assumed to be equal the upper calorific value. 3) Water use and consumption now refer to the complete cradle-to-gate system boundaries; whereas in the Eco-profile for APP from 2016 these values referred to the foreground system only.

Output Parameters

Indicator	Unit	Value	Impact method ref.
GWP	kg CO_2 eq.	1.63	CML 2016
ODP	g CFC-11 eq.	8.62E-12	CML 2016
AP	g SO_2 eq.	5.69	CML 2016
POCP	g Ethene eq.	0.71	CML 2016
EP	g PO_4^{3-} eq.	0.84	CML 2016
Dust/particulate matter[4)]	g PM10	1.45E-03	-
Total particulate matter[4)]	g	0.20	-
Waste[5)]			
• Non-hazardous	kg	1.20	-
• Hazardous	kg	3.97E-04	-
4) Including secondary PM10 5) Waste values refer to the complete cradle-to-gate system boundaries; whereas in the Eco-profile for APP from 2016 these values referred to the foreground system only.			

Additional Environmental and Health Information

This part has been written under the only responsibility of the Data owner and is not part of the LCA practitioner and reviewer work.

Additional Technical Information

This part has been written under the only responsibility of the Data owner and is not part of the LCA practitioner and reviewer work.

APP are a raw material for polyurethane materials. The intrinsic product qualities of polyurethanes are lightweight; strong; durable; resistant to abrasion and corrosion and superior thermal insulation performance.

The incorporated aromatic acid provides thermal stability which allows the rigid foam to meet typical building code flammability tests. The structure of the aromatic ring also provides hydrolysis resistance to the final product.

The scope of this APP Eco-profile does not cover flame retardants which may be added to APP for their supply to customers. This is consistent with the previous approach taken for the 2016 study. As many application areas of APP require different amounts of flame retardant, the input of flame retardant (including its potential environmental burdens) can be easily added afterwards since it is physically mixed and does not require a chemical linkage.

Additional Economic Information

This part has been written under the only responsibility of the Data owner and is not part of the LCA practitioner and reviewer work.

As part of the formulation of rigid polyurethane thermal insulation products, APP enables substantial energy savings of buildings / technical installations / fridges over their use phase.

Programme Owner

PlasticsEurope
Rue Belliard 40 Box 16
B-1040 Brussels, Belgium
Tel.: +32 (0)2 792 30 99
E-mail: info@plasticseurope.org.

For copies of this Eco-profile, for the underlying LCI data ; and for additional information, please refer to www.pu-europe.eu or to http://www.plasticseurope.org/.

Data Owner

PU Europe
Rue Belliard 65
B-1040 Brussels, Belgium
Tel.: +32 (0)2 786 35 54
E-mail: secretariat@pu-europe.eu

LCA practitioner

Sphera Solutions GmbH
Hauptstr. 111-113
70771 Leinfelden-Echterdingen, Germany
Tel.: +49 711 3431870
www.sphera.com

Reviewer

Angela Schindler, Umweltberatung
Tüfinger Str. 12
88682 Salem, Germany
Email: angela@schindler-umwelt.de

References

PlasticsEurope: Eco-profiles and environmental declarations – LCI methodology and PCR for uncompounded polymer resins and reactive polymer precursors (version 3.0, October 2019).

2 Eco-profile Report

Functional Unit and Declared Unit

1 kg of unpacked aromatic polyester polyols "at gate" (production site output) representing a European industry production average with an average gross calorific value of about 22.5 MJ/kg and a hydroxyl value of 150-360 (mg KOH/g) and aromatic content of 5-50%.

Product Description

APP is a reactive polymer precursor used for the production of polyurethane PU rigid insulation foam.
APP are hydroxy-terminated polymers based in ester-repeating units and containing phenylene groups. They are obtained from the polycondensation reaction between dicarboxylic acids and diols/triols. They can also contain other raw materials such as natural oils. APP structure can have a great versatility, in terms of molecular weight and functionality (with minimum 2 reactive groups per molecule), due to the broad range of different monomers that can be used in the polycondensation reaction. In this Eco-profile, the hydroxyl value is given as a range as an information on the covered APP. This is as a measure of the hydroxyl group content (in mg KOH/g of polyol). The higher the hydroxyl number of the polyol, the greater the crosslinking in polyurethane production. More crosslinking leads to harder, stiffer products with higher chemical and thermal resistance.
Polyols end-capped with 2 hydroxyl (OH) groups are named diols; with 3 OH groups they are called triols, and with 4 hydroxyl groups they are called tetrols.

APP product trade names considered in this study are the following:

BASF: LUPRAPHEN 3913/1
COIM: ISOEXTER
PURINOVA: POLIOS 250 PA/LV/06
STEPAN: STEPANPOL® polyester polyol & TERATE POLYOLS
SYNTHESIA: HOOPOL

As some of the considered products/brands consists of a mixture of several APP variants, specific information such as CAS no, formula and calorific value cannot always be delivered.

In the European market, APP can contain recycled content, which could be from recycled PET or other secondary raw materials. Not all manufacturers use recycled feedstock, therefore the specific number can be obtained from the individual producer.

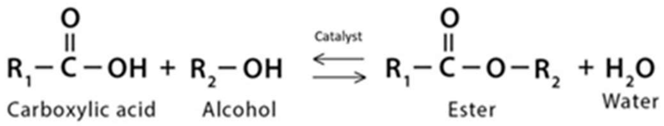
Data for other components of PU foam are available, especially polymeric MDI [ISOPA 2021 TDI-MDI].

Manufacturing Description

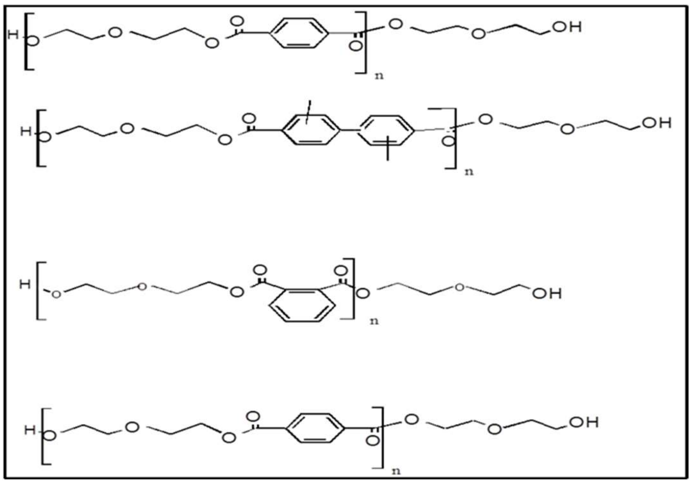
Aromatic polyester polyols are made by polycondensation from a variety of potential input materials such as multifunctional glycols, e.g. diethylene glycol with multifunctional aromatic anhydrides and acids, e.g. phthalic anhydride, terephthalic acid, isophthalic acid. Also, the production technology can differ from producer to producer.

Basically, the process can be described as follows: The glycol is first heated, then dicarboxylic acid/anhydride is added, and the reaction water is removed. The amount of excess glycol determines the molecular weight of the product, which also depends on the processing conditions and the type of glycol. Nitrogen, carbon dioxide or vacuum is used to remove the water and to reach the aimed conversion of more than 99%. Catalysts are used reluctantly because they cannot be removed and can have an undesirable effect on the following PU reaction.

The reaction (polycondensation) between the basic functional groups is:



Some examples representing different APPs:



Producer Description

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

- BASF SE

  Carl Bosch Str 38
  67056 Ludwigshafen
  Germany
  http://www.basf.com

- COIM S.p.A.

  Via Ricengo 21/23
  26010 Offanengo (CR)
  Italy
  http://www.coimgroup.com

- Stepan Netherlands B.V.

  Maltaweg 3-2
  4389 PV Ritthem
  The Netherlands
  http://www.stepan.com

- Stepan Deutschland GmbH

  Rodenkirchener Str. 400
  50389 Wesseling
  Germany
  http://www.stepan.com

- SYNTHESIA TECHNOLOGY EUROPE S.L.U.

  C/Argent, 3 – Àrea Industrial del Llobregat
  08755 Catellbisbal (Barcelona)
  Spain
  http://www.synthesia.com/

- Purinova Sp. z o.o.

  ul. Fordońska 74
  85-719 Bydgoszcz
  Poland
  http://www.purinova.com

System Boundaries

This PlasticsEurope Eco-profile refers to the production of polymers as a cradle-to-gate system (see Figure 1).

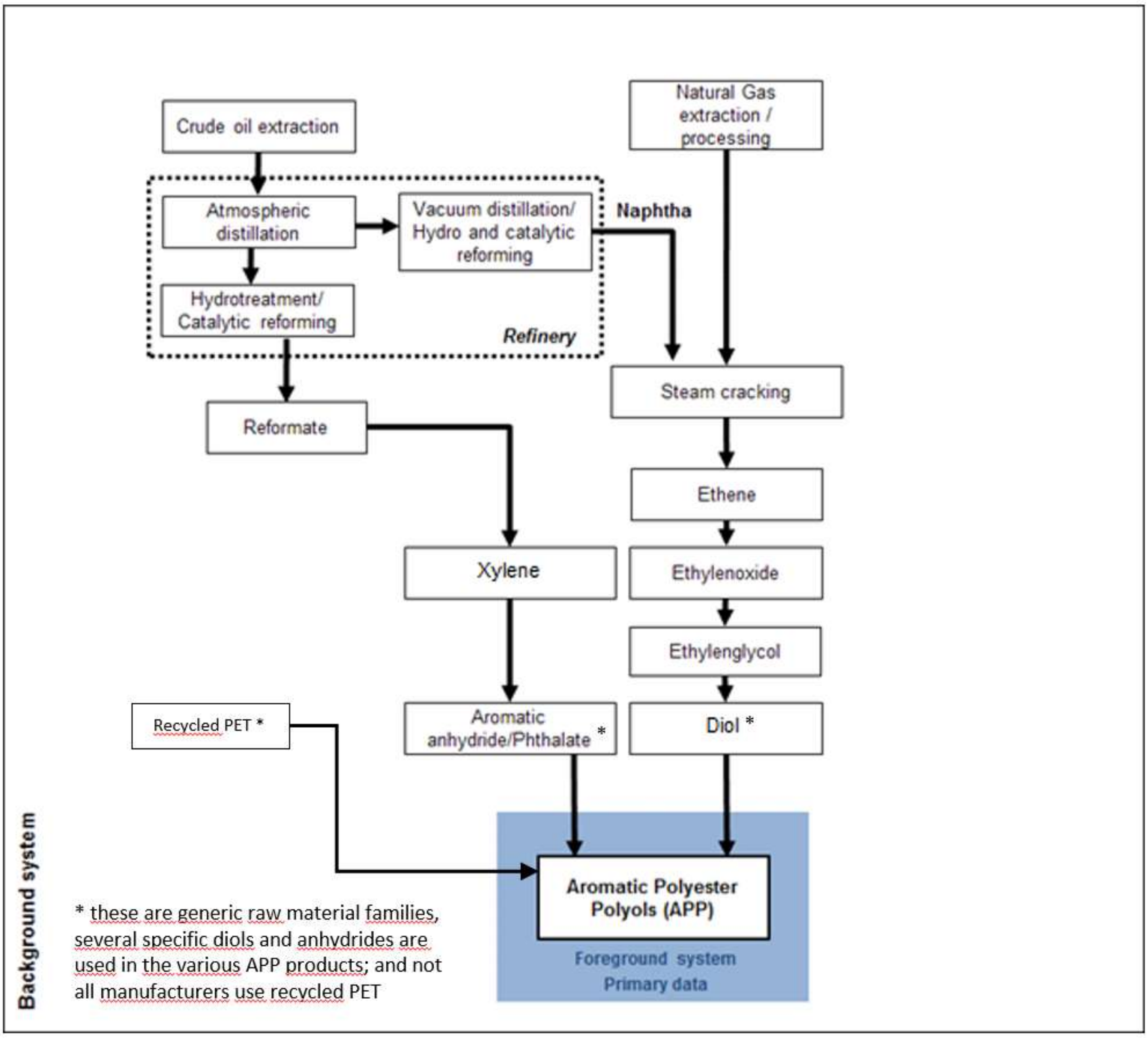


Figure 1. Cradle-to-gate system boundaries (APP).

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 APP, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: five APP producers with six plants in five different European countries.

The data covers 75-85% [PU Europe 2021] of the European APP production in 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 2020 LCI database from Sphera [SPHERA 2020].

Temporal Reference

The LCI data for production is collected as 12-month averages representing the year 2019, to compensate seasonal influence of data. Background data have reference years between 2016 and 2019 - for electricity and thermal energy processes this is 2016 as they refer to the latest official data from the IEA (International Energy Agency). 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 an expected temporal validity until 2026 for the overall Eco-profile.

Geographical Reference

Primary production data for APP production are from five different European suppliers. The inventories for the precursors and the energy supply are adapted according to site-specific (i.e. national) conditions. Inventories for the group of “Other chemicals”, used in smaller amounts, refer to European conditions or geographical conditions as the datasets are available. Therefore, the study results are intended to be applicable within EU boundaries: adjustments might be required if the results are applied to other regions. APP imported into Europe is not considered in this Eco-profile

Cut-off Rules

In the foreground processes, all relevant flows are considered, with no cut-off of material and energy flows. According to the GaBi 2020 LCI database [SPHERA 2020], 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 the influence of cut-offs less than 1% on the total is expected. Transports for all input materials (glycols, phthalates) were considered. The contribution of transportation of auxiliaries is expected to be far less than 1%; hence the transports for auxiliaries are excluded.

Data Quality Requirements

Data Sources

Eco-profiles developed by PU Europe 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 PU Europe (see Producer Description).
The data for the upstream supply chain are taken from the life cycle database of the software system GaBi 2020 LCI database [SPHERA 2020]. Most of the background data used are 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 was sourced from the most important APP producers in Europe to generate a European production average. The environmental contributions of each process to the overall LCI results are included in the Chapter ‘Dominance Analysis’.

Representativeness

The participating companies represent 75-85% of the European APP production volume in 2019. This figure refers to an educated estimate of PU Europe and the participating parties of this study [PU Europe 2021]. The selected background data can be regarded as representative for the intended purpose.

Consistency

To ensure consistency, only primary data of the same level of detail and background data from the GaBi 2020 LCI database are used [SPHERA 2020]. While building up the model, cross-checks ensure the plausibility of mass and energy flows. The methodological framework is consistent throughout the whole model as the same methodological principles are used both in the foreground and background systems. In addition to the external review, an internal independent quality check has been performed.

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 are reviewed, and quality checked.

Completeness

Primary data used for the gate-to-gate production of APP covers 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.

Reproducibility

Reproducibility is given for internal use since the owners of the technologies provided the data under confidentiality agreements. Key information is documented in this report, and data and models are stored in the GaBi 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, full and detailed reproducibility will not be possible for confidentiality reasons. However, experienced practitioners could reproduce suitable parts of the system as well as key indicators in a specific 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 database is updated regularly and continuously validated.

Life Cycle Model

The study is performed with the LCA software GaBi 10 and the GaBi 2020 LCI database [SPHERA 2020]. The associated database integrates ISO 14040/44 requirements. Due to confidentiality reasons, details on software modelling and methods used cannot be shown here. However, provided that appropriate confidentiality agreements are in place, the model can be reviewed in detail; an independent external review has been conducted to this aim. The calculation follows the vertical calculation methodology (see below).

Calculation Rules

Vertical Averaging

When modelling and calculating average Eco-profiles from the collected individual LCI datasets, vertical averages are calculated (Figure 2).

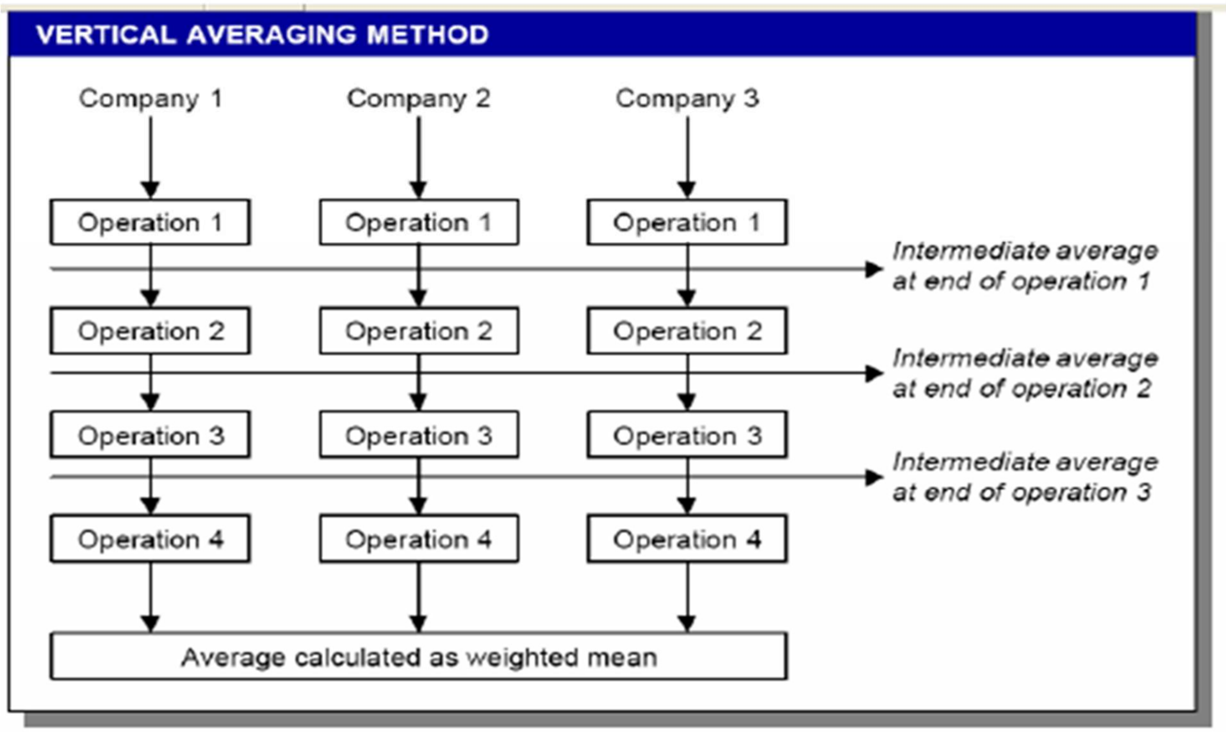


Figure 2. Vertical Averaging

Due to the fact that various APP products exist based on various input materials and production technologies, detailed discussions were held on whether it is possible to provide Eco-profile data for different types of APP products. However, out of the following reasons, only one aggregated dataset for one average APP product is presented:

- The desired performance of an APP can be achieved with different production technologies and different combinations of input materials.

- Similarly, for given application areas of APP, input materials and production technologies are exchangeable.
- As soon as Eco-profiles for specific APP formulations are revealed, the confidentiality of company-specific data may not be ensured. In addition, environmental performance results of specific APP formulations may favour a particular manufacturer which defeats the purpose of this Eco-profile initiative.
- It is common practice that clients of APP are switching suppliers;

Allocation Rules

Production processes in the chemical and plastics industry are usually multi-functional systems, i.e. they have not one, but several valuable products and co-product outputs. Wherever possible, the 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 do not exist, or even alternative technologies show completely different technical performance and product quality output. In such cases, allocation aims 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. If these materials show significant differences and are sold at a different price level (like the condensate), a price allocation is used based on the sales price ratio of the main product and co-product. In case of material declared as off-grade sent to recovery, neither further environmental burden nor credits are given to the modelled system (< 1% of total production). If the co-products are reused in the same process, then the output is looped back as an input.

As recycled material is reported as input to the system (3 % as weighted average), the input dataset used is modelled using the recycled content approach: scrap inputs to the recycled product system are modelled as being free of any primary material burden, only burden for the recycling process is taken into account (see ISO 14044, chapter 4.3.4.3.3 on allocation for secondary material).

Background system

In the refinery operations, co-production is addressed by applying allocation based on mass and net calorific value [SPHERA 2020]. The chosen allocation in downstream petrochemicals is based on several sensitivity analyses, which were reviewed by petrochemical experts. Materials and chemicals needed are modelled using the allocation rule most suitable for the respective product (mass, energy, exergy, economic). For further information on specific product see documentation on www.gabi-software.com.

Life Cycle Inventory (LCI) Results

Delivery and Formats of LCI Dataset

This eco-profile comprises

- A dataset in ILCD format (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.
- This report in pdf format.

Energy Demand

The **primary energy demand** (system input) of 60.4 MJ/kg APP 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 22.50 MJ/kg APP.

The difference (∆) 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.

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

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of monomer)	22.5
Process energy (quantified as difference between primary energy demand and energy content of monomer)	37.9
Total primary energy demand	60.4

Water cradle to gate Use and Consumption

The cradle-to-gate blue water use is 686 kg. The corresponding blue water consumption in the same system boundary is 30.5 kg.

Water foreground (gate to gate) Use and Consumption

The following table shows the weighted average values for water use of the APP 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 1 kg of APP

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	0.11	3.95	0.00	0.00	**4.06**
Deionized	0.00	0.00	0.21	3,92E-05	**0.21**
Untreated (from river/lake/ground)	0.00	1.68	0.00	0.00	**1.68**
Relooped	0.00	0.00	0.17	0.00	**0.17**
Totals	0.11	5.63	0.39	0.00	**6.13**

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

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

Treatment	Water Output [kg]
To WWTP	0.12
Untreated (to river/lake)	1.43
Untreated (to sea)	3.95
Relooped	0.06
Water leaving with products	0.00
Water Vapour	0.28
Formed in reaction (to WWTP)	0.04
Totals	5.89

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) = 0.28 + 3.95 – 0.04 = 4.19 kg

Dominance Analysis

Table 4 shows the main contributions to the results presented above in chapter "Environmental Performance". A weighted average of the participating producers is used. In all analysed environmental impact categories, the precursors contribute to more than 80% of the overall impact. The group "Other chemicals" covers additives, which also show relevant influence on the categories. The direct emissions of the polymerisation step not covered in one of the other groups (mainly NMVOC and water vapour) are included in "production process", but their contribution to any of the impact categories can be neglected (< 1%). Electrical and thermal energy of the considered foreground production process contributes mostly to GWP and total primary energy. Whereas the waste treatment does not show relevant contributions, the transports show slightly more environmental impact regarding the AP and EP indicators.

Table 4: Dominance analysis of impacts per 1 kg APP

	Total Gross Primary Energy	ADP Elements	ADP Fossil	GWP	AP	EP	POCP	ODP
Production Process	0%	0%	0%	0%	0%	0%	0%	0%
Diethylene Glycol	37%	29%	38%	30%	67%	31%	37%	26%
Phthalic anhydride	31%	18%	33%	30%	11%	10%	22%	28%
Other Chemicals	26%	47%	24%	26%	14%	52%	40%	30%
Thermal Energy	4%	1%	4%	8%	1%	1%	1%	0%
Electricity	2%	3%	1%	3%	1%	1%	1%	16%
Utilities	0%	0%	0%	0%	0%	0%	0%	1%
Process Waste Treatment	0%	1%	0%	2%	2%	1%	0%	-1%
Transports	1%	0%	1%	1%	3%	4%	-1%	0%
Total	100%	100%	100%	100%	100%	100%	100%	100 %

Comparison of the present Eco-profile with its previous version

Compared to the previous Eco-profile published in 2016, all environmental impact categories have improved, except the acidification potential. The ODP value is not comparable because in 2016 some background datasets still had a very much higher ODP value.

Also there have been changes in foreground processes as some companies changed their recipes and energy consumptions.

In terms of scope changes, there was one new participating company and an additional production line from one other company.

Finally, for the previous Eco-profile, the characterisation factors from CML2001 - update 2013 have been used and now, CML2001 - update 2016 has been used.

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

Environmental Impact Categories	**Previous Eco-profile (2016)**	**New Eco-profile (2021)**	**Change (%)**
Total gross primary energy from resources [MJ]	70.06	60.4	-14%
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	1.05E-06	6.00E-07	-43%
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	59.46	52.0	-13%
Global Warming Potential (GWP) [kg CO_2 eq.]	1.82	1.63	-10%
Acidification Potential (AP) [g SO_2 eq.]	5.59	5.69	+2%
Eutrophication Potential (EP) [g PO_4^{3-} eq.]	1.1	0.84	-24%
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	2.22E-07	8.62E-12	-100%
Photochemical Ozone Creation Potential [g Ethene eq.]	2.04	0.71	-65%

3 Review

External independent critical review summary

The present Eco-profile is an update of the previous Eco-profile for aromatic polyester polyols (APP) from 2016. The documents are reviewed in May/June 2021.
Main producers have taken part in this study, the technology displays the state-of-the art status. The participants delivered full datasets of their production sites.

The compliance of the documents was reviewed according to the current requirements of the Eco-profiles program and methodology, version 3.0 (Oct 2019) of PlasticsEurope and the accompanying template for Eco-profile reports.

This review covers the APP Eco-profile document and detailed information communicated in a web meeting by the LCA practitioner Sphera.
In the review process, first the Eco-profile document has been commented by the reviewer; in the following web meeting the primary data collection and the software model was shown and the comments discussed.

Due to the availability of the previous and current foreground data a direct comparison could be performed by Sphera. The changes of manufacturing data and the new mapping of material and energy flows with updated background life cycle inventories lead to changes in the results. All relevant alterations were checked in respect to plausibility and traceability per company dataset and in the weighted average by Sphera. The reviewer confirms the presented values and argumentations.

Typically, major input materials are displayed by available PlasticsEurope Eco-profiles for these substances. As these are not valid any more, more up-to-date LCIs of the GaBi database were chosen, which is a reasonable procedure.
The software model applied has undergone a Sphera internal quality check to avoid mistakes of data transfer.

Overall, the project is carried out very thoroughly. Geographical adaptations are integrated wherever data sets are available; transport distances are specifically collected; single additives, reported by the companies, are integrated by specific or approximated inventories.
The final results show slight differences to the previous Eco-profile, resulting from updated foreground data, as well as background data. During the review process, the influence of changed characterisation factors has been checked: the contribution is negligible for the considered material.

For a better application of the Eco-profile the product description as well as the covered manufacturing processes, i.e. the chemism of the applied technologies, are supplemented according to the recommendation in the review process.
The environmental performance displays average values, including variances. This is an acceptable way for the communication of product groups and industry averages.

The methodological approaches follow the PCR requirements, which are not yet fully compliant and harmonized with the requirements of the European Product Environmental Footprint methodology (e.g. regionalisation of water flows). Before applying the LCI for the assessment of further indicators, not assessed within this Eco-profile, the respective ILCD documentation need to be checked, if respective data are included in the inventory.

The structure and description of the Eco-profile is clear and transparent, thus displaying a reliable source of information.

Salem, June 2021

Angela Schindler, Umweltberatung
Salem, Germany
angela@schindler-umwelt.de

4 References

Eyerer 1996	Ganzheitliche Bilanzierung – Werkzeug zum Planen und Wirtschaften in Kreisläufen, 1996
Guinèe et al. 2001	Guinée, J. et. al. Handbook on Life Cycle Assessment - Operational Guide to the ISO Standards. Centre of Environmental Science, Leiden University (CML); The Netherlands, 2001.
Guinée et al. 2002	Handbook on Life Cycle Assessment: An operational Guide to the ISO Standards; Dordrecht: Kluwer Academic Publishers, 2002.
Heijungs 1992	Heijungs, R., J. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin, H.P. de Goede, 1992: Environmental Life Cycle Assessment of products. Guide and Backgrounds. Centre of Environmental Science (CML), Leiden University, Leiden.
ILCD 2010	European Commission (2010): ILCD Handbook – General guide for Life Cycle As-sessment (LCA) – Detailed guidance
IPCC 2007	IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.
ISOPA 2021 TDI-MDI	Eco-profiles and Environmental Product Declarations of the European Plastics Manufacturers, Toluene Diisocyanate (TDI) & Methylenediphenyl Diisocyanate (MDI), ISOPA, May 2021
ISO 14040: 2006	ISO 14040 Environmental Management – Life Cycle Assessment – Principles and Framework. Geneva, 2006
ISO 14044: 2006	ISO 14044 Environmental management -- Life cycle assessment -- Requirements and guidelines. Geneva, 2006
PlasticsEurope 2019	Eco-profiles program and methodology PlasticsEurope. Version 3.0, October 2019.
PU Europe 2016 APP	Previous Eco-profile for APP, PU Europe, 2016
PU Europe 2021	Personal communication of PU Europe and member companies on representativity of the included production volume
SPHERA 2020	GaBi LCA Database Documentation, GaBi Solutions, 2020 (https://gabi.sphera.com)