Eco-profile of moulded PU foam

EURO-MOULDERS

September 2021

EURO MOULDERS
European Association of Manufacturers of Moulded Polyurethane Parts for the Automotive Industry

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 moulded Polyurethane foam (PU) for the reference year 2019. The declared unit is 1 kg of moulded PU foam from cradle-to-gate (from crude oil extraction to moulded PU foam production).

Please keep in mind that comparisons <u>cannot</u> 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	Euro-Moulders aisbl
LCA Practitioner	Sphera Solutions GmbH
Programme Owner	PlasticsEurope AISBL
Reviewer	Angela Schindler, Umweltberatung, Salem
Number of plants included in data collection	5
Representativeness	>50% coverage in terms of production volumes for the automotive sector 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	No allocations in foreground system

Description of the Product and the Production Process

Moulded PU foam is a cellular, thermosetting plastic (flexible foam) which is a widely used material in vehicles. It is by far the preferred cushioning material for automotive seating. Industry data for the production of moulded PU foam has been collected for this Eco-profile from the following 5 companies:

- Adient
- Faurecia
- Fehrer
- Proseat
- Toscana Gomma

Production Process

The production of moulded flexible polyurethane foam is a discontinuous process. Moulded foam articles are made one at a time by injecting the foam mixture (isocyanates (MDI and TDI), polyether polyols, catalysts and additives) into moulds. When the foam rises and expands, it occupies the whole space in the mould, solidifies and the produced part can then be removed from the mould, either mechanically or manually.

Moulding is the preferred process for the production of PU foam parts with complex shapes. It also allows for placing inserts into the moulds for further easier assembly. This is why moulded foam technology is widely used in the automotive industry for producing e.g. seat cushions, seat backs, armrests, headrests, and knee cushions.

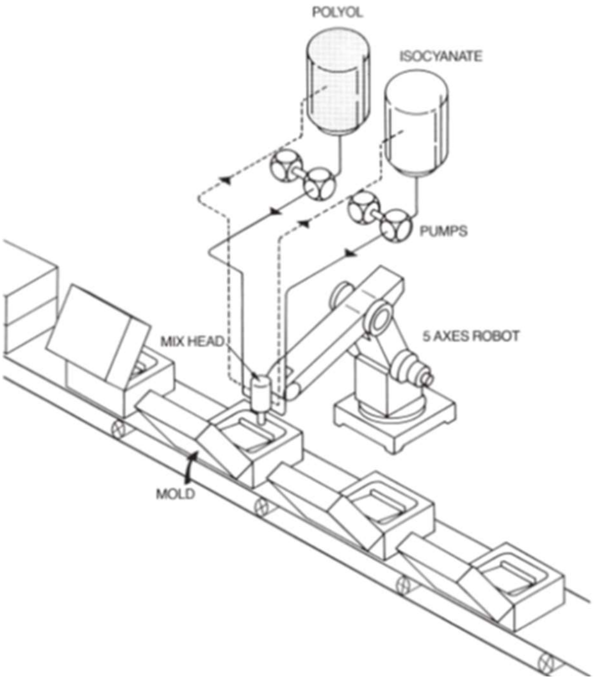

Figure 1-1: Process of moulding PU foam Source: Flexible Polyurethane Foams, Dow Polyurethanes, 1997

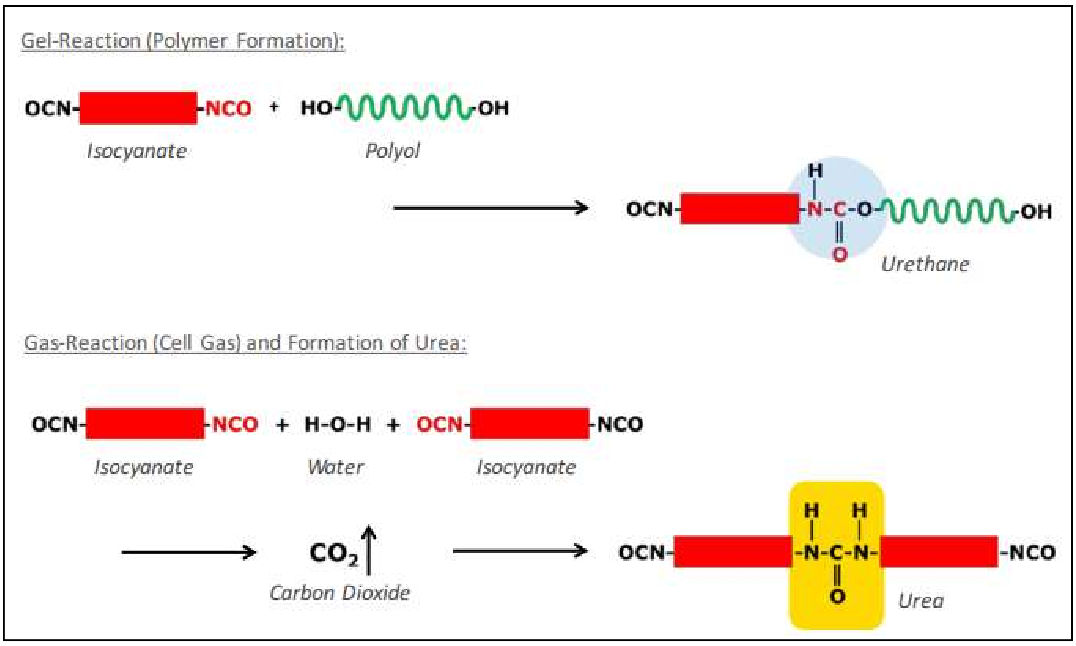

Figure 1-2: Simplified basic reactions of polyurethane formation.

Polyurethane is a polymer in which the basic chemical structural element is called “Urethane”. The urethane link is formed through the reaction of an isocyanate with an alcohol. This reaction is called the ‘gelling’ reaction since it contributes to forming the polymer network, or gel. The ‘blowing’ reaction comes from the reaction of isocyanate with water which results in a urea link and also liberates CO_2 gas which expands to ‘blow’ the foam.

The reference flow, to which all data given in this Eco-Profile refer, is 1 kg of flexible moulded PU foam “at gate”. Other technologies like flexible PU slabstock foams or rigid PU foams are not subject of this Eco-profile.

Data Sources and Allocation

The main data source is a primary data collection from European producers of moulded PU foam, providing site-specific gate-to-gate production data for processes under the operational control of the participating companies: 5 producers manufacturing in 26 plants in 13 different European countries. Data has been collected generally from one or two representative site(s) for each company. For the other sites (twin plants), the production is very similar - same recipes and consumption amounts - and therefore mainly the energy sources (country grid mixes; energy source for thermal energy) have been adjusted to represent the geography according to the production volumes, as applicable. This means, a weighted vertical average has been done with data of the plants from the same company and subsequently also for creating the average of the five companies.

This covers more than 50 % of the total estimated production volume in Europe of just above 250,000 tonnes of the European moulded PU foam production for the automotive sector in 2019.

In the foreground system, no allocations were needed (no co-products). 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 GaBi 2021 (https://gabi.sphera.com/support/gabi) of the software system GaBi 10 [SPHERA 2021].

Use Phase and End-of-Life Management

Use-phase

Due to the stringent tests on mechanical and physical properties that the foam has to pass to be in conformity with OEM specifications, the seat stays in the car for the lifetime of the car usually unless there is a major damage.

End-of-Life phase

Moulded foams from EoL vehicles are typically sent to waste-to-energy plants or to pyrolysis plants. There are two reasons for that: i) the cost of dismantling vs resources would be quite high compared to other more "profitable" sources of polyurethane for recycling such as mattresses or furniture; ii) seats are not removed from cars before the EoL vehicles go to a shredder, the foams thus get contaminated with oils and other fluids that remained in the car, which means the best way of treatment is waste-to-energy / pyrolysis for the time being.

Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg of moulded PU foam (cradle-to-gate).

Input Parameters

Indicator	Unit	Value	Impact method ref.
Non-renewable energy resources[1)]			
• Fuel energy	MJ	71	Gross calorific value
• Feedstock energy[2)]	MJ	27	Gross calorific value
Renewable energy resources (biomass)[1)]			
• Fuel energy	MJ	7.4	Gross calorific value
• Feedstock energy	MJ	0	Gross calorific value
Abiotic Depletion Potential			
• Elements	kg Sb eq	9.07E-06	CML (Jan.2016)
• Fossil fuels	MJ	84.8	CML (Jan.2016)
Renewable materials (biomass)	kg	4.98E-12	n.a.
Water			
• Use	kg	3214	Blue water use
• Consumption	kg	20	Blue water consumption
1) Calculated as gross calorific value (upper heating value, UHV). 2) Since this value cannot be retrieved directly from the LCA model, it was assumed to be equal to the gross calorific value, being 27 MJ/kg.			

Output Parameters

Indicator	Unit	Value	Impact method ref.
GWP	kg CO_2 eq.	3.66	CML 2016
ODP	g CFC-11 eq.	1.93E-07	CML 2016
AP	g SO_2 eq.	5.32	CML 2016
POCP	g Ethene eq.	1.60	CML 2016
EP	g PO_4^{3-} eq.	1.02	CML 2016
Dust/particulate matter[3)]	g PM10	0.194	n.a.
Total particulate matter[3)]	g	0.298	n.a.
Waste			
• Non-hazardous	kg	5.68	n.a.
• Hazardous	kg	0.0022	n.a.
[3)] Including secondary PM10			

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.

PU foam is an article under the REACH regulation and not a mixture of substances. The diisocyanate reagents used for flexible PU foam production have a highly reactive NCO group. This ensures that they are fully consumed during the chemical reaction with polyols yielding the polyurethane foam. Hence, they cannot be released into the air from the foam. That is why there cannot be any exposure of consumers to diisocyanates resulting from PU foam [SCOTT 2012].

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. No additional information declared here.

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. No additional information declared here.

Programme Owner

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

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References

PlasticsEurope - Eco-profiles program and methodology (version 3.0, October 2019).

2 Eco-profile Report

Functional Unit and Declared Unit

1 kg of moulded PU foam "at gate" (production site output) representing a European industry production average with an average gross calorific value of 27 MJ/kg.

Product Description

Moulded PU foam is a widely used material in vehicles. It is by far the preferred cushioning material for automotive seating. Industry data for the production of moulded PU foam has been collected for this Eco-profile from the following 5 companies:

- Adient
- Faurecia
- Fehrer
- Proseat
- Toscana Gomma

The locations of the manufacturing sites which contributed to this Eco-profile are in the following countries: Austria, Germany, Czech Republic, France, Italy, Hungary, Poland, Spain, Romania, Portugal, Slovenia, Slovakia and the United Kingdom.

Manufacturing Description

The processes can be described as follows: The moulded polyurethane foam is produced by reacting the liquid monomer isocyanate with the polyurethane polyol blend (amine/metal catalysts, surfactants, fire retardant, additives, blowing agent) to produce the urethane polymer matrix. Moulding of the polyurethane foam begins by application of spray mould release chemicals into the pre-heated mould (55°C), before the liquid mixed phase nucleated polyurethane mixture is added. Heat from a secondary exothermic urea reaction causes carbon dioxide and the blowing agent to expand and diffuse into the nucleating sites, causing spherical bubbles to grow as the mixture cures in the mould. As the PU foam rises and expands, it occupies the whole space in the mould, solidifies and after approximately 5 minutes the finished PU foam is then removed/de-moulded and sent to crushing systems to open the foams cells. The following steps are visually represented within the figures below.

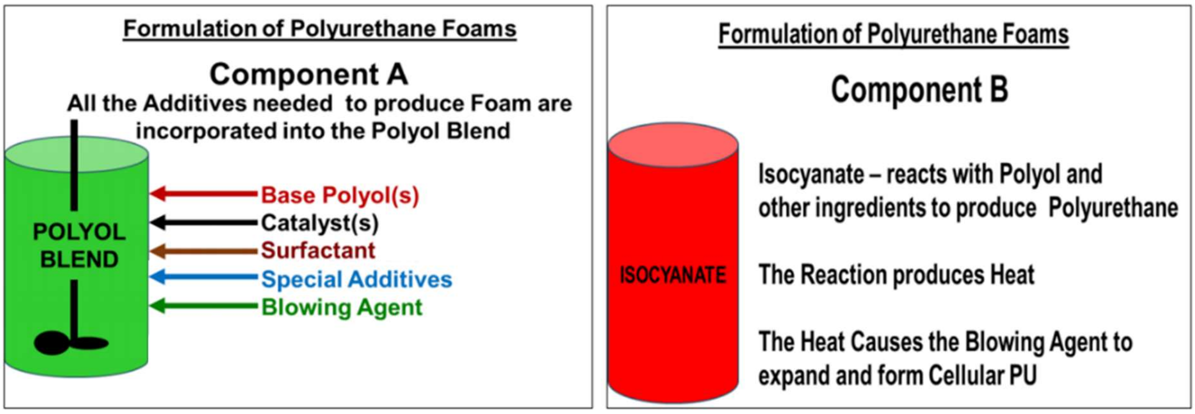

Figure 2-1. Chemical constituents required for moulded polyurethane production reaction.

The following picture is visualizing the moulding process with a different perspective.

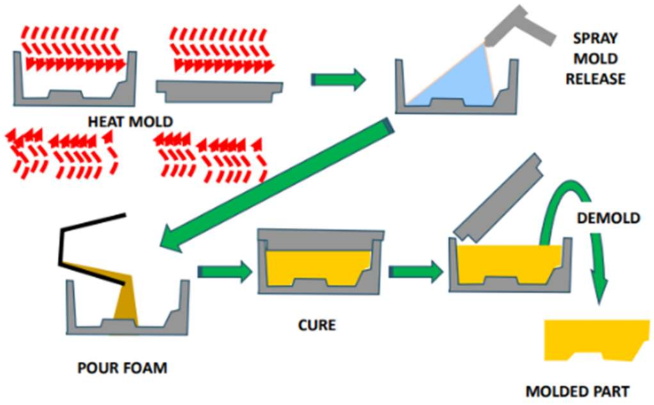

Figure 2-2: Visualizing the moulding process

Producer Description

PlasticsEurope Eco-profiles represent European industry averages within the scope of Euro-Moulders 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 Euro-Moulder's membership and the production sites participating in the Eco-profile data collection. The following companies have participated in the data collection:

Toscana Gomma spa

Via Cavalieri di Vittorio Veneto, 4
27038 Robbio (PV)
Italy
www.toscanagomma.eu

Adient Ltd. & Co. KG
Industriestraße 20-30
51399 Burscheid
Germany
www.adient.com

Fehrer Automotive GmbH

Heinrich-Fehrer-Str. 3
97318 Kitzingen
Germany
www.fehrer.com

Faurecia

23-27 rue des Champs Pierreux

92 000 Nanterre Cedex

France

www.faurecia.com

Proseat GmbH + Co. KG

Hessenring 32

64546 Mörfelden-Walldorf

Deutschland

www.proseat.eu

System Boundaries

This PlasticsEurope Eco-profile refers to the production of moulded PU foam as a cradle-to-gate system (see Figure 2-3).

Any optional inserts (for seat heating etc.) are not part of the system boundaries. The production of the aluminium moulds has been cut-off as not being relevant (see section "Cut-off Rules" at the end of this chapter).

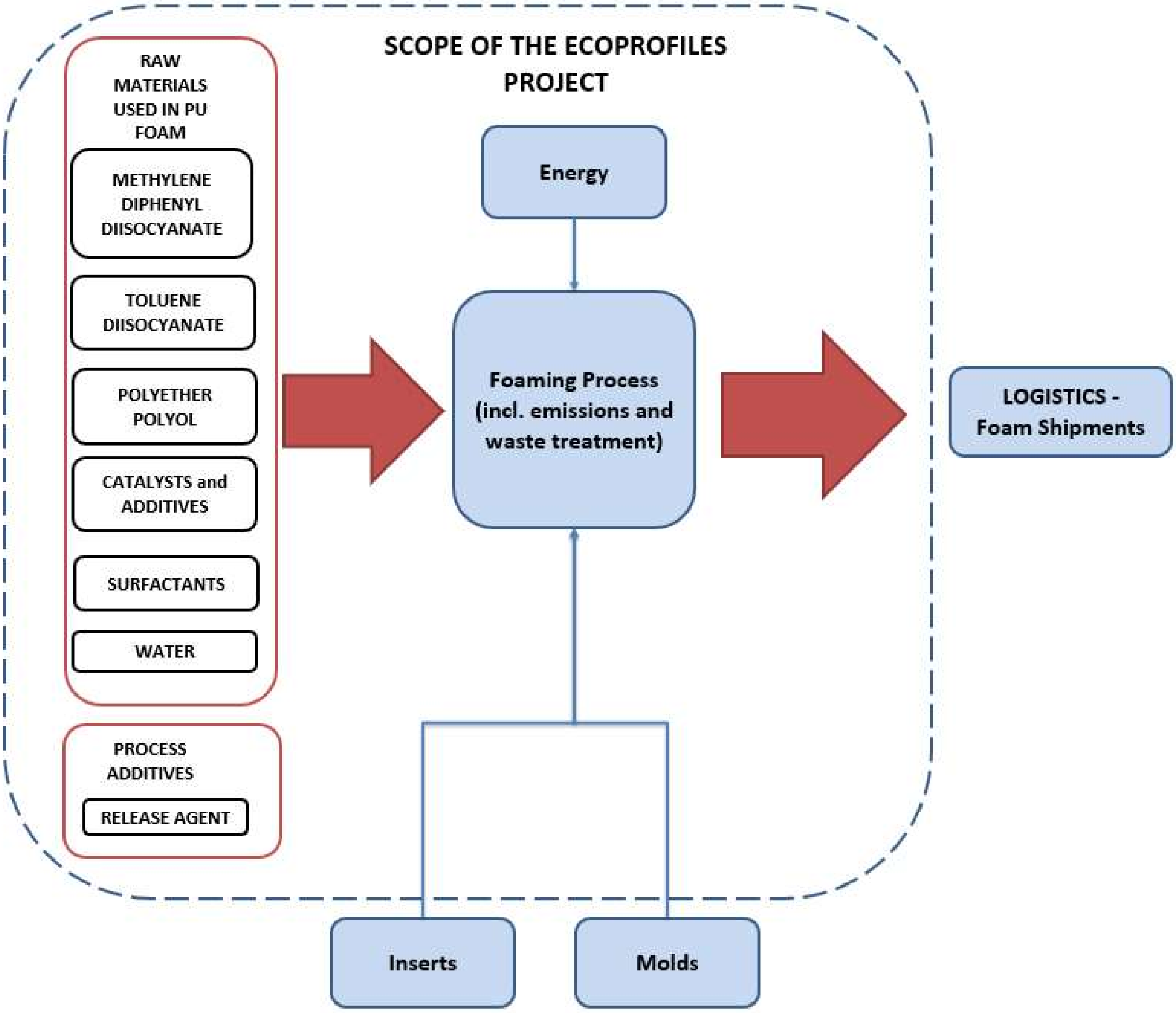

Figure 2-3. Cradle-to-gate system boundaries (moulded PU foam).

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 moulded PU foam, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: five moulded PU foam producers with 26 plants in 13 different European countries.

The data covers >50% of the European moulded PU foam production in 2019 for the automotive sector. 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 Eco-profiles for TDI-MDI and polyether polyol; and from the database of the software system GaBi 2021 [SPHERA 2021].

Due to the use of the most up-to-date European datasets for TDI-MDI and polyether polyol, potential differences arising from country-specific supply chains are not taken into account.

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 2020 - for electricity and thermal energy processes this is 2017 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 moulded PU foam production is from five different European suppliers with a total of 26 plants in 13 different European countries. 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. Moulded PU foam imported into Europe is not considered in this Eco-profile.

Cut-off Rules

In the foreground processes, all relevant flows are considered, with no significant cut-off of material and energy flows. Auxiliaries of very minor importance (e.g. like grease or glue, all together max. 0.05 % of the product mass) have been cut off.
The production of the aluminium moulds has not been considered either, as they are used to produce at least 175,000 seat parts with an average weight of approx. 1 kg. The weight of one mould is approx. 140 kg, so 140 kg for 175,000 moulded parts leads to 0.0008 kg/kg moulded foam. Also, the moulds are recycled at their end-of-life. Therefore, it is assumed that no detectable environmental impacts have been neglected with this cut-off.

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 in the background processes 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 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

This Eco-profile developed by Euro-Moulders uses 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 Euro-Moulders (see Producer Description).

The data for the upstream supply chain is taken from the life cycle database of the software system GaBi 2021 LCI database [SPHERA 2021]. This also includes the published Eco-profile for TDI-MDI [ISOPA 2021 TDI-MDI] and Polyether Polyols [ISOPA 2021 Long Chain Polyether Polyols (flexible)].

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 moulded PU foam manufacturers in Europe to generate a European production average. The environmental contributions of each process to the overall LCI results are included in the Chapter 'Life Cycle Impact Assessment'.

Representativeness

The participating companies represent >50% of the European moulded PU foam production volume for the automotive sector in 2019 [Euro-Moulders 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 2021 LCI database are used [SPHERA 2021]. 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 moulded PU foam 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 and the GaBi 2021 LCI database [SPHERA 2021]. 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 2-4).

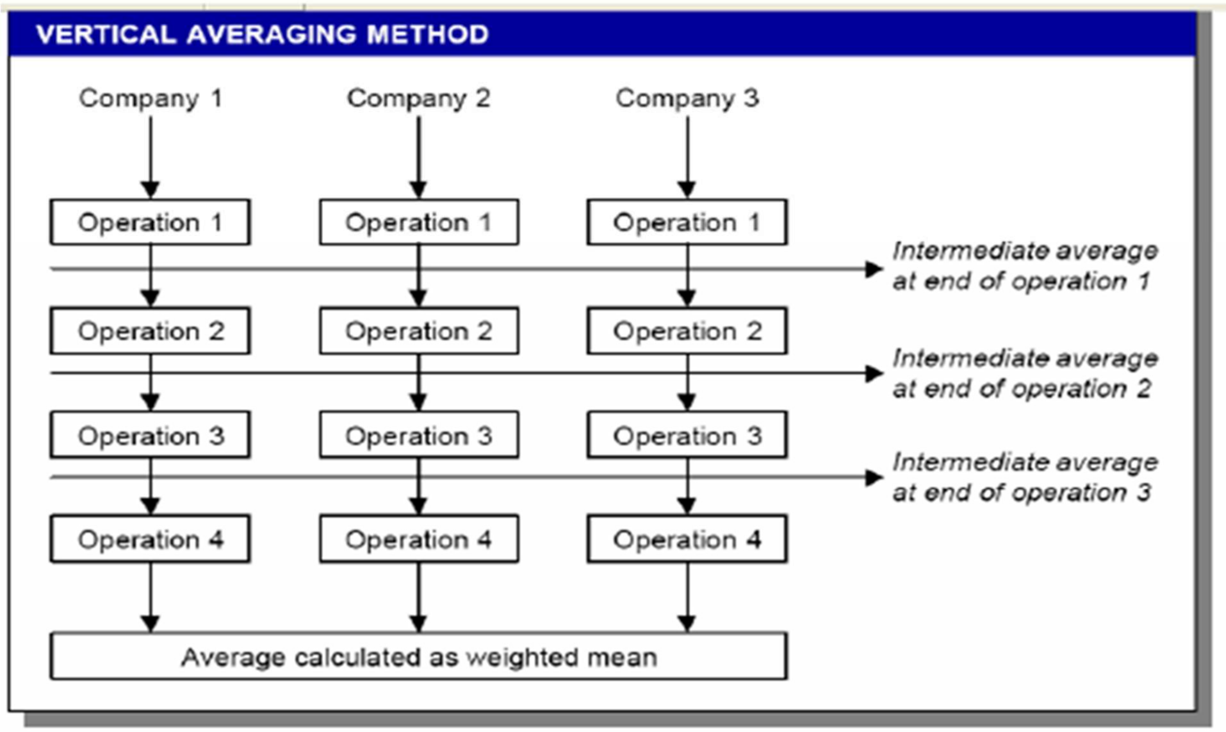

Figure 2-4. Vertical Averaging

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
No allocations in the foreground system (as no co-products).

Background system
In the refinery operations, co-production is addressed by applying allocation based on mass and net calorific value [SPHERA 2021]. 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 https://gabi.sphera.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 105.5 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).

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 (upper heating value, UHV), is 27 MJ/kg moulded foam.

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.

Table 1: Primary energy demand (system boundary level) per 1 kg moulded PU foam.

Primary Energy Demand	**Value [MJ]**
Energy content in polymer (energy recovery potential, quantified as gross calorific value of monomer)	27
Process energy (from non-renewable and renewable energy resources), quantified as difference between primary energy demand and energy content of monomer	78
Total primary energy demand	**105**

Water cradle to gate Use and Consumption

The cradle-to-gate water use is 3214 kg. The corresponding water consumption in the same system boundary is 20 kg.

Water foreground (gate to gate) Use and Consumption

The following table shows the weighted average values for water use of the Polyurethane foam (PU) 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 moulded PU foam.

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	0	0.00018	0	0	0.00018
Deionized	0.000156	0	0.042	0.017	0.059
Untreated (from river/lake/ground)	0	0	0	0	0
Untreated (to sea)	0	0	0	0	0
Relooped	0	0.0010	0	0	0.001
Totals	0.000156	0.0012	0.042	0.017	0.060

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 moulded PU foam.

Treatment	Water Output [kg]
To WWTP	0.000132
Formed in reaction (to WWTP)	0
From raw materials (to WWTP)	0.00039
Untreated (to river/lake)	0
Untreated (to sea)	0
Relooped	0.00098
Water leaving with products (as solvent or moisture)	0
Water Vapour	0.042
Totals	0.044

Based on the water use and output figures above the water consumption (in the foreground system, meaning the production process only; not cradle-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) = 0.025 kg

Dominance Analysis

Table 4 shows the main contributions to the average 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 82 % of the overall impact except for POCP which is only 46 %. The second biggest contributor is the electricity consumption (up to 11 %). Thermal energy consumption is negligibly low. The group "other chemicals" covers additives, which do not show relevant influence on the categories (max. 4 %). Even less are the contributions of the utilities, like compressed air (max. 2 %), The direct emissions are included in "production process", their contribution to most of the impact categories is max. 1 % (GWP), except for the POCP where they contribute 50 % on average, mostly due to the emissions from the solvents of the release agent. It has been considered that some sites are equipped with RTO (after-burner for emissions from release agent) and others not. 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 moulded PU foam.

	Total Primary Energy	**ADP Elements**	**ADP Fossil**	**GWP**	**AP**	**EP**	**POCP**	**ODP**
Production Process	0%	0%	0%	2%	0%	0%	50%	0%
Polyol	57%	84%	59%	54%	57%	66%	31%	100%
Isocyanate	28%	11%	31%	28%	25%	21%	15%	0%
Other Chemicals	3%	4%	3%	3%	3%	3%	1%	0%
Thermal Energy	0%	0%	1%	1%	0%	0%	0%	0%
Electricity	8%	0%	5%	9%	11%	7%	3%	0%
Utilities	2%	0%	2%	1%	1%	1%	1%	0%
Process Waste Treatment	0%	0%	0%	0%	0%	0%	0%	0%
Transports	1%	0%	1%	1%	2%	2%	-2%	0%
Total	100%	100%	100%	100%	100%	100%	100%	100%

3 Review

External independent review

This Eco-profile represents the environmental performance of moulded polyurethane products, manufactured for the automotive industry. In case of using these data for other application areas, this needs to be marked as approximation.

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. The documents are reviewed in June - September 2021.

During the review process the present Eco-profile document was checked and commented; detailed information on the data collection and the LCA calculations were communicated in a web-meeting by the LCA practitioner Sphera; open questions were discussed to find suitable answers and explanations for proper understanding to be included in the Eco-profile document.

The data collection was conducted at representative sites of the participating companies. These data were then transferred by regional adaptation of the geographical electricity consumption and specific transport data to the other company owned sites. Due to this pragmatic approach, a slightly higher uncertainty may be expected. Thus, in the review process this procedure has been checked thoroughly. The variances of the collected foreground data are small; the background data are based on up-to-date PlasticsEurope's average industry data. Overall the representativeness for this specific product and its limited application area is still estimated as high.

Some of the participating parties disclosed detailed and confidential information on catalysts and additives to the LCA practitioner, which supports the preciseness of the results and is much appreciated.

The results display the expected values. In case of the indicator POCP the values are specifically checked on plausibility. The practitioner follows the reviewer's recommendation to assure the correct modelling of the afterburning process.

The reviewer confirms the presented values and argumentations, which comprises the mapping of material and energy flows to the available life cycle inventories. The main pre-products polyols and isocyanates are modelled via currently prepared Eco-profile inventory data.

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.

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. 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.

Reviewer Contact Details

Salem, September 2021

Angela Schindler

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Salem, Germany
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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.
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