Eco-profile of

Flexible Polyurethane (PU) Foam

EUROPUR

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1 SUMMARY

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

It is based upon life cycle inventory (LCI) data from ISOPA [ISOPA 2021 TDI-MDI, ISOPA 2021 PP] and from the Sphera MLC CUP 2024.1 database [Sphera 2024], fulfilling the requirements on Plastics Europe's Eco-profile programme.

It provides environmental performance data representative of the production of flexible polyurethane (PU) foam from cradle to gate in slabstock foam plants (from crude oil extraction to foam at plant).

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 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	EUROPUR aisbl
LCA Practitioner	Sphera Solutions GmbH
Programme Owner	Plastics Europe aisbl
Reviewer	Matthias Schulz, Schulz Sustainability Consulting, Germany
Number of plants included in data collection	9
Representativeness	62.5%
Reference year	Primary data from 2013, data still considered valid for 2024
Year of data collection and calculation	No new data collection (see above), Data calculation 2024
Expected temporal validity	Revision should be considered in 2026
Cut-offs	No significant cut-offs
Data Quality	Overall: Good Confirmed by assessment of individual DQ indicators
Allocation method	Price Allocation

1.1 DESCRIPTION OF THE PRODUCT AND THE PRODUCTION PROCESS

Flexible polyurethane (PU) is a cellular polymer produced in the form of foam blocks. It exists in multiple forms, depending on foam density, on the presence/absence of flame retardant (FR) or other additives, as well as on the isocyanate monomer used (Toluene diisocyanate) TDI or Methylene diphenyl diisocyanate – MDI).

This Eco-profile considers four representative flexible PU foam grades:

- TDI-based PU foam without FR, high density 35 to 40 kg/m³
- TDI-based PU foam without FR, low density 18 to 25 kg/m³
- TDI-based PU foam with FR, density 40 to 54 kg/m³
- MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³.

After production and curing, foam blocks are transported to storage houses, ready for further transformation or incorporation into semi-finished or finished products.

Polyurethane is made by reacting diisocyanates and polyols. To generate PU foam, addition of water to the main reagents causes a side reaction producing carbon dioxide, which acts as a blowing agent. Flexible slabstock polyurethane foams are produced as large blocks using a continuous process with minimal human handling. Continuous foam machines are the standard in Europe today.

As a consequence of this, the declared unit and reference flow of this study, to which all data and results given in this Eco-profile refer, is:

“1 kg of flexible PU foam”

1.2 DATA SOURCES AND ALLOCATION

In terms of data collection, this report is based on primary data originally collected in 2013.

This data collection was conducted by European producers of flexible PU foam blocks, providing site-specific gate-to-gate production data for processes under the operational control of four participating companies, encompassing nine plants of six flexible PU foam producers across six different European countries.

These six producers cover more than 62.5% of the overall flexible PU foam blocks production (EU-27) in 2023 (EUROPUR, personal communication, May 2024).

Regarding this report, there have been no significant updates or changes in the foreground data reported. Therefore, only a background update of the most contributing inputs has been performed. Additionally, the weighted average calculation is based on the same production volumes for each company.

The life cycle inventory data for the three main precursors MDI, TDI and long-chain polyether polyol, are from two 2021 ISOPA Eco-profile studies [ISOPA 2021 PP, ISOPA 2021 TDI-MDI]; further background data are taken from the database of the software Sphera MLC CUP 2024.1 [Sphera 2024]. This database provides additional background data, likely including information on energy, materials, and other inputs used in the production processes of MDI, TDI, and polyether polyols.

All relevant background data, such as energy and auxiliary materials, is from Sphera MLC CUP 2024.1 database; the documentation is publicly available [Sphera 2024]. Most producers sell their foam trimmings co-products on the market for similar or different applications. A producer-specific price allocation is applied between main product and co-product, based on the ratio of their respective prices.

The paragraphs below detail the updated allocation approach between the TDI/MDI Eco-profile from 2012 and the latest version (ISOPA TDI-MDI, 2021).

A partly elemental, partly mass based approach has been chosen for the allocation of the environmental burden of both the production process of TDI and MDI as hydrogen chloride (HCl 100%) results as co-product from both systems. The choice on this allocation procedure took two important aspects into consideration:

- Although the primary purpose of both plants is to produce TDI and MDI, these processes have been specifically designed not only to produce MDI/TDI in the required quality, but also to produce HCl in a quality that can be marketed, i.e. HCl is a desired co product. Therefore, the quality of the HCl is a critical aspect and influences the process design.
- Despite the fact that both products are sold as valuable substances, prices do not reach the same level for both cases, with higher absolute values for TDI and MDI. But as HCl would have to be neutralized and disposed as a waste if it was not sold as product, the actual value of HCl cannot be expressed by the market value alone. Apart from that market values are volatile and can be very different in different regions.

As a consequence of this a physical allocation approach has been considered to better reflect more the reality - however, a pure mass allocation of all consumed materials would not reflect the elemental reality of both by-products. It also leads to a significantly higher result for HCl compared to its on-purpose production process (using hydrogen and chlorine gas). As in both production processes the main pre-cursors MDA and TDA react with on-site produced phosgene (made from carbon monoxide and chlorine gases) it has been decided to allocate CO (as well as MDA/TDA) to MDI/TDI only and the consumed Chlorine only to HCl.

All other raw materials and energy, (waste) water, waste and emissions are allocated by mass. This approach is called “combined elemental + mass allocation” in the following.

Use Phase and End-of-Life Management

Polyurethane exists in two forms: as a solid material or with an open cellular structure, commonly known as foam. Foams can exhibit either flexibility or rigidity.

Flexible polyurethane foam (FPF) has a wide range of applications across various industries. It serves as the primary filling material in furniture, including armchairs, sofas, and beds, providing both comfort and durability. In the automotive sector, FPF is used for seating, offering supportive cushioning. Mattresses commonly feature a polyurethane foam core. Additionally, FPF provides shock absorption in athletic equipment, such as sports gear. In the medical field, it’s utilized for orthopaedic supports and cushions. Beyond that, FPF plays a role in packaging, protecting items during transit, and can be found in footwear insoles. It enhances carpet comfort and longevity as a cushioning material and contributes to soundproofing by reducing noise. Lastly, FPF is even used in filtration systems. [EUROPUR 2024]

With regards to markets, slabstock foam is a specific type of polyurethane foam production method. The primary market for slabstock foam centres around the furniture and bedding industry. Within the European Union, approximately 160 factories produce flexible polyurethane slabstock foam, contributing to an annual production of 1.5 million tonnes. [EUROPUR 2024] Specifically, 50% bedding, 35% furniture, 10% transportation and 5% in other applications. The remaining foam finds applications in diverse areas, including kitchen sponges and clothing. Notably, nearly 90% of EU mattresses contain polyurethane foam, with each mattress typically containing between 2 and 15 kg of PU foam per unit, resulting in a 42% market share for mattresses with a polyurethane foam core. [EUROPUR 2024]

Today, the end-of-life treatment for polyurethane foams (PU foams) encompasses several options, contingent upon factors such as contamination and recyclability:

- Recycling: Clean PU foam waste can be recycled into new raw materials. Advances in recycling technologies have made this an increasingly viable choice.
- Waste-to-Energy: When dealing with difficult-to-recycle or contaminated foam, incineration for energy recovery becomes an alternative.
- Thermochemical Recycling: This process converts PU foam into useful chemicals or fuels.

In summary, the industry actively addresses PU foam waste management to promote sustainability and reduce environmental impact.

1.3 Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg flexible PU foam.

1.3.1 Input Parameters

Indicator	Unit	MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam without FR, density 35 to 40 kg/m³	Impact method ref.
Non-renewable energy resources 1)						
• Fuel energy	MJ	55.77	60.34	55.61	57.23	-
• Feedstock energy	MJ	26.40 - 33.47	26.40 - 33.47	26.40 - 33.47	26.40 - 33.47	Gross calorific value
Renewable energy resources (biomass) 1)						
• Fuel energy	MJ	5.63	9.33	6.53	6.84	-
• Feedstock energy	MJ	0	0	0	0	Gross calorific value
Resource use						
• Minerals and Metals	kg Sb eq	1.52E-06	9.16E-06	3.65E-06	3.77E-06	EF 3.1
• Energy Carriers	MJ	82.19	86.44	82.05	83.57	EF 3.1
Renewable materials (biomass) 2	kg	0	0	0	0	-
Water use	m³ world eq	0.30	0.34	0.25	0.27	EF 3.1

1) Calculated as upper heating value (UHV)

2) In the 2015 PU foam Eco-profile, these values were reported as zero. However, the 2021 ISOPA Eco-profiles for MDI/TDI and Polyols indicated that these values, while present, were small or negligible. This report confirms that MDI and TDI contain no biogenic carbon content, and the long chain polymer has a minimal biogenic carbon content of 0.0054 kg per kg of polymer. Therefore, these values will remain as zero.

1.3.2 Output Parameters

Indicator	Unit	MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam without FR, density 35 to 40 kg/m³	Impact method ref.
Climate change, total	kg CO_2 eq.	3.16	3.79	3.44	3.45	EF 3.1
Ozone depletion	kg CFC-11 eq.	9.48E-13	4.46E-12	1.46E-12	1.61E-12	EF 3.1
Acidification	Mole of H+ eq	5.76E-03	6.94E-03	6.06E-03	6.22E-03	EF 3.1
Photochemical ozone formation	kg NMVOC eq	5.64E-03	6.61E-03	6.02E-03	6.15E-03	EF 3.1
Eutrophication, freshwater	kg P eq	2.06E-05	2.23E-05	2.09E-05	2.27E-05	EF 3.1
Respiratory Inorganics	Disease incidences	4.93E-08	6.20E-08	5.08E-08	5.27E-08	EF 3.1
Waste						
• Non-hazardous	kg	0.12	0.52	0.22	0.22	-
• Hazardous	kg	1.18E-03	1.42E-03	1.19E-03	1.26E-03	-

1.4 Additional Environmental and Health Information

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

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].

Due to country-specific legislation, combustion–modified PU foam is used in upholstery and bedding for the UK and Irish markets or when required by fire regulations for public places (theatres, hospitals, schools, prisons…). As of today, the main flame retarding-substances used in flexible PU foam are Tris(2-chloro-1-methylethyl) phosphate (TCPP) and Melamine. As for any substances used in polyurethane foam production, foam manufacturers closely monitor evolutions linked to flame retardants under the EU's REACH regulation.

1.5 Additional Technical Information

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

The outstanding quality of flexible polyurethane foam lies in its performance (strength, cushion…) to weight ratio. It is also a versatile and easy to process material.

1.6 Additional Economic Information

This part has been written under the responsibility of the data owner only and is not part of the LCA practitioner and reviewer work. Further related information can be found on the Europur webpage: https://europur.org/flexible-pu-foam/elementor-4539/

1.7 Programme Owner

PlasticsEurope

Rue Belliard 40

B-1040 Brussels, Belgium

E-mail: info@plasticseurope.org

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

1.8 DATA OWNER

EUROPUR aisbl

Avenue de Cortenbergh 71,

B-1000 Brussels, Belgium

Tel.: +32 (2) 741 82 81, Fax: +32 (2) 736 70 12

E-mail: info@europur.org

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2 Eco-profile Report

2.1 Functional Unit and Declared Unit

The default declared unit of Plastics Europe Eco-profiles and EPDs are (unless otherwise specified):

1 kg of Flexible Polyurethane Foam – four grades:

- **TDI-based PU foam without FR, high density 35 to 40 kg/m³, hardness 3.8 to 5.0 kPa**
- **TDI-based PU foam without FR, low density 18 to 25 kg/m³, hardness 2.5 to 4.0 kPa – formulation without CO_2**
- **TDI-based PU foam with FR, density 40 to 54 kg/m³, hardness 2.5 to 4.0 kPa – formulation without CO_2**
- **MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³, hardness 2.5 to 4.0 kPa – formulation without CO_2**

These four different grades were selected because they represent the primary applications of flexible PU foam and encompass most of the European production. Specifically, these four different grades, reflect the typical production output for the industry across Europe.

With regards to the description of formulation without CO_2, this refers to the production process. The primary raw materials for PU foam manufacturing are isocyanates and polyols. Water is also incorporated into the formulation as a reacting agent. When isocyanate groups (-NCO) react with water, they form an amine group (-NH_2) and carbon dioxide. The gaseous carbon dioxide creates bubbles in the reaction mixture, making this a "blowing" reaction. This reaction results in CO_2 emissions, as noted in the data. Additionally, some manufacturers inject CO_2 directly as a gas during the foaming process to help form the foam structure.

Consequently, this Eco-profile includes the CO_2 emissions resulting from the chemical reaction and the production of CO_2 in cases when additional CO_2 is used as a blowing agent.

2.2 Product Description

Flexible polyurethane foam serves as a versatile material used in various applications. It is commonly employed in the production of mattresses and upholstered furniture. Additionally, it finds use in acoustic insulation boards, carpet underlays, household sponges, clothing, sportswear, and packaging. Specifically, high-density TDI-based grades are typically utilized in furniture and bedding, while low-density TDI-based grades are preferred for insulation, packaging, building, and footwear. Furthermore, MDI-based foams are increasingly popular for bedding applications due to their viscoelastic properties, which include memory and pressure-relieving capabilities

Polyurethane Foam

- IUPAC name: Ethylurea
- CAS number: 9009-54-5
- chemical formula: C27H36N2O10
- gross calorific value: 26.4 - 33.47 MJ/kg (Kuznia et al 2022)

The difference between the feedstock energy value and the gross calorific value (GCV) for polyurethane (PU) foam lies in what each value represents. The feedstock energy value of **33.47 MJ/kg** includes the total energy content of the raw materials used to produce the foam, accounting for the energy required to extract, process, and transport these materials. In contrast, the GCV of **26.4 MJ/kg** measures the energy released when the foam is completely combusted, focusing solely on the energy output during combustion. The feedstock energy value is higher because it encompasses all the energy inputs involved in creating the raw materials, whereas the GCV only measures the energy released during combustion.

2.3 MANUFACTURING DESCRIPTION

Polyurethane foam is produced by reacting diisocyanates with polyols. Both diisocyanates and polyols are derived from crude oil, although polyols can also be sourced from renewable natural oils as well as recycled polyols and CO_2 polyols. When combined, diisocyanates and polyols undergo a chemical reaction, resulting in the formation of foam. Depending on the intended application, various additives are incorporated into the formulation to control the foam's properties, density, and cell size.

Flexible **slabstock polyurethane foams** are manufactured in large blocks using a semi-continuous process that minimizes human handling. Continuous foam machines have become the standard in Europe today.

While machinery may vary among manufacturers, the fundamental principle remains consistent: raw materials are delivered to a mixing head, which dispenses the foam mixture onto a pour plate. The rising foam is then directed onto a moving conveyor (typically horizontal, occasionally vertical). Both the conveyor and mixing head are situated in a ventilated tunnel designed to exhaust vapours released during the foaming process. For the exhaust gases, the original data in 2015 pertains to the process description. Since this is an exothermic process, aside from the CO_2 produced from the raw materials reaction, there are no other significant gas emissions. Figure 2-1 and Figure 2-2 illustrate typical production processes employed for slabstock foam production. From an Eco-profile perspective, the various machinery technologies used for continuous slabstock foam production exhibit remarkable similarities.

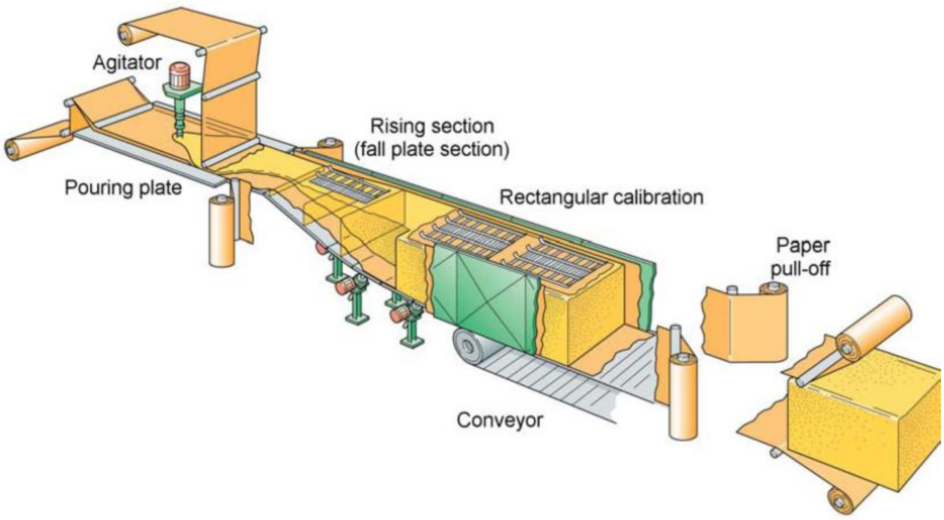

Figure 2-1 3-D representation of a system – without metering device and cut-off saw – for continuous production of flexible rectangular foam blocks by means of the QUADROFOAMAT (QFM) process (source: (Hennecke Group, 2024))

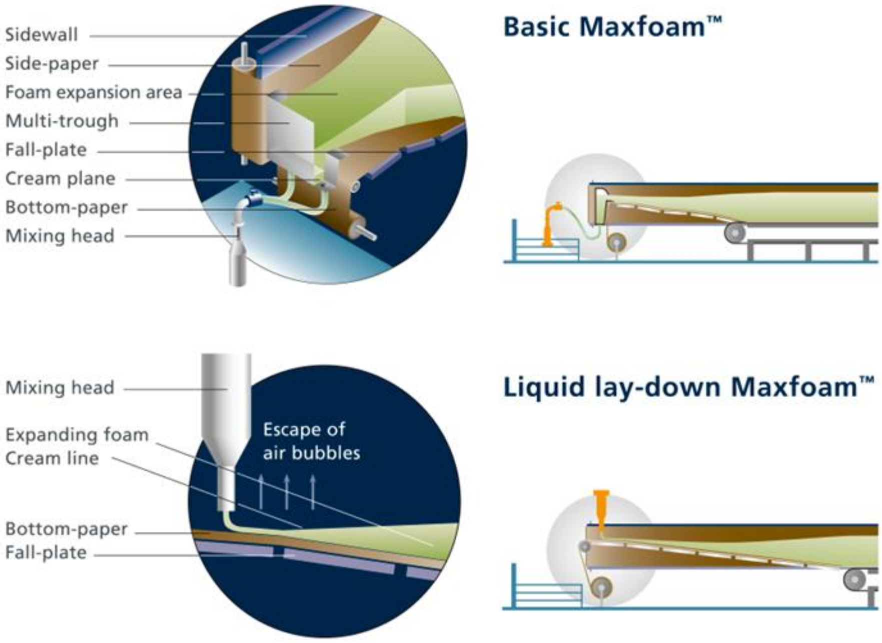

Figure 2-2 The Maxfoam production process (source: (Laader Berg, 2024))

2.4 Producer Description

The Eco-profiles and EPDs published by Plastics Europe represent European industry averages within the scope of the trade federation. These profiles are not attributed to any single producer but rather to the flexible PU foam industry, as represented by EUROPUR's membership and the production sites participating in the Eco-profile data collection. The data contributions were made by various companies as detailed below:

- Ikano
  Ul. Magazinowa 4
  64-610 Rogozno
  Poland
  www.ikanoindustry.pl

- Neveon Holding GmbH
  THE ICON VIENNA / Tower 24 /
  Floor 9, Wiedner Gürtel 9-13, 1100
  Wien, Austria
  www.neveon.com

- Carpenter Europe srl
  Culliganlaan 2F,
  1831 Machelen,
  Belgium
  www.carpenter.com/europe/fr/

- Olmo Giuseppe SpA
  Via Spirano 24
  24040 Comun Nuovo (Bergamo)
  Italy
  www.olmo-group.com

- Orsa Foam SpA.
  Via A. Colombo 60
  21055 Gorla Minore (VA),
  Italy
  www.orsafoam.it

- Vita (Group) Unlimited
  Oldham Road
  Middleton, M24 2 DB
  United Kingdom
  www.thevitagroup.com

2.5 SYSTEM BOUNDARIES

Plastics Europe Eco-profiles and EPDs refer to the production of polymers as a cradle-to-gate system:

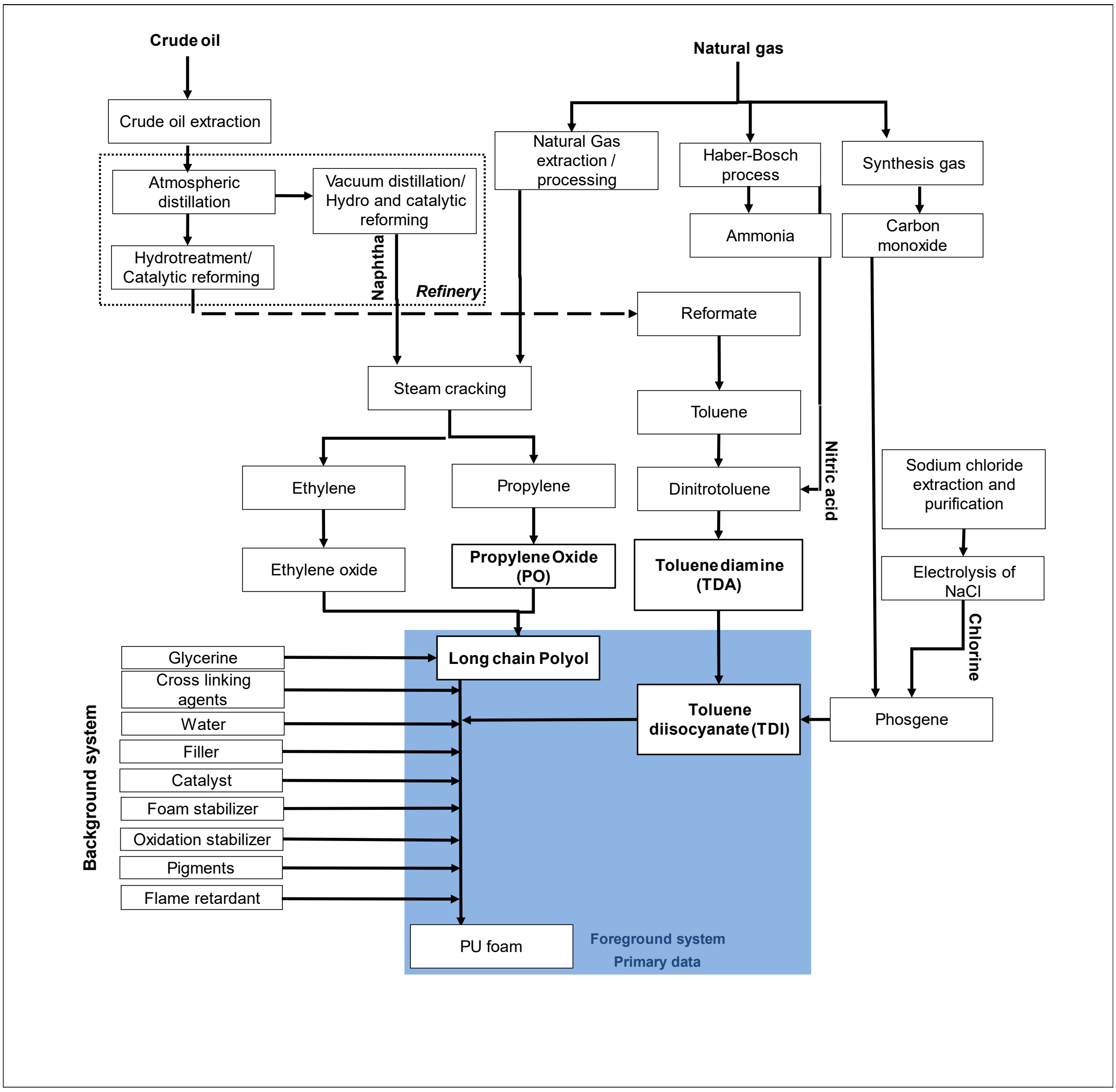

Figure 2-3 Cradle-to-gate system boundaries TDI based Flexible PU Foam

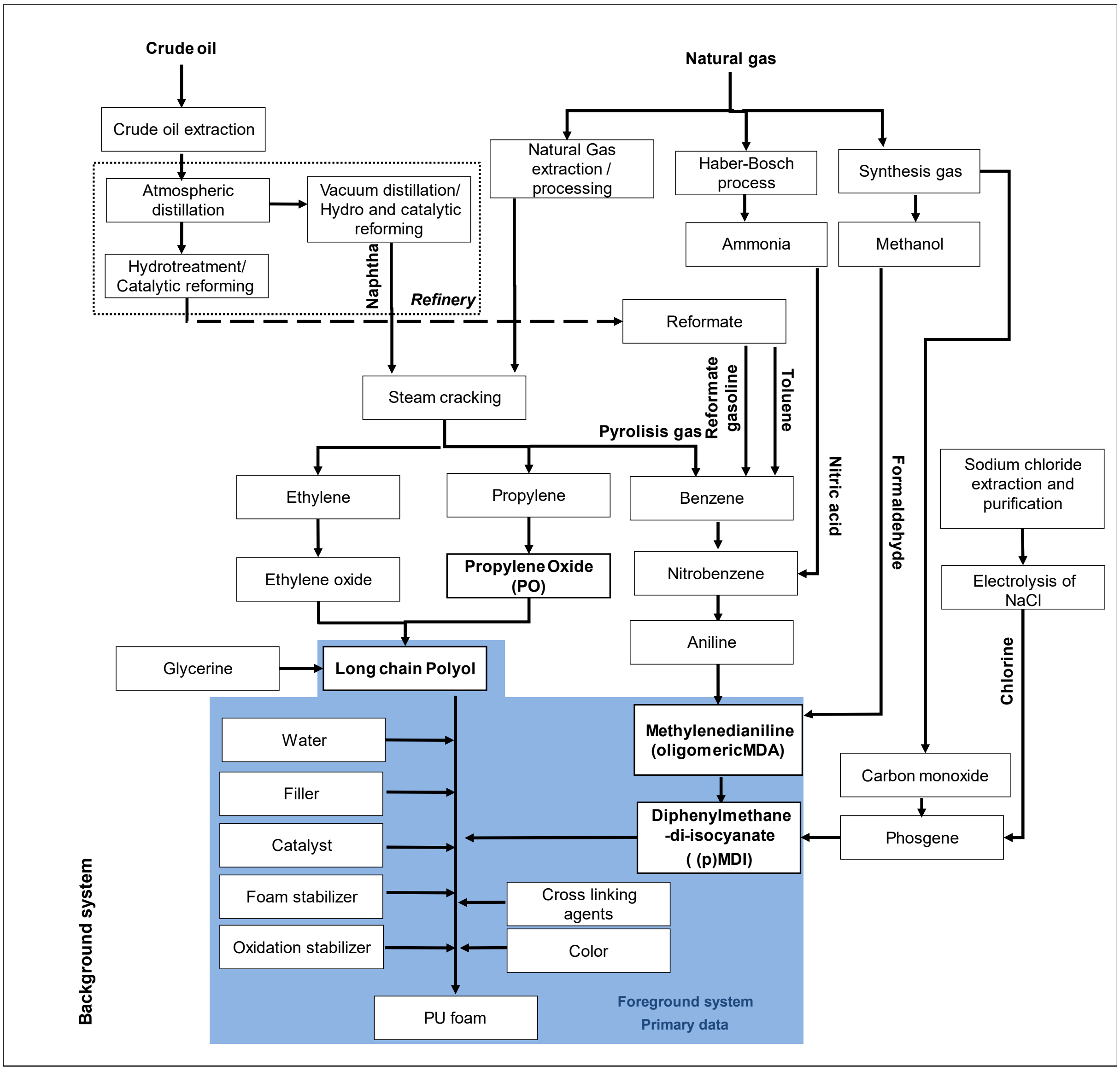

Figure 2-4 Cradle-to-gate system boundaries MDI based Flexible PU Foam

In the context of Life Cycle Assessment (LCA), the model considers various inputs and outputs within the system boundaries. These include precursors and processes, other chemicals, utilities, electricity, thermal energy, transportation, and process waste treatment.

2.6 Technological Reference

The production processes are modelled using specific values obtained from primary data collected on-site. The primary data source comes from European producers of Flexible PU foam, providing site-specific gate-to-gate production data for processes under the operational control of participating companies.

Specifically, six PU foam producers with nine plants across six different European countries contribute to this dataset, covering approximately 62.5% of the European Flexible PU Foam production (EU-27) in 2023 (EUROPUR, personal communication, May 2024). For foreground processes (directly under operational control), primary data are used, while secondary data support background processes (indirectly managed). Additionally, data related to the upstream supply chain up to the precursors are sourced from Eco-profiles for MDI/TDI and Polyols [ISOPA 2021 TDI-MDI, ISOPA 2021 PP] and the Sphera MLC CUP 2024.1 database [Sphera 2024].

In the context of Figure 2-3 and Figure 2-4, two distinct routes for the production of Flexible PU Foam - TDI based and MDI based exist. Both routes utilize the polyol component of the PU foam, specifically long-chain polyether polyol, which is produced through an alkoxylation process. In this process, ethylene oxide or propylene oxide reacts with an initiator containing OH-groups. While glycerine is a common initiator, other carbohydrates like saccharose can also be used. The alkoxylation process requires a catalyst, typically a base such as KOH, for catalysis. By varying the alkoxylation species, different chain lengths and molecular weights can be achieved [ISOPA 2021 PP].

The isocyanate components, TDI or MDI are produced as follows: For TDI, toluene serves as the primary raw material. Initially, toluene is nitrated with mixed acid to yield a mixture of 2,4- and 2,6-dinitrotoluene isomers. Catalytic reduction of this dinitrotoluene mix produces a corresponding mixture of diaminotoluenes (TDA), which are subsequently treated with phosgene to produce TDI. In the case of MDI production, Methylenedianiline (MDA) is first formed by reacting formaldehyde with aniline in the presence of a hydrochloric acid catalyst. Phosgene is then used to react with the separated MDA, resulting in crude MDI, which is subsequently purified [ISOPA 2021 TDI-MDI].

To create flexible PU foam, the two main components polyol and isocyanate are combined in approximate quantity ratios: 100 parts of polyols to 50 parts of TDI, for TDI based foam, and 100 parts of polyols to 85 parts of MDI, for MDI based foam.

2.7 Temporal Reference

Foreground data is still based on the 2013 primary data collection, which is considered valid by the manufacturing companies for the new reference year 2024. Background datasets used from the Sphera MLC CUP 2024.1 database refer to the year 2022/23 (in case of raw materials) and 2020 (in case of energy datasets). Available industry data used for the verification of the Sphera MLC CUP 2024.1 datasets refer to the year of 2018 for MDI, TDI and Polyols.

The dataset is considered to be valid until substantial technological changes in the production chain occur. The overall reference year for the ISOPA Eco-profiles used in this study are 2018 with a recommended temporal validity until 2025 to which the relevance of the revision should be considered according to Eco-profiles program and methodology – Plastics Europe – V3.1 (2022).

Updates to the polyol and isocyanate Eco-profiles are currently in progress. This Eco-profile will be updated accordingly once the new precursor Eco-profiles become available. For further details, please refer to Chapter “Statement on Methane Emissions”

2.8 Geographical Reference

The primary production data for flexible PU foam are sourced from six different European suppliers. For the precursor materials (polyols, MDI, and TDI), the geographic reference is Europe, as the Eco-profile datasets used represent typical European production averages.

Inventories related to other main precursors and energy supply are adjusted based on site-specific (national) conditions. The inventories for the category of "Other chemicals," which are used in smaller quantities, refer to European or available geographical conditions.

Consequently, the study results are intended for application within EU boundaries, and adjustments may be necessary if applied to other regions. Notably, flexible PU foam imported into Europe is not considered in this Eco-profile.

2.9 CUT-OFF RULES

In the foreground processes all relevant flows are considered. In the TDI/MDI input datasets, in single cases additives used in the MDI and/or TDI unit process (<0.1 % m/m of product output) were neglected [ISOPA 2021 TDI-MDI]. For the polyol datasets no cut-off was applied [ISOPA 2021 PP].

According to the Sphera MLC CUP 2024.1 database [Sphera 2024], used in the background processes, at least 95% of mass and energy of the input and output flows were covered and 98% of their environmental relevance (according to expert judgment) was considered, hence an influence of cut-offs less than 1% on the total is expected.

2.10 DATA QUALITY REQUIREMENTS

Data Sources

Eco-profiles and EPDs developed by Plastics Europe and other European producer associations use average data representative of the respective foreground production process, both in terms of technology and market share.

Regarding this report, there have been no significant updates or changes in the foreground data reported. Therefore, only a background update of the most contributing inputs has been performed. Additionally, the weighted average calculation is based on the same production volumes for each company.

The life cycle inventory data for the three main precursors: long-chain polyether polyol, TDI and MDI are from two 2021 ISOPA Eco-profile studies [ISOPA 2021 PP, ISOPA 2021 TDI-MDI]; further background data are taken from the database Sphera MLC CUP 2024.1 [Sphera 2024].

All relevant background data such as pre-cursor materials, energy and auxiliary materials are also taken from the LCA for Experts database [Sphera 2024]. Most of the background data used is publicly available and public documentation of the data sources exists.

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 and 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.

Relevance and Representativeness

Regarding the goal and scope of this Eco-profile, the collected primary data of foreground processes are of high relevance, i.e. data is sourced from the most important flexible PU foam 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'.

The participating companies represent 62.5% of the European flexible PU foam production volume in 2023. This figure refers to an educated estimate of EUROPUR and the participating parties of this study (EUROPUR, personal communication, May 2024). 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 Sphera MLC CUP 2024.1 databases [Sphera 2024] are used. That is especially why Eco-profile data are used for the main precursors TDI, MDI and polyols. 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 was performed.

Reliability

Data of foreground processes are provided directly by producers and are predominantly measured. Although no foreground data collection has been carried out for this update the data is still considered representative for existing processes.

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 quality checked

Completeness

Primary data used for the gate-to-gate production of flexible 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.

It is important to reiterate that increased methane emissions, which are now scientifically proven and accepted by the industry, are not yet included in this Eco-profile because they are not part of the current ISOPA Eco-profiles. This Eco-profile will be updated once the revised ISOPA Eco-profiles become available.

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

All data and information used are either documented in this report or they are available from the processes and process plans designed within the software Sphera MLC CUP 2024.1. 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 secondary foreground data on production derived from the latest version of the route specific Sphera MLC CUP 2024.1 datasets was validated with available industry data in an iterative process several times based on expert knowledge.

The background information from the LCA for Experts database [Sphera 2024] 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 Sphera MLC CUP 2024.1. 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 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 (Fazio, et al., 2020) has been carried out. The DQR considers the following four data quality criteria evaluated for both product systems:

- Technological-representativeness (TeR),
- Geographical-representativeness (GR),
- Time-representativeness (TiR),
- 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 (Fazio, et al., 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 3.1 method through LCA For Experts (formerly, GaBi) software. The datasets that contribute to 80% of LCIA for each product are listed below alongside the weighted DQR results for each individual PU foam.

1. TeR (Technological Representativeness): This is evaluated for the ISOPA datasets listed in the main contribution. These datasets are scored 2 as this score reflects that the datasets represent a European technology mix, which is a good match for the specific technologies used in the production of polyurethane materials. For the other secondary datasets, TeR is also scored 2 as they are exact technology matches.

2. TiR (Temporal Representativeness): This is evaluated at two levels:

- Activity Data: Scored 5 because the primary data is >8 years old relative to the reference year of the datasets.
- Secondary Dataset: Scored 2 since the reference year of the study is 2024 and the secondary datasets were last published in 2021. This score indicates that the data is 3 years old relative to the reference year, which is still considered reasonably current but not the most up to date.

3. GR (Geographical Representativeness): Evaluated at the level of the secondary dataset and scored 2 due to the lack of specific country of origin information for the ISOPA datasets.

4. Precision: Evaluated at the level of activity data:

- Scored 2 because the ISOPA datasets is measured, calculated, and internally verified by the company.

Weighted DQR results for Flexible PU Foam - MDI-based, no flame retardant:

Weighted DQRs				
Tech	Time	Geo	Precision	DQR of created dataset
2.0	3.0	2.0	2.0	2.3

- Primary DQR contributors: Long Chain Polyether Polyols
- Methylene diphenyl diisocyanate ((p)MDI)

Weighted DQR results for Flexible PU Foam - TDI-based, with flame retardant:

Weighted DQRs				
Tech	Time	Geo	Precision	DQR of created dataset
1.6	2.4	1.6	1.6	1.8

Primary DQR contributors:

- Long Chain Polyether Polyols
- Toluene diisocyanate (TDI)
- Silicone fluids (highly viscous) / polydimethylsiloxanes (from organo-silanes)

Weighted DQR results for Flexible PU Foam - TDI-based, no flame retardant, high density:

Weighted DQRs				
Tech	Time	Geo	Precision	DQR of created dataset
1.5	2.2	1.5	1.5	1.7

Primary DQR contributors:

- Long Chain Polyether Polyols
- Toluene diisocyanate (TDI)

Weighted DQR results for Flexible PU Foam - TDI-based, no flame retardant, low density:

Weighted DQRs				
Tech	Time	Geo	Precision	DQR of created dataset
1.4	2.1	1.4	1.4	1.5

Primary DQR contributors:

- Long Chain Polyether Polyols
- Toluene diisocyanate (TDI)

2.11 Calculation Rules

Vertical Averaging

According to the Plastics Europe methodology [PlasticsEurope 2022], vertical averaging should be applied wherever possible. Vertical averaging involves analysing data collected within a single time period to understand how different components are distributed and composed at various vertical levels, such as different stages in a product's life cycle. For example, in a life cycle assessment (LCA) of a building, vertical averaging can help identify patterns and variations in environmental impacts across different stages like raw material extraction, manufacturing, use, and end-of-life. This method provides insights into the structure and behaviour of the product's environmental footprint throughout its life cycle. For this study horizontal averaging was applied for pre-cursors and vertical averaging for the rest of the data.

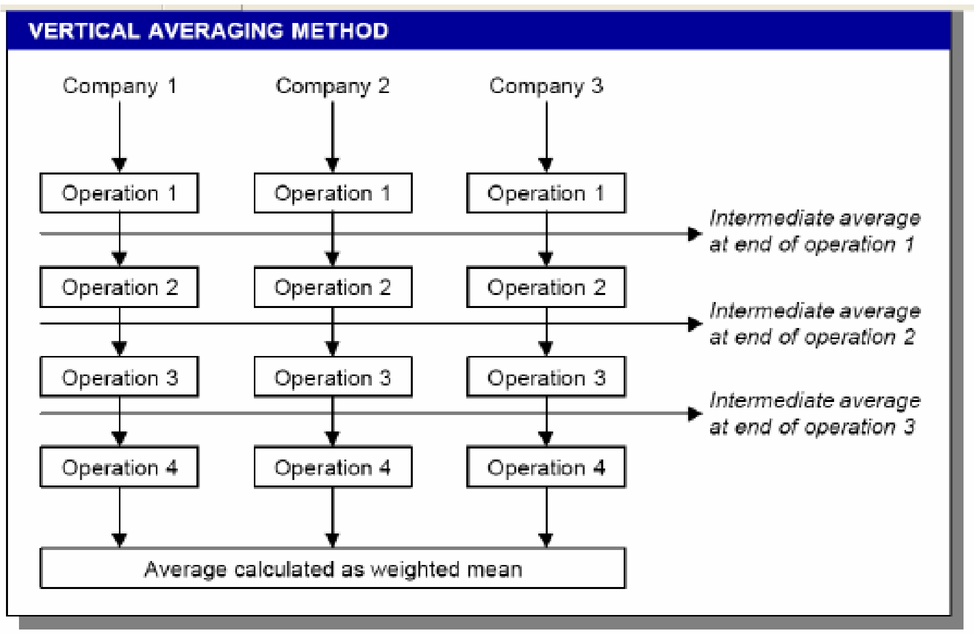

Figure 2-5 Vertical Averaging source: ((ECPI), 2001)

When specific, route-specific data from individual clients or suppliers is not available (as is the case here), horizontal averaging allows for the use of aggregated data over time, ensuring the analysis can proceed with reasonable accuracy. This method helps identify trends and patterns over multiple periods, providing a broader context for decision-making, such as changes in raw material costs or emissions. Plastics Europe's Eco-profile methodology emphasizes using representative data, and horizontal averages from reliable sources like ISOPA datasets to ensure consistency with industry standards.

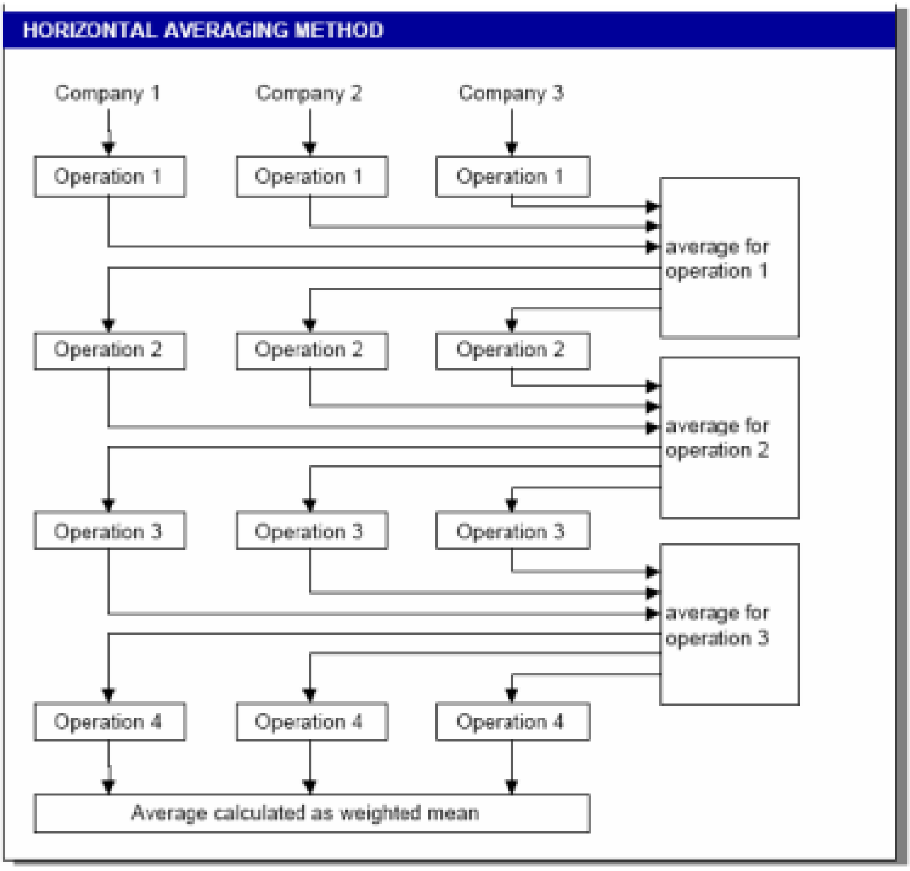

Figure 2-6 Horizontal Averaging source ((ECPI), 2001)

Allocation Rules

Production processes in chemical and plastics industry are usually multi-functional systems, i.e. they have not one, but several valuable product and co-product outputs. Wherever possible, allocation should be avoided by expanding the system to include the additional functions related to the co-products. Often, however, avoiding allocation is not feasible in technical reality, as alternative stand-alone processes do not exist or even 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. If these materials show only slight differences and are sold at comparable price-level, they are assumed as product output (< 2% of total production); on the contrary, if, they show significant differences and are sold at a different price level (like the flexible PU foam trimmings), a price allocation is used based on the sales price ratio of the main product and co-product; in terms of mass, this off-grade material represents from 2 to 6% of the foam output. In case of material declared as off-grade sent to recovery, neither further environmental burden nor credits are given to the modelled system (< 2% of total production). 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 is addressed by applying allocation based on mass and net calorific value [Sphera 2024]. 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).

In the previous study a pure mass allocation approach was used for TDI and MDI (co-product HCl). This method allocated the environmental burdens based solely on the mass of the products and co-product. However, this approach resulted in a significantly high burden on hydrogen chloride (HCl), which is only a co-product, while the main objective of the manufacturing process is to produce MDI and TDI. The shift to a combined elemental and mass-based approach in the 2021 report was made to better reflect the reality of the processes involved and to provide a fairer allocation of the burdens. A detailed explanation of this allocation approach is described in section 1.2.

A sensitivity analysis on the influence of price vs. mass vs combined elemental + mass allocation for TDI/MDI and their consequences for flexible PU foam is performed at the end of this report.

2.12 LIFE CYCLE INVENTORY (LCI) RESULTS

Delivery and Formats of LCI Dataset

This Eco-profile comprises

- 4 datasets in ILCD/EF 3.1 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.
- 4 datasets in LCA for Experts format (. GaBiDB)
- This report in pdf format.

Energy Demand

The **primary energy demand** (system input) 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** flexible PU foam 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 33.47 MJ/kg flexible PU foam.

Table 2-1 Primary energy demand (system boundary level) per 1kg flexible PU foam

Primary Energy Demand	MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³ [MJ]	TDI-based PU foam with FR, density 40 to 54 kg/m³ [MJ]	TDI-based PU foam without FR, density 18 to 25 kg/m³ [MJ]	TDI-based PU foam without FR, density 35 to 40 kg/m³ [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of monomer)	33.47	33.47	33.47	33.47
Process energy (quantified as difference between primary energy demand and energy content of monomer)	61.40	69.67	62.14	64.07
Total primary energy demand	**94.87**	**103.14**	**95.61**	**97.54**

The difference (Δ) between primary energy input and energy content in the flexible PU foam 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).

Water cradle to gate Use and Consumption

The following table shows the cradle-to-gate water use as well as the corresponding water consumption in the same system boundary per 1 kg of flexible PU foam.

Table 2-2 Water cradle to gate use and consumption per 1kg flexible PU foam

Impact Indicator	MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³ [kg]	TDI-based PU foam with FR, density 40 to 54 kg/m³ [kg]	TDI-based PU foam without FR, density 18 to 25 kg/m³ [kg]	TDI-based PU foam without FR, density 35 to 40 kg/m³ [kg]
Blue water use (kg)	1857.64	2503.83	2045.83	2125.16
Blue water consumption (Kg)	18.10	21.46	18.03	18.89

Water foreground (gate to gate) Use and Consumption

The following tables (Table 2-3 - Table 2-6) show the average values for water use of the average flexible PU foam production process (gate-to-gate level). For each of the typical water applications the water sources are shown:

Table 2-3 Water use and source per 1kg of MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	0	0	0	1.76E-01	1.76E-01
Deionized / Softened	0	1.03E-05	0	9.60E-03	9.61E-03
Untreated (from river/lake)	0	0	0	0	0
Untreated (from sea)	0	0	0	0	0
Relooped	0	0	0	0	0
Totals	**0**	**1.03E-05**	**0**	**1.85E-01**	**1.85E-01**

Table 2-4 Water use and source per 1kg of TDI-based PU foam with FR, density 40 to 54 kg/m³

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	0	0	0	0	0
Deionized / Softened	0	0	0	1.46E-02	1.46E-02
Untreated (from river/lake)	0	0	0	0	0
Untreated (from sea)	0	0	0	0	0
Relooped	0	0	0	0	0
Totals	**0**	**0**	**0**	**1.46E-02**	**1.46E-02**

Table 2-5 Water use and source per 1kg of TDI-based PU foam without FR, density 18 to 25 kg/m³

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	6.24E-04	0	0	0	6.24E-04
Deionized / Softened	0	0	0	2.09E-02	2.09E-02
Untreated (from river/lake)	0	0	0	0	0
Untreated (from sea)	0	0	0	0	0
Relooped	0	0	0	0	0
Totals	**6.24E-04**	**0**	**0**	**2.09E-02**	**2.15E-02**

Table 2-6 Water use and source per 1kg of TDI-based PU foam without FR, density 35 to 40 kg/m³

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	4.71E-03	0	0	0	4.71E-03
Deionized / Softened	0	0	0	1.59E-02	1.59E-02
Untreated (from river/lake)	0	0	0	0	0
Untreated (from sea)	0	0	0	0	0
Relooped	0	0	0	0	0
Totals	**4.71E-03**	**0**	**0**	**1.59E-02**	**2.06E-02**

The following tables (Table 2-7 - Table 2-10) show the further handling/processing of the water output of the average production process of PU foam:

Table 2-7 Treatment of Water Output per 1kg of MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³

Treatment	Water Output [kg]
To WWTP	1.74E-01
Untreated (to river/lake)	0
Untreated (to sea)	0
Relooped	0
Water leaving with products	0
Water Vapour	1.15E-02
Formed in reaction (to WWTP)	0
Totals	**1.85E-01**

Table 2-8 Treatment of Water Output per 1kg of TDI-based PU foam with FR, density 40 to 54 kg/m³

Treatment	Water Output [kg]
To WWTP	0
Untreated (to river/lake)	0
Untreated (to sea)	0
Relooped	0
Water leaving with products	0
Water Vapour	1.46E-02
Formed in reaction (to WWTP)	0
Totals	**1.46E-02**

Table 2-9 Treatment of Water Output per 1kg of TDI-based PU foam without FR, density 18 to 25 kg/m³

Treatment	Water Output [kg]
To WWTP	1.84E-02
Untreated (to river/lake)	0
Untreated (to sea)	0
Relooped	0
Water leaving with products	0
Water Vapour	3.07E-03
Formed in reaction (to WWTP)	0
Totals	**2.15E-02**

Table 2-10 Treatment of Water Output per 1kg of TDI-based PU foam without FR, density 35 to 40 kg/m³

Treatment	Water Output [kg]
To WWTP	2.03E-02
Untreated (to river/lake)	0
Untreated (to sea)	0
Relooped	0
Water leaving with products	0
Water Vapour	2.75E-04
Formed in reaction (to WWTP)	0
Totals	**2.06E-02**

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 + seawater used)

Table 2-11 Water consumption calculation per 1kg of flexible PU foam

Impact Indicator	MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³ [kg]	TDI-based PU foam with FR, density 40 to 54 kg/m³ [kg]	TDI-based PU foam without FR, density 18 to 25 kg/m³ [kg]	TDI-based PU foam without FR, density 35 to 40 kg/m³ [kg]
Consumption	-0.174	0	-0.018	-0.016

Regarding the negative water consumption values illustrated here: These can be explained by the fact that there is water contained in the pre-cursor products, which partly evaporates and partly goes to wastewater treatment, the latter resulting in a negative water consumption value.

Dominance Analysis

Table 2-12-Table 2-15 show the main contributions to the results presented above. A weighted average of the participating producers is used. For three PU foam grades without flame retardant, the precursors long chain polyether polyols and MDI/ TDI contribute to more than 85% of the overall impact in all analysed environmental impact categories except in Ozone Depletion and Resource Use (minerals and metals). For the PU foam grade with flame retardant, the same trend in results can be seen, with the contributions being lower, ranging between 70 to 90%.

For most of the grades, the raw materials are the primary contributors across all analysed environmental impact categories except in Ozone Depletion and Resource use (minerals and metals). For the Ozone Depletion, the primary contributors are split between raw materials and chemicals for the TDI foam grades whereas for the MDI, along with raw materials and chemicals also electricity use is a significant contributor. With regards to Resource Use (minerals and metals), chemicals are the primary contributors with raw materials being a secondary contributor. In the category of chemicals, zinc stearate (as a stabilizer) and silicone fluids are the primary contributors to Resource Use (minerals and metals) results.

The source of the primary contributors to both Ozone Depletion and Resource Use can be attributed to the dataset - Silicone fluids. Silicone fluids are silicone oils (polydimethylsiloxane PDMS) which exhibit different degrees of polymerization. When PDMS is exposed to UV/ozone treatment, it undergoes modification, resulting in the formation of a thin surface layer with silicon-oxygen (SiOx) bonds, which release silicon atoms (Si) into the atmosphere. Silicon atoms can participate in ozone-depleting reactions, similar to chlorine (Cl) atoms found in chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). While PDMS itself is not a major contributor to ozone depletion, the SiOx layer formed during UV/ozone treatment can release Si atoms, affecting the ozone layer.

Overall, all 3 grades without flame retardant present similar dominance profiles in all environmental categories: the density of TDI-based grades, or the presence of TDI vs. MDI plays little role. The grade with flame retardant presents the same dominance profiles albeit with lower overall percentage contributions.

Regarding total primary energy, raw materials are the main contributors across all four grades, followed by chemicals. The remaining categories contribute minimally or not at all.

With regards to electricity, this does make some contributions particularly for the three PU foam grades without flame retardant. Electricity itself does not directly contribute to ozone depletion. However, certain industrial processes and consumer products that rely on electricity can emit ozone-depleting substances (ODSs) into the atmosphere.

The latter also goes for the consumption of transportation and process waste treatment.

Table 2-12 Dominance analysis of impacts per 1 kg MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³

	Total Primary Energy	Acidificati-on	Climate change, total	Eutrophic-ation, freshwater	Ozone depletion	Photoche-mical ozone formation	Resource use, energy carriers	Resource use, minerals and metals
Raw Materials and Process	96.32%	88.92%	94.55%	96.56%	21.86%	90.59%	97.06%	29.21%
Other Chemicals	2.51%	5.41%	2.81%	2.19%	52.76%	3.97%	1.88%	66.91%
Utilities	0.21%	0.30%	0.23%	0.15%	2.72%	0.27%	0.20%	3.54%
Electricity	0.42%	0.53%	0.65%	0.26%	24.28%	0.36%	0.30%	0.12%
Thermal Energy	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%
Transports	0.72%	4.93%	1.38%	0.88%	5.04%	4.88%	0.70%	0.25%
Process Waste Treatment	-0.19%	-0.09%	0.37%	-0.05%	-6.66%	-0.09%	-0.15%	-0.04%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 2-13 Dominance analysis of impacts per 1 kg TDI-based PU foam with FR, density 40 to 54 kg/m³

	Total Primary Energy	Acidificati-on	Climate change, total	Eutrophic-ation, freshwater	Ozone depletion	Photoche-mical ozone formation	Resource use, energy carriers	Resource use, minerals and metals
Raw Materials and Process	80.83%	69.36%	75.65%	89.14%	4.70%	73.52%	83.80%	4.95%
Other Chemicals	18.03%	25.91%	22.06%	9.24%	91.27%	22.23%	15.12%	90.72%
Utilities	0.48%	0.91%	0.47%	0.81%	1.72%	0.45%	0.44%	4.28%
Electricity	0.26%	0.32%	0.40%	0.16%	3.36%	0.22%	0.20%	0.01%
Thermal Energy	0.04%	0.02%	0.06%	0.00%	0.00%	0.03%	0.04%	0.00%
Transports	0.55%	3.53%	0.99%	0.70%	0.54%	3.58%	0.56%	0.03%
Process Waste Treatment	-0.19%	-0.05%	0.37%	-0.06%	-1.60%	-0.03%	-0.16%	-0.01%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 2-14 Dominance analysis of impacts per 1 kg TDI-based PU foam without FR, density 18 to 25 kg/m³

	Total Primary Energy	Acidification	Climate change, total	Eutrophication, freshwater	Ozone depletion	Photochemical ozone formation	Resource use, energy carriers	Resource use, minerals and metals
Raw Materials and Process	94.17%	84.71%	91.81%	96.07%	14.70%	87.25%	95.56%	13.31%
Other Chemicals	4.76%	8.81%	5.49%	2.29%	79.42%	7.14%	3.45%	76.56%
Utilities	0.20%	0.80%	0.18%	0.61%	2.27%	0.28%	0.15%	10.00%
Electricity	0.32%	0.56%	0.59%	0.15%	7.14%	0.33%	0.26%	0.03%
Thermal Energy	0.03%	0.01%	0.04%	0.00%	0.00%	0.02%	0.03%	0.00%
Transports	0.78%	5.21%	1.41%	0.96%	2.48%	5.07%	0.76%	0.11%
Process Waste Treatment	-0.26%	-0.11%	0.48%	-0.07%	-6.01%	-0.10%	-0.21%	-0.02%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 2-15 Dominance analysis of impacts per 1 kg TDI-based PU foam without FR, density 35 to 40 kg/m³

	Total Primary Energy	Acidification	Climate change, total	Eutrophication, freshwater	Ozone depletion	Photochemical ozone formation	Resource use, energy carriers	Resource use, minerals and metals
Raw Materials and Process	94.56%	85.70%	91.99%	96.63%	18.22%	87.98%	95.90%	13.28%
Other Chemicals	4.44%	8.15%	5.25%	1.75%	71.26%	6.72%	3.20%	74.96%
Utilities	0.24%	0.94%	0.22%	0.66%	2.29%	0.33%	0.18%	11.63%
Electricity	0.42%	0.47%	0.54%	0.22%	14.88%	0.31%	0.31%	0.05%
Thermal Energy	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Transports	0.70%	4.84%	1.32%	0.84%	1.10%	4.71%	0.70%	0.10%
Process Waste Treatment	-0.36%	-0.10%	0.67%	-0.10%	-7.74%	-0.05%	-0.29%	-0.03%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Sensitivity Analysis on allocation method for TDI/MDI

The production processes of TDI and MDI, two of the main precursors of polyurethane foam, result in co-synthesis of hydrogen chloride (HCl): for this reason, the question of allocation must be addressed.

In the 2012 Eco-profile of TDI/MDI, a sensitivity analysis was performed on the impacts of mass and price allocation in comparison to the base case, for which a "combined elemental + mass allocation" was performed (see a detailed description of this allocation approach in section 1.2). Price allocation was found to increase the potential environmental burdens by 46% / 38% for TDI and 22% / 16% for MDI regarding the indicators GWP / primary energy in comparison to the “combined elemental + mass allocation” approach. Mass allocation was found to decrease the potential environmental burdens by 21% / 25% for TDI and 16% / 20% for MDI regarding the indicators GWP / primary energy in comparison to the “combined elemental + mass allocation” approach [ISOPA 2012 TDI-MDI].

To align with this approach and explore uncertainties in the environmental impacts of flexible PU foam, a sensitivity analysis was conducted on the polyurethane foam LCA models. This analysis compared the base case allocation for TDI/MDI ("combined elemental + mass allocation") with 100% mass and 100% price allocation.

Calculation of the sensitivity analysis was conducted via the following method:

- Results were calculated for each PU foam grade, focusing on EF 3.1 Climate Change – total and primary energy demand.
- Results were grouped by product type: MDI, TDI, Polyols, and others.
- For MDI and TDI, individual contributions were divided by the allocation values per 1 kg of MDI or TDI, as calculated in the ISOPA TDI-MDI report (2021).
- Contributions from each raw material were summed and illustrated in the tables below.

As shown in Table 2-16 - Table 2-19, the results vary based on the allocation method. When compared to mass allocation across all product types, GWP decreases by up to 7% and primary energy by up to 8%, depending on the PU foam grade. Conversely, with price allocation, GWP increases by up to 13% and primary energy by up to 10%, depending on the PU foam grade.

Table 2-16 Sensitivity analysis on the impact of allocation method for MDI/TDI precursor datasets; results per 1 kg MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m

Environmental Impact Category	Mass allocation on MDI	Elemental + Mass allocation on MDI	Variation
EF 3.1 Climate Change - total [kg CO_2 eq.]	3.01	3.16	- 5%
Total primary energy demand [MJ]	88.85	94.87	- 7%

Environmental Impact Category	Price allocation on MDI	Elemental + Mass allocation on MDI	Variation
EF 3.1 Climate Change - total [kg CO_2 eq.]	3.38	3.16	+ 6%
Total primary energy demand [MJ]	99.63	94.87	+ 5%

Table 2-17 Sensitivity analysis on the impact of allocation method for MDI/TDI precursor datasets; results per 1 kg TDI-based PU foam with FR, density 40 to 54 kg/m³

Environmental Impact Category	Mass allocation on TDI	Elemental + Mass allocation on TDI	Variation
EF 3.1 Climate Change - total [kg CO_2 eq.]	3.62	3.79	- 5%
Total primary energy demand [MJ]	97.82	103.14	- 5%

Environmental Impact Category	Price allocation on TDI	Elemental + Mass allocation on TDI	Variation
EF 3.1 Climate Change - total [kg CO_2 eq.]	4.17	3.79	+ 9%
Total primary energy demand [MJ]	111.05	103.14	+ 7%

Table 2-18 Sensitivity analysis on the impact of allocation method for MDI/TDI precursor datasets; results per 1 kg TDI-based PU foam without FR, density 18 to 25 kg/m³

Environmental Impact Category	Mass allocation on TDI	Elemental + Mass allocation on TDI	Variation
EF 3.1 Climate Change - total [kg CO_2 eq.]	3.21	3.44	- 7%
Total primary energy demand [MJ]	88.50	95.61	- 8%

Environmental Impact Category	Price allocation on TDI	Elemental + Mass allocation on TDI	Variation
EF 3.1 Climate Change - total [kg CO_2 eq.]	3.94	3.44	+ 13%
Total primary energy demand [MJ]	106.18	95.61	+ 10%

Table 2-19 Sensitivity analysis on the impact of allocation method for MDI/TDI precursor datasets; results per 1 kg TDI-based PU foam without FR, density 35 to 40 kg/m³

Environmental Impact Category	Mass allocation on TDI	Elemental + Mass allocation on TDI	Variation
EF 3.1 Climate Change - total [kg CO_2 eq.]	3.27	3.45	- 6%
Total primary energy demand [MJ]	91.82	97.54	- 6%

Environmental Impact Category	Price allocation on TDI	Elemental + Mass allocation on TDI	Variation
EF 3.1 Climate Change - total [kg CO_2 eq.]	3.85	3.45	+ 10%
Total primary energy demand [MJ]	106.04	97.54	+ 8%

Comparison of the present Eco-profile with its previous version

Comparing the environmental profiles of polyurethane foam cannot be done without considering the individual environmental profiles of methylene diphenyl diisocyanate (MDI), toluene diisocyanate (TDI), and polyether polyols. The previous environmental profile for polyurethane foam, conducted in 2015, used MDI, TDI, and polyols data from 2010. In contrast, the current environmental profile for polyurethane foam, conducted in 2024, is based on MDI, TDI, and polyols data from 2018. While there is a minor increase in polyols, there is a more significant increase in GWP impacts in both MDI and TDI by approximately 16% compared to the previous Eco-profile study (see Table 2-20). The increase in MDI and TDI results was significantly influenced by the choice of allocation method utilised.

Table 2-20 : Comparison of the MDT, TDI and polyols from previous Eeco-profile reports – Environmental impact method for results are: CML2001 - Aug. 2016, Global Warming Potential (GWP 100 years) [kg CO_2 eq.]

Reference Year	Methylenediphenyl diisocyanate ((p)MDI)	Toluene diisocyanate (TDI)	Long Chain Polyether Polyols mix
2010	2.39	2.71	2.90
2018	2.76	3.14	2.93
Difference (%)	+ 15.47%	+ 15.98%	+ 1.20%

In the previous study a pure mass allocation approach was used. This method allocated the environmental burden based solely on the mass of the products and co-products. However, this approach resulted in a significantly high burden on hydrogen chloride (HCl), which is only a co-product, while the main objective of the manufacturing process is to produce MDI and TDI. The shift to a combined elemental and mass-based approach in the 2021 report was made to better reflect the reality of the processes involved and to provide a fairer allocation of the burdens.

Table 2-21 - Table 2-24 compare the PU foam Eco-profile from 2015 with the updated report from 2024. The analysis uses the most common impact indicators and applies the same environmental impact method to ensure consistency.

Table 2-21 Comparison of PU foam 2015 vs PU foam 2024 for 1 kg MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m– Environmental impact method for results are based on: CML2001 - Aug. 2016, Global Warming Potential (GWP 100 years) [kg CO_2 eq.]

Environmental Impact Categories	Previous PU foam (2015) CML2001 - Aug. 2016	New PU foam (2024) CML2001 - Aug. 2016	Percentage Change (%)
Gross primary energy from resources [MJ]	84.94	94.87	12%
Abiotic Depletion (ADP elements) [kg Sb eq.]	1.00E-05	8.94E-06	-11%
Abiotic Depletion (ADP fossil) [MJ]	72.62	79.21	9%
Global Warming Potential (GWP 100 years) [kg CO_2 eq.]	2.95	3.12	6%
Acidification Potential (AP) [kg SO_2 eq.]	6.17E-03	4.50E-03	-27%
Eutrophication Potential (EP) [kg Phosphate eq.]	8.90E-04	9.33E-04	5%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	2.71E-06	1.14E-12	-100%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1.11E-03	5.62E-04	-49%

Table 2-22 Comparison of PU foam 2015 vs PU foam 2024 for 1 kg TDI-based PU foam with FR, density 40 to 54 kg/m³– Environmental impact method for results are based on: CML2001 - Aug. 2016, Global Warming Potential (GWP 100 years) [kg CO_2 eq.]

Environmental Impact Categories	Previous PU foam (2015) CML2001 - Aug. 2016	New PU foam (2024) CML2001 - Aug. 2016	Percentage Change (%)
Gross primary energy from resources [MJ]	93.80	103.14	10%
Abiotic Depletion (ADP elements) [kg Sb eq.]	3.09E-05	1.77E-05	-43%
Abiotic Depletion (ADP fossil) [MJ]	77.91	82.76	6%
Global Warming Potential (GWP 100 years) [kg CO_2 eq.]	3.56	3.75	5%
Acidification Potential (AP) [kg SO_2 eq.]	7.40E-03	5.56E-03	-25%
Eutrophication Potential (EP) [kg Phosphate eq.]	1.16E-03	1.14E-03	-2%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	3.53E-08	5.28E-12	-100%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1.22E-03	7.88E-04	-35%

Table 2-23 Comparison of PU foam 2015 vs PU foam 2024 for 1 kg TDI-based PU foam without FR, density 18 to 25 kg/m³– Environmental impact method for results are based on: CML2001 - Aug. 2016, Global Warming Potential (GWP 100 years) [kg CO_2 eq.]

Environmental Impact Categories	Previous PU foam (2015) CML2001 - Aug. 2016	New PU foam (2024) CML2001 - Aug. 2016	Percentage Change (%)
Gross primary energy from resources [MJ]	85.54	95.61	12%
Abiotic Depletion (ADP elements) [kg Sb eq.]	1.55E-05	1.09E-05	-29%
Abiotic Depletion (ADP fossil) [MJ]	72.03	79.01	10%
Global Warming Potential (GWP 100 years) [kg CO_2 eq.]	3.18	3.39	7%
Acidification Potential (AP) [kg SO_2 eq.]	6.31E-03	4.81E-03	-24%
Eutrophication Potential (EP) [kg Phosphate eq.]	9.90E-04	1.01E-03	2%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4.08E-08	1.74E-12	-100%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1.12E-03	7.01E-04	-37%

Table 2-24 Comparison of PU foam 2015 vs PU foam 2024 for 1 kg TDI-based PU foam without FR, density 35 to 40 kg/m³– Environmental impact method for results are based on: CML2001 - Aug. 2016, Global Warming Potential (GWP 100 years) [kg CO_2 eq.]

Environmental Impact Categories	Previous PU foam (2015) CML2001 - Aug. 2016	New PU foam (2024) CML2001 - Aug. 2016	Percentage Change (%)
Gross primary energy from resources [MJ]	88.67	97.54	10%
Abiotic Depletion (ADP elements) [kg Sb eq.]	1.57E-05	1.18E-05	-25%
Abiotic Depletion (ADP fossil) [MJ]	74.97	80.38	7%
Global Warming Potential (GWP 100 years) [kg CO_2 eq.]	3.22	3.41	6%
Acidification Potential (AP) [kg SO_2 eq.]	6.48E-03	4.92E-03	-24%
Eutrophication Potential (EP) [kg Phosphate eq.]	9.90E-04	1.03E-03	4%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	3.83E-08	1.92E-12	-100%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1.18E-03	7.00E-04	-41%

Between the reference years 2010 and 2018, the Eco-profiles for PU foam experienced an increase of about 5% for GWP, while polyols only increased by approximately 1%.

Establishing a direct correlation between the impacts of MDI or TDI and the overall increase in environmental impact is challenging. This is because the results are based on weighted averages from multiple producers. Even if MDI or TDI have significant individual impacts, their overall contribution might be small compared to other producers. As a result, their impact on the total increase appears relatively smaller.

The largest share of the increase for PU is due to the allocation approach taken for MDI/TDI.

The "greening" of supply chains typically aims to reduce overall energy consumption and carbon emissions. However, there can be instances where the shift to greener technologies or processes might lead to lower energy use but higher CO_2 intensity. This can happen if the greener processes rely on energy sources or materials that, while more efficient, have higher associated CO_2 emissions.

Statement on Methane Emissions

Methane emissions play a major role in the greenhouse effect. Unlike carbon dioxide emissions, which can often be directly calculated from energy resource consumption and have been reported for decades, methane emissions from the supply chains of natural gas, crude oil, and coal are still infrequently and inconsistently documented.

The advanced quantification of methane emissions is therefore the focus of the assessment of greenhouse gas emissions from the supply of fossil energy carriers. Hmiel et al. (2020) demonstrate through carbon-14 measurements on pre-industrial ice cores that methane emissions from fossil fuel extraction and use are underestimated in current studies that use bottom-up estimates. Combined data from Hmiel et al. (2020) and Saunois et al. (2020) show an increase of methane emissions from fossil fuel supply chains and fossil fuel use by 36 Mt CH_4/a to 164 Mt CH_4/a, or a relative increase of methane emissions by about 28% compared to previous assumptions.

According to the current state of research, it is not yet clear to what extent the supply and use of oil, natural gas (and coal) causes these methane emissions.

The data quality of methane emission factors may be improved by the combined use of bottom up and top-down measurements. The exact determination of methane emissions requires the use of detailed data of the activities and facilities along the supply chain. The more detailed the data regarding processes with methane emissions and the respective magnitudes, the higher the quality of the emission factors.

Emission factors for methane vary considerably, as they depend on many influencing factors, including:

- Facility design,
- Gas composition,
- Type of production and processing (e.g., combined oil and gas production),
- Age and technical standard of machinery and equipment, and
- Operating conditions, maintenance conditions, and other operational activities.

Based on current research, few studies have been conducted on top-down measurements of methane emissions. Therefore, top-down measurements and calculation methods for methane emissions are not yet harmonized, neither internationally nor between sectors. Further research needs regarding top-down measurements include the handling of accidental releases and the proper scaling of emissions to the functional unit(s) as a yearly average to account for seasonal variations. Based on the current state of research, data from top-down measurements are therefore not yet consistently applicable to LCAs.

Research and sector alignment is therefore needed, for example, on the allocation of methane emissions between oil and gas in combined oil and gas production. Measurements of methane emissions may represent snapshots and are subject to large fluctuations, which is not yet properly documented in existing studies.

Enhanced and consistent bottom up and top-down analyses and methodologies will contribute to an improved quantification of methane emissions. Sphera closely follows the publication of current studies in this subject area, checks the applicability in LCA and adjusts its LCA datasets when methods lead to an improvement in data quality.

Regarding this study, the polyol and MDI/TDI Eco-profiles, which form the basis for this Eco-profile, do not include the higher methane emissions. Therefore, the GWP (Global Warming Potential) results are likely underestimated.

In 2025, Sphera, in collaboration with ISOPA, will begin a project to update the polyol and MDI/TDI Eco-profiles, which formed the basis of this Eco-profile for PU. The project is expected to be completed by the end of 2025 at the earliest, but more likely in early 2026. Afterwards, the Eco-profile for PU will be updated.

3 EF 3.1 Indicator Results

Table 3-1 to Table 3-4 illustrate the LCA results for all four different grades of 1 kg of flexible PU foam when applying the EF3.1 impact assessment methodology.

Please note when importing the delivered LCI dataset in ILCD/EF3.1 (.xml) format only these results can be recovered in the LCA software tool.

Table 3-1 LCA results for 1 kg of MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³ applying EF3.1 impact assessment methodology

Indicator	Unit	MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m3
Climate change, total	kg CO_2 eq.	3.16E+00
Climate Change, biogenic	kg CO_2 eq.	1.30E-02
Climate Change, fossil	kg CO_2 eq.	3.14E+00
Climate Change, land use and land use change	kg CO_2 eq.	4.36E-03
Ozone depletion	kg CFC-11 eq.	9.48E-13
Acidification	Mole of H+ eq	5.76E-03
Photochemical ozone formation	kg NMVOC eq	5.64E-03
Eutrophication, freshwater	kg P eq	2.06E-05
Eutrophication, marine	kg N eq.	1.86E-03
Eutrophication, terrestrial	Mole of N eq.	1.98E-02
Respiratory Inorganics	Disease incidences	4.93E-08
Ionising radiation, human health	kBq U235 eq.	1.19E-01
Human toxicity, cancer – total	CTUh	1.08E-09
Human toxicity, cancer inorganics	CTUh	8.24E-10
Human toxicity, cancer organics	CTUh	2.55E-10
Human toxicity, noncancer – total	CTUh	5.53E-08
Human toxicity, noncancer inorganics	CTUh	5.47E-08
Human toxicity, noncancer organics	CTUh	5.22E-10
Ecotoxicity, freshwater – total	CTUe	3.76E+01
Ecotoxicity, freshwater inorganics	CTUe	3.73E+01
Ecotoxicity, freshwater organics	CTUe	3.29E-01
Land Use	Pt	1.09E+01
Resource use, energy carriers	MJ	8.22E+01
Resource use, minerals and metals	kg Sb eq.	1.52E-06
Water scarcity	m^3 world equiv.	3.05E-01

Table 3-2 LCA results for 1 kg of TDI-based PU foam with FR, density 40 to 54 kg/m³ applying EF3.1 impact assessment methodology

Indicator	**Unit**	**TDI-based PU foam with FR, density 40 to 54 kg/m3**
Climate change, total	kg CO_2 eq.	3.79E+00
Climate Change, biogenic	kg CO_2 eq.	1.56E-02
Climate Change, fossil	kg CO_2 eq.	3.77E+00
Climate Change, land use and land use change	kg CO_2 eq.	4.73E-03
Ozone depletion	kg CFC-11 eq.	4.46E-12
Acidification	Mole of H+ eq	6.94E-03
Photochemical ozone formation	kg NMVOC eq	6.61E-03
Eutrophication, freshwater	kg P eq	2.23E-05
Eutrophication, marine	kg N eq.	2.30E-03
Eutrophication, terrestrial	Mole of N eq.	2.27E-02
Respiratory Inorganics	Disease incidences	6.20E-08
Ionising radiation, human health	kBq U235 eq.	1.36E-01
Human toxicity, cancer – total	CTUh	1.14E-09
Human toxicity, cancer inorganics	CTUh	8.44E-10
Human toxicity, cancer organics	CTUh	2.97E-10
Human toxicity, noncancer – total	CTUh	5.86E-08
Human toxicity, noncancer inorganics	CTUh	5.80E-08
Human toxicity, noncancer organics	CTUh	6.24E-10
Ecotoxicity, freshwater – total	CTUe	3.93E+01
Ecotoxicity, freshwater inorganics	CTUe	3.90E+01
Ecotoxicity, freshwater organics	CTUe	3.48E-01
Land Use	Pt	2.37E+01
Resource use, energy carriers	MJ	8.64E+01
Resource use, minerals and metals	kg Sb eq.	9.16E-06
Water scarcity	m³ world equiv.	3.42E-01

Table 3-3 LCA results for 1 kg of TDI-based PU foam without FR, density 18 to 25 kg/m³ applying EF3.1 impact assessment methodology

Indicator	**Unit**	**TDI-based PU foam without FR, density 18 to 25 kg/m³**
Climate change, total	kg CO_2 eq.	3.44E+00
Climate Change, biogenic	kg CO_2 eq.	1.41E-02
Climate Change, fossil	kg CO_2 eq.	3.42E+00
Climate Change, land use and land use change	kg CO_2 eq.	4.63E-03
Ozone depletion	kg CFC-11 eq.	1.46E-12
Acidification	Mole of H+ eq	6.06E-03
Photochemical ozone formation	kg NMVOC eq	6.02E-03
Eutrophication, freshwater	kg P eq	2.09E-05
Eutrophication, marine	kg N eq.	2.00E-03
Eutrophication, terrestrial	Mole of N eq.	2.06E-02
Respiratory Inorganics	Disease incidences	5.08E-08
Ionising radiation, human health	kBq U235 eq.	1.15E-01
Human toxicity, cancer – total	CTUh	1.13E-09
Human toxicity, cancer inorganics	CTUh	8.40E-10
Human toxicity, cancer organics	CTUh	2.91E-10
Human toxicity, noncancer – total	CTUh	5.76E-08
Human toxicity, noncancer inorganics	CTUh	5.60E-08
Human toxicity, noncancer organics	CTUh	1.59E-09
Ecotoxicity, freshwater – total	CTUe	3.86E+01
Ecotoxicity, freshwater inorganics	CTUe	3.83E+01
Ecotoxicity, freshwater organics	CTUe	3.14E-01
Land Use	Pt	1.43E+01
Resource use, energy carriers	MJ	8.20E+01
Resource use, minerals and metals	kg Sb eq.	3.65E-06
Water scarcity	m³ world equiv.	2.48E-01

Table 3-4 LCA results for 1 kg of TDI-based PU foam without FR, density 35 to 40 kg/m³ applying EF3.1 impact assessment methodology

Indicator	Unit	TDI-based PU foam without FR, density 35 to 40 kg/m3
Climate change, total	kg CO_2 eq.	3.45E+00
Climate Change, biogenic	kg CO_2 eq.	1.47E-02
Climate Change, fossil	kg CO_2 eq.	3.43E+00
Climate Change, land use and land use change	kg CO_2 eq.	5.05E-03
Ozone depletion	kg CFC-11 eq.	1.61E-12
Acidification	Mole of H+ eq	6.22E-03
Photochemical ozone formation	kg NMVOC eq	6.15E-03
Eutrophication, freshwater	kg P eq	2.27E-05
Eutrophication, marine	kg N eq.	2.04E-03
Eutrophication, terrestrial	Mole of N eq.	2.12E-02
Respiratory Inorganics	Disease incidences	5.27E-08
Ionising radiation, human health	kBq U235 eq.	1.21E-01
Human toxicity, cancer – total	CTUh	1.54E-09
Human toxicity, cancer inorganics	CTUh	8.71E-10
Human toxicity, cancer organics	CTUh	6.71E-10
Human toxicity, noncancer – total	CTUh	6.97E-08
Human toxicity, noncancer inorganics	CTUh	5.87E-08
Human toxicity, noncancer organics	CTUh	1.10E-08
Ecotoxicity, freshwater – total	CTUe	4.00E+01
Ecotoxicity, freshwater inorganics	CTUe	3.96E+01
Ecotoxicity, freshwater organics	CTUe	3.56E-01
Land Use	Pt	1.46E+01
Resource use, energy carriers	MJ	8.36E+01
Resource use, minerals and metals	kg Sb eq.	3.77E-06
Water scarcity	m³ world equiv.	2.70E-01

4 Review

4.1 Review Details

Commissioned by:	EUROPUR aisbl
Prepared by:	Dr Raheel Afzal 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 four types of representative flexible polyurethane (PU) foam grades:

- TDI-based PU foam without FR, high density 35 to 40 kg/m³
- TDI-based PU foam without FR, low density 18 to 25 kg/m³
- TDI-based PU foam with FR, density 40 to 54 kg/m³
- MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³.

The critical review included two iterations of final Eco-profile report review (January and February 2025) in which the reviewer provided comments for clarification by the LCA practitioner. On 27.01.2025, 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 completed on 10.02.2025. 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.

Regarding primary data, the same data as in the last version of the Eco-profile for flexible PU foam (EUROPUR 2015) was used (reference year 2013). Back then, the data was collected from nine plants of six flexible PU foam producers in six different European countries. The manufacturers confirmed that there have been no significant updates or changes in the foreground data since then. According to EUROPUR, the data of these six producers equates to a representativeness of more than 62.5% of the overall flexible PU foam blocks production (EU-27) in 2024.

Data for the key precursors long-chain polyether polyol, methylene diphenyl diisocyanate (MDI) and toluene diisocyanate (TDI) were based on the most recent Eco-profiles (ISOPA 2021 PP, ISOPA 2021 TDI-MDI). All other background data are taken from the database of the software Sphera MLC CUP 2024.1 (Sphera 2024).

The following should be kept in mind when interpreting the results of this version of the Eco-profile for flexible PU foam:

There is rising awareness in scientific literature about unwanted methane emissions during oil and gas extraction, processing and transport which are higher than assumed in previously published Eco-profiles. Whilst the background data taken from the Sphera MLC database already considers these higher methane emissions, they are not yet included in the key precursor Eco-profiles for polyether polyol, MDI and TDI. This most likely leads to an underestimation of the potential environmental impacts for the four types of representative flexible PU foam grades for the impact category global warming potential (GWP). Updates of the respective precursor Eco-profiles are currently underway and will then also consider these increased levels of methane emissions. As soon as these updated precursor Eco-profiles become available, this Eco-profile for the four types of flexible PU foams will also be updated. This Eco-profile can therefore be seen as a temporary interim status. Relevant statements are clearly integrated into this report.

Allocation in the foreground system was applied for small amounts of PU foam trimming co-products. Allocation was based on the ratio of their respective prices. The effects on the results can be considered negligible.

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 the four types of representative flexible PU foam grades are quantified using the EF v3.1 methodology, as recommended in the current PlasticsEurope methodology. The contribution analysis shows the predominant influence of the precursors polyether polyol, MDI and TDI for the majority of environmental indicators. Please see the ‘Dominance analysis’ in the report for further details.

This Eco-profile includes a comparison of the environmental performance of flexible PU foam grades with the last version from 2015. It shows that potential environmental impacts have increased slightly for key indicators (see

Table 2-21 - Table 2-24). This increase is mainly due to a different allocation approach in MDI and TDI production (co-product HCl), which was determined in the most recent MDI/TDI Eco-profile (ISOPA 2021). A sensitivity analysis shows how the environmental performance for flexible PU foam would change if different allocation approaches for MDI and TDI were applied. Please see ‘Sensitivity Analysis on allocation method for TDI/MDI’ and ‘Comparison of the present Eco-profile with its previous version’ for further details.

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 Plastics Europe’s Eco-profiles methodology version 3.1 (2022) and represents best available data for representative flexible PU foam grade production in Europe.

Stuttgart, Germany, 12.02.2025

M. Schulz

Matthias Schulz, Schulz Sustainability Consulting

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