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

Flexible Polyurethane (PU) Foam
EUROPUR
August 2015

EUROPUR
European Association of Flexible Polyurethane Foam Blocks Manufacturers

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Environmental Product Declaration

Introduction

This Environmental Product Declaration (EPD) is based upon life cycle inventory (LCI) data from ISOPA [ISOPA 2012 TDI-MDI, ISOPA 2012 PP] and from the GaBi database 2014 [GaBi 6], fulfilling the requirements on PlasticsEurope's Eco-profile programme. It has been prepared according to **PlasticsEurope's Eco-profiles and Environmental Declarations – LCI Methodology and PCR for Uncompounded Polymer Resins and Reactive Polymer Precursors** (PCR version 2.0, April 2011) [PlasticsEurope 2011]. EPDs provide environmental performance data, but no information on the economic and social aspects which would be necessary for a complete sustainability assessment. EPDs do not imply a value judgement between environmental criteria.

This EPD describes 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 cannot be made on the level of the polymer material alone**: it is necessary to consider the full life cycle of an application in order to compare the performance of different materials and the effects of relevant life cycle parameters. This EPD is intended to be used by member companies, to support product-orientated environmental management; by users of plastics, as a building block of life cycle assessment (LCA) studies of individual products; and by other interested parties, as a source of life cycle information.

Meta Data

Data Owner	EUROPUR aisbl
LCA Practitioner	thinkstep AG
Programme Owner	PlasticsEurope aisbl
Programme Manager, Reviewer	DEKRA Assurance Services GmbH
Number of plants included in data collection	9
Representativeness	60%
Reference year	2013
Year of data collection and calculation	2014-2015
Expected temporal validity	2023
Cut-offs	No significant cut-offs
Data Quality	Good
Allocation method	Price allocation

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.

Production Process

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.

The reference flow for the four PU foam types considered, to which all data given in this Eco-profile refer, is 1 kg of flexible PU foam.

Data Sources and Allocation

The main data source is a primary data collection from European producers of flexible PU foam blocks, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: nine plants of seven flexible PU foam producers in six different European countries.

These seven producers cover more than 60 % of the overall flexible PU foam blocks production (EU-27) in 2013 [EUROPUR 2014].

The life cycle inventory data for the three main precursors long-chain polyether polyol, TDI and MDI are from two 2012 ISOPA Eco-profile studies [ISOPA 2012 PP, ISOPA 2012 TDI-MDI]; further background data are taken from the database of the software system GaBi 6 [GaBi 6].

All relevant background data, such as energy and auxiliary materials, is from the GaBi 6 database; the documentation is publicly available [GaBi 6].

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.

Use Phase and End-of-Life Management

Flexible polyurethane foam is used to manufacture mattresses, upholstered furniture and car seats, but also acoustic insulation boards, carpet underlays, household sponges, clothing and sportswear, packaging and many other applications. The bedding and furniture sector is the main market for slabstock foam. Around 48% of mattresses in the EU have a polyurethane foam core (EBIA, 2012) and around 90% of furniture upholstery is made out of PU foam.

Production block cut-offs (trim foam) are used in applications such as carpet underlay, gymnastic mats or headrests. Chemical recycling (transformation of clean production waste into new raw-materials) is also an option for production waste. The first chemical recycling plants have started to operate.

Today, the main process for treating end-of-life flexible polyurethane foam after it was used for several years or even decades) is energy recovery. Gasification or other technologies may become processing options in the future but still have to demonstrate economic and technical feasibility on an industrial scale. Finally, a proportion of products containing polyurethane foam is still being landfilled in Europe, although a phase-out of the landfilling of energy-rich waste is being foreseen by 2025 under the EU's proposals for a Circular Economy.

Environmental Performance

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

Input Parameters

Indicator	Unit	TDI-based PU foam without FR, density 35 to 40 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³
Non-renewable energy resources[1)]	MJ	85.67	82.56	89.38	82.45
• Fuel energy	MJ	52.20	49.09	55.91	48.98
• Feedstock energy	MJ	33.47	33.47	33.47	33.47
Renewable energy resources (biomass)[1)]	MJ	3.00	2.98	4.42	2.49
• Fuel energy	MJ	3.00	2.98	4.42	2.49
• Feedstock energy	MJ	0	0	0	0
Abiotic Depletion Potential					
• Elements	kg Sb eq	1.57E-05	1.55E-05	3.09E-05	1.00E-05
• Fossil fuels	MJ	74.97	72.03	77.91	72.62
Renewable materials (biomass)	kg	0	0	0	0
Water use (key foreground process level)	kg	1.86E-02	2.64E-02	8.70E-03	1.85E-01
• for process	kg	n.a.	n.a.	n.a.	n.a.
• for cooling	kg	n.a.	n.a.	n.a.	n.a.

[1)] Calculated as upper heating value (UHV); na= not available – details see

Output Parameters

Indicator	Unit	TDI-based PU foam without FR, density 35 to 40 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³
GWP	kg CO_2 eq	3.22	3.18	3.56	2.95
ODP	g CFC-11 eq	3.83E-05	4.08E-05	3.53E-05	2.71E-03
AP	g SO_2 eq	6.48	6.31	7.40	6.17
POCP	g Ethene eq	1.18	1.12	1.22	1.11
EP	g PO_4 eq	0.99	0.99	1.16	0.89
Dust/particulate matter[2)]	g PM10	1.15E-01	1.13E-01	1.40E-01	9.67E-02
Total particulate matter[2)]	g	2.66E-01	2.65E-01	4.77E-01	2.17E-01
Waste					
• Radioactive waste	kg	1.67E-03	1.70E-03	1.85E-03	1.42E-03
• Non-radioactive waste [3)]	kg	1.26E-01	1.24E-01	3.11E-01	7.40E-02

[2)] Including secondary PM10

[3)] Non-radioactive wastes include: spoil, tailings, and waste, deposited

Additional Environmental and Health Information

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.

Additional Technical Information

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.

Information

Data Owner

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Programme Manager & Reviewer
DEKRA Assurance Services GmbH
This Environmental Product Declaration has been reviewed by DEKRA Assurance Services GmbH. It was approved according to the Product Category Rules PCR version 2.0 (2011-04) and ISO 14025:2006 [ISO 14025: 2006].
Registration number: PlasticsEurope 2015-007, validation expires on 30 August 2018 (date of next revalidation review).

Programme Owner

PlasticsEurope
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E-mail: info@plasticseurope.org.

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

References

PlasticsEurope: Eco-profiles and environmental declarations – LCI methodology and PCR for uncompounded polymer resins and reactive polymer precursors (version 2.0, April 2011).

Goal & Scope

Intended Use & Target Audience

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

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

PlasticsEurope Eco-profiles and EPDs are prepared in accordance with the stringent ISO 14040–44 requirements [ISO 14040: 2006, ISO 14044: 2006]. Since the system boundary is »cradle-to-gate«, however, their respective reference flows are disparate, namely referring to a broad variety of polymers and precursors. This implies that, in accordance with ISO 14040–44, a direct comparison of Eco-profiles is impossible. While ISO 14025, Clause 5.2.2 does allow EPDs to be used in comparison, PlasticsEurope EPDs are derived from Eco-profiles, i.e. with the same »cradle-to-gate« system boundaries.

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

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

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

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

Product Category and Declared Unit

Product Category

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

Functional Unit and Declared Unit

The default Functional Unit and Declared Unit of PlasticsEurope 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 kPa
- TDI-based PU foam without FR, low density 18 to 25 kg/m³, hardness 2.5 to 4 kPa – formulation without CO_2
- TDI-based PU foam with FR, density 40 to 54 kg/m³, hardness 2.5 to 4 kPa – formulation without CO_2
- MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³, hardness 2.5 to 4 kPa – formulation without CO_2

respectively, »at gate« (production site output) representing a European industry production average.

These four different grades were chosen because they well represent the main different applications of flexible PU foam as well as cover most of the European production.

Product and Producer Description

Product Description

Flexible polyurethane foam is used to manufacture mattresses, upholstered furniture and car seats, but also acoustic insulation boards, carpet underlays, household sponges, clothing and sportswear, packaging and many other applications More specifically, the high density TDI-based grades are typically used in furniture and bedding, whereas the low-density TDI-based grades are preferred for insulation, packaging, building and footwear. The MDI-based foams are increasingly used for bedding applications due to their viscoelastic properties (also known as "memory" and pressure-relieving properties.

Production Process Description

Polyurethane foam is made by reacting diisocyanates and polyols. Both are products derived from crude oil, but polyols can also be made of natural oils from renewable sources. When mixed, the diisocyanates and the polyols react and “foam”. Depending on the application the foam will be used for, a number of additives are also being added to the formulation to control its properties, density and cell-size.

Flexible ***slabstock polyurethane foams*** are produced as large blocks using a semi-continuous process with minimal human handling. Continuous foam machines are the standard in Europe today.

While the machinery may be different from one manufacturer to the other, the general principle is always the same: the raw materials are delivered into a mixing head, which pours the foam mixture onto a pour plate, which delivers the rising foam onto a moving conveyor (usually horizontal, sometimes vertical). Both the conveyor and the mixing head are located in a ventilated tunnel fitted for exhausting vapors released during the foaming process. Figure 1 and Figure 2 below provide some examples of typical production processes used for slabstock foam production. From an eco-profile point of view, the different machinery technologies used for continuous slabstock foam production can be considered as very similar.

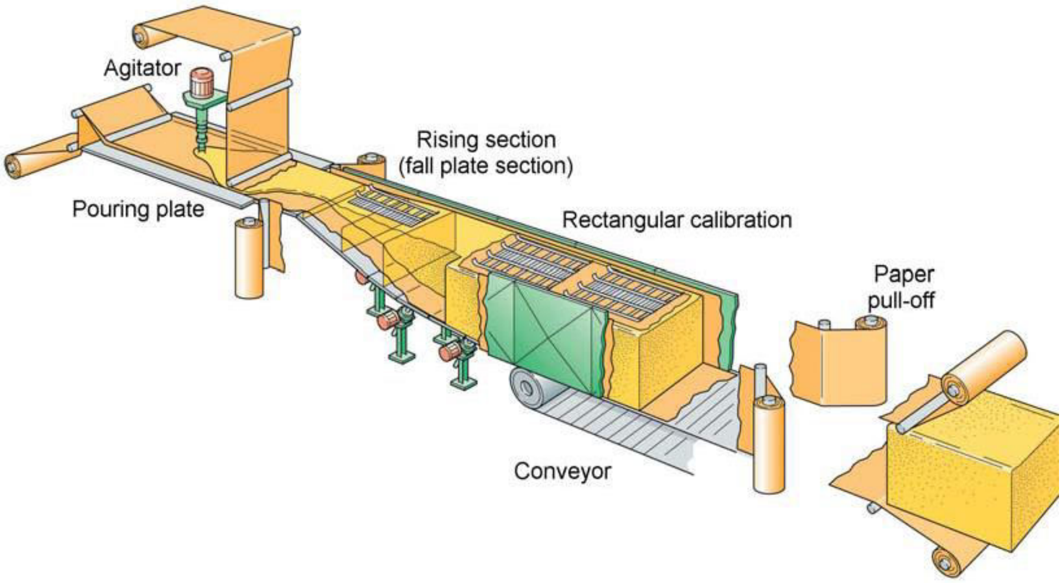

Figure 1: 3-D representation of a system – without metering device and cut-off saw – for continuous production of flexible rectangular foam blocks by means of the QFM process (source: Hennecke GmbH)

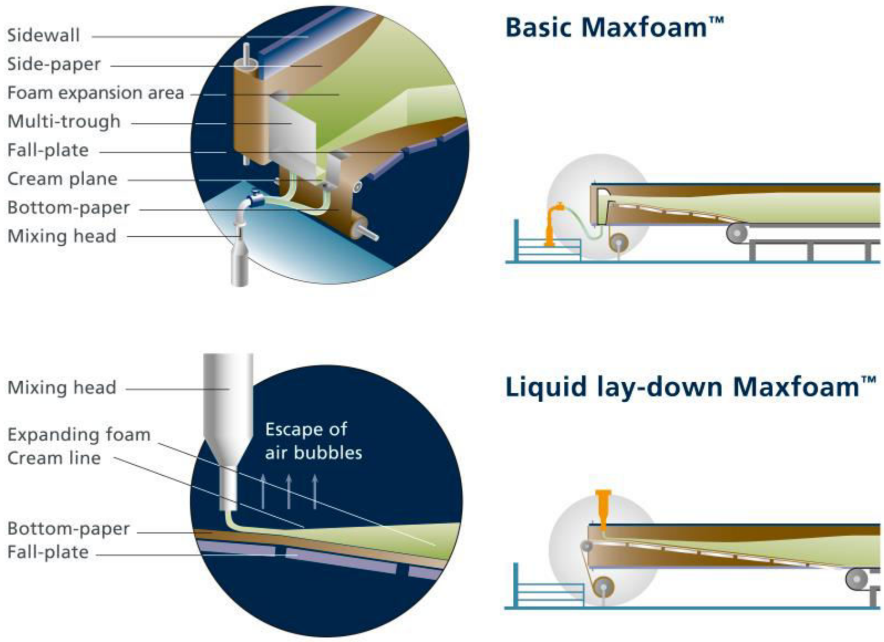

Figure 2: The Maxfoam production process (source: Laader Berg)

Producer Description

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

- Dendro Poland Ltd. Sp. Zo. o

  Ul. Magazinowa 4
  64-610 Rogozno
  Poland
  www.dendro.pl

- Eurofoam GmbH

  Business Park Vienna
  Wienerbergstrasse 7
  1100 Vienna
  Austria
  www.eurofoam.eu

- FoamPartner Group

  Fritz Nauer A.G
  Oberwolfhauserstrasse 9
  8633 Wolfhausen
  Switzerland
  www.foampartner.com

- 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

- Recticel N.V

  Olympiadenlaan 2
  1140 Brussels
  Belgium
  www.recticel.com

- Vita (Group) Unlimited

  Oldham Road
  Middleton, M24 2 DB
  United Kingdom
  www.thevitagroup.com

Eco-profile – Life Cycle Inventory

System Boundaries

PlasticsEurope Eco-profiles and EPDs refer to the production of polymers as a cradle-to-gate system (see Figure 3 and Figure 4).

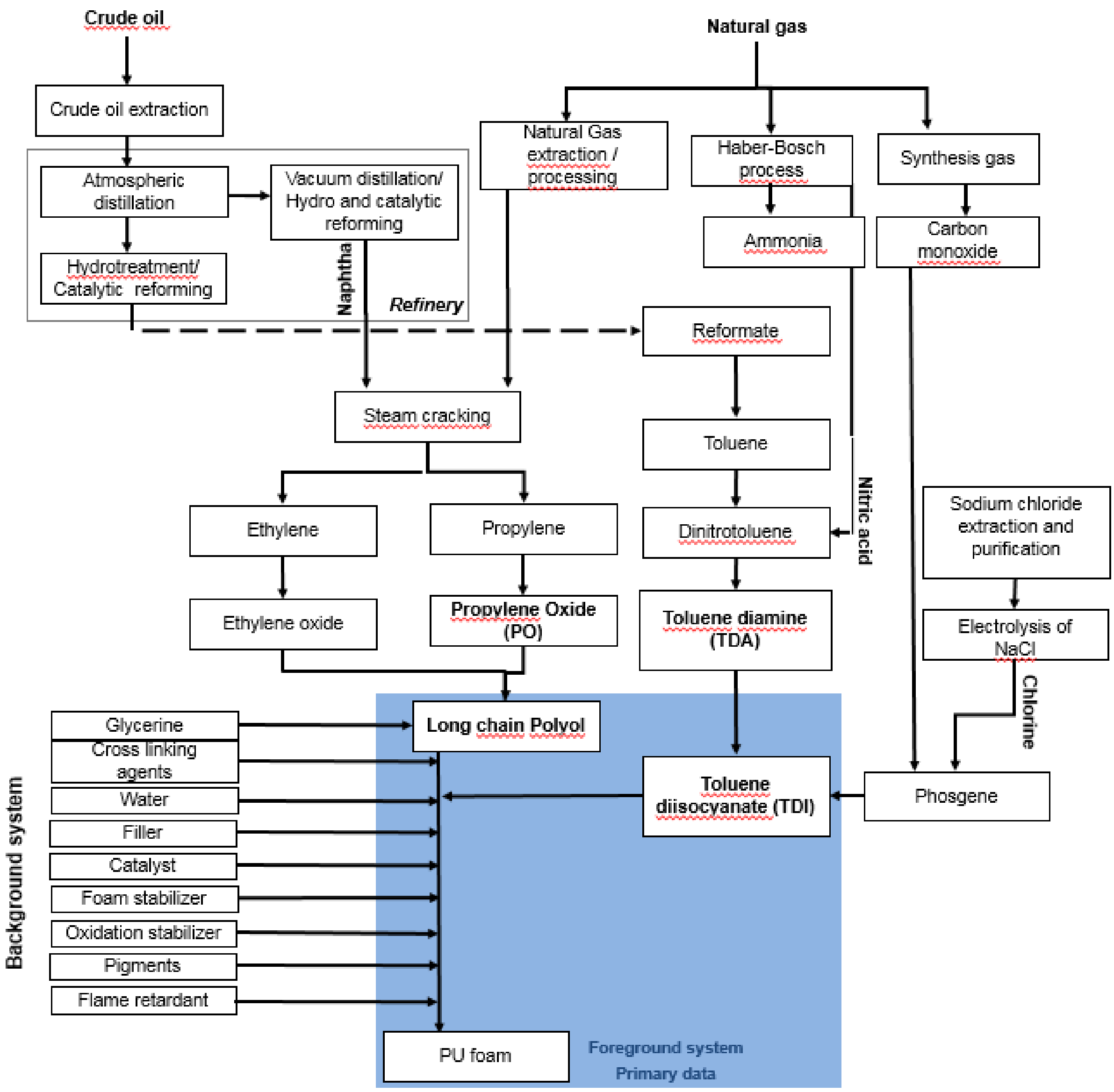

Figure 3: Cradle-to-gate system boundaries TDI based Flexible PU Foam

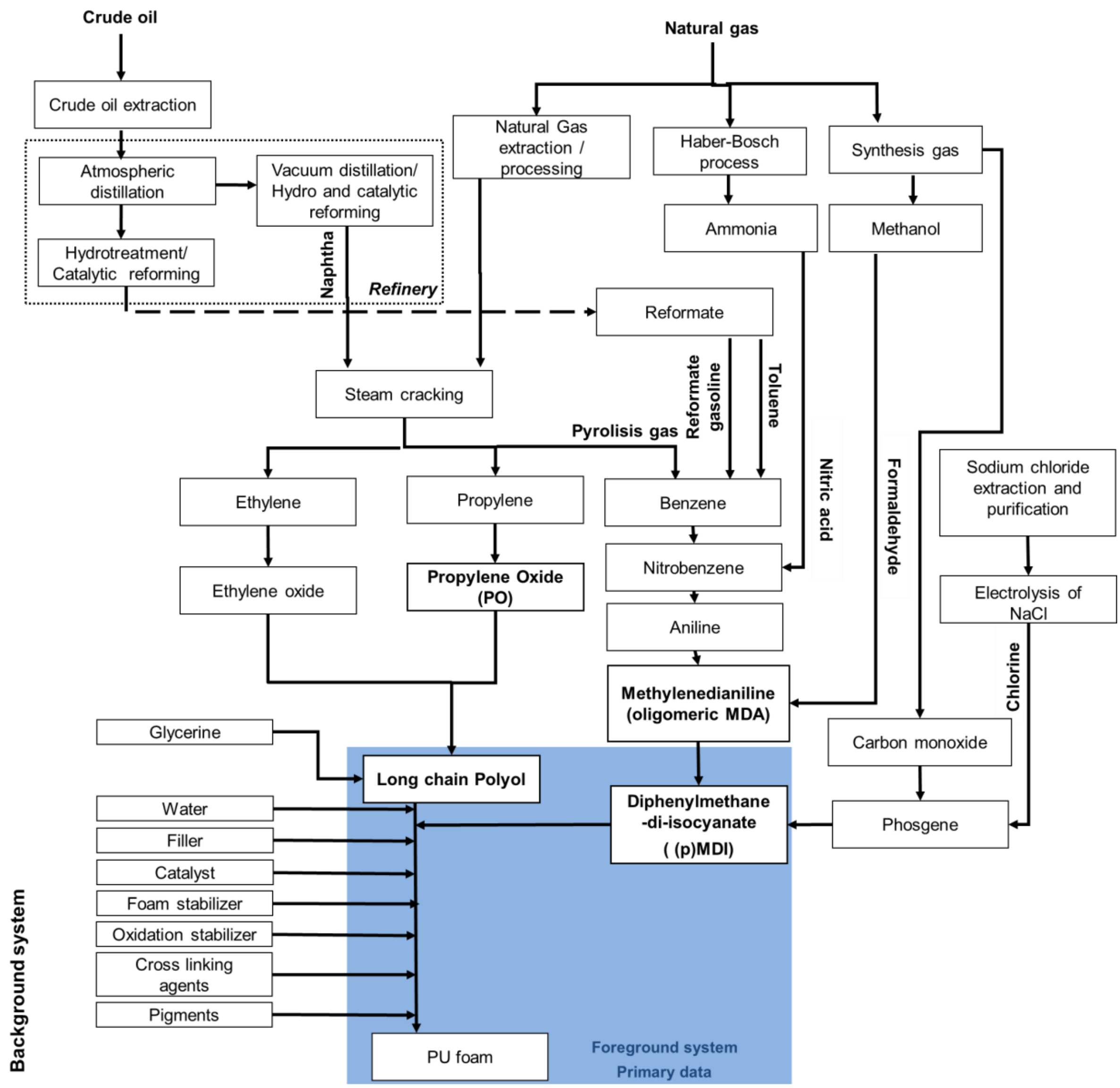

Figure 4: Cradle-to-gate system boundaries MDI based Flexible PU Foam

Within the system boundaries described in both figures below, the following inputs and outputs are considered in the LCA model: Precursors and Process, Other chemicals, Utilities, Electricity, Thermal Energy, Transport, Process waste treatment.

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 Flexible PU foam, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: seven PU foam producers with nine plants in seven different European countries.
This covers 60% of the European Flexible PU Foam production (EU-27) in 2013 [EUROPUR 2014]. 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 Eco-profiles for MDI/TDI and Polyols [ISOPA 2012 PP, ISOPA 2012 TDI-MDI], and from the database of the software system GaBi 6 [GABI 6].

As shown in Figure 3 and Figure 4, two different routes for the production of Flexible PU Foam (TDI-based and MDI based) exist.

Used in both routes, the polyol component of the PU foam, here long chain polyether polyol, is produced by an alkoxylation process. This is an addition reaction where ethylene oxide or propylene oxide reacts with an initiator containing OH-groups. Glycerine is a common initiator but other carbohydrates such as saccharose can be used as well. The alkoxylation process requires a catalyst and in this case, a base like KOH is used for catalysis. The amount of alkoxylation species can be varied to achieve different chain lengths and molecular weights [ISOPA 2012 PP].

The isocyanate components TDI or MDI are produced as follows: Toluene is the primary raw material for industrial TDI manufacture. To produce TDI, toluene is firstly nitrated with mixed acid to produce a mixture of 2,4- and 2,6-dinitrotoluene isomers. Catalytic reduction of the dinitrotoluene mix produces a corresponding mix of diaminotoluenes (TDA), which are subsequently treated with phosgene to produce TDI. In the production of MDI, Methylenedianiline (MDA) is formed firstly through the reaction of formaldehyde with aniline in the presence of a hydrochloric acid catalyst. Phosgene is reacted with the separated MDA to produce crude MDI, which is then purified [ISOPA 2012 TDI-MDI].

To produce flexible PU foam, the two main components polyol and isocyanate are reacted together with the approximative following quantity ratios: 100 parts of polyols and 50 parts of TDI for the TDI-based foam; 100 parts of polyols and 85 parts of MDI for the MDI-based foam.

Temporal Reference

The LCI data for production is collected as 12 month averages representing the year 2013, to compensate seasonal influence of data. Background data have reference years 2011 for electricity and thermal energy processes. The dataset is considered to be valid until substantial technological changes in the production chain occur. In view of the latest technology development, the overall reference year for this Eco-profile is 2013, with a maximum temporal validity until 2023 for the foreground system.

Geographical Reference

Primary production data for flexible PU foam are from seven different European suppliers. For the precursors polyols, MDI and TDI, the geographic reference taken is Europe, as the Eco-profile datasets used reflect representative European production averages. The inventories for other main precursors as well as for 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. Flexible PU foam imported into Europe is not considered in this Eco-profile.

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 2012 TDI-MDI]. For the polyol datasets no cut-off was applied [ISOPA 2012 PP]. According to the GaBi database [GABI 6] used for the other background processes, at least 95% of mass and energy of the input and output flows are covered and 98% of their environmental relevance (according to expert judgement) are considered, hence an influence of cut-offs less than 1% on the total is expected. Transports for the main input materials contribute less than 5% to the overall environmental burden. The contribution of transport of small material proportions is expected to be less than 1%; hence the transports for minor input amounts are excluded.

Data Quality Requirements

Data Sources

Eco-profiles and EPDs developed by PlasticsEurope and other European producer associations use average data representative of the respective foreground production process, both in terms of technology and market share. The primary data are derived from site specific information for processes under operational control supplied by the participating member companies of the associations (see Producer Description).
The life cycle inventory data for the three main precursors long-chain polyether polyol, TDI and MDI are from two 2012 ISOPA Eco-profile studies [ISOPA 2012 PP, ISOPA 2012 TDI-MDI]; further background data are taken from the database of the software system GaBi 6 [GABI 6].
All relevant background data, such as energy and auxiliary materials, is from the GaBi 6 database; the documentation is publicly available [GABI 6].

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 is sourced from the most important flexible PU foam producers in Europe in order 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 60% of the European flexible PU foam production volume in 2014. This figure refers to an educated estimate of EUROPUR and the participating parties of this study [EUROPUR 2014]. 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 6 databases [GABI 6] are used. That is especially why Eco-profile data are used for the main precursors TDI, MDI and polyol. 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 (see 'Internal Independent Quality Assurance Statement').

Reliability

Data of foreground processes provided directly by producers are predominantly measured. Data of relevant background processes are measured at several sites – alternatively, they are determined from literature data, or estimated for some flows, which usually have been reviewed and 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.

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 6 software 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 certain confidence range.

Data Validation

The data on production collected by the project partners and the data providing companies are validated in an iterative process several times. The collected data are validated using existing data from published sources or expert knowledge. The background information from the GaBi database is updated regularly and continuously validated.

Life Cycle Model

The study is performed with the LCA software GaBi 6 [GABI 6]. The associated database integrates ISO 14040/44 requirements [ISO 14040: 2006, ISO 14044: 2006]. 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 external independent 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 5).

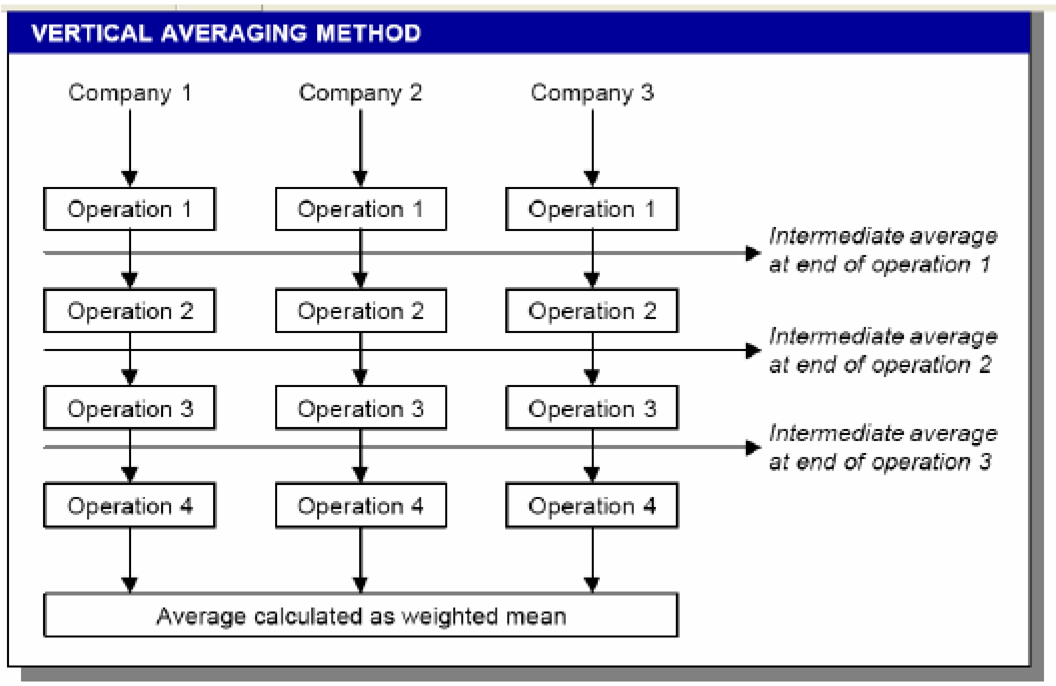

Figure 5: *Vertical Averaging (source: Eco-profile of high volume commodity phthalate esters, ECPI (European Council for Plasticisers and Intermediates, 2001)*

Allocation Rules

Production processes in chemical and plastics industry are usually multi-functional systems, i.e. they have not one, but several valuable product and co-product outputs. Wherever possible, allocation should be avoided by expanding the system to include the additional functions related to the co-products. Often, however, avoiding allocation is not feasible in technical reality, as alternative stand-alone processes 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 [GaBi 6]. 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.gabi-software.com.

In the case of the precursors TDI/MDI, their production process yields hydrogen chloride (HCl) as co-product. In the respective Eco-profile, the co-product HCl was treated by a mass allocation. In the 2012 Eco-profile, a sensitivity analysis was performed on the impacts of mass vs. price allocation on the impact results; the latter was found to increase the impact values by up to 92% [ISOPA 2012 TDI-MDI]. Mass allocation was finally chosen for two reasons: the TDI/MDI production processes have also been optimised to produce HCl in a quality that can be marketed, i.e. HCl is a desired co-product. Moreover, although lower than the TDI/MDI market value, the actual value of HCl cannot be expressed by the market value alone, as HCl would have to be neutralised and disposed as a waste if it was not sold as product.

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

Life Cycle Inventory (LCI) Results

Formats of LCI Dataset

The Eco-profile is provided in four electronic formats:

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

Key results are summarised below.

Energy Demand

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

As a measure of the share of primary energy incorporated in the product, and hence indicating a recovery potential, the **energy content in the polymer** (system output), quantified as the gross calorific value (UHV), is 33,47 MJ/kg for flexible PU foam.

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

Primary Energy Demand	**TDI-based PU foam without FR, density 35 to 40 kg/m³[MJ]**	**TDI-based PU foam without FR, density 18 to 25 kg/m³ [MJ]**	**TDI-based PU foam with FR, density 40 to 54 kg/m³ [MJ]**	**MDI-based vis-coelastic PU foam with-out FR, density 45 to 53 kg/m³ [MJ]**
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	33.47	33.47	33.47	33.47
Process energy (quantified as dif-ference between primary energy demand and energy content of pol-ymer)	58.97	55.84	64.10	55.24
Total primary energy demand	**88.67**	**85.54**	**93.80**	**84.94**

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

Table 2 shows how the total energy input (primary energy demand) is used as fuel or feedstock. Fuel use means generating process energy, whereas feedstock use means incorporating hydrocarbon resources into the polymer. Note that some feedstock input may still be valorised as energy; furthermore, process energy requirements may also be affected by exothermal or endothermal reactions of intermediate products. Hence, there is a difference between the feedstock energy input and the energy content of the polymer (measurable as its gross calorific value). Considering this uncertainty of the exact division of the process energy as originating from either fuels or feedstocks, as well as the use of average data (secondary data) in the modelling with different country-specific grades of crude oil and natural gas, the feedstock energy is presented as approximate data.

Table 2: *Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per 1 kg* ***TDI-based PU foam without FR, density 35 to 40 kg/m³***

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	3.22	0.11		3.22
Oil	38.40	0.85	16.95	21.46
Natural gas	37.45	0.76	16.52	20.92
Lignite	2.48	0.18		2.48
Peat	0.02			0.02
Nuclear	4.09	8.95E-06		4.09
Biomass	0.00			0.00
Hydro	0.45			0.45
Solar	1.92			1.92
Geothermics	2.67E-03			2.67E-03
Waves	1.21E-13			1.21E-13
Wood	1.12E-11			1.12E-11
Wind	0.62			0.62
Other renewable fuels	0.00	0.00	0.00	0.00
Sub-total renewable	**3.00**	**0.00**	**0.00**	**3.00**
Sub-total Non-renewable	**85.67**	**1.91**	**33.47**	**52.20**
Total	**88.67**	**1.91**	**33.47**	**55.20**

Table 3: *Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per 1 kg* ***TDI-based PU foam without FR, density 18 to 25 kg/m³***

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	3.23	0.12		3.23
Oil	36.02	0.80	16.59	19.44
Natural gas	36.67	0.75	16.88	19.78
Lignite	2.46	0.18		2.46
Peat	0.03	0.00		0.03
Nuclear	4.15	9.21E-06		4.15
Biomass	0.00			0.00
Hydro	0.46			0.46
Solar	1.92			1.92
Geothermics	3.15E-03			3.15E-03
Waves	1.06E-13			1.06E-13
Wood	9.80E-12			9.80E-12
Wind	0.60			0.60
Other renewable fuels	0.00	0.00	0.00	0.00
Sub-total renewable	**2.98**	**0.00**	**0.00**	**2.98**
Sub-total Non-renewable	**82.56**	**1.85**	**33.47**	**49.09**
Total	**85.54**	**1.85**	**33.47**	**52.07**

*Table 4: Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per 1 kg **TDI-based PU foam with FR, density 40 to 54 kg/m³***

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	5.01	0.18		5.01
Oil	36.18	0.80	15.74	20.44
Natural gas	40.77	0.83	17.73	23.04
Lignite	2.83	0.21		2.83
Peat	0.02			0.02
Nuclear	4.57	1.01E-05		4.57
Biomass	0.00			0.00
Hydro	0.68			0.68
Solar	2.96			2.96
Geothermics	1.40E-02			1.40E-02
Waves	3.74E-13			3.74E-13
Wood	3.44E-11			3.44E-11
Wind	0.76			0.76
Other renewable fuels	0.00	0.00	0.00	0.00
Sub-total renewable	**4.42**	**0.00**	**0.00**	**4.42**
Sub-total Non-renewable	**89.38**	**2.03**	**33.47**	**55.91**
Total	**93.80**	**2.03**	**33.47**	**60.33**

Table 5: Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per 1 kg ***MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³***

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	3.14	0.11		3.14
Oil	38.50	0.85	17.52	20.98
Natural gas	35.04	0.72	15.95	19.09
Lignite	2.28	0.17		2.28
Peat	0.02			0.02
Nuclear	3.48	7.71E-06		3.48
Biomass	0.00			0.00
Hydro	0.37			0.37
Solar	1.52			1.52
Geothermics	5.17E-03			5.17E-03
Waves	6.39E-14			6.39E-14
Wood	5.89E-12			5.89E-12
Wind	0.59			0.59
Other renewable fuels	0.00	0.00	0.00	0.00
Sub-total renewable	**2.49**	**0.00**	**0.00**	**2.49**
Sub-total Non-renewable	**82.45**	**1.85**	**33.47**	**48.98**
Total	**84.94**	**1.85**	**33.47**	**51.47**

Table 6 shows that nearly all of the primary energy demand is from non-renewable resources. Since the focus scope of EUROPUR and its member companies is the polymer production, Table 7 analyses the types of useful energy inputs in the polymerisation process: electricity has a dominant contribution compared to thermal energy (heat). This represents the share of the energy requirement that is under operational control of the polymer producer, which is about 1% of the total (see Figure 6 and Table 8). The rest and majority (99%) of the primary energy demand is accounted for by upstream (pre-chain) processes. Finally, Table 9 provides a more detailed overview of the key processes along the production system, their contribution to primary energy demand and how this is sourced from the respective energy resources. This puts the predominant contribution of the production into perspective with the precursors (»precursors«). In order to analyse these upstream operations more closely, please refer to the Eco-profiles and GaBi documentations of the respective precursors. It should be noted, however, that the LCI tables in the annex account for the entire cradle-to-gate primary energy demand of the flexible PU foam system.

Table 6: Primary energy demand by renewability per 1 kg PU flexible foam

Fuel/energy input type	TDI-based PU foam without FR, density 35 to 40 kg/m³[MJ]	%	TDI-based PU foam without FR, density 18 to 25 kg/m³ [MJ]	%	TDI-based PU foam with FR, density 40 to 54 kg/m³ [MJ]	%	MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³ [MJ]	%
Renewable energy resources	3.00	3%	2.98	3%	4.42	5%	2.49	3%
Non-renewable energy resources	85.67	97%	82.56	97%	89.38	95%	82.45	97%
Total	**88.67**	**100%**	**85.54**	**100%**	**93.80**	**100%**	**84.94**	**100%**

Table 7: Analysis by type of useful energy (production – key foreground process level) per 1 kg PU flexible foam

Type of useful energy in process input	TDI-based PU foam without FR, density 35 to 40 kg/m³[MJ]	TDI-based PU foam without FR, density 18 to 25 kg/m³ [MJ]	TDI-based PU foam with FR, density 40 to 54 kg/m³ [MJ]	MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³ [MJ]
Electricity	0.13	0.10	0.09	0.13
Heat, thermal energy	0.00	0.02	0.03	0.01
Other types of useful energy (relevant contributions to be specified)	0.00	0.00	0.00	0.00
Total (for selected key unit process)	**0.13**	**0.12**	**0.12**	**0.13**

Table 8: Contribution to primary energy demand (dominance analysis) per 1 kg flexible PU foam

Contribution to Primary Energy per segment	TDI-based PU foam without FR, density 35 to 40 kg/m³[MJ]	%	TDI-based PU foam without FR, density 18 to 25 kg/m³ [MJ]	%	TDI-based PU foam with FR, density 40 to 54 kg/m³ [MJ]	%	MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³ [MJ]	%
Production (electricity, steam, unit process, utilities, waste treatment)	0.78	1%	0.83	1%	1.02	1%	0.93	1%
Pre-chain	87.89	99%	84.71	99%	92.78	99%	84.01	99%
Total	**88.67**	**100%**	**85.54**	**100%**	**93.80**	**100%**	**84.94**	**100%**

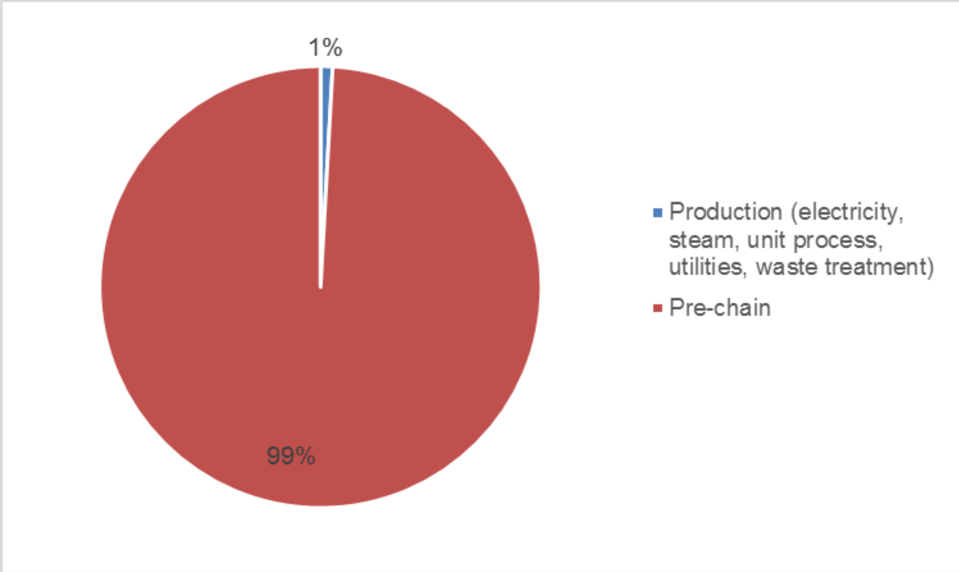

Figure 6: Contribution to primary energy demand per segment for all four flexible PU foam grades

The Table 9 to Table 12 are using groupings to simplify the contributions analysis. The following groupings are defined at the foreground level (PU production process), as sketched on Figure 7 below.

- Precursors – long chain polyether polyol, TDI, MDI, other polymers and direct emissions of PU production process
- other chemicals: filler, catalysts, cross linkers, foam stabilizer, flame retardants, pigments,
- utilities: water, industrial gases
- electricity – under operational control
- thermal energy – under operational control
- transport – under operational control
- process waste treatment – under operational control

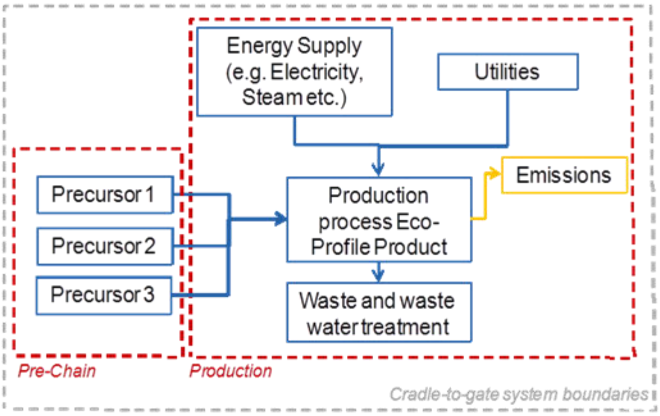

Figure 7: System boundaries and model groupings

Table 9: *Contribution of life cycle stages to total primary energy demand (gross calorific values) per 1 kg TDI-based PU foam without FR, density 35 to 40 kg/m³, see Figure 6*

Total Primary Energy [MJ]	Precursors	Other Chemicals	Utilities	Electricity	Thermal Energy	Transport	Process Waste Treatment
Coal	2.60E+00	5.24E-01	8.54E-03	1.17E-01	2.60E-06	4.67E-03	-3.28E-02
Oil	3.76E+01	3.72E-01	3.61E-02	7.93E-03	3.47E-06	4.38E-01	-5.41E-03
Natural gas	3.61E+01	1.33E+00	1.11E-01	7.85E-02	8.41E-04	4.32E-02	-2.30E-01
Lignite	2.21E+00	2.02E-01	8.59E-03	7.89E-02	3.32E-07	3.75E-03	-2.64E-02
Peat	1.19E-03	2.34E-02	1.15E-04	1.34E-05	6.25E-10	5.83E-05	-4.82E-04
Nuclear	3.82E+00	2.39E-01	1.14E-02	7.44E-02	1.19E-06	7.70E-03	-6.06E-02
Biomass	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydro	3.51E-01	1.00E-01	2.04E-03	5.87E-03	1.15E-06	1.36E-03	-9.81E-03
Solar	1.02E+00	8.12E-01	5.66E-02	2.63E-02	1.72E-06	2.57E-02	-1.33E-02
Geothermics	2.11E-03	6.11E-04	6.41E-05	3.47E-04	3.81E-07	6.90E-05	-5.30E-04
Waves	8.10E-15	1.01E-13	4.17E-15	1.73E-14	1.59E-18	1.41E-15	-1.09E-14
Wood	7.47E-13	9.33E-12	3.84E-13	1.60E-12	1.46E-16	1.30E-13	-1.00E-12
Wind	5.57E-01	5.92E-02	2.84E-03	1.19E-02	4.37E-07	1.26E-03	-9.92E-03
Other renewa-ble fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**84.23**	**3.66**	**0.24**	**0.40**	**0.00**	**0.53**	**-0.39**

Table 10: *Contribution of life cycle stages to total primary energy demand (gross calorific values) per 1 kg TDI-based PU foam without FR, density 18 to 25 kg/m³, see Figure 6*

Total Primary Energy [MJ]	Precursors	Other Chemicals	Utilities	Electricity	Thermal Energy	Transport	Process Waste Treatment
Coal	2.54E+00	5.46E-01	7.75E-03	1.51E-01	2.10E-04	9.51E-03	-2.42E-02
Oil	3.51E+01	4.40E-01	3.25E-02	7.10E-03	8.45E-05	4.59E-01	-3.92E-03
Natural gas	3.53E+01	1.40E+00	7.89E-02	3.16E-02	2.35E-02	5.07E-02	-1.71E-01
Lignite	2.16E+00	2.06E-01	7.64E-03	9.71E-02	1.26E-04	7.80E-03	-1.92E-02
Peat	1.10E-03	2.82E-02	1.07E-04	1.45E-05	3.37E-08	1.26E-04	-3.58E-04
Nuclear	3.91E+00	2.52E-01	1.07E-02	1.12E-02	1.47E-05	1.64E-02	-4.50E-02
Biomass	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydro	3.53E-01	1.02E-01	1.90E-03	4.33E-03	1.18E-05	2.76E-03	-7.28E-03
Solar	9.56E-01	8.81E-01	4.74E-02	1.71E-02	3.22E-05	2.88E-02	-9.83E-03
Geothermics	1.97E-03	8.91E-04	6.48E-05	4.72E-04	2.68E-06	1.44E-04	-3.94E-04
Waves	9.18E-16	1.03E-13	3.64E-15	4.11E-15	1.34E-17	3.02E-15	-8.00E-15
Wood	8.47E-14	9.45E-12	3.35E-13	3.79E-13	1.24E-15	2.78E-13	-7.37E-13
Wind	5.39E-01	6.10E-02	2.55E-03	6.62E-03	9.90E-06	2.70E-03	-7.34E-03
Other renewa-ble fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**80.80**	**3.91**	**0.19**	**0.33**	**0.02**	**0.58**	**-0.29**

Table 11: *Contribution of life cycle stages to total primary energy demand (gross calorific values) per 1 kg TDI-based PU foam with FR, density 40 to 54 kg/m³, see Figure 6*

Total Primary Energy [MJ]	Precursors	Other Chemicals	Utilities	Electricity	Thermal Energy	Transport	Process Waste Treatment
Coal	2.36E+00	2.54E+00	1.60E-02	1.03E-01	4.09E-04	6.33E-03	-1.93E-02
Oil	3.38E+01	1.88E+00	1.22E-01	6.29E-03	1.34E-04	3.56E-01	-3.09E-03
Natural gas	3.26E+01	7.93E+00	2.61E-01	6.52E-02	3.87E-02	3.81E-02	-1.36E-01
Lignite	2.01E+00	7.60E-01	1.91E-02	5.72E-02	2.62E-04	5.18E-03	-1.54E-02
Peat	1.05E-03	1.83E-02	9.81E-05	1.01E-05	6.30E-08	8.33E-05	-2.85E-04
Nuclear	3.48E+00	1.08E+00	1.80E-02	1.12E-02	1.57E-05	1.08E-02	-3.58E-02
Biomass	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydro	3.20E-01	3.61E-01	2.69E-03	3.80E-03	1.01E-05	1.84E-03	-5.79E-03
Solar	9.19E-01	1.96E+00	5.56E-02	1.42E-02	4.58E-05	2.19E-02	-7.82E-03
Geothermics	1.89E-03	1.20E-02	5.07E-05	2.49E-04	7.50E-07	9.55E-05	-3.13E-04
Waves	8.53E-17	3.65E-13	9.59E-15	3.67E-15	7.93E-18	1.99E-15	-6.37E-15
Wood	7.86E-15	3.36E-11	8.84E-13	3.38E-13	7.31E-16	1.84E-13	-5.87E-13
Wind	5.04E-01	2.43E-01	5.43E-03	7.76E-03	1.53E-05	1.78E-03	-5.84E-03
Other renewa-ble fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**75.99**	**16.79**	**0.50**	**0.27**	**0.04**	**0.44**	**-0.23**

Table 12: *Contribution of life cycle stages to total primary energy demand (gross calorific values) per 1 kg MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³, see Figure 6*

Total Primary Energy [MJ]	Precursors	Other Chemicals	Utilities	Electricity	Thermal Energy	Transport	Process Waste Treatment
Coal	2.78E+00	2.27E-01	6.23E-03	1.26E-01	2.09E-05	1.25E-02	-1.74E-02
Oil	3.76E+01	4.73E-01	4.62E-02	9.89E-03	2.80E-05	4.10E-01	-2.81E-03
Natural gas	3.42E+01	7.03E-01	1.22E-01	1.01E-01	6.77E-03	5.01E-02	-1.23E-01
Lignite	2.10E+00	9.65E-02	6.42E-03	8.14E-02	2.67E-06	1.03E-02	-1.38E-02
Peat	1.27E-03	1.85E-02	5.33E-05	1.42E-05	5.03E-09	1.70E-04	-2.57E-04
Nuclear	3.34E+00	1.17E-01	8.61E-03	2.43E-02	9.58E-06	2.18E-02	-3.23E-02
Biomass	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydro	3.20E-01	4.06E-02	1.32E-03	7.06E-03	9.28E-06	3.63E-03	-5.23E-03
Solar	9.70E-01	4.96E-01	9.40E-03	2.47E-02	1.38E-05	2.73E-02	-7.06E-03
Geothermics	3.85E-03	3.74E-04	5.14E-05	9.76E-04	3.07E-06	1.91E-04	-2.83E-04
Waves	5.90E-17	4.74E-14	2.98E-15	1.52E-14	1.28E-17	4.03E-15	-5.75E-15
Wood	5.44E-15	4.37E-12	2.75E-13	1.40E-12	1.18E-15	3.71E-13	-5.30E-13
Wind	5.54E-01	2.83E-02	1.95E-03	1.23E-02	3.52E-06	3.60E-03	-5.27E-03
Other renewa-ble fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**81.81**	**2.20**	**0.20**	**0.39**	**0.01**	**0.54**	**-0.21**

Water Consumption

Table 13 shows the water use at cradle-to-gate level. Water use (incl. fresh- and seawater; blue- and green water) equals the measured water input into a product system or process. Water use is determined by total water withdrawal (water abstraction).

Table 13: Water use (fresh- and seawater; blue- and greenwater) table per 1 kg flexible PU foam (cradle-to-gate)

Input	TDI-based PU foam without FR, density 35 to 40 kg/m³ [kg]	TDI-based PU foam without FR, density 18 to 25 kg/m³ [kg]	TDI-based PU foam with FR, density 40 to 54 kg/m³ [kg]	MDI-based viscoelas-tic PU foam with-out FR, density 45 to 53 kg/m³ [kg]
Water (ground water)	18.63	17.65	21.14	18.56
Water (lake water)	61.42	62.52	120.35	46.52
Water (rain water)	13.99	13.21	15.01	13.53
Water (river water)	1842.46	1851.95	2122.97	1541.67
Water (sea water)	1.54	1.55	4.22	1.43
Water (fossil groundwater)	0.00	0.00	0.00	0.00
Overall water use [kg]	**1938.04**	**1946.88**	**2283.69**	**1621.72**

Table 14 provides the corresponding freshwater part in the water balance. Freshwater is naturally occurring water on the Earth's surface in ponds, lakes, rivers and streams, as ice, and underground as groundwater in aquifers and underground streams. The term specifically excludes seawater and brackish water. Blue water refers to surface and groundwater used.

Table 14: Freshwater (blue water not including rain water) use table per 1 kg flexible PU foam (cradle-to-gate)

Input	TDI-based PU foam without FR, density 35 to 40 kg/m³ [kg]	TDI-based PU foam without FR, density 18 to 25 kg/m³ [kg]	TDI-based PU foam with FR, density 40 to 54 kg/m³ [kg]	MDI-based viscoelastic PU foam with-out FR, densi-ty 45 to 53 kg/m³ [kg]
Water (ground water)	18.63	17.65	21.14	18.56
Water (lake water)	61.42	62.52	120.35	46.52
Water (river water)	1842.46	1851.95	2122.97	1541.67
Water (fossil groundwater)	0.00	0.00	0.00	0.00
Total fresh water use [kg]	**1922.51**	**1932.12**	**2264.46**	**1606.75**

Output	Value [kg]	Value [kg]	Value [kg]	Value [kg]
Water (river water from technosphere, cooling water)	109.69	99.75	113.35	97.53
Water (river water from technosphere, turbined)	1773.22	1795.35	2108.82	1471.45
Water (river water from technosphere, waste water)	16.14	14.86	16.83	15.45
Water (lake water from technosphere, cooling water)	0.00	0.00	0.00	0.00
Water (lake water from technosphere, turbined)	0.00	0.00	0.00	0.00
Water (lake water from technosphere, waste water)	0.00	0.00	0.00	0.00
Total fresh water release from technosphere (degradative use) [kg]	**1899.05**	**1909.95**	**2239.00**	**1584.43**
Total fresh water consumption (blue water)	**23.46**	**22.17**	**25.45**	**22.32**

Figure 8 to Figure 11 display the same results in pie charts. In all cases freshwater use is largely dominated by river water going through hydraulic power plants turbines. Turbined river water also makes up most of freshwater release; overall, the net freshwater consumption is less than 2% of the freshwater use.

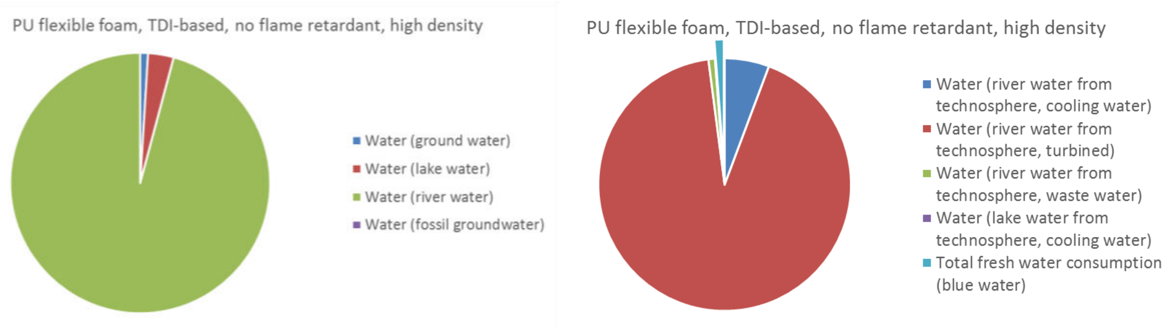

Figure 8 : Total freshwater use (input), freshwater release (output) and freshwater consumption (TDI-based PU foam without FR, density 35 to 40 kg/m³)

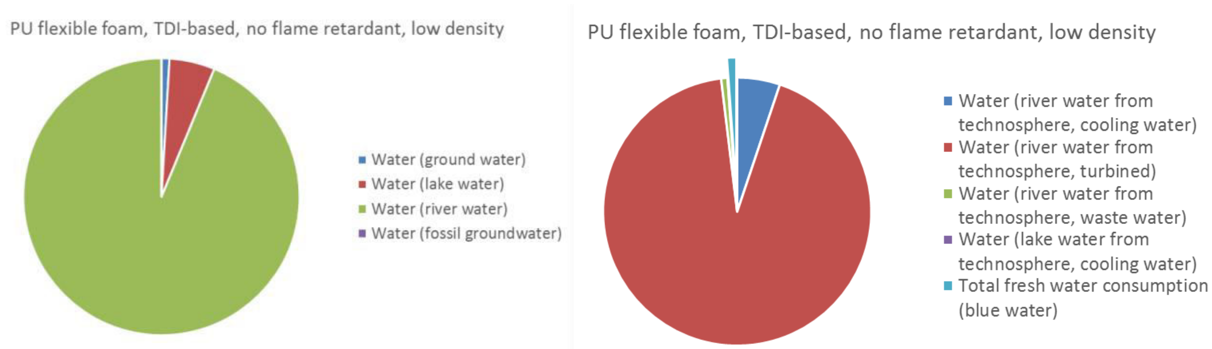

Figure 9: Total freshwater use (input), freshwater release (output) and freshwater consumption (TDI-based PU foam without FR, density 18 to 25 kg/m³)

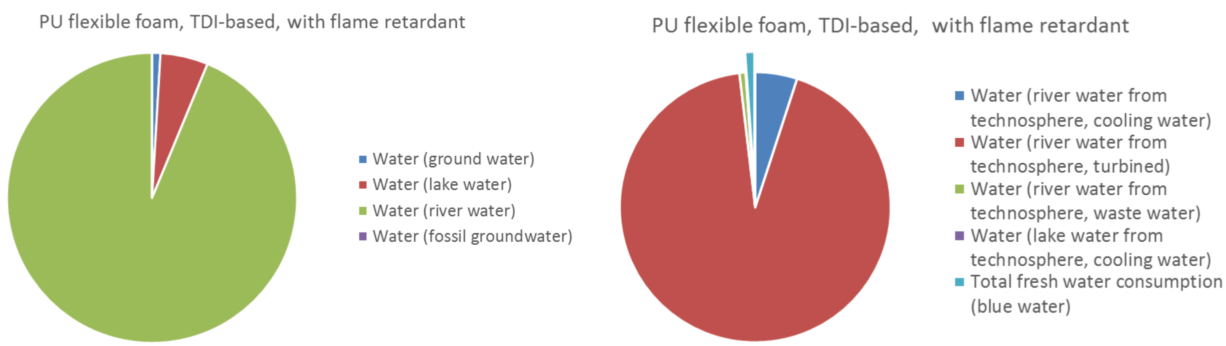

Figure 10: Total freshwater use (input), freshwater release (output) and freshwater consumption (TDI-based PU foam with FR, density 40 to 54 kg/m³)

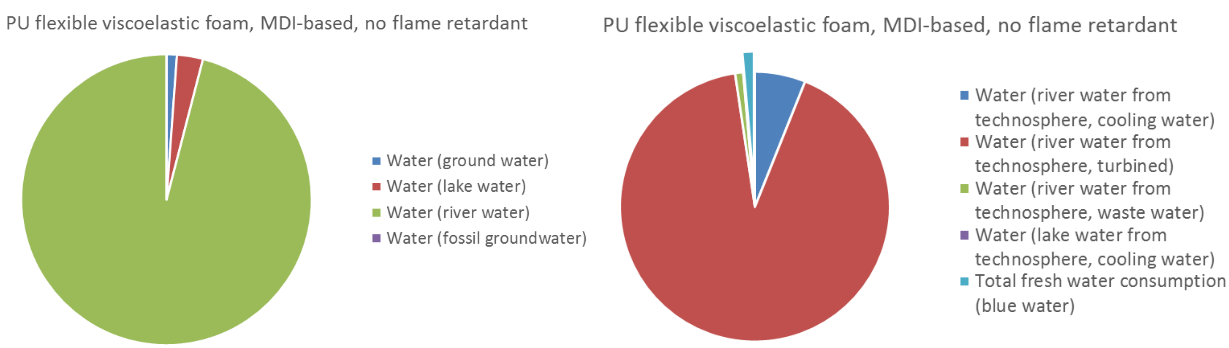

Figure 11: Totalfresh water use (input), freshwater release (output) and freshwater consumption *(MDI-based vis-coelastic PU foam without FR, density 45 to 53 kg/m³*

Table 15 shows the water balance at key foreground process level.

Table 15: Water balance table per 1 kg flexible PU foam (key foreground process level)

Input	**TDI-based PU foam without FR, density 35 to 40 kg/m³ [kg]**	**TDI-based PU foam without FR, density 18 to 25 kg/m³ [kg]**	**TDI-based PU foam with FR, density 40 to 54 kg/m³ [kg]**	**MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³ [kg]**
Water (cooling water)				
Water (process water)				
Water (deionised)	1.39E-02	2.58E-02	8.70E-03	9.02E-03
Water (tap water)	4.71E-03	6.24E-04	0.00E+00	1.76E-01
Water (ground water)				
Water (river water)				
Water (sea water)				
Total water input	**1.86E-02**	**2.64E-02**	**8.70E-03**	**1.85E-01**
Output	**Value [kg]**	**Value [kg]**	**Value [kg]**	**Value [kg]**
Water vapour	1..15E-05	0..00E+00	0..00E+00	0..00E+00
Water (waste water, untreated) to WWTP	8..60E-04	9..14E-05	0..00E+00	1..74E-01
	Water direct released to the environment without WWTP			
Water (river water from technosphere, cooling water)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water (river water from technosphere, turbined)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water (river water from technosphere, waste water)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water (sea water from technosphere, cooling water)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water (sea water from technosphere, turbined)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water (sea water from technosphere, waste water)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water (lake water from technosphere, cooling water)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water (lake water from technosphere, turbined)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total water output	**8.71E-04**	**9.14E-05**	**0.00E+00**	**1.74E-01**

Air Emission Data

Table 16 shows a few selected air emissions which are commonly reported and used as key performance indicators; for a full inventory of air emissions, please refer to the complete LCI table in the annex of this re-port.

Table 16: Selected air emissions per 1 kg flexible PU foam

Air emissions	TDI-based PU foam without FR, density 35 to 40 kg/m³ [kg]	TDI-based PU foam without FR, density 18 to 25 kg/m³ [kg]	TDI-based PU foam with FR, density 40 to 54 kg/m³ [kg]	MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³ [kg]
Carbon dioxide, fossil (CO_2, fossil)	2.87	2.82	3.20	2.67
Carbon monoxide (CO)	1.77E-03	1.77E-03	2.19E-03	1.64E-03
Methane (CH_4)	8.38E-03	8.18E-03	9.25E-03	7.70E-03
Sulphur dioxide (SO_2)	3.16E-03	3.08E-03	3.66E-03	3.04E-03
Nitrogen oxides (NO_x)	4.37E-03	4.25E-03	5.03E-03	4.11E-03
Particulate matter ≤ 10 µm (PM 10)	2.66E-04	2.65E-04	4.77E-04	2.17E-04

Wastewater Emissions

Table 17 shows a few selected wastewater emissions which are commonly reported and used as key performance indicators; for a full inventory of wastewater emissions, please refer to the complete LCI table in the annex of this report.

Table 17: Selected water emissions per 1 kg flexible PU foam

Water emissions	TDI-based PU foam without FR, density 35 to 40 kg/m³ [kg]	TDI-based PU foam without FR, density 18 to 25 kg/m³ [kg]	TDI-based PU foam with FR, density 40 to 54 kg/m³ [kg]	MDI-based viscoelastic PU foam without FR, density 45 to 53 kg/m³ [kg]
Biological oxygen demand after 5 days (BOD 5)	1.58E-04	1.45E-04	1.68E-04	1.44E-04
Chemical oxygen demand (COD)	8.11E-04	7.96E-04	1.09E-03	7.21E-04
Total organic carbon (TOC)	2.29E-05	2.12E-05	2.25E-05	1.98E-05

Solid Waste

Table 18: Solid waste generation per 1 kg TDI-based PU foam without FR, density 35 to 40 kg/m³ [kg] (key foreground process level)

Waste for –	Incineration kg	Landfill kg	Recovery kg	Unspecified kg	Total kg
Non-hazardous	9.35E-03	5.78E-05	7.05E-04	0.00E+00	1.01E-02
Hazardous	1.29E-03	0.00E+00	1.72E-05	0.00E+00	1.30E-03
Unspecified	4.18E-03	0.00E+00	0.00E+00	0.00E+00	4.18E-03
Total	1.48E-02	5.78E-05	7.22E-04	0.00E+00	1.56E-02

Table 19: Solid waste generation per 1 kg TDI-based PU foam without FR, density 18 to 25 kg/m³ [kg] (key foreground process level)

Waste for –	**Incineration kg**	**Landfill kg**	**Recovery kg**	**Unspecified kg**	**Total kg**
Non-hazardous	8.97E-03	6.17E-05	2.14E-03	0.00E+00	1.12E-02
Hazardous	7.61E-04	0.00E+00	1.59E-06	0.00E+00	7.63E-04
Unspecified	6.08E-04	0.00E+00	0.00E+00	0.00E+00	6.08E-04
Total	1.03E-02	6.17E-05	2.14E-03	0.00E+00	1.25E-02

Table 20: Solid waste generation per 1 kg TDI-based PU foam with FR, density 40 to 54 kg/m³ [kg] (key foreground process level)

Waste for –	**Incineration kg**	**Landfill kg**	**Recovery kg**	**Unspecified kg**	**Total kg**
Non-hazardous	6.17E-03	9.87E-05	3.51E-04	0.00E+00	6.62E-03
Hazardous	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Unspecified	2.26E-03	0.00E+00	0.00E+00	0.00E+00	2.26E-03
Total	8.43E-03	9.87E-05	3.51E-04	0.00E+00	8.88E-03

Table 21: Solid waste generation per 1 kg MDI-based viscoelastic PU foam, density 45 to 53 kg/m³ [kg] (key foreground process level)

Waste for –	**Incineration kg**	**Landfill kg**	**Recovery kg**	**Unspecified kg**	**Total kg**
Non-hazardous	6.49E-03	1.24E-04	1.93E-03	0.00E+00	8.55E-03
Hazardous	7.78E-04	0.00E+00	0.00E+00	0.00E+00	7.78E-04
Unspecified	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	7.27E-03	1.24E-04	1.93E-03	0.00E+00	9.33E-03

The End-of-life scenarios for different waste fractions is considered in partial stream calculations; i.e. the resource depletion and emissions referring to incineration and landfilling and the respective credits for energy gain depend on calorific value and actual elementary composition, which is relevant for the life cycle assessment. This is independent from the official attribution into hazardous/non-hazardous categories not consistently provided in the data collection.

Life Cycle Impact Assessment

The results for the impact assessment are calculated applying characterisation factors according CML 2001, latest update April 2013.

Input

Natural Resources

Table 22: Abiotic Depletion Potential per 1 kg flexible PU foam

Natural resources	TDI-based PU foam without FR, density 35 to 40 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	MDI-based vis-coelastic PU foam without FR, density 45 to 53 kg/m³
Abiotic Depletion Potential (ADP), ele-ments [kg Sb eq]	1.57E-05	1.55E-05	3.09E-05	1.00E-05
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	74.97	72.03	77.91	72.62

The impacts of each foam type show more variability in this indicator than for other impact categories. This is mostly due to the different average amounts of one of the stabilizing additives, depending on the foam grade considered.

Output

Climate Change

Table 23: Global Warming Potential (100 years) per 1 kg flexible PU foam

Climate change	TDI-based PU foam without FR, density 35 to 40 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	MDI-based vis-coelastic PU foam with-out FR, density 45 to 53 kg/m³
Global Warming Potential (GWP) [kg CO2 eq.]	3.22	3.18	3.56	2.95

Acidification

Table 24: Acidification Potential per 1 kg flexible PU foam

Acidification of soils and water bodies	TDI-based PU foam without FR, density 35 to 40 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	MDI-based vis-coelastic PU foam without FR, density 45 to 53 kg/m³
Acidification Potential (AP) [g SO_2 eq.]	6.48	6.31	7.40	6.17

Eutrophication

Table 25: Eutrophication Potential per 1 kg flexible PU foam

Eutrophication of soils and water bodies	TDI-based PU foam without FR, density 35 to 40 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	MDI-based vis-coelastic PU foam without FR, density 45 to 53 kg/m³
Eutrophication Potential (EP), total [g PO43- eq.]	0.99	0.99	1.16	0.89

Ozone Depletion

Table 26: Ozone Depletion Potential per 1 kg flexible PU foam

Ozone Depletion Potential	TDI-based PU foam without FR, density 35 to 40 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	MDI-based vis-coelastic PU foam with-out FR, density 45 to 53 kg/m³
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	3.83E-05	4.08E-05	3.53E-05	2.71E-03

Here, the impact of 1kg MDI-based foam on ODP is about 2 orders of magnitude greater than for 1kg of TDI-based foam. This is 99% due to the isocyanate precursor MDI, the ODP impact of which is also two orders of magnitude greater than the one of the TDI precursor.

Summer Smog

Table 27: Photochemical Ozone Creation Potential per 1 kg flexible PU foam

Photochemical Ozone Creation Potential	TDI-based PU foam without FR, density 35 to 40 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	MDI-based vis-coelastic PU foam with-out FR, density 45 to 53 kg/m³
Photochemical Ozone Creation Potential [g Ethene eq.]	1.18	1.12	1.22	1.11

Dust & Particulate Matter

Table 28: PM10 emissions per 1 kg flexible PU foam (includes secondary PM10)

Particulate matter [g PM10 eq.]	TDI-based PU foam without FR, density 35 to 40 kg/m³	TDI-based PU foam without FR, density 18 to 25 kg/m³	TDI-based PU foam with FR, density 40 to 54 kg/m³	MDI-based viscoelas-tic PU foam with-out FR, density 45 to 53 kg/m³
Particulate matter ≤ 2.5 µm	1.50E-01	1.52E-01	3.38E-01	1.20E-01
Particulate matter 2.5-10 µm	1.15E-01	1.13E-01	1.40E-01	9.67E-02
Particulate matter > 10 µm	9.81E-05	9.74E-05	1.35E-04	9.24E-05
Particulate matter total	2.66E-01	2.65E-01	4.77E-01	2.17E-01

Dominance Analysis

Table 29 to Table 32 show the main contributions to the results presented above. A weighted average of the participating producers is used. For the 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 ADP elements. The production of deionised water, included in the group “Utilities” requires salt, which influences the impact category ADP elements more than the other indicators. The group “Other chemicals” covers additives, which also show significant influence to the category ADP elements and explains the different contribution pattern in this category. This group also influences impact categories AP and EP more than the other impact categories.

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 highest potential impacts in nearly all categories.

Moreover, as already seen for the contribution to total primary energy, electrical and thermal energy of the considered foreground production process contributes to a very low share in all impact categories.

Table 29: Dominance analysis of impacts per 1 kg TDI-based PU foam without FR, density 35 to 40 kg/m³

	Total Primary Energy [MJ]	**ADP Elements [kg Sb eq.]**	**ADP Fossil [MJ]**	**GWP [kg CO_2 eq.]**	**AP [g SO_2 eq.]**	**EP [g PO_4^{3-} eq]**	**ODP [g CFC-11 eq]**	**POCP [g Ethene eq.]**
Precursors and Process	95.00%	47.32%	96.20%	93.26%	89.05%	88.37%	99.94%	99.13%
Other chemicals	4.13%	49.77%	3.00%	4.24%	7.15%	5.92%	0.04%	4.37%
Utilities	0.27%	2.88%	0.20%	0.15%	0.50%	1.49%	0.00%	0.24%
Electricity	0.45%	0.01%	0.35%	0.75%	1.67%	0.70%	0.03%	0.58%
Thermal Energy	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Transport	0.59%	0.01%	0.61%	1.03%	2.31%	3.73%	0.00%	-4.01%
Process waste treatment	-0.44%	0.00%	-0.36%	0.56%	-0.67%	-0.21%	-0.02%	-0.32%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 30: Dominance analysis of impacts per 1 kg TDI-based PU foam without FR, density 18 to 25 kg/m³

	Total Primary Energy [MJ]	**ADP Elements [kg Sb eq.]**	**ADP Fossil [MJ]**	**GWP [kg CO_2 eq.]**	**AP [g SO_2 eq.]**	**EP [g PO_4^{3-} eq]**	**ODP [g CFC-11 eq]**	**POCP [g Ethene eq.]**
Precursors and Process	94.46%	47.41%	95.70%	93.03%	87.32%	87.46%	99.96%	98.52%
Other chemicals	4.57%	50.13%	3.34%	4.46%	7.76%	6.69%	0.05%	5.00%
Utilities	0.22%	2.44%	0.16%	0.12%	0.44%	1.22%	0.00%	0.22%
Electricity	0.38%	0.00%	0.37%	0.83%	2.41%	0.85%	0.00%	0.82%
Thermal Energy	0.03%	0.00%	0.03%	0.04%	0.02%	0.01%	0.00%	0.02%
Transport	0.68%	0.01%	0.68%	1.13%	2.59%	3.97%	0.00%	-4.31%
Process waste treatment	-0.34%	0.00%	-0.28%	0.38%	-0.53%	-0.21%	-0.01%	-0.26%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 31: Dominance analysis of impacts per 1 kg TDI-based PU foam with FR, density 40 to 54 kg/m³

	Total Primary Energy [MJ]	**ADP Elements [kg Sb eq.]**	**ADP Fossil [MJ]**	**GWP [kg CO_2 eq.]**	**AP [g SO_2 eq.]**	**EP [g PO_4^{3-} eq]**	**ODP [g CFC-11 eq]**	**POCP [g Ethene eq.]**
Precursors and Process	81.01%	21.99%	83.45%	76.07%	70.34%	68.70%	99.76%	85.79%
Other chemicals	17.90%	76.67%	15.45%	21.76%	26.46%	26.68%	0.24%	16.60%
Utilities	0.53%	1.33%	0.49%	0.48%	0.57%	1.57%	0.00%	0.37%
Electricity	0.29%	0.00%	0.27%	0.55%	1.25%	0.51%	0.00%	0.47%
Thermal Energy	0.04%	0.00%	0.05%	0.06%	0.03%	0.02%	0.00%	0.03%
Transport	0.47%	0.00%	0.48%	0.78%	1.69%	2.63%	0.00%	-3.08%
Process waste treatment	-0.24%	0.00%	-0.20%	0.30%	-0.34%	-0.11%	-0.01%	-0.18%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 32: Dominance analysis of impacts per 1 kg MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³

	Total Primary Energy [MJ]	**ADP Elements [kg Sb eq.]**	**ADP Fossil [MJ]**	**GWP [kg CO_2 eq.]**	**AP [g SO_2 eq.]**	**EP [g PO_4^{3-} eq]**	**ODP [g CFC-11 eq]**	**POCP [g Ethene eq.]**
Precursors and Process	96.31%	70.87%	97.01%	95.19%	91.60%	89.28%	100.00%	100.06%
Other chemicals	2.59%	28.50%	1.92%	2.22%	4.22%	5.62%	0.00%	3.02%
Utilities	0.24%	0.60%	0.23%	0.25%	0.28%	0.46%	0.00%	0.23%
Electricity	0.46%	0.02%	0.40%	0.90%	1.82%	0.82%	0.00%	0.64%
Thermal Energy	0.01%	0.00%	0.01%	0.01%	0.00%	0.00%	0.00%	0.01%
Transport	0.64%	0.02%	0.62%	1.13%	2.47%	3.98%	0.00%	-3.78%
Process waste treatment	-0.24%	0.00%	-0.20%	0.30%	-0.39%	-0.17%	0.00%	-0.19%
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 vs. price allocation on the impact results; the latter was found to increase the potential environmental burdens by 92% for TDI and 55% for MDI regarding the indicators GWP and primary energy [ISOPA 2012 TDI-MDI].

To be coherent with this approach and in order to investigate this uncertainty in potential environmental impacts with respect to flexible PU foam, a sensitivity analysis on the polyurethane foam LCA models was performed, in order to compare results from models either generated with mass-allocated TDI/MDI datasets or with price-allocated datasets. As shown in Table 33 to Table 36, depending on the allocation procedure adopted, taking the mass allocation as a base case, GWP results might increase by up to 27% (price allocation) and primary energy by up to 22% (price allocation) depending on the PU foam grade considered.

Table 33: Sensitivity analysis on the impact of allocation method for 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	Price allocation on TDI	Variation
Global Warming Potential (GWP) [kg CO2 eq]	3.22	3.91	+ 22%
Gross primary energy from resources [MJ]	88.67	103.98	+ 17%

Table 34: Sensitivity analysis on the impact of allocation method for 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	Price allocation on TDI	Variation
Global Warming Potential (GWP) [kg CO2 eq]	3.18	4.05	+ 27%
Gross primary energy from resources [MJ]	85.54	104.58	+ 22%

Table 35: Sensitivity analysis on the impact of allocation method for 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	Price allocation on TDI	Variation
Global Warming Potential (GWP) [kg CO2 eq]	3.56	4.21	+ 18%
Gross primary energy from resources [MJ]	93.80	108.04	+ 15%

Table 36: Sensitivity analysis on the impact of allocation method for TDI precursor datasets; results per 1 kg MDI-based viscoelastic PU foam with-out FR, density 45 to 53 kg/m³

Environmental Impact Category	Mass allocation on MDI	Price allocation on MDI	Variation
Global Warming Potential (GWP) [kg CO2 eq]	2.95	3.41	+ 15%
Gross primary energy from resources [MJ]	84.94	97.11	+ 14%

Comparison of the Present Eco-profile with its Previous Version (2005)

In 2005, an Eco-profile of polyurethane flexible foam was carried out by Boustead based on primary production data from 1996 [BOUSTEAD 2005 PU].

Unfortunately, no detailed information on foreground data and applied background LCIs is available to enable precise comparison with the current Eco-profile. Moreover, the previous Eco-profile covered a single average PU foam type instead of differentiating four different types like in the present version. Finally, in that past Eco-profile, the results consisted mostly of partial life cycle inventory (LCI) results that are too sparse to be reused to calculate a comparative LCIA.

However, even considering the above restrictions, two final life cycle impact assessment (LCIA) results reported in 2005 are still methodologically consistent with the current ones, hence relevant for semi-quantitative comparison: GWP and total primary energy. Table 33 below compares the 2005 results with the current results of TDI-based PU foam with FR (the PU type with the highest impact in both categories of the four considered here):

Table 37: Comparison of the present Eco-profile of flexible PU foam with its previous version (2005)

Environmental Impact Categories	Eco-profile flexible PU foam (2005)	TDI-based PU foam with FR, density 40 to 54 kg/m³ (2015)	Difference
Gross primary energy from resources [MJ]	102.13	93.80	-8%
Global Warming Potential (GWP) [kg CO_2 eq.]	4.66	3.56	-24%

Although the previous model is unavailable for review, interpretations and explanations can be given based on the current results and thinkstep's experience.

The dominance analysis earlier shows that both raw material inputs (main precursors and other chemicals) as well as energy supply have significant impact on the GWP and primary energy results. Therefore, the respective 24% and 8% reduction in GWP and total primary energy reflects the following technological improvements in the last 10 years in the production processes of the precursors as well as the PU foam itself:

- Increased energy efficiency;
- Reduction of greenhouse gases emissions (especially by replacement of high-GWP added blowing agents by in-situ formation of CO_2).

Other factors that have an influence on the current results in reference to the previous study can be qualitatively summarised as follows.

- Changes in the foreground and background system:
  - Higher efficiency due to plants with higher production capacities
  - Improvements in energy management in the supply chain and the processing itself
  - Changes in the energy carrier mix used in the overall process chain
  - Stricter pollution and emissions control, such as exhaust air purification (POCP)
  - Changes in the electricity grid mix, in particular electricity from renewables becoming relevant, caused improvements in all impact categories.
- Methodological changes:

- Compared with the 2005 version, the system boundaries now include the waste treatment of all wastes occurring in the process, so that only elementary flows cross the system boundary: this causes small changes in all impact categories. Please note that for the sake of comparability, waste arising is also reported on a foreground unit process level.

Reviews

Internal Independent Quality Assurance Statement

As part of the overall quality assurance during the preparation of this Eco-profile, *thinkstep AG* conducted an internal review of this work.

Internal Independent Quality Assurance Statement

On behalf of thinkstep AG and its subsidiaries

Document prepared by	Victoire Goust
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Date	07.08.2015

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Signature	
Date	22.04.2015

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External Independent Review Summary

The subject of this critical review is the development of the Eco-profiles for four different grades of Flexible Polyurethane (PU) Foams, i.e. a TDI-based, high density PU foam without flame retardants (FR), a TDI-based, low density PU foam without FR, a TDI-based PU foam with FR and a MDI-based PU foam without FR.

The review process included various meetings/web-conferences between the LCA practitioner and the reviewer, which encompassed a model and database review as well as spot checks of data and calculations. Furthermore, the Eco-profile report was reviewed by the reviewer as well as industry participants involved in this project. Both the results and the report were also presented and discussed in detail with representatives of EUROPUR. All questions and recommendations were taken forward to the LCA practitioner, and the report was adapted and revised accordingly.

Primary industry data were collected for the foreground processes comprising the production of the four grades of flexible PU foam and taking into account the specific production processes of the participating companies. Background data representing the main precursors, i.e. long-chain polyether polyol, TDI and MDI were taken from existing Eco-profiles [ISOPA 2012 PP; ISOPA 2012 MDI-TDI]. All other relevant material and energy inputs were taken from the GaBi database. Primary industry data for the four grades of flexible PU foam was collected from 7 producers and 9 plants, which lead to an estimated overall representativeness of 60% of the installed EU27 production capacity in 2013.

The potential environmental impacts for flexible PU foam are largely dominated by the precursors across all impact categories (except ADPe). Both salt (needed for the production of deionised water) and other additives contribute to the impact category ADPe. The use of both electrical and thermal energy do not contribute to the potential environmental impacts of flexible PU foam production in any significant manner. For further details, please refer to the main report.

Due to the fact that the choice of the allocation approach for the co-product HCl in MDI and TDI production leads to significant differences in potential environmental impact results and was discussed in great detail during the respective project (and in depending other Eco-profile projects afterwards), this also had to be considered in this project. Not least, it is given LCA practice to investigate how different methodological choices in the Eco-profile of flexible PU foam production influence the results. To be consistent with the existing Eco-profile of MDI and TDI, the mass allocation approach was chosen as a base case, and a sensitivity analysis was performed considering a price allocation between TDI/MDI and the co-product HCl. The results of the sensitivity analysis are presented in the main report exemplarily for the indicators GWP and primary energy and show the expected outcomes.

With regards to the comparison of this Eco-profile with a previous version published in 2005 (with data from 1996), the potential environmental burdens for flexible PU foam could be reduced. However, the comparison is difficult due to different methodological aspects as listed in the main report.

The LCA practitioners have demonstrated very good competence and experience, with a track record of LCA projects in the chemical and plastics industry. The critical review confirms that this Eco-profile adheres to the rules set forth in the PlasticsEurope's Eco-profiles and Environmental Declarations – LCI Methodology and PCR for Uncompounded Polymer Resins and Reactive Polymer Precursors (PCR version

2.0, April 2011). As a result, this dataset is assessed to be a reliable and high quality representation of flexible PU foam produced in Europe.

Name and affiliation of reviewer:

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