



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

Long and Short-chain Polyether Polyols for Polyurethane Products ISOPA

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Environmental Product Declaration

Introduction

This Environmental Product Declaration (EPD) is based upon life cycle inventory (LCI) data from 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). EPDs provide environmental performance data, but no information on the economic and social aspects which would be necessary for a complete sustainability assessment. Further, they do not imply a value judgment between environmental criteria.

This EPD describes the production of polyether polyols from cradle to gate (from crude oil extraction to granules or resin at plant). Please keep in mind that comparisons cannot be made on the level of the polyether polyols 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	ISOPA
LCA practitioner	PE International AG
Programme owner	PlasticsEurope
Programme manager, reviewer, database manager	DEKRA Industrial GmbH
Number of plants included in data collection	7 (long-chain polyether polyols) 4 (short-chain polyether polyols)
Representativeness	90% coverage in terms of production volumes
Reference year	2010
Year of data collection and calculation	2011
Expected temporal validity	2022
Cut-offs	No significant cut-offs
Data quality	Very good
Allocation method	Varies, see chapter "Allocation Rules"

Description of the Product and the Production Process

This EPD is for long-chain polyether polyols (MW > 1000 g/mol) and short-chain polyether polyols (MW < 1000 g/mol), polyether polyols used in the production of flexible and rigid polyurethanes (PU).

Polyether polyols are polymeric compounds containing ether groups (R-O-R) and OH- groups. They are liquids at short-chain lengths and when chains are longer, they are waxy solids.

Polyether polyols are one of the precursors of polyurethane foam. There are two types of polyether polyols; short-chain polyether polyols and long-chain polyether polyols. Short-chain polyether polyols are used to produce rigid PU foams while long-chain polyether polyols are used to produce flexible PU foams.

A combination of the different building blocks can be used for a variety of other polyurethane applications. (see Eco-profile Toluene diisocyanate (TDI) & Methylenediphenyl diisocyanate (MDI))

The reference flows, to which all data given in this EPD refer, is 1 kg of long-chain and 1 kg of short-chain polyether polyols.

Production Process

Polyether polyols are produced by the alkoxylation process. An addition reaction takes place where ethylene oxide or propylene oxide reacts with an initiator containing OH- groups like glycerine, saccharose and other carbohydrates. A base like KOH is needed as a catalyst and fed into the solution. The reaction runs under elevated temperature and pressure and is strongly exothermic. The process takes place in a batch reactor. When the reaction is complete, the polyether polyol products are separated from by-products and water by means of precipitation and distillation. The amount of alkoxylation species can be varied to achieve different chain lengths and molecular weights.

Data Sources and Allocation

The main data source was a data collection from European producers of polyether polyol. Primary data on gate-to-gate polyether polyol production is derived from site-specific information for processes under operational control supplied by the participating companies of this study.

Six different producers of long-chain polyether polyols with seven plants in three European countries participated in the primary data collection. They cover 90% polyether polyol producers in Europe (EU27) in 2010.

Three different producers of short-chain polyether polyols with four plants in three European countries participated in the primary data collection. They cover 90% polyether polyol producers in Europe (EU27) in 2010.

The data for the upstream supply chain until the precursors are taken from the database of the software system GaBi 5 [GaBi 5 2011]. All relevant background data such as energy and auxiliary material are also taken from the GaBi databases 2011. Most of the background data used is publicly available and public documentation exists [GaBi 5 2011].

For the main precursor propylene oxide primary data was collected.

Allocation was applied for the production process of single cases, as minor by-products result from these specific polyether polyol production processes. The by-products had lower assignments than the main product polyether polyol. The process intention is the production of polyether polyol only and in case the by-product is sold, price allocation was applied. Nevertheless, for these single cases, mass and price allocation led to differences of less than 1% in the results.

For the main precursor propylene oxide mainly price allocation was applied based on feedback from the producers. The sensitivity analysis has shown that even if mass allocation was applied the differences in the results would be 2-3 %.

Use Phase and End-of-Life Management

Polyether polyols produced from glycerine and propylene oxide are typically used in polyurethane-foam production.

Flexible polyurethane foams produced from TDI or MDI and polyether polyols are typically used in upholstery, mattresses and automotive seats.

Rigid polyurethane foams produced from MDI and polyether polyols have good thermal insulation properties and are used in the manufacture of freezers and refrigerators, and in building and automotive applications.

Post-consumer recycling of polyurethane products is common for applications where high volumes are available and no, or limited, sorting is necessary. A range of mechanical (regrinding, bonding, pressing, and moulding) and chemical (glycolysis, hydrolysis, pyrolysis) recycling technologies are available to produce alternative products and chemical compounds for subsequent domestic, industrial and chemical applications.

For all post-consumer polyurethane waste, for which recycling has not proven to be economically feasible due to complex collection and/or dismantling steps (e.g. automotive shredding), energy recovery is the option of choice.

Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg of long-chain and short-chain polyether polyol. Please note that considering the 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 and fuel energy are presented as a range.

Input Parameters

Indicator	Unit	Value	
		Polyether Polyols	
		Long-chain	Short-chain
Non-renewable energy resources ¹⁾			
• Fuel energy	MJ	38.2 – 42.2	46.4 – 50.4
• Feedstock energy	MJ	44.8 – 48.8	24.8 – 28.8
Renewable energy resources (biomass) ¹⁾			
• Fuel energy	MJ	2.07	8.75
• Feedstock energy	MJ	-	-
Abiotic Depletion Potential			
• Elements	kg Sb eq	7.44E-06	5.20E-06
• Fossil fuels	MJ	77.14	65.94
Renewable materials (biomass) ²⁾	kg	0.073	0.536
Water use	kg	54.4	42.8
• for process	kg	3.6	5.0
• for cooling	kg	50.8	37.8
¹⁾ Calculated as upper heating value (UHV)			
²⁾ Calculated based on biogenic CO input and a carbon content of 40% for 2			

Output Parameters

Indicator	Unit	Value	
		Polyether Polyols	
		Long-chain	Short-chain
GWP	kg CO ₂ eq	2.90	2.20
ODP	g CFC-11 eq	2.65E-05	3.25E-05
AP	g SO ₂ eq	6.19	5.89
POCP	g Ethene eq	1.30	0.70
EP	g PO ₄ eq	0.84	1.19
Dust/particulate matter ³⁾	g PM10	0.103	0.088
Total particulate matter ³⁾	g	0.29	0.27
Waste			
• Non-hazard.	kg	3.98E-03	1.45E-02
• Hazard.	kg	2.20E-06	1.95E-06
³⁾ Including secondary PM10			

Additional Environmental and Health Information

The manufacturers of polyether polyols are working through ISOPA to promote Product Stewardship and responsible practice in the value chain. These activities include driver training, tank farm assessments and HSE training in the use of polyurethane raw materials through the “Walk the Talk” programme.

Additional Technical Information

Polyether polyols are raw materials for polyurethane materials. The intrinsic product qualities of polyurethanes are: lightweight, strong, durable, resistant to abrasion and corrosion. In addition, polyurethane insulation materials in building applications, refrigerators and freezers enable very large energy savings in heating & cooling to be made.

Additional Economic Information

Polyether polyols are raw materials for polyurethane materials. Polyurethane materials find wide application as coatings, flexible foams, rigid foams and elastomers. Fields of application include construction, transport, clothing, shoes, bedding, furniture, refrigerators and freezers.

Information

Data Owner

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E-mail: main@isopa.org.

Programme Manager & Reviewer

DEKRA Industrial GmbH

This Environmental Product Declaration has been reviewed by DEKRA Industrial GmbH. It was approved according to the Product Category Rules PCR version 2.0 (2011-04) and ISO 14025:2006.

Registration number: PlasticsEurope 2012-0002, valid until 30 April 2015 (date of next revalidation review).

Programme Owner

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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 <http://www.plasticseurope.org/>.

References

- Product photographs on cover with kind permission by BASF SE.
- PlasticsEurope: Eco-profiles and environmental declarations – LCI methodology and PCR for uncompounded polymer resins and reactive polymer precursor (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. 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, or 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 specified¹):

1 kg of primary long-chain respectively short-chain polyether polyol »at gate« (production site output) representing a European industry production average.

Product and Producer Description

Product Description

- IUPAC name: Polyether Polyol
- chemical formula: $\text{HO}-(\text{AO})_m\text{ZO}-(\text{BO})_n-\text{H}$ (A, Z, B...organic rest)

Polyether polyols are polymeric organic compounds including ether groups (R-O-R) and hydroxyl groups (OH). They are liquids at short-chain lengths (short-chain polyether polyols, MW < 1000 g/mol) and when chains are longer (long-chain polyether polyols, MW > 1000 g/mol), they are waxy solids. The following picture shows the polypropylene oxide triol as an example.

Polyether polyols are one of the pre-cursors of polyurethane foam. There are two main types of polyether polyols, short-chain polyether polyols and long-chain polyether polyols. Short-chain polyether polyols combined with MDI-are used to produce rigid foams, while long-chain polyether polyols combined with TDI resulting in flexible foams. Later in this report, short-chain and long-chain polyether polyols are discussed separately. For this description an average of all polyether polyols is shown.

Production Process

Polyether polyols are produced by 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.

The reaction mechanism is shown below. In the first step, the initiator is turned into an alcoholate-anion by the base. In the second step, the epoxide (propylene oxide) is added to the anion by ring opening. The resulting epoxide-based monomer then combines with other resulting monomers to achieve longer polymer chains.

¹ Exceptions can occur when reporting Eco-profiles of, for instance, process energy, such as on-site steam, or conversion processes, such as extrusion.

The following equation shows the example of polypropylene glycol produced by propylene glycol and propylene oxide:

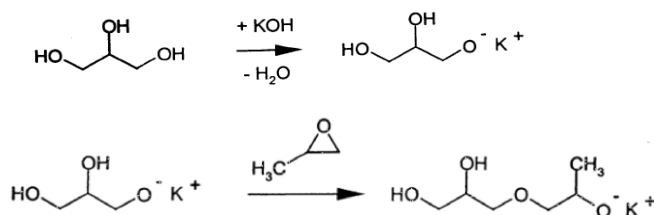


Figure 1: Example for the production of a polyether polyol

The process takes place in a batch reactor. It starts with the introduction of the initiator and the base into the reactor to start the first reaction step shown above. After this the epoxide is added. The reaction runs under elevated temperature (ca. 100- 130°C) [SCIEN 2001] and pressure (ca. 2-5bar) [SCIEN 2001] and is strongly exothermic so the heat given off has to be removed.

The final product (polyether polyol) has to be purified i.e. separated from the spent catalyst and the by-products. To remove the catalyst, an acid is introduced which reacts with the base to form an insoluble salt which is easily removed by filtering. The other by-products are removed by distillation.

The main process feedstocks, propylene oxide and ethylene oxide, are derived from propylene or ethylene, both of which are products of petroleum cracking.

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 European plastics industry as represented by PlasticsEurope's membership and the production sites participating in the Eco-profile data collection. The following companies contributed data to this Eco-profile and EPD:

- BASF Polyurethanes Europe
PO Box 1140
D-49448 Lemfoerde
Germany
www.polyurethanes.basf.de
- Huntsman Polyurethanes
Everslaan 45
B-3078 Everberg
Belgium
www.huntsman.com
- Bayer MaterialScience AG
D-51373 Leverkusen
Germany
www.bayermaterialscience.com
- Repsol
Paseo de la Castellana 278-280
ES- 28046, Madrid
Spain
www.repsol.com
- The Dow Chemical Company
Bachtobelstrasse 3
CH-8810 Horgen
Switzerland
www.dow.com
- Deutsche Shell Chemie GmbH
Rheinland Raffinerie Wesseling
Ludwigshafener Straße
D-50389 Wesseling
Germany
www.shell.de

Life Cycle Inventory

System Boundaries

PlasticsEurope Eco-profiles and EPDs refer to the production of polymers as a cradle-to-gate system (see Figure 2 for long-chain polyether polyols and Figure 3 for short-chain polyether polyols).

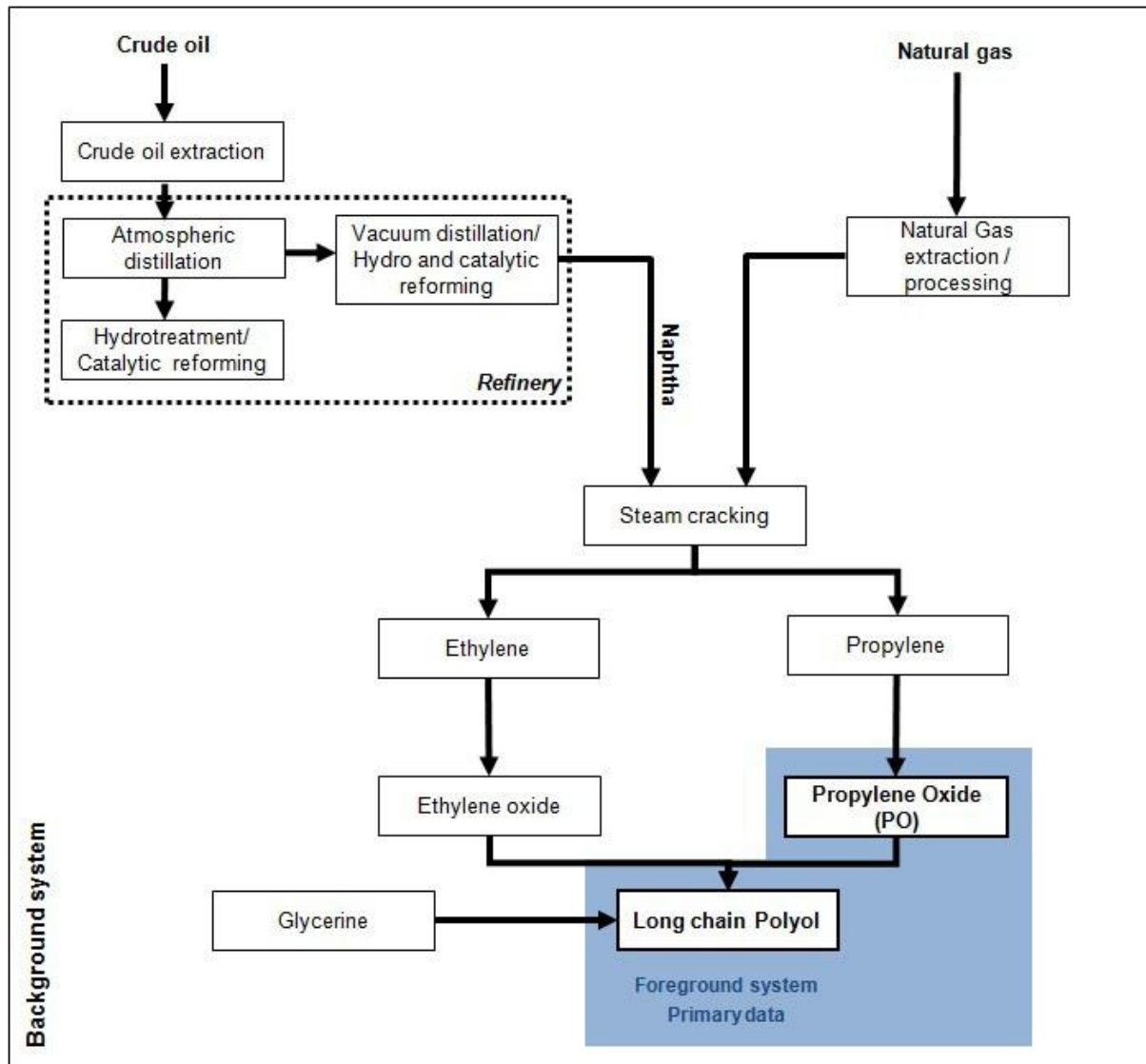


Figure 2: Cradle-to-gate system boundaries (long-chain polyether polyols)

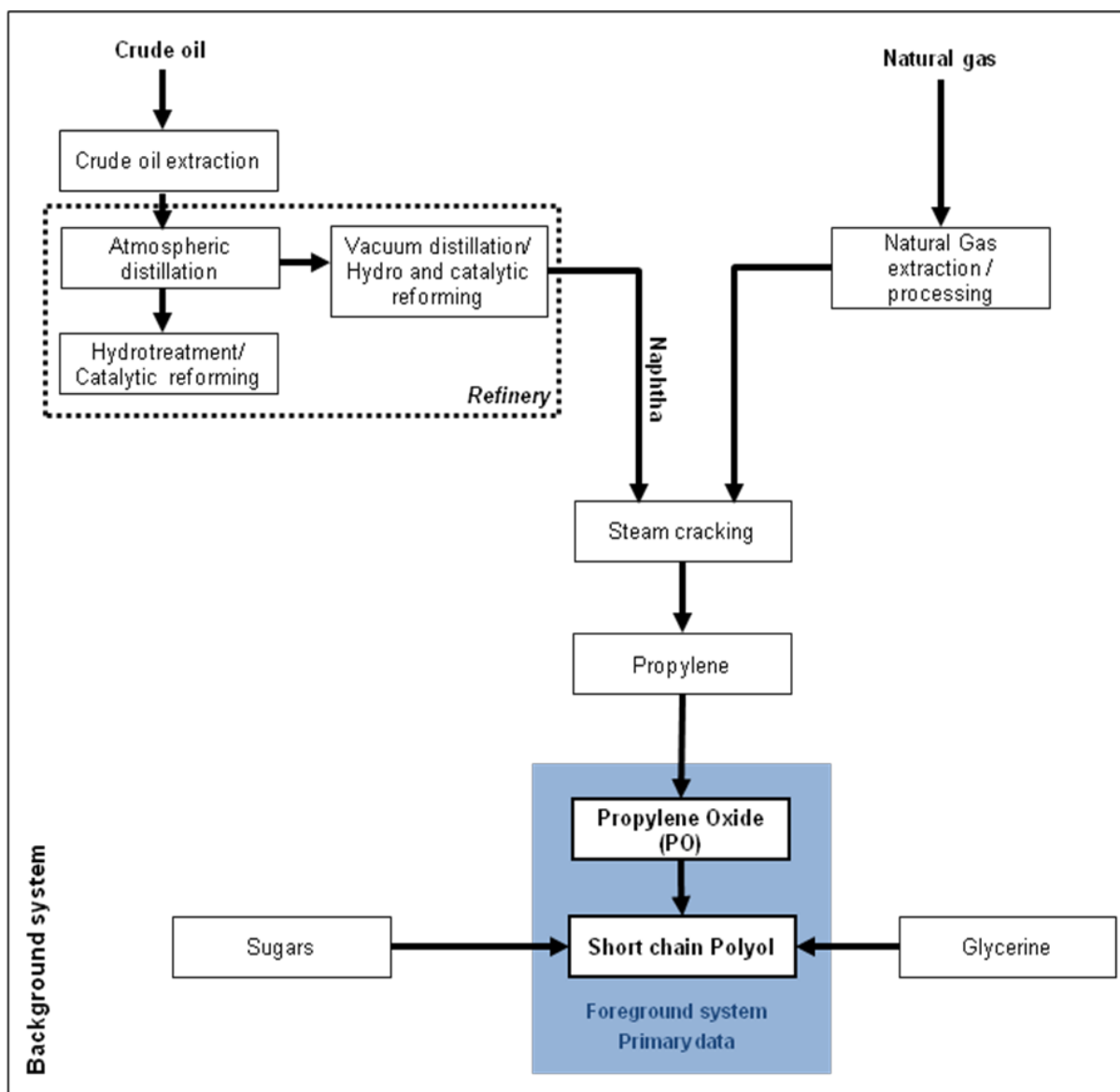


Figure 3: Cradle-to-gate system boundaries (short-chain polyether polyols)

Technological Reference

The production processes were modelled using specific values from primary data collection at site, representing the specific technology for the six companies. The LCI data represent technology in use in the defined production region employed by participating producers. The considered participants cover 90% of the European production in 2010.

Primary data were used for all foreground processes (under operational control) complemented with primary data for the precursor propylene oxide and secondary data from background processes (under indirect management control).

Temporal Reference

The LCI data for production was collected as 12 month averages representing the year 2010, to compensate seasonal influence of data. Background data have reference years from 2010. The dataset is considered to be valid until substantial technological changes in the production chain occur. Having the latest technology development

in mind, the companies participating in this Eco-profile defines as temporal reference: the overall reference year for this Eco-profile is 2010 with a maximal temporal validity until 2022.

Geographical Reference

Primary production data for flexible polyether polyol production is from six different suppliers in the EU. For rigid polyether polyol production data is from three different European suppliers. Fuel and energy inputs in the system reflect average European conditions and whenever applicable, site specific conditions were applied, to reflect representative situations. Therefore, the study results are intended to be applicable within EU boundaries and in order to be applied in other regions adjustments might be required. Polyether polyol imported into Europe was not considered in this Eco-profile.

Cut-off Rules

In the foreground processes all relevant flows were considered, trying to avoid any cut-off of material and energy flows. In single cases additives used in the polyether polyols unit process (<0.1 % m/m of product output) were neglected. In all cases it was assured that no hazardous substances or metals were present in this neglected part.

According to the GaBi Databases 2011 [GaBi 5 2011], 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. All transports in the pre-chain contribute maximum 0.2 % to the overall environmental burden. Including production the contribution of all transports is expected to be less than 1 %, thus transports are excluded from this investigation.

Data Quality Requirements

Data Sources

Eco-profile and EPDs developed by ISOPA 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 ISOPA (see Producer Description). The data for the upstream supply chain are taken from the life cycle database of the software system GaBi 5 [GaBi 5 2011]. For the most relevant intermediate to the polyether polyol processes, propylene oxide, primary data for the production was provided.

All relevant background data such as energy and auxiliary material are also taken from the GaBi databases 2011. Most of the background data used is publicly available and public documentation exists. The dominance analysis (Table 35 and Table 36) showed that the contribution of these background datasets on impact indicators is limited, with the exception of the indicators ADP elements and EP.

Relevance

With regard to the goal and scope of this Eco-profile, the collected primary data of foreground processes are of high relevance, i.e. data was sourced from the most important polyether polyol producers in Europe in order to generate a European industry average. The environmental contributions of each process to the overall LCI results are included in the Chapter 'Life Cycle Impact Assessment'.

Representativeness

The considered participants covered 90% of the polyether polyol production in Europe in 2010. The selected background data can be regarded as representative for the intended purpose, as it is average data and not in the focus of the analysis.

Consistency

To ensure consistency only primary data of the same level of detail and background data from the GaBi databases 2011 [GaBi 5 2011] were used. While building up the model, cross-checks concerning the plausibility of mass and energy flows were continuously conducted. The methodological framework is consistent throughout the whole model as the same methodological principles are used both in foreground and background system.

Reliability

Data reliability ranges from measured to estimated data. Data of foreground processes provided directly by producers were predominantly measured. Data of relevant background processes were measured at several sites or determined by literature data or estimated for some flows, which usually have been reviewed and checked for its quality.

Completeness

Primary data used for the gate-to-gate production of polyether polyol covers all related flows in accordance with the cut off criteria. In this way all relevant flows were quantified and data is considered complete.

Precision and Accuracy

As the relevant foreground data is primary data or modelled based on primary information sources of the owner of the technology, better precision is not reachable within this goal and scope. All background data is consistently GaBi professional data with related public documentation.

Reproducibility

All data and information used are either documented in this report or they are available from the processes and process plans designed within the GaBi 5 software. The reproducibility is given for internal use since the owners of the technology provided the data and the models are stored and available in a database. Sub-systems are modelled by 'state of art' technology using data from a publicly available and internationally used database. It is worth noting that for external audiences, it may be the case that full reproducibility in any degree of detail will not be available for confidentiality reasons. However, experienced experts would easily be able to recalculate and reproduce suitable parts of the system as well as key indicators in a certain confidence range.

Data Validation

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

The background information from the GaBi databases 2011 is updated regularly and validated and benchmarked daily by its various users worldwide.

Life Cycle Model

The study has been performed with the LCA software GaBi 5 [GaBi 5 2011]. The associated databases integrate 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, i.e. that the averaging is done after modelling the specific processes.

Calculation Rules

Vertical Averaging

When modelling and calculating average Eco-profiles from the collected individual LCI datasets, vertical averages were calculated (Figure 4).

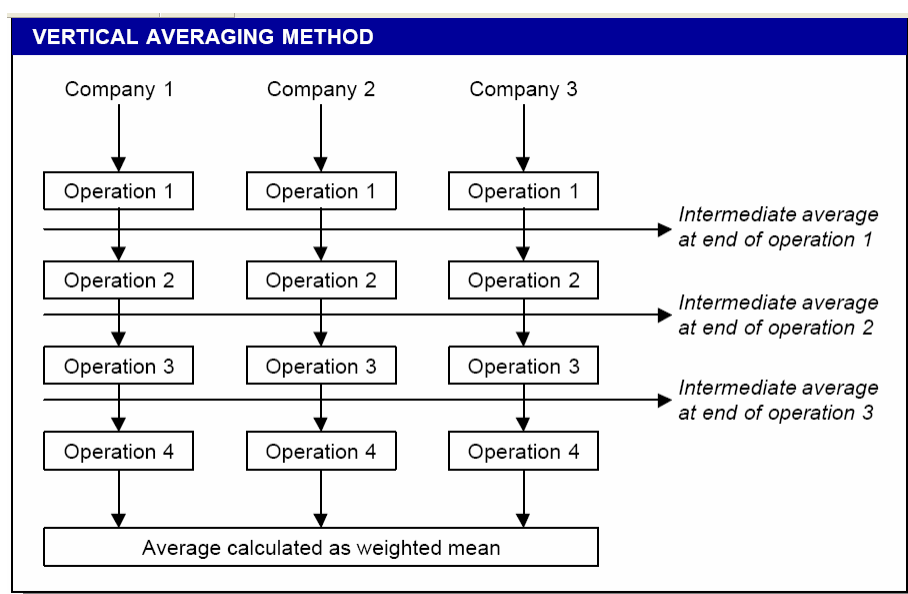


Figure 4: Vertical Averaging (source: Eco-profile of high volume commodity phthalate esters, ECPI European Council for Plasticisers and Intermediates, 2001)

Allocation Rules

Production processes in the 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 in reality or alternative technologies show completely different technical performance and product quality output. In such cases, the aim of allocation is to find a suitable partitioning parameter so that the inputs and outputs of the system can be assigned to the specific product sub-system under consideration.

Allocation was applied for the production process of single cases, as minor by-products result from these specific polyether polyol production processes. The by-products had lower assignments than the main product polyether polyol. The process intention is the production of polyether polyol only and in case the by-product is sold, price allocation was applied. Nevertheless, for these single cases, mass and price allocation led to differences of less than 1% in the results.

For the main precursor propylene oxide mainly price allocation was applied based on feedback from the producers. The sensitivity analysis has shown that even if mass allocation was applied the differences in the results would be 2–3 %.

In the refinery operations, co-production was addressed by applying allocation based on mass and net calorific value [GaBi 5 2011]. The chosen allocation in refinery is based on several sensitivity analyses, which was accompanied by petrochemical experts. The relevance and influence of possible other allocation keys in this context is small. In steam cracking allocation according to net calorific value is applied. Relevance of other allocation rules (mass) is below 2 %.

Life Cycle Inventory (LCI) Results

Formats of LCI Dataset

The Eco-profile is provided in three 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>)

Key results are summarised below.

Energy Demand

As a key indicator on the inventory level, the primary energy demand (system input) of 89.1 MJ/kg long-chain polyether polyols and 83.9 MJ/kg short-chain polyether polyols 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 35 – 40 MJ/kg.

Table 1: Primary energy demand (system boundary level) per 1kg long-chain polyether polyols

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	35 – 40
Process energy (quantified as difference between primary energy demand and energy content of polymer)	49.1 – 54.1
Total primary energy demand	89.1

Table 2: Primary energy demand (system boundary level) per 1kg short-chain polyether polyols

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	35 – 40
Process energy (quantified as difference between primary energy demand and energy content of polymer)	43.9 – 48.9
Total primary energy demand	83.9

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

Table 3 and Table 4 show 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 a range.

Table 3: Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per 1kg long-chain polyether polyols

Primary energy re- source input	Total Energy In- put [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	2.65	0.10	0.00	2.65
Oil	43.35	0.96	33.6 – 35.6	7.99 – 9.99
Natural gas	35.59	0.73	11.2 – 13.2	22.39 – 24.39
Lignite	2.24	0.17	0.00	2.24
Nuclear	3.20	7.10E-06	0.00	3.20
Biomass				
Hydro	0.32	0.00	0.00	0.32
Solar	1.17	0.00	0.00	1.17
Geothermics	0.00	0.00	0.00	0.00
Waves	0.00	0.00	0.00	0.00
Wood	0.00	0.00	0.00	0.00
Wind	0.58	0.00	0.00	0.58
Other renewable fuels	0.00	0.00	0.00	0.00
Sub-total renewable	2.07	0.00	0.00	2.07
Sub-total Non- renewable	87.04	1.95	44.8 – 48.8	38.24 – 42.24
Total	89.11	1.95	44.8 – 48.8	40.31 – 44.31

Table 4: Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per 1kg short-chain polyether polyols

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	2.66	0.10	0.00	2.66
Oil	29.19	0.65	18.8 – 20.8	8.39 – 10.39
Natural gas	38.10	0.78	6 - 8	30.10 – 32.10
Lignite	1.99	0.15	0.00	1.99
Nuclear	3.26	7.22E-06	0.00	3.26
Biomass				
Hydro	0.29	0.00	0.00	0.29
Solar	7.96	0.00	0.00	7.96
Geothermics	0.00	0.00	0.00	0.00
Waves	0.00	0.00	0.00	0.00
Wood	0.00	0.00	0.00	0.00
Wind	0.50	0.00	0.00	0.50
Other renewable fuels	0.00	0.00	0.00	0.00
Sub-total renewable	8.75	0.00	0.00	8.75
Sub-total Non-renewable	75.19	1.67	24.8 – 28.8	46.39 – 50.39
Total	83.94	1.67	24.8 – 28.8	55.14 – 59.14

Table 5 and Table 6 show that nearly all of the primary energy demand is from non-renewable resources. Since the scope of ISOPA and their member companies is the polyether polyol production, Table 7 and Table 8 analyses the types of useful energy inputs in the polymerisation: electricity has a minor contribution, whereas the majority is thermal energy (heat). This represents the share of the energy requirement that is under operational control of the polyether polyol producer (Figure 5). Accordingly, Table 9 and Table 10 show that the majority (98 % for long-chain and short-chain polyether polyols) of the primary energy demand is accounted for by upstream processes. Finally, Table 11 and Table 12 provide a more detailed overview of the key processes along the production systems, 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 (»other chemicals«). In order to analyse these upstream operations more closely, please refer to the Eco-profiles 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 long-chain and short-chain polyether polyols systems.

Table 5: Primary energy demand by renewability per 1kg long-chain polyether polyols

Fuel/energy input type	Value [MJ]	%
Renewable energy resources	2.07	2%
Non-renewable energy resources	87.04	98%
Total	89.11	100%

Table 6: Primary energy demand by renewability per 1kg short-chain polyether polyols

Fuel/energy input type	Value [MJ]	%
Renewable energy resources	8.75	10%
Non-renewable energy resources	75.19	90%
Total	83.95	100%

Table 7: Analysis by type of useful energy (Polyether Polyol production – unit process level) per 1kg long-chain polyether polyols

Type of useful energy in process input	Value [MJ]
Electricity	0.26
Heat, thermal energy	0.59
Other types of useful energy (relevant contributions to be specified)	0.00
Total (for selected key process)	0.85

Table 8: Analysis by type of useful energy (Polyether Polyol production – unit process level) per 1kg short-chain polyether polyols

Type of useful energy in process input	Value [MJ]
Electricity	0.37
Heat, thermal energy	1.32
Other types of useful energy (relevant contributions to be specified)	0.00
Total (for selected key process)	1.69

Table 9: Contribution to primary energy demand (dominance analysis) per 1kg long-chain polyether polyols

Contribution to Primary Energy per segment	Value [MJ]	%
Production (electricity, steam, unit process, utilities, waste treatment)	2	2%
Pre-chain	88	98%
Total	89	100%

Table 10: Contribution to primary energy demand (dominance analysis) per 1kg short-chain polyether polyols

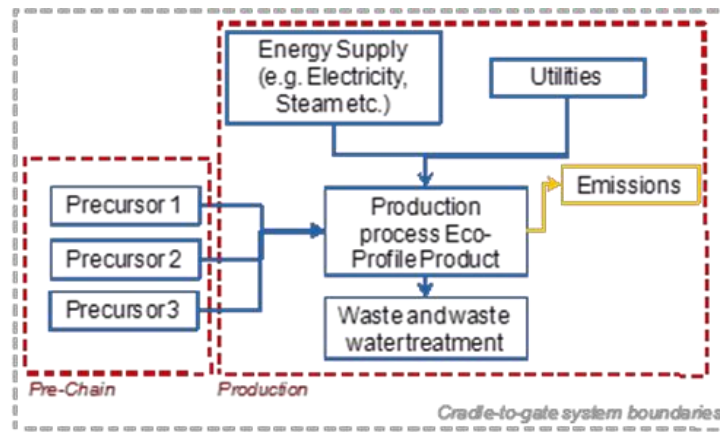
Contribution to Primary Energy per segment	Value [MJ]	%
Production (electricity, steam, unit process, utilities, waste treatment)	2	2%
Pre-chain	82	98%
Total	84	100%

Table 11: Contribution of life cycle stages to total primary energy demand (gross calorific values) per 1kg long-chain polyether polyols, see Figure 5

Total Primary Energy [MJ]	PO and Polyether Polyols process	Other Chemicals	Utilities	Electricity	Thermal Energy	Process Waste Treatment
Coal	2.22	0.34	0.02	0.05	1.05E-03	8.29E-04
Oil	38.84	4.76	0.01	0.02	2.51E-03	1.51E-03
Natural gas	31.15	3.20	0.04	0.39	0.84	-8.57E-04
Lignite	2.03E+00	1.76E-01	5.69E-03	3.47E-03	1.35E-04	5.40E-04
Nuclear	2.61E+00	3.70E-01	3.91E-02	1.59E-01	1.18E-03	5.46E-04
Biomass	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	2.64E-01	3.84E-02	2.43E-03	1.09E-02	1.84E-04	6.23E-05
Solar	5.45E-01	5.97E-01	3.87E-03	1.44E-02	2.26E-04	1.20E-04
Geothermics	1.93E-03	4.80E-04	2.48E-05	8.34E-06	2.09E-07	1.68E-06
Waves	0.00	0.00	0.00	0.00	0.00	0.00
Wood	0.00	0.00	0.00	0.00	0.00	0.00
Wind	4.88E-01	6.35E-02	3.46E-03	2.01E-02	2.47E-04	1.07E-04
Other renewable fuels	0.00	0.00	0.00	0.00	0.00	0.00
Total	78.16	9.54	0.12	0.67	0.84	0.00

Table 12: Contribution of life cycle stages to total primary energy demand (gross calorific values) per 1kg short-chain polyether polyols, see Figure 5

Total Primary Energy [MJ]	PO and Polyether Polyols process	Other Chemicals	Utilities	Electricity	Thermal Energy	Process Waste Treatment
Coal	1.53	1.10	0.03	0.00	0.00	0.00
Oil	23.54	5.66	0.01	0.00	0.00	0.00
Natural gas	24.88	11.30	0.04	0.84	1.04	0.00
Lignite	1.27	0.69	0.03	0.00	0.00	0.00
Nuclear	2.38	0.84	0.03	0.00	0.00	0.00
Biomass	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	0.18	0.11	0.00	0.00	0.00	0.00
Solar	0.37	7.57	0.01	0.00	0.00	0.00
Geothermics	1.00E-03	2.68E-03	2.97E-05	3.18E-07	3.86E-07	8.29E-06
Waves	0.00	0.00	0.00	0.00	0.00	0.00
Wood	0.00	0.00	0.00	0.00	0.00	0.00
Wind	3.03E-01	1.89E-01	6.73E-03	2.90E-04	3.33E-04	3.06E-04
Other renewable fuels	0.00	0.00	0.00	0.00	0.00	0.00
Total	54.45	27.45	0.15	0.85	1.05	0.01



Contribution to Primary Energy Demand

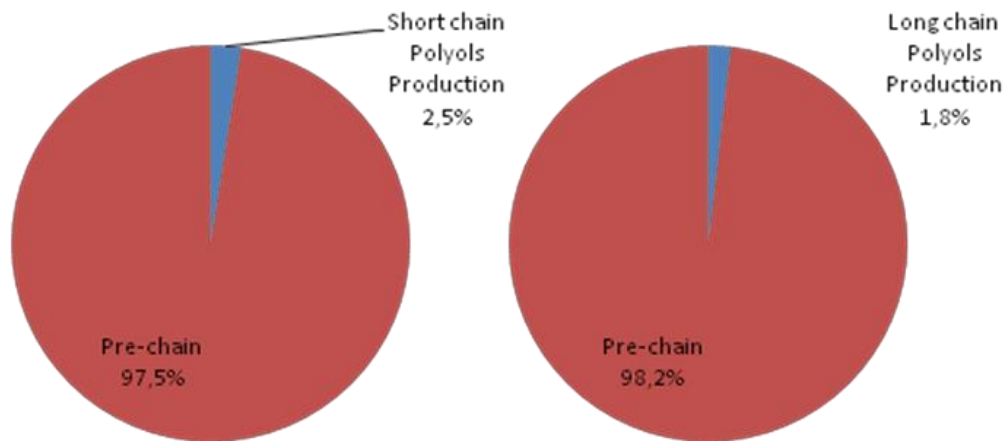


Figure 5: Contribution to primary energy demand per segment

Water Consumption

Table 13: Gross water resources table per 1kg long-chain polyether polyols

Source	Process water [kg]	Cooling water [kg]	Total [kg]
Public supply	-	-	-
River/canal	2.4	50.8	53.1
Sea	1.3	-	1.3
Unspecified	-	-	-
Well	-	-	-
Totals	3.6	50.8	54.4

Table 14: Gross water resources table per 1kg short-chain polyether polyols

Source	Process water [kg]	Cooling water [kg]	Total [kg]
Public supply	-	-	-
River/canal	4.0	37.8	41.7
Sea	1.0	-	1.0
Unspecified	-	-	-
Well	-	-	-
Totals	5.0	37.8	42.8

Air Emission Data

Table 15 and Table 16 show 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 tables in the annex of this report. For only fossil is shown in Table 15 and Table 16. In the production process of long and short-
CO₂ CO₂

chain polyether polyols biogenic CO₂ is incorporated in the products. This influences the value for GWP (especially for short-chain polyether polyols).

Table 15: Selected air emissions per 1kg long-chain polyether polyols

Air emissions	kg
Carbon dioxide, fossil (CO ₂ , fossil)	2.65
Carbon monoxide (CO)	1.53E-03
Sulphur dioxide (SO ₂)	3.12E-03
Nitrogen oxides (NO _x)	4.10E-03
Particulate matter ≤ 10 µm (PM 10)	1.03E-04

Table 16: Selected air emissions per 1kg short-chain polyether polyols

Air emissions	kg
Carbon dioxide, fossil (CO ₂ , fossil)	2.61
Carbon monoxide (CO)	1.40E-03
Sulphur dioxide (SO ₂)	2.34E-03
Nitrogen oxides (NO _x)	3.80E-03
Particulate matter ≤ 10 µm (PM 10)	8.75E-05

Wastewater Emissions

Table 17 and Table 18 show 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 tables in the annex of this report.

Table 17: Selected water emissions per 1kg long-chain polyether polyols

Water emissions	kg
Biological oxygen demand after 5 days (BOD 5)	1.96E-04
Chemical oxygen demand (COD)	7.25E-04
Total organic carbon (TOC)	2.17E-05

Table 18: Selected water emissions per 1kg short-chain polyether polyols

Water emissions	kg
Biological oxygen demand after 5 days (BOD 5)	1.56E-04
Chemical oxygen demand (COD)	5.72E-04
Total organic carbon (TOC)	1.70E-05

Solid Waste

Table 19: Solid waste generation per 1kg long-chain polyether polyols (key foreground process level)

Waste for –	Incineration	Landfill	Recovery	Unspecified	Total
	kg	kg	kg	kg	kg
Non-hazardous	3.56E-03	4.19E-04	-	-	3.98E-03
Hazardous	2.20E-06	-	-	-	2.20E-06
Unspecified	-	-	-	-	-
Total	3.56E-03	4.19E-04	-	-	3.98E-03

Table 20: Solid waste generation per 1kg short-chain polyether polyols (key foreground process level)

Waste for –	Incineration	Landfill	Recovery	Unspecified	Total
	kg	kg	kg	kg	kg
Non-hazardous	1.41E-02	3.72E-04	-	-	1.45E-02
Hazardous	1.95E-06	-	-	-	1.95E-06
Unspecified	-	-	-	-	-
Total	1,41E-02	3,72E-04	-	-	1,45E-02

Life Cycle Impact Assessment

Input

Natural Resources

Table 21: Abiotic Depletion Potential per 1kg long-chain polyether polyols

Natural resources	Value
Abiotic Depletion Potential (ADP). elements [kg Sb eq]	7.44E-06
Abiotic Depletion Potential (ADP). fossil fuels [MJ]	77.14

Table 22: Abiotic Depletion Potential per 1kg short-chain polyether polyols

Natural resources	Value
Abiotic Depletion Potential (ADP). elements [kg Sb eq]	5.20E-06
Abiotic Depletion Potential (ADP). fossil fuels [MJ]	65.94

Please note that differences between the primary energy demand and the “Abiotic Depletion Potential (ADP), fossil fuels” can be expected, as the latter considers the net calorific value of average whereas the primary energy demand presented in this report refers to the gross calorific value and considers country-specific resources.

Output

Climate Change

Table 23: Global Warming Potential (100 years) per 1kg long-chain polyether polyols

Climate change	kg CO₂ eq.
Global Warming Potential (GWP)	2.90

Table 24: Global Warming Potential (100 years) per 1kg short-chain polyether polyols

Climate change	kg CO₂ eq.
Global Warming Potential (GWP)	2.20

Acidification

Table 25: Acidification Potential per 1kg long-chain polyether polyols

Acidification of soils and water bodies	g SO₂ eq.
Acidification Potential (AP)	6.19

Table 26: Acidification Potential per 1kg short-chain polyether polyols

Acidification of soils and water bodies	g SO₂ eq.
Acidification Potential (AP)	5.89

Eutrophication

Table 27: Eutrophication Potential per 1kg long-chain polyether polyols

Eutrophication of soils and water bodies	g PO₄³⁻ eq.
Eutrophication Potential (EP), total	0.84

Table 28: Eutrophication Potential per 1kg short-chain polyether polyols

Eutrophication of soils and water bodies	g PO₄³⁻ eq.
Eutrophication Potential (EP), total	1.19

Ozone Depletion

Table 29: Ozone Depletion Potential per 1kg long-chain polyether polyols

	g CFC-11 eq.
Ozone Depletion Potential (ODP)	2.65E-05

Table 30: Ozone Depletion Potential per 1kg short-chain polyether polyols

	g CFC-11 eq.
Ozone Depletion Potential (ODP)	3.25E-05

Summer Smog

Table 31: Photochemical Ozone Creation Potential per 1kg long-chain polyether polyols

	g Ethene eq.
Photochemical Ozone Creation Potential	1.30

Table 32: Photochemical Ozone Creation Potential per 1kg short-chain polyether polyols

	g Ethene eq.
Photochemical Ozone Creation Potential	0.70

Dust & Particulate Matter

Table 33: PM10 emissions per 1kg long-chain polyether polyols

Particulate matter	g PM10 eq.
Particulate matter ≤ 10 μm. Total	0.103
Particulate matter ≤ 10 μm (direct emissions)	-
Particulate matter ≤ 10 μm. secondary	0.103

Table 34: PM10 emissions per 1kg short-chain polyether polyols

Particulate matter	g PM10 eq.
Particulate matter ≤ 10 µm. Total	0.088
Particulate matter ≤ 10 µm (direct emissions)	-
Particulate matter ≤ 10 µm. secondary	0.088

Dominance Analysis

Table 35 and Table 36 show the main contributions to the results presented above. An average based on the weighted mean from the different technologies of the participating producers is used.

Regarding long-chain polyether polyols in all analysed environmental impact categories, intermediates contribute 95 % or more of the total impact, with propylene oxide dominating with around 80 % or more.

Regarding short-chain polyether polyols in all analysed environmental impact categories, intermediates contribute 95 % or more of the total impact, with propylene oxide dominating with around 70 % or more (the only exception being the indicators AP and EP). The use of high quality data especially for this case is therefore decisive to the environmental profiles of flexible and short-chain polyether polyols. Primary data was therefore collected for propylene oxide.

Table 35: Dominance analysis of impacts per 1kg long-chain polyether polyols

	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.]	POCP [g Ethene eq.]
PO and polyol Process	87.5%	93.6%	88.3%	88.4%	83.8%	79.0%	90.0%
Other chemicals	10.7%	6.2%	10.1%	8.8%	14.5%	19.3%	9.1%
Utilities	0.1%	0.2%	0.1%	0.2%	0.2%	0.2%	0.1%
Electricity	0.8%	0.02%	0.5%	1.0%	1.0%	0.6%	0.4%
Thermal Energy	0.9%	0.01%	1.0%	1.5%	0.5%	0.6%	0.4%
Process waste treatment	0.0%	0.01%	0.00%	0.2%	0.0%	0.4%	0.0%
Total	100%	100%	100%	100%	100%	100%	100%

Table 36: Dominance analysis of impacts per 1kg short-chain polyether polyols

	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.]	POCP [g Ethene eq.]
PO and polyol Process	64.8%	81.9%	71.3%	83.4%	55.0%	37.2%	70.1%
Other chemicals	32.7%	17.4%	26.0%	11.1%	43.4%	61.2%	28.1%
Utilities	0.2%	0.5%	0.1%	0.4%	0.3%	0.2%	0.2%
Electricity	1.0%	0.03%	1.2%	2.1%	0.6%	0.4%	0.7%
Thermal Energy	1.3%	0.04%	1.4%	2.2%	0.6%	0.5%	0.8%
Process waste treatment	0.02%	0.02%	0.02%	0.9%	0.2%	0.5%	0.1%
Total	100%	100%	100%	100%	100%	100%	100%

Comparison of the present Eco-profile with its previous version (2005)

PlasticsEurope had previously published an Eco-profile for average polyether polyols without differentiation between long-chain and short-chain polyether polyols. Their respective shares in the average and the data collection had not been reported. Hence, the results of this Eco-Profile are not directly comparable to the previous Eco-Profile.

Table 37: Comparison of the present long and short-chain Eco-profile with its previous version (2005)

Environmental Impact Categories	Eco-profile polyether polyols (2005)	Eco-profile long-chain polyether polyols (2011)	Eco-profile short-chain polyether polyols (2011)	Comment
Gross primary energy from resources [MJ]	89.63	89.11	83.95	
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	3.29E-05	7.44E-06	5.20E-06	
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	75.73	77.14	65.9	These results are not comparable.
Global Warming Potential (GWP) [kg CO ₂ eq.]	3.61	2.90	2.20	Please see comment above.
Acidification Potential (AP) [g SO ₂ eq.]	13.98	6.19	5.89	
Eutrophication Potential (EP) [g PO ₄ ³⁻ eq.]	5.66	0.84	1.19	
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	0.00	2.65E-05	3.25E-05	
Photochemical Ozone Creation Potential [g Ethene eq.]	1.37	1.30	0.70	

Review

Review Details

The project included regular milestone meetings with representatives of all participating producers and PlasticsEurope as system operator. The reviewer participated in these meetings. In addition, a review meeting between the LCA practitioner and the reviewer was held, including a model and database review, and spot checks of data and calculations.

Review Summary

The LCA practitioner has demonstrated a very good competence and experience, with a track record of LCA projects in the chemical and plastics industry. A dominance analysis was conducted to identify sensitive data requirements prior to the data collection. Original data were collected for all foreground processes, while background process data were taken from the GaBi database which is likewise of good quality².

The precursor propylene oxide (PO) was shown to have the most substantial influence on the results. Although the precision of the dataset was not formally calculated by means of a statistical analysis, it is assessed to be very good for two reasons: first, because of the clear procedure adopted, and second, because of the robustness achieved by being based upon an average of different discrete European production sites. The sites were individually analysed and specifically modelled, representing the respective technologies. The deviation among the degree of detail and consistency was found to be low.

Calculation and reporting were subject to extensive analysis and review. As a result, this dataset is assessed to be a reliable and high-quality representation of long and short-chain polyether polyol production in Europe.

Reviewer Name and Institution

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² The results reported in this Eco-profile are determined by the original data collected for all foreground processes. In view of the dominance analysis, the use of generic datasets from the GaBi 5 database is not considered to have a substantial influence on the results. As the GaBi 5 database is well documented and good quality, this choice is deemed appropriate and reproducible.

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