Eco-profile of Styrene Acrylonitrile (SAN) and Acrylonitrile Butadiene Styrene (ABS)

December 2023

PlasticsEurope
Association of Plastics Manufacturers

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1 SUMMARY

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

It provides environmental performance data representative of the average European production of Styrene Acrylonitrile (SAN) and Acrylonitrile Butadiene Styrene (ABS), from cradle to gate (from crude oil extraction to granules or resin at plant, i.e., SAN and ABS production site output).

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

1.1 META DATA

Data Owner	PlasticsEurope
LCA Practitioner	Sphera Solutions GmbH
Programme Owner	PlasticsEurope
Reviewer	Matthias Schulz, Schulz Sustainability Consulting, Germany
Number of plants included in data collection	• 5 (SAN/AMSAN) • 5 (ABS)
Representativeness	The participating companies represent about 90% of the European SAN/AMSAN and ABS production volume in 2022.
Reference year	2022
Year of data collection and calculation	2023
Expected temporal validity	Revision should be considered in 2027
Cut-offs	<1%
Data Quality	Overall: Good Confirmed by assessment of individual DQ indicators
Allocation method	None

1.2 DESCRIPTION OF THE PRODUCT AND THE PRODUCTION PROCESS

Styrene Acrylonitrile (SAN) is a co-polymer with statistical repetition of styrene and acrylonitrile units in the polymer chain. The described average product comes from materials with about 75% styrene and 25% acrylonitrile (in mass%). A variant using Alpha Methyl Styrene (AMS) as a monomer also exists: AMSAN. This material is included in the average calculation[1].

Acrylonitrile Butadiene Styrene (ABS) is a thermoplastic two-phase polymer. The proportions of the monomer components can vary. This Eco-profile covers an average of product compositions of about 45-65% styrene, 15-20% acrylonitrile and 10-25% butadiene (in mass%).

The co-polymerisation of styrene with further monomers leads to materials which show advantages compared to polystyrene with regard to hardness, strength, resistance to heat distortion and environmental stress cracking.

Production Process

For the production of SAN/AMSAN, suspension and continuous bulk technologies are applied; ABS is produced by emulsion polymerisation, bulk polymerisation or combined processes. The type of production technology influences the material's properties. While mass ABS process is mainly used for general purpose ABS applications with excellence flow/hardness performance, emulsion polymerization is preferred to produce ABS products with high gloss and toughness requirements. The full range of ABS properties for injection moulding and extrusion processing is available when products made by different technologies are mixed in compounding.

The reference flows, to which all data given in this Eco-profile refer, are 1 kg SAN/AMSAN granulates and 1 kg of ABS granulates, respectively.

1.3 DATA SOURCES AND ALLOCATION

The main data source is a primary data collection from European producers of SAN/AMSAN and ABS, providing site-specific gate-to-gate production data for processes under operational control of the four participating companies.

Each participant of the study delivered data for SAN and ABS production. Overall, four sites for SAN production, one for AMSAN and five sites for ABS production are included in the average calculations. This covers 90 % of the European SAN and ABS production (EU-27) in 2022, respectively. The data for the precursors upstream supply chain (alpha-methyl styrene, acrylonitrile, and butadiene) are obtained from Managed LCA Content (MLC) databases (formerly, GaBi database) (Sphera, 2023). For styrene, LCI mix of EBSM and POSM from latest Eco-profile data implemented in MLC database is used (PlasticsEurope, 2022). All other relevant background data, such as energy and auxiliary materials, is from the MLC database; the documentation is publicly available (Sphera, 2023).

[1] Comparing the (confidential) foreground data for AMSAN and SAN regarding energy demand and the overall results of the main impact categories, both production routes do not show significant differences outside the range of variation of all single results.

Use Phase and End-of-Life Management

SAN is marketed for a range of applications such as cookware, transparent parts in electronics and electrical appliances, instrument panels, sanitary and medical goods, or cosmetic packaging. SAN can also be used as the rigid component for ABS manufacturing. AMSAN is used as a modifier for increasing the heat resistance of ABS and PVC.

Due to its combination of strength and impact resistance, ABS is widely used as an engineering material. The main consumers are the automotive industry, the domestic appliances industry, the data technology and telecommunications area, and producers of refrigeration equipment, toys, sports articles, and semi-finished articles.

SAN and ABS can be mechanically recycled, used articles can be ground and directly recycled into finished goods. Furthermore, energy recovery by incineration is also possible.

1.4 Environmental Performance

1.5 Programme Owner

PlasticsEurope

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

1.6 Data Owner

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70771 Leinfelden-Echterdingen, Germany

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1.8 REVIEWER

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2 ECO-PROFILE REPORT

2.1 FUNCTIONAL UNIT AND DECLARED UNIT

1 kg of unpacked primary Styrene Acrylonitrile (SAN) / Alpha Methyl Styrene Acrylonitrile (AMSAN) granules »at gate« (production site output) representing 90% of the European industry production average

or

1 kg of primary Acrylonitrile Butadiene Styrene (ABS) granules »at gate« (production site output) representing about 90% of the European industry production.

2.2 PRODUCT DESCRIPTION

Styrene Acrylonitrile (SAN) / Alpha Methyl Styrene Acrylonitrile (AMSAN) and Acrylonitrile Butadiene Styrene (ABS) are thermoplastic polymers, used in many applications such as cookware, electronics and electrical appliances, automotive parts, instrument panels, sanitary and medical goods, cosmetic packaging, and toys.

Styrene Acrylonitrile (SAN)

CAS no. 9003-54-7

Chemical formula $(C_8H_8)_x (C_3H_3N)_y$

Gross calorific value ca. 40 MJ/kg

Alpha-Methyl Styrene Acrylonitrile (AMSAN)

CAS no. 25747-74-4

Chemical formula $(C_9H_{10})_x (C_3H_3N)_y$

Gross calorific value ca. 40 MJ/kg

Acrylonitrile Butadiene Styrene (ABS)

CAS no. 9003-56-9

Chemical formula $(C_8H_8)_x (C_4H_6)_y \cdot (C_3H_3N)_z$

Gross calorific value ca. 40 MJ/kg

2.3 MANUFACTURING DESCRIPTION

Styrene Acrylonitrile (SAN) and Alpha-Methyl Styrene Acrylonitrile (AMSAN) are commonly made using a bulk polymerisation process. The process consists of continuous feeds of the monomers as well as possibly initiators chain transfer agents and solvent, to one or more polymerisation reactors. Polymerisation takes place between 80°C and 170°C; adequate agitation is critical for proper temperature and composition control. The product then goes to devolatilisation units and pelletiser. Unreacted monomers are recycled to maintain conversion and composition at desired levels.

Acrylonitrile Butadiene Styrene (ABS) can be produced by emulsion polymerisation, bulk polymerisation or combined processes. In the first, ABS graft rubber and SAN matrix are either polymerised separately then compounded or polymerised together. The second starts with butadiene rubber in solvent, followed by a pre-polymerisation of the rubber-monomers mixture under continuous mixing. The polymerisation is finally completed; the product is centrifuged, dried, and compounded.

For SAN or ABS sold to the market, additives such as lubricants, antioxidants or light stabilisers can also be added.

2.4 PRODUCER DESCRIPTION

PlasticsEurope Eco-profiles 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 to provide data to this Eco-profile:

- Elix Polymers S.L.

Carretera La Pineda a Vila-seca s/n
43110 La Canonja, Tarragona
Spain
http://www.elix-polymers.com

- INEOS Styrolution Group GmbH

Mainzer Landstraße 50
60325 Frankfurt
Germany
http://www.ineos-styrolution.com

- Trinseo Europe GmbH

Gwattstrasse 15

Pfaeffikon CH-8808

Switzerland

https://www.trinseo.com/

- VERSALIS S.p.A.

Piazza Boldrini, 1
20097 San Donato Milanese (MI)
Italy
https://www.versalis.eni.com/en-IT/home.html

2.5 SYSTEM BOUNDARIES

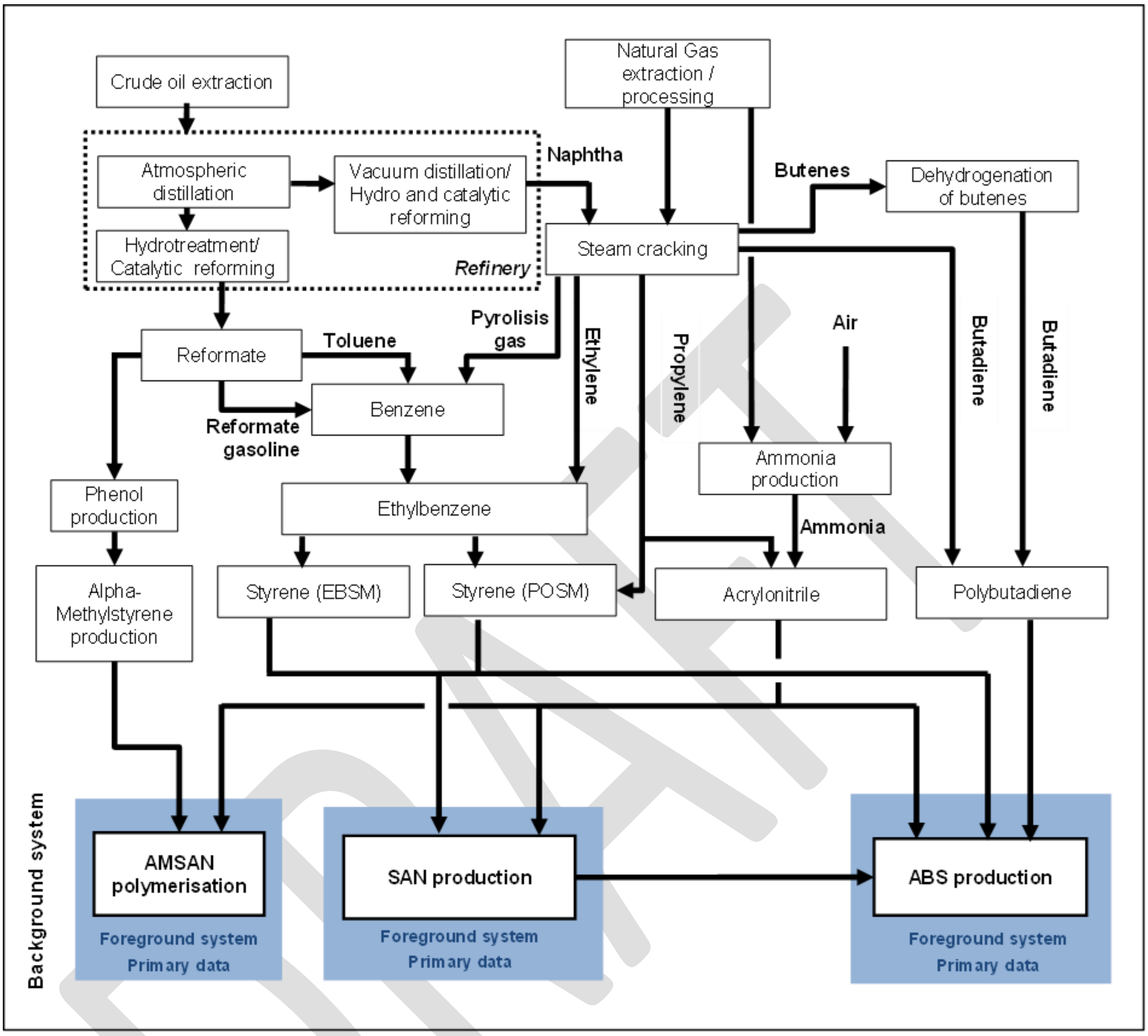

Figure 1 Cradle-to-gate system boundaries (SAN/AMSAN and ABS)

2.6 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 SAN/AMSAN and ABS, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: four SAN and one AMSAN producers with five plants in four different European countries; five ABS producers with five plants in five European countries. This covers 90% of the European SAN/AMSAN and ABS production capacity (EU-27) in 2022. Primary data are used for all foreground processes (under operational control) complemented with secondary data for background processes (under indirect management control). The data for the upstream supply chain until the precursors are taken from the database of the software system Managed LCA Content (Sphera, 2023).

As shown in Figure 1, two different routes for the production of styrene (EBSM and POSM) are modelled. The ethylbenzene styrene monomer (EBSM) process is based on the catalytic dehydrogenation of ethylbenzene and renders styrene as its main product and minor quantity of toluene as co-product. The propylene oxide styrene monomer (POSM) process involves the co-production of propylene oxide and styrene: in this case, ethylbenzene is oxidized to form ethylbenzene hydroperoxide (EBHP).

2.7 TEMPORAL REFERENCE

The foreground data for production is collected as 12-month averages representing the year 2022, to compensate seasonal influence of data. Most of the foreground data from the previous Eco-profile published in 2015 (data reference year 2013) have been retained since there have not been any significant changes in the production process. The parameters which contributed significantly to the previous Eco-profile were updated. These modifications include shifts in electricity requirements and sources (from grid mix to renewable), variations in production yield, and adjustments in thermal energy needs. Background data have reference years 2022 and 2019 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 2022 with a recommended temporal validity until 2027 to which the relevance of the revision should be considered according to Eco-profiles program and methodology –PlasticsEurope – V3.1 (2022).

2.8 GEOGRAPHICAL REFERENCE

Primary production data for both SAN/AMSAN and ABS production are from four different European suppliers each. The inventories for the precursors and the energy supply are adapted according to site specific (i.e., national) conditions, except for styrene where latest Eco-profile is used. 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. SAN and ABS imported into Europe are not considered in this Eco-profile.

2.9 CUT-OFF RULES

In the foreground processes all relevant flows are considered. In single cases additives used in the SAN and/or ABS foreground unit process (<0.3% m/m of product output) are neglected. In such cases, it is assured that no hazardous substances or metals are present in this neglected part. According to the Managed LCA Content (Sphera, 2023), used in the background processes, at least 95% of mass and energy of the input and output flows are covered and 98% of their environmental relevance (according to expert judgment) are considered, hence an influence of cut-offs less than 1% on the total is expected. Transports for the main input materials (styrene, alpha-methyl styrene, acrylonitrile, and butadiene) contribute less than 1% 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.

2.10 DATA QUALITY REQUIREMENTS

Data Sources

Eco-profiles developed by PlasticsEurope use 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 PlasticsEurope (see Producer Description).

All relevant background data such as energy and auxiliary material are also taken from the MLC 2023 LCI database (formerly, GaBi database) (Sphera, 2023). Most of the background data used is publicly available and public documentation exists.

Styrene as the relevant intermediate originates from two different technology routes.

EBSM (ethyl benzene styrene monomer) is based on catalytic dehydrogenation of ethylbenzene, with styrene as its main product. The process for POSM (propylene oxide-styrene monomer) involves the oxidation of ethylbenzene; the process delivers styrene and propylene oxide.

The current LCI for styrene (mix of EBSM and POSM) from PlasticsEurope (PlasticsEurope, 2022) has been applied throughout the models.

Relevance and Representativeness

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 SAN and ABS producers in Europe in order to generate a European production average.

The participating companies represent 90% of the European SAN and ABS production volume in 2022. This figure refers to an educated estimate of PlasticsEurope and the participating parties of this study. The selected background data can be regarded as representative for the intended purpose.

The environmental contributions of each process to the overall LCI results are included in the Chapter Dominance Analysis.

Consistency

To ensure consistency only foreground data of the same level of detail and background data from the Managed LCA Content 2023 (formerly GaBi databases) (Sphera, 2023) 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 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 checked for its quality (see chapter Data Sources). These secondary data are mainly based on a mix of data related from market studies, industry information, publicly available statistics and complemented by necessary calculations and estimations based on expert knowledge.

In general, all Sphera background datasets are reviewed internally before adding them to the MLC dataset pool und undergo annual updates, which not only includes refreshment of background energy mixes but also import mixes of raw materials and process technology and efficiencies once these become known.

Completeness

Primary data used for the gate-to-gate production of SAN and ABS covers all related flows in accordance with the above defined cut-off criteria. In this way all relevant flows are quantified, and data is considered sufficiently 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.

The quantification of methane emissions from natural gas and crude oil supply chains is still rarely and inconsistently reported. Hmiel et al. (2020) showed the current studies using bottom-up estimates underestimate methane emissions from fossil fuel extraction and use. Emission factors for methane vary considerably, as they depend on many factors at an oil and gas production site. The data quality of methane emission factors may be improved by the combined use of bottom-up and top-down measurements, but only few studies on top-down measurements exist (Hmiel et al., 2020), (Saunois et al., 2020). Measurements of methane emissions may represent snapshots and are subject to large fluctuations. Top-down calculation methods are also not yet fully reliable, although the International Methane Emissions Observatory launched in 2021 will contribute to improved accuracy. Given the underdeveloped state of methane emissions estimates from the natural gas supply chain, Sphera MLC default parameters have been used for this sector, acknowledging that this results in an underestimation of emissions linked to oil and gas extraction. Please refer to Chapter 6: Statement on methane emissions.

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. All background data is consistently MLC (formerly, GaBi) data or PlasticsEurope Eco-profile data in case of styrene 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 LCA For Experts (formerly, GaBi software). The reproducibility is given for internal use since the models are stored and available in a database. Sub-systems are modelled by ´state of art´ technology using data from a publicly available and internationally used database. It is worth noting that for external audiences, it may be the case that full reproducibility in any degree of detail will not be available for confidentiality reasons. However, experienced experts would 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 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 MLC database (formerly GaBi databases) (Sphera, 2023) 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, LCA For Experts (formerly GaBi). The associated database integrates ISO 14040/44 requirements. Due to confidentiality reasons details on software modelling and methods used cannot be shown here. However, in principle the model can be reviewed in detail if the data owners agree. The calculation of ABS and SAN/AMSAN production follows the vertical calculation methodology as far as possible, i.e., that the averaging is done after modelling the specific processes.

A data quality rating (DQR) based on the criteria and calculation rules described in the guide to develop EF (environmental footprint) compliant datasets (Fazio, et al., 2020) has been carried out. The DQR considers the following four data quality criteria evaluated for both product systems:

- technological-representativeness (Te_R),
- geographical-representativeness (G_R),
- time-representativeness (Ti_R),
- precision (P).

The overall DQR of the created datasets represents the arithmetic mean of the four data quality criteria presented above according to F.1 (Fazio, et al., 2020). Since the DQR calculation applies to company-specific datasets, the DQR of the activity data and direct (foreground) elementary flows shall be assessed, as well as the sub-processes linked to the activity data.

All direct (foreground) elementary flows and datasets that contribute at least 80% of the total LCIA results have been identified. The latter was done using a normalization and weighting process based on the EF 3.1 method through LCA For Experts (formerly, GaBi) software. The datasets that contribute to 80% of LCIA impacts for both products include, styrene, acrylonitrile, 1,3-butadiene, and styrene acrylonitrile.

TeR is evaluated at the level of the secondary dataset (styrene) and is scored 2 since the styrene dataset represents a European technology mix (horizontal average). For other secondary data, TeR is scored at 2 as these are exact technology matches. TiR is evaluated twice, at the level of activity data and at the level of the secondary dataset. TiR is scored with 1 for the secondary dataset since the reference year of the datasets falls within the time validity of the datasets used, and with 2 for the activity data where the data is 3 years old with respect to the reference year of the datasets and 3 as an average where data is collected from literature. GR is evaluated at the level of the secondary data set and is scored in the range of 1 to 3 depending on the geographies of background datasets. Precision is evaluated at the level of activity data and is scored with 2 for styrene and styrene acrylonitrile since the data is measured/calculated and (internally) verified by the company, and 3 for other background datasets. The Weighted DQR results for SAN and ABS are shown below:

Weighted DQR results for SAN:

Weighted DQRs				
Tech	**Time**	**Geo**	**Precision**	**DQR of created dataset**
2.00	2.06	1.76	2.38	2.05

Weighted DQR results for ABS:

Weighted DQRs				
Tech	**Time**	**Geo**	**Precision**	**DQR of created dataset**
1.90	1.96	1.65	2.25	1.94

2.11 CALCULATION RULES

Vertical Averaging

According to the PlasticsEurope methodology vertical averaging should be applied wherever possible. As far as known and available, route specific pre-cursor datasets matching the real supply chain conditions have been used for modelling individual datasets accordingly (Figure 2). However, in the case of the pre-cursor styrene horizontal averaging has been applied (Figure 3).

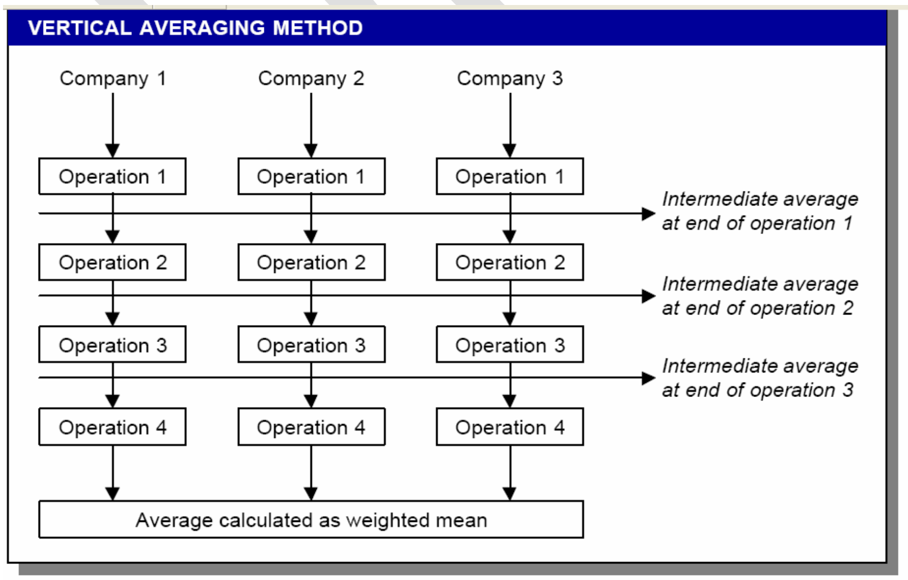

Figure 2: Vertical Averaging

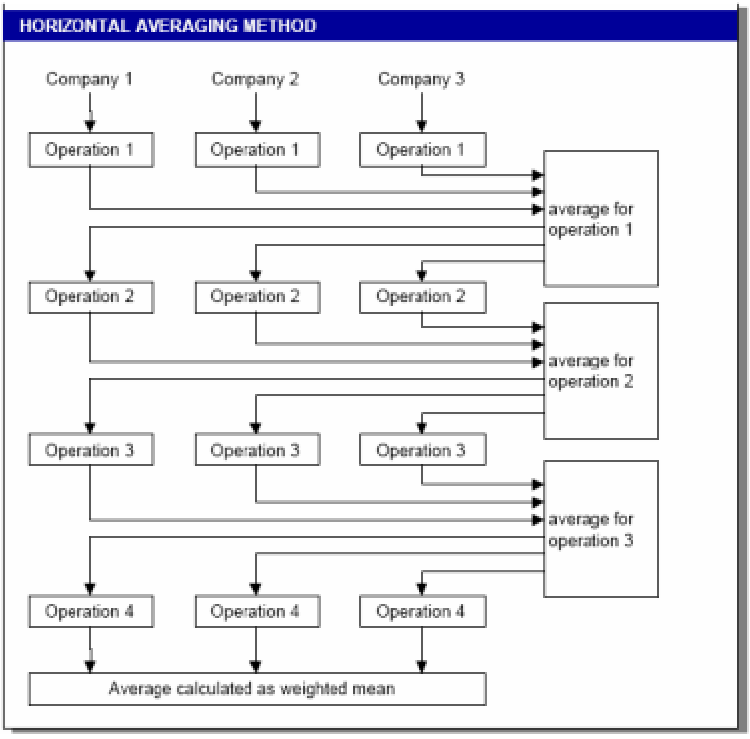

Figure 3 Horizontal Averaging

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 are not existing, 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.

Foreground system

In some companies' information, output material with deviations from the required specification is reported (about 0.1–0.6%); in case of material declared as off-grade sent to recovery, neither further environmental burden nor credits are given to the modelled system (cut-off).

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 was addressed by applying allocation based on mass and net calorific value (Sphera, 2023). 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 %.

2.12 LIFE CYCLE INVENTORY (LCI) RESULTS

Delivery and Formats of LCI Dataset

This eco-profile comprises of,

- A dataset in ILCD/EF 3.1 format (.xml) (http://lct.jrc.ec.europa.eu) according to the last version at the date of publication of the eco-profile.
- A dataset in LCA For Expert format (.GaBiDB)
- This report in pdf format.

Energy Demand

The **primary energy demand** (system input) of 92.17 MJ/kg for SAN and 92.57 MJ/kg for ABS indicates the cumulative energy requirements at the resource level, accrued along the entire process chain (system boundaries), quantified as gross calorific value (upper heating value, UHV).

The **energy content in the polymer** indicates a measure of the share of primary energy incorporated in the product, and hence a recovery potential (system output), quantified as the gross calorific value (UHV), is about 40 MJ/kg for both SAN and ABS.

The difference (∆) between primary energy input and energy content in the SAN and ABS output is a measure of **process energy** which may be either dissipated as waste heat or recovered for use within the system boundaries. Useful energy flows leaving the system boundaries were treated according to the cut -off approach (no credits associated to main product system).

Table 1 Primary energy demand (system boundary level) per 1 kg SAN

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	40.00
Process energy (quantified as difference between primary energy demand and energy content of polymer)	52.17
Total primary energy demand	**92.17**

Table 2 Primary energy demand (system boundary level) per 1 kg ABS

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	40.00
Process energy (quantified as difference between primary energy demand and energy content of polymer)	52.57
Total primary energy demand	**92.57**

Water cradle-to-gate Use and Consumption

The cradle-to-gate water **use** is 685.1 kg per 1 kg of SAN and 747.5 kg per 1 kg of ABS. The corresponding water **consumption** in the same system boundary is 10.1 kg for SAN and 18.5 kg for ABS.

Water foreground (gate-to-gate) Use and Consumption

Table 3 and Table 4 show the average values for water use of the SAN and ABS production processes (gate-to-gate level). For each of the typical water applications the water sources are shown.

Table 3 Water use and source per 1 kg of SAN (gate-to-gate)

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	0.00	0.00	0.00	0.00	**0.00**
Deionized / Softe-ned	0.14	0.00	0.01	0.00	**0.15**
Untreated (from ri-ver/lake)	0.00	34.83	0.00	0.00	**34.83**
Untreated (from sea)	0.00	0.00	0.00	0.00	**0.00**
Relooped	0.00	0.00	0.09	0.00	**0.09**
Totals	**0.14**	**34.83**	**0.10**	**0.00**	**35.07**

Table 4 Water use and source per 1 kg of ABS (gate-to-gate)

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	0.26	0.00	0.00	0.00	**0.26**
Deionized / Softe-ned	11.66	0.00	0.09	0.00	**11.75**
Untreated (from ri-ver/lake)	0.00	16.16	0.00	0.00	**16.16**
Untreated (from sea)	0.00	0.00	0.00	0.00	**0.00**
Relooped	0.00	0.00	0.09	0.00	**0.09**
Totals	**11.92**	**16.16**	**0.18**	**0.00**	**28.26**

Table 5 and Table 6 show the further handling/processing of the water output of the average production process of SAN and ABS.

Table 5 Treatment of Water Output per 1 kg of SAN (gate-to-gate)

Treatment	Water Output [kg]
To WWTP	1.04
Untreated (to river/lake)	32.28
Untreated (to sea)	0.00
Relooped	0.09
Water leaving with products	0.00
Water Vapour	1.65
Formed in reaction (to WWTP)	0.00
Totals	**35.07**

Table 6 Treatment of Water Output per 1 kg of ABS (gate-to-gate)

Treatment	Water Output [kg]
To WWTP	1.96
Untreated (to river/lake)	16.16
Untreated (to sea)	0.00
Relooped	0.09
Water leaving with products	0.00
Water Vapour	10.05
Formed in reaction (to WWTP)	0.00
Totals	**28.26**

Based on the water use and output figures above the **water consumption (gate-to-gate)** can be calculated as:

Consumption = (water vapour + water lost to the sea) – (water generated by using water containing raw materials + water generated by the reaction + seawater used)

- SAN = 1.65 kg
- ABS = 10.05 kg

Dominance Analysis

Table 7 and Table 8 present dominance analyses for the production of 1 kg SAN and 1 kg ABS respectively.

For SAN, in all analysed environmental impact categories, precursors contribute about 70% or more of the total impact. Precursors in the process include styrene/alpha-methyl styrene and acrylonitrile. Their contribution is over 90% in impact categories; acidification, climate change, photochemical ozone formation, total primary energy, and resource use (energy carriers). Amongst other activities, electricity use contributes 8% and 11% to Resource use, minerals and metals, and Ozone depletion impact categories, respectively.

For ABS, precursors contribute over 90% in total primary energy, resource use (energy carriers), climate change, acidification, photochemical ozone formation. Precursors in this process include, styrene, acrylonitrile and (poly)butadiene. For the impact categories Resource use (minerals and metals) and eutrophication, other chemicals contribute 47% and 37% to the impacts, respectively. These impacts come from synthetic waxes, and dispersing agents used in the production. Utilities contribute 9% and 8% to Eutrophication freshwater and Ozone depletion, respectively. The impact comes mainly from the use of deionised water and compressed air during the production process. In case of deionised water, water going to a wastewater treatment plant contribute to the eutrophication result and chemicals used in the treatment of the water contribute to the ODP result. For the compressed air, the impact of ODP comes from the use of electricity.

The process waste treatment contribution to freshwater eutrophication for both SAN and ABS comes from the emissions to water in the discharge of the waste water treatment plant. The wastewater treatment was modelled using secondary data from Sphera MLC in absence of primary dataset.

Table 7 Dominance analysis of impacts per 1kg SAN

	Total Primary Energy	**Resource use, energy carriers**	**Resource use, minerals and metals**	**Climate change, total**	**Acidifi-cation**	**Eutrophi-cation, freshwater**	**Photo-chemical ozone formation**	**Ozone depletion**
Precursors	95%	97%	88%	93%	95%	73%	96%	87%
Other Chemicals	0%	0%	3%	0%	1%	10%	0%	1%
Utilities	0%	0%	0%	0%	0%	1%	0%	3%
Electricity	2%	1%	9%	1%	1%	1%	0%	11%
Thermal Energy	2%	2%	1%	4%	1%	0%	1%	0%
Transport	0%	0%	0%	0%	2%	0%	2%	0%
Process Waste Treatment	0%	0%	-1%	1%	0%	14%	0%	-3%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 8 Dominance analysis of impacts per 1kg ABS

	Total Primary Energy	**Resource use, energy carriers**	**Resource use, minerals and metals**	**Climate change, total**	**Acidifi-cation**	**Eutrophi-cation, freshwater**	**Photo-chemical ozone formation**	**Ozone depletion**
Precursors	93%	96%	42%	92%	92%	39%	96%	77%
Other Chemicals	2%	1%	47%	2%	5%	37%	2%	6%
Utilities	1%	0%	1%	1%	1%	9%	0%	8%
Electricity	3%	1%	11%	2%	1%	1%	1%	10%
Thermal Energy	2%	2%	0%	3%	1%	0%	1%	0%
Transport	0%	0%	0%	0%	1%	0%	1%	0%
Process Waste Treatment	0%	0%	0%	1%	0%	14%	0%	-1%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Comparison of the present Eco-profile with its previous version

A comparison of current LCIA results for SAN and ABS with the last Eco-profiles from 2015 are presented in Table 9 and Table 10.These results have been calculated according to the same impact assessment methodology that was used for the Eco-profiles in 2015.

The GWP results are 9% lower for SAN and 15% lower for ABS compared to the previous Eco-profiles. These reductions can be attributed to increase of renewable energy use in the processes. Companies using renewable energy have provided certificates of origin. For example, the use of wind electricity instead of grid electricity mix in Europe results in a 96% lower GWP result.

The changes in gross primary energy and abiotic depletion potential (fossil fuels) are small and correspond with the minor changes in the unit process data. The observed improvements in most impact categories (ADP elements, GWP, AP, EP and POCP) are plausible as Sphera MLC (formerly GaBi) datasets build the basis for the former and current eco-profiles and given the long time period in-between, electricity grid mixes increased their shares of renewable power, as well as process efficiencies increased.

Table 9 Comparison of the present Eco-profile with its previous version per 1 kg SAN with old methodology

Environmental Impact Categories	**Previous SAN (2015) CML 2001 (April 2013)**	**New SAN (2023) CML 2001 (April 2013)**	**Difference (%)**
Gross primary energy from resources [MJ]	92.88	92.17	-1%
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	8.87E-07	4.21E-07	-53%
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	82.93	81.38	-2%
Global Warming Potential (GWP) [kg CO_2 eq.]	2.96	2.69	-9%
Acidification Potential (AP) [g SO_2 eq.]	8.04	4.47	-44%
Eutrophication Potential (EP) [g PO_4^{3-} eq.]	1.02	0.89	-13%
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	8.32E-08	3.36E-09	-96%[3]
Photochemical Ozone Creation Potential [g Ethene eq.]	1.19	0.70	-42%

[3] For ODP, significantly lower impacts are noticed. Since the use of certain halogenated substances has been banned following the implementation of the Montreal Protocol, the following emissions are not present anymore in the updated Sphera datasets: Halon (1301), R 11 (trichlorofluoromethane), R 114 (dichlorotetrafluoroethane) and R 12 (dichlorodifluoromethane) and R22 (chlorodifluoromethane). Particularly R22, which has been removed, has the profound effect of reducing the remaining, already greatly reduced ODP impacts by several orders of magnitude for most datasets. This consequently further reduces the impact results for ODP for many datasets in the database.

Table 10 Comparison of the present Eco-profile with its previous version per 1 kg ABS with old methodology

Environmental Impact Categories	**Previous ABS (2015) CML 2001 (April 2013)**	**New ABS (2023) CML 2001 (April 2013)**	**Difference (%)**
Gross primary energy from resources [MJ]	92.18	92.57	0.4%
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	1.48E-06	7.90E-07	-47%
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	81.37	80.10	-2%
Global Warming Potential (GWP) [kg CO_2 eq.]	3.10	2.64	-15%
Acidification Potential (AP) [g SO_2 eq.]	7.690	4.14	-46%
Eutrophication Potential (EP) [g PO_4^{3-} eq.]	1.03	0.88	-14%
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	2.60E-07	3.56E-09	-99%[3]
Photochemical Ozone Creation Potential [g Ethene eq.]	1.09	0.66	-39%

3 EF 3.1 INDICATOR RESULTS

The following table shows the LCA results for 1 kg SAN and ABS when applying the EF3.1 impact assessment methodology.

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

Table 11 LCA results for 1 kg SAN and ABS applying EF3.1 impact assessment methodology

Indicator	**Unit**	**SAN**	**ABS**
Climate change (total)	kg CO_2 eq.	2.72	2.69
Climate Change, biogenic	kg CO_2 eq.	7.12E-03	7.32E-03
Climate Change, fossil	kg CO_2 eq.	2.71	2.69
Climate Change, land use and land use change	kg CO_2 eq.	1.92E-04	6.76E-04
Ozone depletion	kg CFC-11 eq.	2.85E-12	3.02E-12
Acidification	Mole of H+ eq	5.86E-03	5.45E-03
Photochemical ozone formation	kg NMVOC eq	7.06E-03	6.30E-03
Eutrophication, freshwater	kg P eq	4.39E-06	8.47E-06
Eutrophication, marine	kg N eq.	2.21E-03	1.98E-03
Eutrophication, terrestrial	Mole of N eq.	2.26E-02	2.06E-02
Respiratory Inorganics	Disease incidences	3.37E-08	3.22E-08
Ionising radiation, human health	kBq U235 eq.	0.04	0.05
Human toxicity, cancer - total	CTUh	8.93E-10	1.02E-09
Human toxicity, cancer inorganics	CTUh	6.88E-10	7.54E-10
Human toxicity, cancer organics	CTUh	2.05E-10	2.65E-10
Human toxicity, non-cancer - total	CTUh	3.08E-08	4.11E-08
Human toxicity, non-cancer inorganics	CTUh	3.03E-08	4.06E-08
Human toxicity, non-cancer organics	CTUh	5.02E-10	5.04E-10
Ecotoxicity, freshwater - total	CTUe	3.65E+01	3.62E+01
Ecotoxicity, freshwater inorganics	CTUe	3.61E+01	3.58E+01
Ecotoxicity, freshwater organics	CTUe	4.35E-01	4.39E-01
Land Use	Pt	1.56E+00	4.60E+00
Resource use, energy carriers	MJ	82.09	81.00
Resource use, minerals and metals	kg Sb eq.	2.01E-07	3.93E-07
Water use	m^3 world equiv.	2.82E-01	6.74E-01

4 Review

4.1 Review Details

Commissioned by:	PlasticsEurope
Prepared by:	Alejandra Martinez and Abhijeet G. Parvatker, PhD Sphera Solutions GmbH
Reviewed by:	Matthias Schulz Schulz Sustainability Consulting
References:	• PlasticsEurope (2022): Eco-profiles program and methodology –PlasticsEurope – V3.1 (2022). • ISO 14040 (2018): Environmental Management – Life Cycle Assessment – Principles and Framework • ISO 14044 (2018): Environmental Management – Life Cycle Assessment – Requirements and Guidelines

4.2 Review Statement

According to the PlasticsEurope methodology version 3.1 (2022), a critical review of the Eco-profile report by independent experts should be conducted before publication of the dataset. The outcome of the critical review is reproduced below.

The subject of this critical review was the development of the Eco-profile for Styrene Acrylonitrile (SAN) and Acrylonitrile Butadiene Styrene (ABS).

The critical review included one iteration of final Eco-profile report review (November – December 2023) in which the reviewer provided comments for clarification by the LCA practitioner. On 13.12.2023, a web-based review meeting was held in which open issues were discussed and spot checks of data, modelling and calculations were carried out. The final version of the report was completed on 14.12.2023. The reviewer checked the implementation of the comments and agreed to conclude the critical review process. The reviewer acknowledges the unrestricted access to all requested information, the dedicated efforts of the practitioner to address comments, as well as the open and constructive dialogue during the entire critical review process. All versions of the documentation (reports and data), including the reviewer's comments, questions and associated answers, are archived and can be made available upon request.

Primary data was collected for five plants from four SAN producers in four different European countries and for five plants from four ABS producers in four different European countries. This equates to a representativeness of approximately 90% of the European SAN and ABS production volume in 2022. It should be noted that some foreground data remains the same as for the previous SAN/ABS Eco-profile from 2015 (reference year 2013) as there have not been any significant changes in the production process. However, most relevant input data, such as SAN and ABS production volumes of the different producers, amounts of relevant precursor products and energy data (including sources of electricity generation) have been updated. Data for the key precursor styrene monomer was based on the most recent Eco-profile (PlasticsEurope 2022), in which a split of the dominant styrene production routes was assumed; i.e. 60:40 dehydrogenation of ethylbenzene (EBSM): propylene oxide styrene monomer (POSM) process.

Allocation in the foreground system was not relevant for this Eco-profile. Co-production of small amounts of off-grade SAN and ABS were modelled using the cut-off approach.

All background datasets used for this Eco-profile are described in the report and are considered appropriate for the goal and scope of this study. Besides background data for styrene monomer (see info above), all other background datasets stem from the most recent Managed LCA Content 2023 LCI database (formerly known as GaBi).

The following should be kept in mind when interpreting the results of this Eco-profile: There is rising awareness in scientific literature about unwanted methane emissions during oil and gas extraction, processing and transport which are higher than assumed in previous PlasticsEurope Eco-profiles and in current LCA databases. Relevant data are reported by the International Energy Agency's Methane Tracker[4]. Due to the fact that there is no commonly agreed procedure yet on how to deal with these emissions, they are not incorporated in the relevant datasets used in this Eco-profile. PlasticsEurope is aware of this issue and is driving activities towards finding an acceptable solution. Sphera added a statement on this topic in Chapter 6 of this Eco-profile report, acknowledging that this results in an underestimation of greenhouse gas emissions linked to oil and gas extraction as well as the respective GWP results of SAN and ABS.

The reviewer carried out various plausibility checks of the data and results. In the end, all questions raised were clarified, and the reviewer found the data and results to be credible and without perceivable errors or shortcomings.

The potential environmental impacts for SAN and ABS are quantified using the EF v3.1 methodology, as recommended in the current PlasticsEurope methodology. The contribution analysis shows the predominant influence of the precursors styrene/alpha-methyl styrene and acrylonitrile for SAN and styrene, acrylonitrile and (poly)butadiene for ABS. Please see the 'Dominance analysis' in the report for further details.

This Eco-profile also includes a comparison of the environmental performance with the last version from 2015 (based on data from 2013). It shows that various improvements have been achieved both for SAN and ABS for most environmental indicators. Please see the 'Comparison of the present Eco-profile with its previous version' for further details.

The LCA practitioner has demonstrated high levels of competence and experience, with a track record of LCA projects in the chemical and plastics industry. The critical review confirms that this Eco-profile adheres to the rules set forth in the PlasticsEurope's Eco-profiles methodology version 3.1 (2022) and represents best available data for SAN and ABS production in Europe.

[4] Global Methane Tracker 2023: https://www.iea.org/reports/global-methane-tracker-2023

5 REFERENCES

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6 STATEMENT ON METHANE EMISSIONS

Methane emissions contribute significantly to the greenhouse effect. In contrast to determining carbon dioxide emissions, which can be often derived directly from the consumption of energy resources and has been included in reporting for decades, the quantification of methane emissions from the supply chains of natural gas, crude oil (and coal) is still rarely and inconsistently reported.

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

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

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

Emission factors for methane vary considerably, as they depend on a large number of influencing factors, including:

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

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

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

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