Eco-profiles of the European Plastics Manufacturers

Methyl methacrylate (MMA)
PlasticsEurope
February 2024

1. Summary

This Eco-Profile has been prepared according to **the PlasticsEurope Eco-profiles program and methodology** (September 2022). It provides 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 Eco-profile describes the production of the methyl methacrylate (MMA) monomer from cradle to gate (from crude oil extraction to monomer at plant). **Please keep in mind that comparisons cannot be made on the level of the material alone**: it is necessary to consider the full life cycle of an application in order to compare the performance of different materials and the effects of relevant life cycle parameters. This Eco-profile 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	Cefic, Methacrylates Sector Group
LCA Practitioner	Deloitte Conseil
Programme Owner	PlasticsEurope
Reviewer	Angela Schindler
Number of plants included in data collection	4
Representativeness	European production (89%)
Reference year	2021
Year of data collection and calculation	2022 – 2023
Expected temporal validity	5 years
Cut-offs	<2% in mass and energy except for the flows with environmental significance -0%)
Data Quality	Good
Allocation method	System expansion for ammonium sulphate, mass allocation for hydrogen gas

1.2. Description of the Product and the Production Process

This Eco-profile represents the European average production of methyl methacrylate (MMA) monomer from cradle to gate.

MMA is an organic compound with the formula C5H8O2.

It is a key intermediate chemical, due to its ability to undergo polymerization and copolymerization.

MMA is mainly used for the production of polymethylmethacrylate (PMMA).

Several methods exist for the production of MMA. The main route, which is used by the European producers participating in this study and is therefore modelled in this Eco-profile, is the “acetone cyanohydrin route”. This route is based on three steps.

The first step of the process is intended to produce hydrogen cyanide (HCN), from methane and ammonia. In the second step, hydrogen cyanide and acetone are used as reagents for the production of acetone cyanohydrin (ACH). In the third step, MMA is produced from acetone cyanohydrin, sulphuric acid and methanol. Firstly, acetone cyanohydrin undergoes sulphuric acid assisted hydrolysis and is converted into a sulphate ester of methacrylamide. Secondly, an esterification with methanol gives MMA. During the third step, sulphuric acid is used as an intermediate reagent. After the reactions, ammonium bisulphate may be recycled to sulphuric acid and reused for the MMA production or may be neutralised with ammonia, producing ammonium sulphate as a co-product.

1.3. Data Sources

This Eco-profile is based on a collective LCA study performed by the three main European producers of MMA: Trinseo, Röhm and Mitsubishi Chemicals. The primary data used in this study and then in this Eco-profile comes from four plants located in three different European countries and is site-specific gate-to-gate production data.

The three producers participating to this Eco-profile cover 89 % of the European MMA production capacity in 2021.

Data for the upstream supply chain until the precursors and all relevant background data (such as energy and auxiliary materials) are taken from the ecoinvent 3.8 database, except for acetone which is taken from the European Solvents Industry Group (ESIG) EF LCA database.

1.4. Allocation

In this Eco-profile, system expansion was applied to the ammonium sulphate co-product, and mass allocation was applied to the hydrogen gas co-product.

1.5. Use Phase and End-of-Life Management

The disposal of waste from production processes is considered within the system boundaries of this Eco-profile. The use phase and end-of-life processes are outside the system boundaries of this cradle-to-gate system.

MMA and PMMA, the polymer made from monomer MMA, are important solutions providers in EU industrial ecosystems like Automotive, Construction, Health as well as Electronics and appliances. The durability and light weight aspect of MMA and PMMA containing products is one key element to reach EU sustainability and energy efficiency targets.

Due to advantages over other polymers such as durability, transparency and ability to form copolymers, PMMA and MMABP (MMA based polymers) have a wide range of applications, such as in automotive (rear) lights, glazing, aerospace, signs and displays, indoor and outdoor lighting, bathtubs, appliances, LCD screens, surface coatings and niche markets like bone cement, dentures and artificial teeth or intraocular lenses.

With regards to recyclability, mechanical and chemical recycling processes for the different PMMA grades and products are established for post-industrial scrap and post-consumer waste after sorting the waste streams. Unlike most other polymers, PMMA is a unique material. Through a depolymerisation process called molecular recycling, it easily breaks down to its original molecule, MMA. When exposed to high temperature, its polymer chains break and revert to the monomer, MMA. This temperature is far lower than what is typically required for pyrolysis. As a result, PMMA has a very high recovery rate and recycling potential. In addition, PMMA can also be mechanically recycled. Typically, waste from PMMA production is ground down and repelletised, so that it can be fed back into the production process.

1.6. Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg of MMA.

Input Parameters

Indicator	Unit	Value
Non-renewable energy resources[1]		
• Fuel energy	MJ	63
• Feedstock energy	MJ	27
Renewable energy resources (biomass)[1]		
• Fuel energy	MJ	1.7
• Feedstock energy	MJ	-
Resource use[2]		
• Minerals and metals	kg Sb eq	2.3E-06
• Energy carriers	MJ	84
Water scarcity[2]	m^3 world eq	0.74

(1) Calculated as upper heating value (UHV)
(2) Calculated with EF3.0 characterisation method

Output Parameters

Indicator	Unit	Value
Climate change, total	kg CO_2 eq	3.7
Ozone depletion	kg CFC-11 eq	4.1E-07
Acidification	Mole of H+ eq	7.9E-03
Photochemical ozone formation	kg NMVOC eq	7.2E-03
Eutrophication, freshwater	kg P eq	2.3E-05
Particulate matter	Disease incidences	4.0E-08

1.7. Additional Environmental and Health Information

Methacrylate monomers are reactive substances which must be handled according to safe use guidance (please refer to the Safe Handling

Manuals MSG and MPA). These documents provide product stewardship advice for the safe storage, handling and use of these products. Along with the Safety Datasheets provided by each supplier, they should be read and understood before ordering, storing and using methacrylates. Because methacrylate esters are contact allergens, the use of un-reacted liquid monomers in mixtures which are intended to encounter skin or nails, e.g. nail sculpting, is not recommended. More information on methacrylates and human health can be found on the MPA website.

1.8. Additional Technical Information

The polymer PMMA, made from monomer MMA, is characterized by its robust properties and by the fact that it is easy to process.

Thanks to its properties (light reflexion and transmission, mechanical resistance, low-density, capacity to be thermoformed...), PMMA can be used for a wide range of fields and applications (automobile industry, medical technologies, decoration, anti-noise walls, bathtubs and showers, advertising signs...).

1.9. Additional Economic Information

MMA is produced for use as monomer for production of polymers and as intermediate for synthesis of other methacrylate esters. The substance is manufactured in industrial settings in closed systems and used by industry for manufacture of polymers in closed and semi-closed systems. Downstream use of MMA is almost exclusively in the form of polymer although some products used by professionals and hobbyists may contain significant quantities of the liquid monomer.

1.10. Information

Data Owner

Methacrylates Sector Group, a Cefic Sector Group

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Programme Owner

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

References

PlasticsEurope: Eco-profiles program and methodology (version 3.1, September 2022).

2. Eco-profile Report

Eco-profiles (LCIs) 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 using polymers. It is essential to note that comparisons cannot be made at the level of the polymer or its precursors. Comparisons can only be made through LCAs applied at the level of a product using these different materials as different options on the basis of the same functional unit of this product.

Eco-profiles 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.

2.1. Functional Unit and Declared Unit

The Functional Unit (or Declared Unit) of this Eco-profile is:

1 kg of primary methyl methacrylate (MMA) “at gate” (production site output) representing a European industry production average.

2.2. Product Description

Methyl methacrylate (MMA) is an organic compound with the formula $C_5H_8O_2$.

It is a key intermediate chemical, due to its ability to undergo polymerization and copolymerization.

MMA is mainly used for the production of polymethylmethacrylate (PMMA).

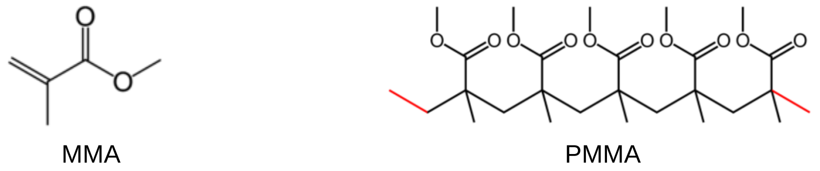

Figure 1: MMA and PMMA formulas

- IUPAC name: Methyl 2-methylprop-2-enoate
- Molar mass: 100.12 g/mol
- CAS no. 80-62-6
- Chemical formula: $C_5H_8O_2$
- Gross calorific value: 27.0 MJ/kg.

2.3. Manufacturing Description

Several methods exist for the production of MMA. The main route, which is used by the European producers participating in this study and is therefore modelled in this Eco-profile, is the “acetone cyanohydrin route”.

This route is based on three steps described in the following paragraphs and in Figure 2.

The first step of the process is intended to produce hydrogen cyanide (HCN). Hydrogen cyanide is usually produced from methane and ammonia according to the Andrussow process or the Degussa process.

- The Andrussow process is a catalytic oxidative dehydrogenation of methane and ammonia, in the presence of oxygen. This process is exothermic and hydrogen cyanide yields of 60 to 70% can be expected. Because of the presence of oxygen, water is produced during this process.
- The Degussa process is a dehydrogenation of methane and ammonia, in absence of air. The reaction is endothermic and then heat must be supplied to the reactor. However, up to 90% of the ammonia can be converted to hydrogen cyanide. In the absence of oxygen, the dehydrogenation results in the co-production of hydrogen.

Within these two processes, ammonia in excess is neutralised with sulphuric acid, producing ammonium sulphate as a co-product.

In the second step, hydrogen cyanide and acetone are used as reagents for the production of acetone cyanohydrin (ACH). In the third step, MMA is produced from acetone cyanohydrin, sulphuric acid and methanol. Firstly, acetone cyanohydrin undergoes sulphuric acid assisted hydrolysis and is converted into a sulphate ester of methacrylamide. Secondly, an esterification with methanol gives MMA. During the third step, sulphuric acid is used as an intermediate reagent. After the reactions, ammonium bisulphate may be recycled to sulphuric acid and reused for the MMA production or may be neutralised with ammonia, producing ammonium sulphate as a co-product.

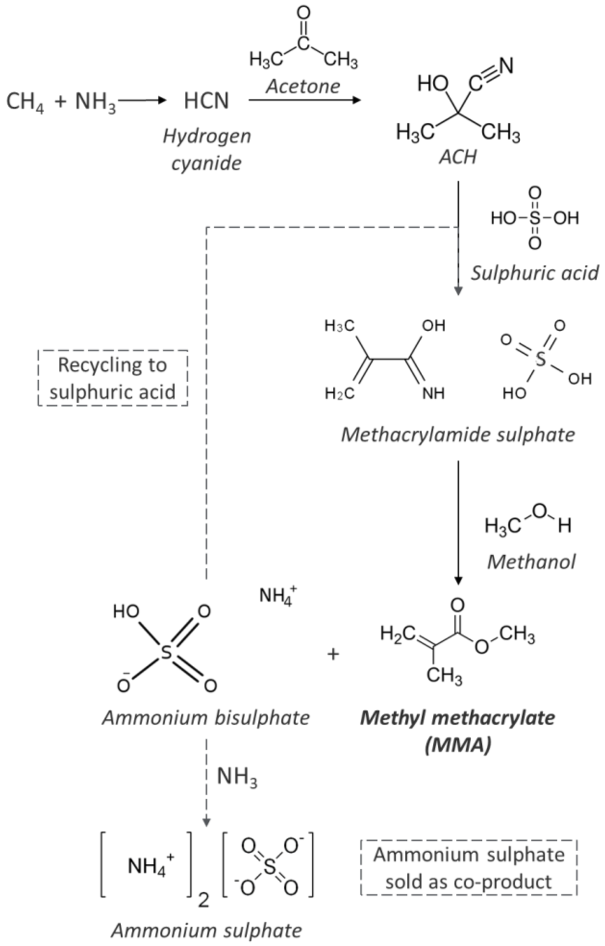

Figure 2: Overview of MMA production process

2.4. Producer Description

PlasticsEurope Eco-profiles represent European industry averages within the scope of Cefic and PlasticsEurope as the issuing trade federations. Hence they are not attributed to any single producer, but rather to the European plastics industry as represented by Cefic's membership and the production sites participating in the Eco-profile data collection. The three following companies, which are the three main European producers of MMA, contributed data to this Eco-profile:

- **Mitsubishi Chemical UK Limited**

  Cassel Works, New Road,

  Billingham TS23 1LE,

  United Kingdom

  https://mitsubishichemical.co.uk/

- **Röhm GmbH**

  Deutsche-Telekom-Allee 9,

  64295 Darmstadt

  Germany

  https://www.roehm.com/en/

- **Trinseo Europe GmbH**

  Gwattstrasse 15,

  8808 Pfäffikon,

  Switzerland

  https://www.trinseo.com/

The total production capacities of these companies represent 89% of the MMA production capacity in Europe. Consequently, the technological coverage is understood as representative.

2.5. System Boundaries

This Eco-profile refers to the production of MMA monomer as a cradle-to-gate system.

Two different systems are considered depending on how the sulphuric acid used in the third step of the production process is managed. After the reactions, the spent sulphuric acid may be recycled and reused for the MMA production or may be neutralised with ammonia, producing ammonium sulphate as a co-product (Figure 3).

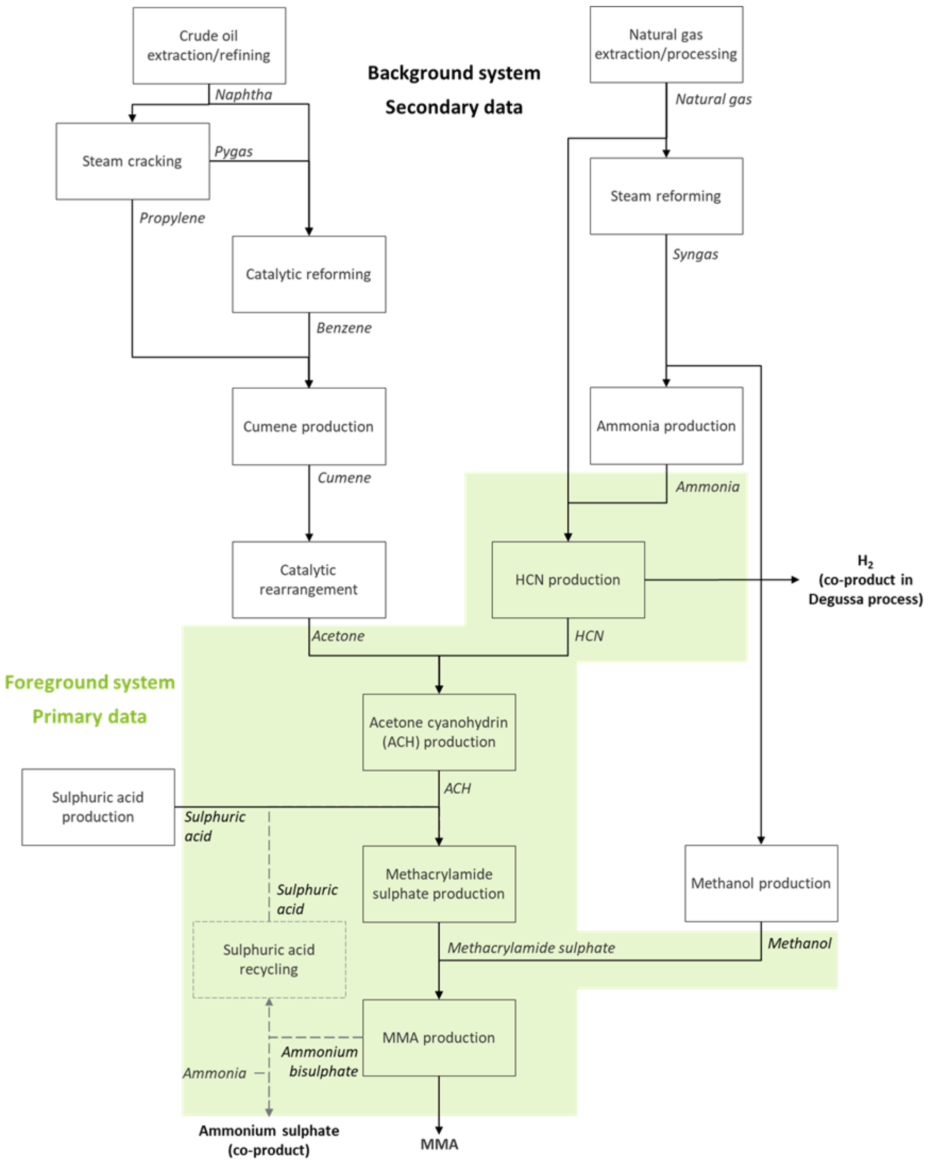

Figure 3: Cradle-to-gate system boundaries

2.6. Technological reference

This Eco-profile represents the European average technology for the production of MMA monomer.

The production process considered, which is used by the European producers participating to this Eco-profile, is the "acetone cyanohydrin route". This process is described in the section Manufacturing description.

For the first step of the process, which aims at producing hydrogen cyanide, 2 routes used by the participating companies are considered: the Andrussow process and the Degussa process.

For the last step of the process, which aims at producing MMA out of acetone cyanohydrin, sulphuric acid and methanol, 2 technologies are implemented by the participating companies and are considered: recycling and internal reuse of spent sulphuric acid or neutralisation of spent sulphuric acid with ammonia, producing ammonium sulphate as a co-product.

Primary data were used for all foreground processes (under operational control) complemented with secondary data for background processes (under indirect management control).

2.7. Temporal reference

The primary data used for this Eco-profile is representative of the year 2021. The primary data was collected as 12-month averages to compensate for seasonal influence of data.

Background datasets used are from the ecoinvent v3.8 database that was released in 2021. The ESIG acetone dataset was released in 2018.

The overall reference year for this Eco-profile is 2021 with a maximal temporal validity until 2028 to which the relevance of the revision should be considered.

2.8. Geographical reference

Primary data for MMA production is from three different producers in Europe (including UK). 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 European (including UK) boundaries. For other regions, adjustments might be required. MMA imported into Europe was not considered in this Eco-profile.

2.9. Cut-off Rules

All relevant flows of the foreground process are considered, trying to avoid any cut-off of material or energy flows. However, for a few select commodities (input <0.2% in mass of product output), generic datasets have been used.

Note that capital, i.e. the construction of plant and equipment as well as the maintenance of plants, vehicles and machinery is outside the LCI system boundaries of this study and is therefore not included in this Eco-profile.

Regarding potential cut-off in background data, please refer to the ecoinvent documentation.

2.10. Data Quality Requirements

Data Sources and Types of Data

The primary data used in this Eco-profile comes from four plants located in three different European countries and is site-specific gate-to-gate production data.

Hence, this Eco-profile uses average data representative of the respective foreground production process, both in terms of technology and market share.

All the datasets are taken from the ecoinvent database 3.8 with the exception of acetone production dataset, which is taken from the ESIG EF LCA database. Reasons for this choice is the fact that the ESIG dataset for acetone was considered more relevant (cross-check with other sources on acetone production such as emission trading reports), more recent and based on European industry data rather than on literature data. A sensitivity analysis was conducted on the influence of the acetone dataset on the LCA results.

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 from the most important producers in Europe in order to generate a European industry average production. The considered participants covered 89% of the MMA European production capacity in 2021.

The selected background data can be regarded as representative for the intended purpose. The dataset for acetone has been taken from ESIG EF LCA database to be more representative of European industry.

Consistency

To ensure consistency, primary data of the same level of detail 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.

It must be noted that major input flows origin both from ecoinvent and Gabi (for the acetone dataset). There are differences and this may influence the consistency.

Reliability and uncertainty

Data reliability ranges from measured to estimated data. Data of foreground processes were provided directly by producers and were predominantly measured. Regarding background processes data were taken from the ecoinvent 3.8 database. All these data are considered to be reliable.

Completeness

Thanks to primary data collected by the three participating companies for the elaboration of this Eco-profile, one may consider that all relevant flows were quantified, and data is 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.

Reproducibility

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.

Data Validation

All activity data was collected directly from the four production sites of the three participating companies. The activity data collected from the project partners and the data providing companies was validated in an iterative process. The collected data was validated using existing data from published sources or expert knowledge. The data itself has been checked with regards to mass, water and elemental balance performing stoichiometric checks. Environmental data is mainly from ecoinvent v3.8 with the ESIG dataset used for acetone. The eco-profile has been verified by an independent expert.

Life Cycle Model

The study was performed with the LCA Software SimaPro and the ecoinvent database. This database integrates ISO 14040/44 requirements. Due to confidentiality reasons details on software modelling and methods used cannot be shown here. The calculation follows the vertical calculation methodology as far as possible, i.e. that the averaging is done after modelling the specific processes.

2.11. Calculation Rules

Vertical Averaging aggregated datasets

The calculation follows the vertical calculation methodology, i.e. that the averaging is done after modelling specific processes of each participating company (Figure 4).

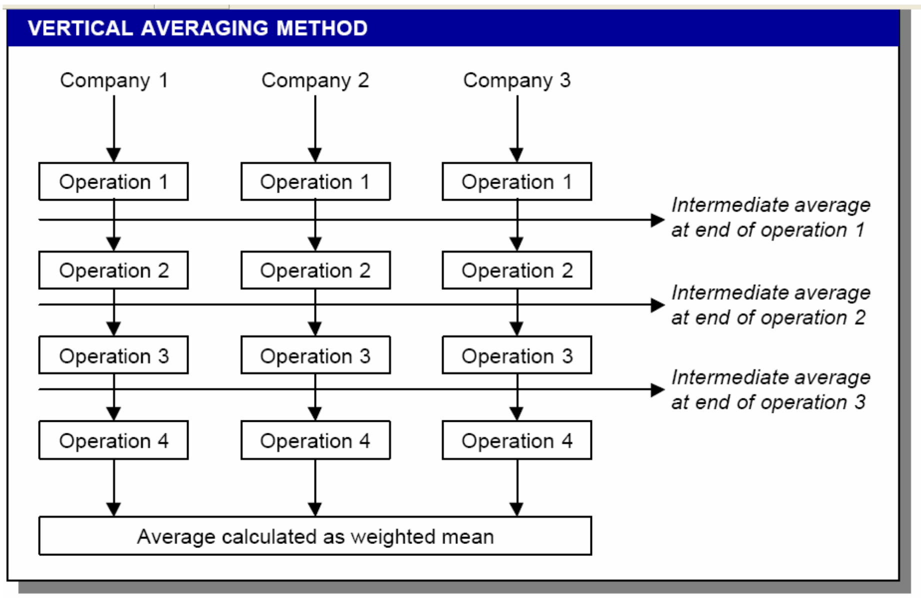

Figure 4: Vertical Averaging (source: Plastics Europe, 2022)

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. To this aim, a generic process with the same function (product) can be introduced, and the examined system receives credits for the associated burdens avoided elsewhere ("avoidance allocation", avoided burden).

For the considered MMA production technology applied by each of the sites considered in this Eco-profile, the fertiliser material ammonium sulphate is gained as co-product.

In this case, process subdivision was not possible. Different allocation methods were considered during the project (mass allocation, economic allocation, system expansion…). When deciding on the most suitable one, the following aspects should be kept in mind:

- Although the primary purpose of the plants is to produce MMA, these processes have been specifically designed not only to produce the main product in the required quality, but also to produce ammonium sulphate in a quality that can be marketed, i.e., ammonium sulphate is a desired co-product, for which ammonia is specifically used. Therefore, the quality of the ammonium sulphate is a critical aspect and influences the process design.
- Despite that fact that both products are sold as valuable substances, prices do not reach the same level for both cases, with higher absolute values for MMA (assumed price ratio about 9:1). Furthermore, market values are volatile and differs with respect to regions and market demand, amplified by the fact that the materials are applied in different sectors.

- The ratio in terms of product volume between main product and co-product depends on the operational control and can range from 0,3 to 2 kg of ammonium sulphate in relation to 1 kg of MMA.

After discussion with the Cefic and the participating companies, system expansion by substitution was selected as the most relevant option for this Eco-profile: the quantity of ammonium sulphate produced along with MMA replaces the conventional production of ammonium sulphate in Europe, through ammonia and sulphuric acid (background data from ecoinvent v3.8). Other allocation methods are tested in a sensitivity analysis.

Additionally, a very small quantity of hydrogen gas is produced as a co-product along with MMA and ammonium sulphate, for which mass allocation was applied (mass ratio: 2g of H_2 for 1 kg of MMA).

2.12. Life Cycle Inventory (LCI) Results

Delivery and Formats of LCI Dataset

The Eco-profile is provided in two electronic formats:

- As input/output table in Excel®
- 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 92 MJ/kg indicates the cumulative energy requirements at the resource level, accrued along the entire process chain (system boundaries), quantified as gross calorific value (upper heating value, UHV).

As a measure of the share of primary energy incorporated in the product, and hence indicating a recovery potential, the **energy content in the monomer** (system output), quantified as the gross calorific value (UHV), is 27.0 MJ/kg.

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

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

Primary Energy Demand	Value [MJ]
Energy content in monomer (energy recovery potential, quantified as gross calorific value of monomer)	27
Process energy (quantified as difference between primary energy demand and energy content of monomer)	65
Total primary energy demand	**92**

Water Use and Consumption

- **Cradle-to-gate water consumption**

The cradle-to-gate water consumption is 13 kg per 1 kg of MMA.

- **Gate-to-gate water use and consumption**

Table 2 shows the weighted average values for water use of the foreground production process. For each of the typical water applications the water sources are shown.

Table 2: Water use and source per 1kg of MMA

Source	Process water [kg]	Cooling water [kg]	Steam Water [kg]	Water in Raw Materials [kg]	Total [kg]
From Tap	0.18	0.57	-	-	0.75
Deionised	2.5	-	-	7.1E-03	2.5
From River	14	32	0.22	-	46
Relooped	-	-	-	-	-
Totals	**17**	**32**	**0.22**	**7.1E-03**	**50**

Table 3 shows the further handling/processing of the water output of the MMA production process.

Table 3: Treatment of Water Output per 1kg of MMA

Treatment	Water output [kg]
To WWTP	3.4
To Sea (after WWTP)	-
To River (untreated)	45
Reloop to process	-
Water Vapour	0.99
Formed in reaction (to WWTP)	0.44
Totals	**50**

Based on the water use and output figures above the **water consumption** can be calculated as:

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

= 0.99 kg

Dominance Analysis

Table 4 presents dominance analysis of impacts of MMA production process. The analysis shows the dominance of the production of chemicals, and especially of acetone, to the production of MMA.

Table 4: Dominance analysis of impacts per 1kg of MMA

	Total Primary Energy	**Resource use, minerals and metals**	**Resource use, fossil**	**Climate change, total**	**Acidification**	**Eutrophication, freshwater**
Acetone	**37%**	6%	**39%**	**27%**	9%	6%
Ammonia	**15%**	10%	14%	**20%**	8%	8%
Methanol	11%	**24%**	10%	5%	5%	**17%**
Other chemicals	12%	59%	12%	9%	**25%**	**29%**
Utilities	1%	0%	0%	0%	1%	7%
Emissions in the air	0%	0%	0%	5%	**37%**	0%
Emissions in the water	0%	0%	0%	0%	0%	0%
Energy	**22%**	0%	**21%**	**28%**	9%	**16%**
Transport	2%	0%	2%	3%	5%	1%
Process Waste Treatment	1%	1%	1%	1%	1%	**16%**
Water	0%	0%	0%	0%	0%	1%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Sensitivity Analyses

The influence of the allocation method for the ammonium sulphate co-product has been studied. Table 5 compares the results obtained via system expansion by substitution of ammonium sulphate (AS) to the results with:

- Mass allocation (mass ratio: 0.5 kg of AS for 1 kg of MMA), and
- Economic allocation (price ratio of approximately 9:1 for MMA:AS).

Table 5: Comparison of the LCA results per 1kg of MMA with different allocation methods for the co-product ammonium sulphate

	Total Primary Energy [MJ]	**Resource use, minerals and metals [kg Sb eq.]**	**Resource use, fossil [MJ]**	**Climate change, total [kg CO_2 eq.]**	**Acidification [mol H+ eq.]**	**Eutrophication, freshwater [kg P eq.]**
System expansion by substitution – Ammonium sulphate (base case)	92	2.3E-06	84	3.7	7.9E-03	2.3E-05
Mass allocation	74	1.7E-06	62	2.8	9.6E-03	1.9E-05
Economic allocation	92	2.2E-06	82	3.7	1.3E-02	2.5E-05

The results for the cradle-to-gate LCA of MMA are similar on most of the indicators with both system expansion and economic allocation methods.

- Mass allocation is the most misleading method. Indeed, it namely decreases the LCA results on climate change by 24% compared to the results obtained with system expansion by substitution of ammonium sulphate. This is due to the large quantity of ammonium sulphate produced along with MMA.
- Economic allocation in an allocation methodology that could certainly reflect market realities, but the economic values used can be opaque and subject to market volatility, and therefore not stable overtime.
- System expansion is the preferred method following the hierarchy provided by the ISO 14040 and ISO 14044 standards, in the case where process subdivision is not possible. This method is all the more relevant as ammonium sulphate is generated in the process additionally, but it is not the main product of the production process. All sites are operated for and optimised to produce ammonium sulphate as a co-product of MMA production.

A second sensitivity analysis has been conducted. on the influence of the acetone dataset on the LCA results. Table 6 compares the results obtained with the ESIG acetone dataset to the results obtained with the ecoinvent v3.8 acetone dataset.

Table 6: Comparison of the LCA results per 1kg of MMA with the ecoinvent acetone dataset to the results with ESIG acetone dataset

	Total Primary Energy [MJ]	**Resource use, minerals and metals [kg Sb eq.]**	**Resource use, fossil [MJ]**	**Climate change, total [kg CO_2 eq.]**	**Acidification [mol H+ eq.]**	**Eutrophication, freshwater [kg P eq.]**
Acetone from ESIG dataset (base case)	92	2.3E-06	84	3.7	7.9E-03	2.3E-05
Acetone from ecoinvent v3.8 dataset	117	2.4E-06	86	4.0	1.3E-02	9.2E-05

The discrepancy between LCA results for 1kg of MMA with one or the other acetone dataset is due to the dominant impact of acetone on these results, and to the difference in impacts between the ESIG and ecoinvent acetone datasets. The ecoinvent acetone dataset is indeed based on literature data whereas the ESIG dataset has been more recently generated and is based on averaged European industry data.

Comparison of the present Eco-profile with its previous version

Table 7: Comparison of the present Eco-profile with its previous version for 1 kg of MMA

Environmental Impact Categories (CML 2013)	Eco-profile MMA (2013)	Eco-profile MMA (2024)	Difference (%)
Abiotic depletion (elements) [kg Sb eq.]	2.6E-06	2.3E-06	-10%
Abiotic Depletion Potential (ADP). fossil fuels [MJ]	94	81	-13%
Global Warming Potential (GWP) [kg CO2 eq.]	3.5	3.5	2%
Acidification Potential (AP) [kg SO2 eq.]	1.9E-02	3.2E-03	-83%
Eutrophication Potential (EP) [kg PO43- eq.]	2.0E-03	5.2E-02	2522%
Ozone layer depletion (ODP) [kg CFC-11 eq.]	3.2E-07	3.5E-07	8%
Photochemical Ozone Creation Potential [kg Ethene eq.]	1.1E-03	6.6E-04	-38%

Please note: The results as presented in table above have been calculated with CML 2013 impact methodology and are therefore not to be compared with any other result table in this report.

When interpreting the results. it should be kept in mind that the previous results have been calculated using the Ecoinvent v2.2 database and are based on a different allocation for the ammonium sulphate co-product, which adds further uncertainty into the conclusions of a direct result comparison. In the 2013 eco-profile. mass allocation on steps 1 and 3 of the MMA production process was applied, whereas system expansion by substitution is used in this eco-profile. Furthermore, the previous Eco-profile was constructed from separate LCAs, and the consistency of the methodological approaches was therefore not guaranteed.

3. EF 3.0 Indicator results

Table 8 shows the LCA results for 1 kg of considered MMA when applying the EF3.0 impact assessment methodology.

Table 8: LCA results for 1 kg of average MMA applying EF 3.0 impact assessment methodology

Indicator	**Unit**	**MMA**
Climate change, total	kg CO2 eq.	3.7
Climate Change, biogenic	kg CO2 eq.	9.3E-03
Climate Change, fossil	kg CO2 eq.	3.7
Climate Change, land use and land use change	kg CO2 eq.	1.1E-03
Ozone depletion	kg CFC-11 eq.	4.1E-07
Acidification	Mole of H+ eq	7.9E-03
Photochemical ozone formation	kg NMVOC eq	7.2E-03
Eutrophication, freshwater	kg P eq	2.3E-05
Eutrophication, marine	kg N eq.	3.7E-06
Eutrophication, terrestrial	Mole of N eq.	1.1E-02
Particulate matter	Disease incidences	4.0E-08
Ionising radiation, human health	kBq U235 eq.	7.6E-02
Human toxicity, cancer – total	CTUh	6.3E-10
Human toxicity, cancer inorganics	CTUh	1.8E-20
Human toxicity, cancer metals	CTUh	4.8E-10
Human toxicity, cancer organics	CTUh	1.6E-10
Human toxicity, noncancer – total	CTUh	2.5E-08
Human toxicity, noncancer inorganics	CTUh	4.9E-09
Human toxicity, noncancer metals	CTUh	2.0E-08
Human toxicity, noncancer organics	CTUh	9.9E-10
Ecotoxicity, freshwater – total	CTUe	-53
Ecotoxicity, freshwater inorganics	CTUe	-65[1]
Ecotoxicity, freshwater metals	CTUe	11
Ecotoxicity, freshwater organics	CTUe	0.52
Land Use	Pt	1.6
Resource use, energy carriers	MJ	84
Resource use, minerals and metals	kg Sb eq.	2.3E-06
Water scarcity	m^3 world equiv.	0.74

[1] The negative value for Ecotoxicity, freshwater inorganics is due to the substitution of the Ammonium Sulphate production.

4. Review

The following pages present the review statement.

DEKRA

Critical Review Statement

Eco-profile for Methyl methacrylate (MMA)

DEKRA Alles im grünen Bereich

Commissioned by:	Cefic, Methacrylates Sector Group
Version:	Eco-profile, February 2024
Prepared by:	Deloitte Conseil
Reviewed by:	Angela Schindler Accredited partner of DEKRA Assurance Services GmbH

References:

- ISO 14071 (2016): Environmental management – Life cycle assessment – Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006
- ISO 14040 (2006): Environmental Management – Life Cycle Assessment – Principles and Framework
- ISO 14044 (2006): Environmental Management – Life Cycle Assessment – Requirements and Guidelines
- Eco-profiles program and methodology – PlasticsEurope, v.3.1, Sept. 2022

EXTERNAL INDEPENDENT REVIEW

The reviewer was tasked with assessing whether:

- the methods and inventory modelling used to carry out the Life Cycle Assessment are scientifically and technically valid and conform with ISO 14044:2006 and the methodological protocol of PlasticsEurope,
- the data and model results used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The critical review was performed at the end of the LCA study according to paragraph 4.3.3 of ISO 14071 and 6.2 of ISO 14044 by one independent external expert. This critical review statement is only valid for the specific report in its final version dated February 2024.

The verification of the LCI model and individual background datasets is outside the scope of this review.

1. REVIEW PROCESS

The review process was performed in accordance with ISO/TS 14071 and coordinated between Cefic/Deloitte and the reviewer. A first draft of the Eco-profile was submitted on 24.11.2023. The reviewer provided comments to Deloitte/Cefic on 06.12.2023, which were discussed to avoid any misunderstandings in a webmeeting on 18.12.2023. The webmeeting also served to show detailed and confidential background information on the data collection and the LCA calculations by the LCA practitioner Deloitte to the reviewer.

A thoroughly revised version was provided by Deloitte on 18.01.2024. Minor questions were clarified in a webmeeting on 08.02.2024. The reviewer checked the full implementation of the issues in the last and final version and agreed to conclude the critical review process on 12.02.2024.

2. GENERAL EVALUATION

The present Eco-profile is an update of the previous Eco-profile for Methyl methacrylate (MMA) from 2014.

The compliance of the document was reviewed according to the current requirements of the Eco-profile program and methodology, version 3.1 (Sept. 2022) of PlasticsEurope and the accompanying template for Eco-profile reports.

Main producers have taken part in this study. Thus, the Eco-profile can be seen as representative for the European market.

The LCA practitioners checked the plausibility of input data, the variance of materials and energy of comparable applied technologies and the variance of the results' data.

Minor data gaps of input flows could be closed by using approximated generic inventory data; direct emissions of the plants were reported and included in the calculation. Participants using green electricity were requested to deposit respective evidence on electricity certificates (guarantees of origin) with the LCA practitioners. The participants delivered sufficient information on waste treatment processes, which were also included in the LCA modelling.

The applied system expansion for the co-product ammonium sulphate in the MMA production is traceable. The justification has been discussed in the review process and is described in the MMA Eco-profile. Further sensitivity analysis supports the argumentation.

Some participants have implemented a recycling process for sulphuric acid, which requires energy and reduces the amount of the produced ammonium sulphate. These different technological approaches require different methodological implementations in the calculation model, which have effects on the final results. By averaging the result values, the Eco-profile fulfils the aim to display an average environmental profile, including different technologies applied in Europe for this product. The Eco-profile's objective is to declare the environmental indicators without assessing the impacts of different technologies.

Due to the change of assessment indicators, the Eco-profile is supplemented also by an evaluation applying the impact categories of the preliminary Eco-profile. This principally allows a relative comparison of the results. Both background data and foreground data are updated and previous confidential foreground data are not available to the LCA-practitioner. This enables only a limited statement of the actual improvement in respect to sustainable development.

All related questions were solved in the course of this critical review:

- The LCA practitioner and the sector group delivered information on the declared representativity of the study.
- The indicators for primary energy were checked and adapted following the requirements of the methodological protocol and the template for Eco-profiles.
- The figures displaying the process chain and the description of foreground and background system were optimized for clear understanding.
- All editorial recommendations and initiated re-phrasings for unambiguous understanding were implemented by the practitioners.

The reviewer confirms the presented values and argumentations.

3. CONCLUSION

The software model applied has undergone a Deloitte internal quality check to avoid mistakes of data transfer. Overall, the project is carried out very thoroughly.

The structure and description of the Eco-profile is clear and transparent, thus displaying a reliable source of information. Furthermore, the underlying data, the life cycle model, the assumptions and calculations are appropriate and valid and lead to plausible results.

Eco-profiles are often used as background data for construction products. So far, Eco-profiles do not have the requirement to be conform with EN 15804+A2. With the methodological approach of the system expansion, the resulting inventory displays a slight deviation from these rules. The sensitivity analysis still justifies this approach, especially in comparison to economic allocation. Thus, the application of this Eco-profile also for projects following EN 15804+A2 is recommended.

Despite all necessary due diligence performed during the critical review process by the reviewer, the commissioner of the LCA study remains liable for the underlying information and data.

Salem, 12.02.2024

Angela Schindler

Angela Schindler
Accredited partner of DEKRA Assurance Services GmbH, Stuttgart, Germany

5. References

ISO 14040: 2006	ISO 14040 Environmental Management – Life Cycle Assessment – Principles and Framework. Geneva, 2006
ISO 14044: 2006	ISO 14044 Environmental management -- Life cycle assessment -- Requirements and guidelines. Geneva, 2006ilc
JRC 2020	Simone Fazio, Luca Zampori, An De Schryver, Oliver Kusche, Lionel Thellier, Edward Diaconu. Guide for EF compliant data sets. Version 2.0, Luxembourg, 2020. ISBN 978-92-76-17951-1 (online). doi:10.2760/537292 (online). JRC120340.
PLASTICSEUROPE 2022	Eco-profiles program and methodology. Version 3.1, September 2022.

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