



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

# Vinyl chloride (VCM) and Polyvinyl chloride (PVC) Plastics Europe / The European Council of Vinyl Manufacturers (ECVM)

December 2022  
Water update March 2023  
Revised June 2023  
Revised January 2026



# Environmental Product Declaration

## Introduction

This Environmental Product Declaration (EPD) is based upon life cycle inventory (LCI) data from Plastics Europe's Eco-profile programme. It has been prepared according to **Eco-profiles program and methodology – Plastics Europe – v3.1 (2022)** [Plastics Europe 2022].

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 the vinyl chloride monomer and the polyvinyl chloride polymer 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 monomer or polymer material alone:** it is necessary to consider the full life cycle of an application in order to compare the performance of different materials and the effects of relevant life cycle parameters. This EPD is intended to be used by member companies, to support product-oriented 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	Plastics Europe, ECVM
LCA Practitioner	Sabrina Ludmann, Thomas Fröhlich, ifeu Heidelberg GmbH, Germany
Programme Owner	Plastics Europe, ECVM
Reviewer	Matthias Schulz Schulz Sustainability Consulting
Number of plants included in data collection	39
Representativeness	VCM 68% S-PVC 73% - E-PVC 81%
Year of validity	2023
Reference year	2013/2020 VCM/PVC process data
Year of data collection and calculation	2023 Oil/gas upstream 2015 Refinery data 2018-19 Steam cracker

	2013/2020 VCM/PVC process 2025 Calculation
Expected temporal validity	The relevance of an update will be considered every 5 years Methodology V3.1, Chapter 4
Cut-offs	none
Data Quality	Overall good quality (DQ rating 2.2, Confirmed by assessment of each single DQ indicator)
Allocation method	physical and economic

## Description of the Product and the Production Process

This Eco-profile and EPD represents the average industrial production of both vinyl chloride monomer (VCM) and polyvinyl chloride (PVC) from cradle to gate. The Eco-profile treats the two main production processes for PVC separately: S-PVC from suspension polymerisation and E-PVC from emulsion polymerisation.

### Production Process

Polyvinyl chloride (PVC) is manufactured by polymerisation of vinyl chloride monomer (VCM), which in Europe is produced by the thermal cracking of ethylene dichloride (EDC).

In Europe (EU27+NO+CH+UK), most ethylene used in the manufacture of EDC is produced by steam cracking of naphtha. Chlorine is produced by electrolysis of sodium chloride (NaCl) according to the latest EuroChlor Eco-profile.

The model of this Eco-profile includes the refinery of crude oil for the ethylene production as well as production of EDC and the final polymerisation of VCM into PVC. The model of the polymer production process represents the major commercial PVC production technologies, which are suspension process (S-PVC) and emulsion process (E-PVC).

Impacts related to abnormal process conditions (e.g. accidents) are not considered in this study.

### Data Sources and Allocation

Ethylene production is modelled based on the reviewed Eco-profile and EPD for ethylene and steam cracker products of Plastics Europe [Plastics Europe 2026], and chlorine production is based on

the Eco-profile and EPD for chlorine [EuroChlor 2022]. For the production of those raw materials all upstream processes until raw material extraction were considered.

The production of the precursor ethylene dichloride (EDC), of the monomer vinyl chloride (VCM) and the polymer production processes themselves are based on confidential process and emission data collected from participating production sites (primary data).

Country-specific electricity mixes are used for grid electricity supply. On-site production of electricity and steam is partially modelled using primary data from the polymer producers; data gaps in on-site energy production are closed using European average data of power plants and steam boilers.

Representative literature data is used to fill gaps wherever primary data is unavailable, and in order to cross-check primary data. Allocation within the foreground system is intended to be avoided; where necessary, processes are allocated by

physical properties, such as mass, exergy or enthalpy. Products with different economic values are allocated using the known relative prices (see Eco-profile for details).

### Use Phase and End-of-Life Management

The use phase and end-of-life processes of the investigated polymer are outside the system boundaries of this cradle-to-gate system: since the objects of this study are VCM and PVC, which is widely applied, even a qualitative discussion of these aspects was deemed inappropriate. However, the disposal of waste from production processes is considered within the system boundaries of this Eco-profile.

### Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg of VCM and each PVC type.

### Input Parameters

Indicator	Unit	Vinyl chloride	Suspension PVC	Emulsion PVC
		(VCM)	(S-PVC)	(E-PVC)
Non-renewable energy resources (UHV)	MJ	47.6	56.1	63.4
Renewable energy resources (UHV)	MJ	1.99	2.49	2.77
Resource Use (or Abiotic Depletion Potential)				
Elements (minerals and metals)	kg Sb eq	1.0E-05	1.1E-05	1.2E-05
Fossil fuels	MJ	44.30	52.06	58.76
Water use	kg	163.67	195.15	226.65
for process	kg	13.59	21.60	21.78
for cooling	kg	150.08	173.54	204.87
Water consumption (w/o sea water)	kg	45.01	47.97	50.93

## Output Parameters, LCIA Results

Impact Category	Unit	Vinyl chloride	Suspension PVC	Emulsion PVC
		(VCM)	(S-PVC)	(E-PVC)
Climate change	kg CO <sub>2</sub> eq	1.64	2.08	2.45
Acidification	mol H <sup>+</sup> eq	3.8E-03	4.5E-03	5.8E-03
Eutrophication, freshwater	kg P eq	5.0E-04	6.0E-04	7.6E-04
Eutrophication marine	kg N eq	9.5E-04	1.2E-03	1.4E-03
Eutrophication, terrestrial	mol N eq	9.0E-03	1.1E-02	1.6E-02
Ozone depletion	kg CFC11 eq	8.2E-07	8.4E-07	8.6E-07
Photochemical ozone formation	kg NMVOC eq	6.0E-03	6.9E-03	7.4E-03
Particulate Matter	disease incidents	2.2E-08	2.6E-08	3.7E-08
Ionising radiation	kg U235 eq	2.2E-01	2.7E-01	3.0E-01
Human toxicity, cancer	CTUh	5.0E-09	5.1E-09	5.8E-09
Human toxicity, non-cancer	CTUh	6.9E-09	8.3E-09	9.7E-09
Ecotoxicity, freshwater	CTUe	8.32	9.36	11.41
Water use	m <sup>3</sup> world eq	1.35	1.44	1.47
Land Use	-	2.76	3.36	3.40

An evaluation of how the results have changed in comparison to the previous Eco-profile can be found in the main report (p. 34ff.).

### Additional Environmental and Health Information – PVC

Like many other materials, the manufacture of PVC involves the use of some hazardous chemicals. Such manufacturing processes are very tightly regulated and the risks are adequately controlled. Regulations are completed since the 1990s by voluntary commitments (ECVM Charters). PVC is probably the world's most researched plastic/polymer.

A substantial volume of research and over 50 years of experience support the fact that PVC can be safely used even in the most sensitive of applications (such as medical devices).

PVC is one of the most recyclable of polymers but can be disposed of, if required, quite safely.

Building upon the achievements of the VinylPlus sustainability programme, the European PVC industry launched VinylPlus 2030 in 2021, the new ten-year voluntary commitment of the European PVC industry. It addresses three sustainability pathways, including Scaling up PVC Value Chain Circularity, Advancing towards Carbon Neutrality

and Minimising our Environmental Footprint and Building Global Coalitions and Partnering for the SDGs (more information can be found here<sup>1</sup>). Recycling and more generally end-of-life treatment of PVC is described in the "PVC recycling technologies brochure available for download from [VinylPlus 2017]. Due to the low thermal stability of PVC, heat stabilisers have to be added. Furthermore, plasticisers are necessary to ensure the flexibility required by some applications. To meet the product requirements various further substances are added to the PVC resin (more information can be found here<sup>2</sup>).

The current Eco-profile includes only those additives which are used and added within the declared boundaries of the model system. Further additives that may be applied during later processing are thus not considered within the current study.

### Additional Technical Information – PVC

The chemistry of PVC has been understood since the end of the last century. PVC was first

<sup>1</sup> <https://www.vinylplus.eu/about-us/vinylplus-2030-commitment/>

<sup>2</sup> <https://pvc.org/>

commercially produced in Europe in the 1930's and has since then undergone continuous development and improvement. PVC's adaptability comes from its molecular structure. This makes possible many different blends of ingredients providing a range of properties, enabling the PVC industry to respond to the commercial and technical needs of many market sectors.

PVC can be found in an extremely wide range of applications whether transparent or pigmented, such as construction products like window frames, pipes and facade elements, or as products for mechanical or electrical engineering like cable insulation. PVC also has applications in food packaging or consumer goods.

## Information

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

### Programme Owner

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### Data Owner

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PVC products are characterised by low natural flammability and high chemical and biological inertness.

## Additional Economic Information

Together with polyolefins, PVC is one of the economically most prominent thermoplastics. The PVC production in Europe sums up to about 5 million tons/year.

The production volumes of PVC have been slightly decreasing within Europe in recent years due to a depression of the construction sector in the Covid pandemic; from a global point of view, however, demand and production of PVC are still growing.

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## References

- EuroChlor (2022): An Eco-profile and Environmental Product Declaration of the European Chlor-Alkali Industry. Chlorine (The Chlor-Alkali Process). Euro Chlor. <https://www.eurochlor.org/wp-content/uploads/2022/02/2022-Euro-Chlor-Eco-profile.pdf> (26.09.2022).

- Plastics Europe (2022): Eco-profiles program and methodology, version 3.1 (September 2022) <https://PlasticsEurope.org/wp-content/uploads/2022/11/Ecoprofiles-Methodology-V3.1.zip>
- Plastics Europe (2026): Eco-profile of Steam Cracker Products: Ethylene, Propylene, Butadiene, Pyrolysis Gasoline, Ethylene Oxide (EO), Ethylene Glycols (MEG, DEG, TEG), Plastics Europe, Belgium, January 2026.
- VinylPlus 2017: PVC recycling technologies. VinylPlus. [https://vinylplus.eu/wp-content/uploads/2017/02/VinylPlus\\_PVC\\_recycling\\_tech\\_20092017.pdf](https://vinylplus.eu/wp-content/uploads/2017/02/VinylPlus_PVC_recycling_tech_20092017.pdf) (26.09.2022).

# Eco-profile Report

## Functional Unit and Declared Unit

The Functional Unit and Declared Unit of this Plastics Europe Eco-profile and EPD are:

- 1 kg of vinyl chloride (VCM),
- 1 kg of polyvinyl chloride from suspension polymerisation (S-PVC) and
- 1 kg of polyvinyl chloride from emulsion polymerisation (E-PVC).

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

## Product Description

The products considered in this Eco-profile and EPD are vinyl chloride (VCM), polyvinyl chloride from suspension polymerisation process (S-PVC) and polyvinyl chloride from emulsion polymerisation process (E-PVC). This Eco-profile represents the average European industrial production of each product. Main characteristics of the products under investigation are presented in Table 1. Hence, it is not attributed to any single producer, but rather to the European PVC industry, which is represented by ECVM.

Table 1: Characteristics of the polymer precursors under consideration in this Eco-profile.

Common name	IUPAC name	CAS no.	Chemical formula	Density g/cm <sup>3</sup>	Melting Point	Gross calorific value MJ/kg <sup>b)</sup>
Vinyl chloride	Chloroethene	75-01-4	C <sub>2</sub> H <sub>3</sub> Cl	0.003	-154°C	17.5 <sup>a)</sup>
Polyvinyl chloride	Poly(1-chloroethene)	9002-86-2	(C <sub>2</sub> H <sub>3</sub> Cl) <sub>n</sub>	1.38-1.40	> 180°C	20.0 <sup>b)</sup>

<sup>a)</sup> calculated using the heats of formation of the reactants [NIST 2022]

<sup>b)</sup> communications with ECVM, value for PVC resin

Vinyl chloride (VCM) is a colourless, toxic, flammable, and carcinogenic gas with a sweet odour. It is almost exclusively used for the production of polyvinyl chloride.

Polyvinyl chloride (PVC) is one of the most important commodity polymers. After polyethylene (PE) and polypropylene (PP), polyvinyl chloride (PVC) is among the top 3 resin types. PVC production in 2021 had a share of 11.4 % on the European (EU27+NO+CH+UK) polymer market [Plastics Europe 2022]. In 2021 the European demand of polyvinyl chloride is indicated with about 5.2 Mt/year [Plastics Europe 2022].

The main application for PVC is in the building and construction sector (see Figure 1). The applied products include window frames, pipes and fittings, other profiles, e.g. rolling shutters as well as flooring, roofing, electrical insulation etc. Furthermore, PVC is used for packaging products like blisters or films, and for other products such as toys, signs, or credit cards [Plastics Europe 2021b].

The applications for S-PVC and E-PVC differ due to different material characteristics. S-PVC is better suited for the large volume production of a limited number of grades. Thus, S-PVC is the general-purpose grade and is used for most rigid PVC applications such as pipes, profiles, other building materials and hard foils. It is also plasticised and used for flexible applications such as cable insulation, soft foils and medical products. A number of specific applications require E-PVC or gain advantages from the use of E-PVC. It is primarily used for coating applications such as PVC coated fabrics. Due to the different applications it is necessary to produce an adequate proportion of PVC via the emulsion process in order to supply specific markets for which E-PVC is technically more suitable than S-PVC.

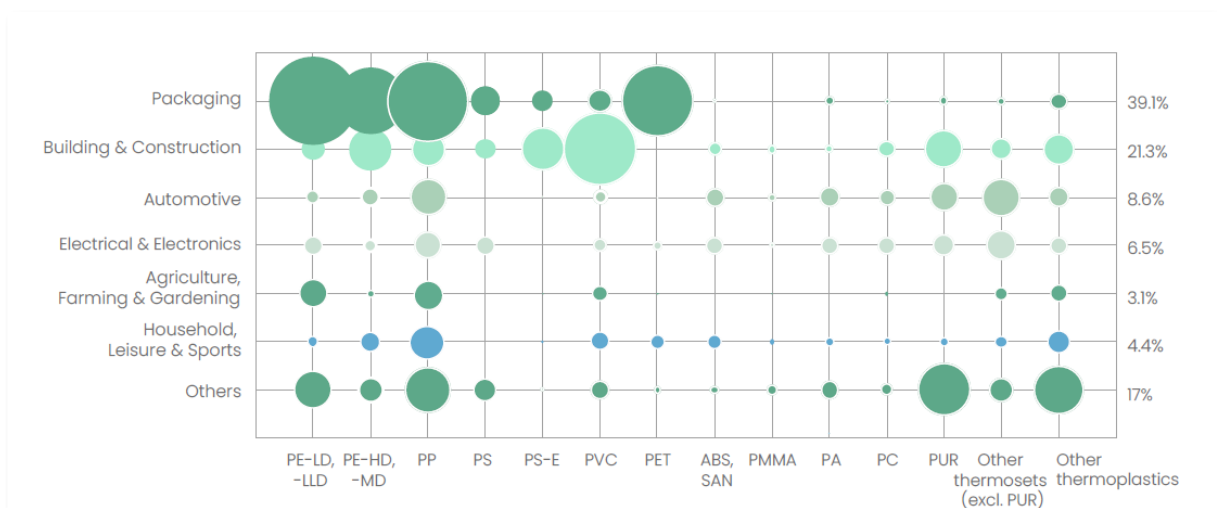


Figure 1: European (EU27+3) plastics demand by segment and resin type 2021 (Total 50.3 Mt). Source: Plastics Europe Market Research Group (PEMRG) and Conversio Market & Strategy GmbH. Quoted from: [Plastics Europe 2022]

Polyvinyl chloride is a chlorinated hydrocarbon polymer, based on the raw materials chloride and ethylene. PVC is mainly produced as a homopolymer. About 90 % of the PVC consumed worldwide is polymerised using the suspension process. The structure of polyvinyl chloride is shown in Figure 2.

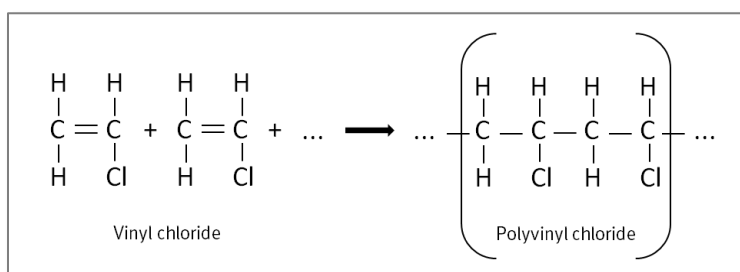


Figure 2: Polymerisation of vinyl chloride yields polyvinyl chloride

PVC, especially when produced by suspension process, is a very pure product with e.g. high stiffness and toughness, low natural flammability and with chemical and biological inertness. PVC, however, is never used in its pure form. To make the processing of the resin possible and to meet later product requirements, it is always mixed with heat stabilisers and lubricants, and sometimes with plasticisers, fillers and other additives.

## Manufacturing Description

[LVOC BREF 2017, Fischer 2014]

Polyvinyl chloride (PVC) is manufactured by polymerisation of vinyl chloride monomer (VCM), which is produced by the thermal cracking of ethylene dichloride (EDC). In Europe (EU27+NO+CH+UK) most of the ethylene used in the manufacture of ethylene dichloride is produced by steam cracking of naphtha. The chlorine is derived from common salt (NaCl) by electrolysis.

For a technological description of the raw materials ethylene and chlorine please refer to the corresponding EPDs and Eco-profiles, in particular the Eco-profile and EPD of steam cracker products (ethylene; Plastics Europe 2026), and the Eco-profile and EPD for chlorine (chlor-alkali process) [EuroChlor 2020]. The manufacturing of the precursors EDC and VCM will be described in the following section.

### **Production of ethylene dichloride (EDC) and vinyl chloride monomer (VCM)**

EDC, also known as 1,2-dichloroethane, is the precursor of VCM. It is mainly used for the purpose of VCM production, which is schematically illustrated in Figure 3. Originally, VCM was produced by the gas-phase hydrochlorination of acetylene (ethyne) with hydrochloric acid (HCl) over a mercuric chloride-based catalyst. Due to the high cost of acetylene and the emergence of large steam-crackers providing abundant ethylene the acetylene route has been replaced by chlorination of ethylene within the European industrial EDC production. Today, the original acetylene route is still widely used in Chinese production due to the availability of coal as a feedstock for acetylene production from calcium carbide.

The chlorination of ethylene can either be carried out by using chlorine (direct chlorination) or by using hydrogen chloride and oxygen (oxychlorination). Thermal cracking of dry, pure EDC then produces VCM and HCl. When all the HCl generated in EDC cracking is re-used in an oxychlorination section, and when no EDC or HCl is imported or exported, then the VCM unit is called a 'balanced unit'. By using both, direct chlorination and oxychlorination, for EDC production, balanced units achieve a high level of chlorine utilisation without producing HCl as a by-product. Assuming a complete incorporation of chlorine input into EDC within a balanced unit, half of the produced EDC originates from each of the applied processes, direct chlorination and oxychlorination.

Additionally, the heat gain from both highly exothermic chlorination processes may be used in the associated VCM production, optimising the overall energy demand of the EDC/VCM/PVC production.



(typically around 1 kg/t VCM in suspension and around 10–20 kg/t in emulsion). Organic peroxides or peresters are used as initiators (typically < 1 kg/t VCM) for the production of suspension and micro-suspension PVC, while e.g. hindered phenols are used to stop the reaction (typically < 1 kg/t VCM). For the production of emulsion PVC inorganic peroxides are common.

PVC suspension or latex can be concentrated before drying. For PVC suspension this is usually achieved by dewatering via centrifugation. The PVC is then dried using a combination of temperature and airflow in dryers of various designs. E-PVC is usually spray dried.

## Producer Description

Plastics Europe Eco-profiles and EPDs represent European industry averages within the scope of Plastics Europe as the issuing trade federation. Hence, they are not attributed to any single producer but to the European plastics industry as represented by Plastics Europe members and the production sites participating in the Eco-profile data collection. The following companies contributed data to this Eco-profile and EPD:

- *Cires, Shin-Etsu Group (Companhia Industrial de Resinas Sintéticas, Cires, LDA)*
- *ERCROS, SA*
- *INOVYN EUROPE Ltd.*
- *Shin-Etsu Chemical Co., Ltd.*
- *VESTOLIT GmbH*
- *Vinnolit GmbH & Co. KG*
- *VYNOVA Group NV*

Data was collected from the European vinyl chloride and polyvinyl chloride production units of the above-mentioned companies. The data collection aimed at information on all energy and material inputs and outputs of the production of ethylene dichloride (EDC), vinyl chloride monomer (VCM) and polyvinyl chloride (PVC). Data for S-PVC and E-PVC as well as EDC/VCM were requested separately. In addition to production input and output information, the requested data also included information on distances and means of transportation of each material input, emissions to air and water, and the type, amount, destination, and transport distances of wastes produced inside the system boundaries. Furthermore, the same sets of data were collected regarding the on-site production of electricity and steam by either power plants or steam, delivering energy directly (i.e. not via the national electricity grid) to the polyvinyl chloride production unit. Total amounts for one year (data collection reference year 2021) were requested from a number of ECVM plants volunteering for this data collection; these plants were found to exhibit significant changes; for plants with no significant changes the latest available primary data were used: data from the previous Eco-profile (2013 data) were used wherever more recent information was not available; a small group of plants is represented by data from 2017 – 2020, since the practitioner has gained confidential and more recent information on these plants during other projects, exhibiting the same data quality and system boundaries as required for the present Eco-profile.

## System Boundaries

This Eco-profile refers to the production of VCM (polymer precursor) and S-PVC and E-PVC (polymer) and is based on a cradle-to-gate system (see Figure 4).

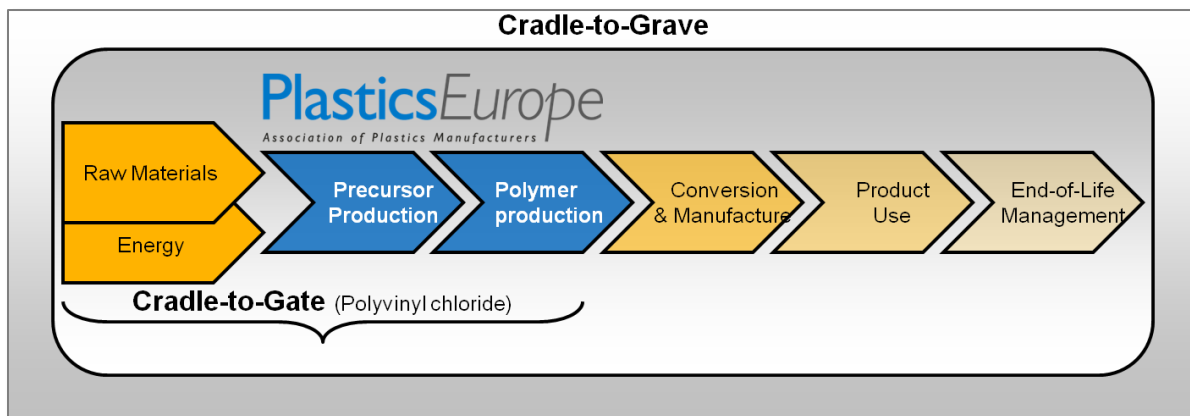


Figure 4: Cradle-to-gate system boundaries for the production of polyvinyl chloride (PVC)

### Cradle-to-Gate System Boundaries for Production

The following processes are included in the cradle-to-gate LCI system boundaries (see Figure 5):

- Extraction of non-renewable resources (e.g. of oil and natural gas)
- Growing and harvesting of renewable resources (e.g. biomass production)
- Beneficiation or refining, transfer and storage of extracted or harvested resources into feedstock for production;
- Recycling of production waste or secondary materials for use in production
- Converting of non-renewable or renewable resources or waste into energy
- Production processes
- All relevant transportation processes (transport of materials, fuels and intermediate products at all stages)
- Management of production waste streams and related emissions generated by processes within the system boundaries.

According to the methodology of Eco-profiles [Plastics Europe 2022] capital goods, i.e. the construction of plants and equipment as well as the maintenance of plants, vehicles, and machinery is outside the LCI system boundaries. The end-of-life treatment of PVC and its consecutive products is also outside the LCI system boundaries of this Eco-profile. Inputs and outputs of secondary materials and wastes for recovery (e.g. used catalysts for recycling) are noted as crossing the system boundaries without environmental burdens. An exception is low-radioactive waste from electricity generation for which a final storage has not been found yet; it is declared as output.

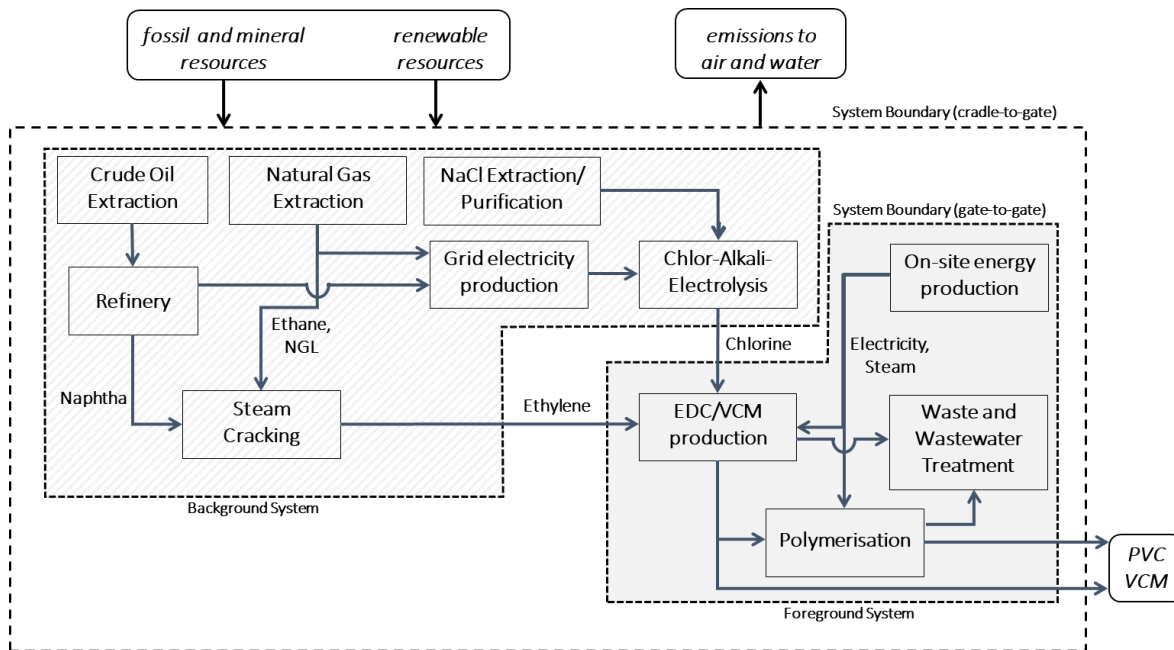


Figure 5: Flowchart of PVC production with the most important background and foreground processes, indicating the cradle-to-gate system boundaries and gate-to-gate system boundaries (the latter referring to processes under direct control of ECVM).

## Technological Reference

The production processes were modelled using specific values from primary data collection at site, representing the specific technology for the precursor and polymer production of the companies. The LCI data represent the production mix of technologies in use in the defined production region employed by participating producers. For the on-site energy supply, primary data were collected as well.

Primary data were used for all foreground processes (under operational control of ECVM members) as well as for the provision of on-site-energy.

The Eco-profile participants cover **73 %** of S-PVC producers and **81 %** of E-PVC producers in Europe in 2021 (with respect to the installed nameplate capacity of all European producers, Source: communications with Plastics Europe, 2022), so the technological coverage is understood as fairly representative. The coverage with respect to VCM production comprises **68 %** of the sum of nameplate capacities of European plants. Additionally, the Eco-profile includes one pure EDC producing plant. The coverage with respect to EDC production is difficult to access, though, since EDC is also exported from combined EDC/VCM plants in varying amounts. Please refer to Table 2 for an overview of the nameplate capacity sum of all participating plants compared to reported production of EDC/VCM and S-/E-PVC in the reporting years 2013 to 2021.

Table 2: Participating VCM and PVC production units: nameplate capacity vs. reported production.

	Nameplate capacity <sup>1)</sup> sum in kt	Reported production sum in kt	Production / Nameplate capacity %
<b>S-PVC</b>	4,100	3,706	90%
<b>E-PVC</b>	690	607	88%
<b>VCM</b>	4,705	4,053	86%

From the total number of 59 EDC, VCM and PVC producing plants in Europe 39 volunteered to take part in this study, constituting the ECVM member plants. 9 of these plants were requested to provide new complete primary data of 2021 production processes for this Eco-profile, while the other plants did not undergo major changes and were modelled considering data from previous Eco-profiles, i.e. [Plastics Europe 2016], assuming the present production process data to be still valid. This Eco-profile relies on complete data sets for the ethylene dichloride (EDC) and vinyl chloride monomer (VCM) production from 13 plants, and for polyvinyl chloride (PVC) production from 26 plants. Of these PVC producing plants, 17 were producing suspension polyvinyl chloride (S-PVC) and 9 emulsion polyvinyl chloride (E-PVC).

Relating to the individual products (EDC, VCM and PVC), the data coverage in relation to the European nameplate capacity can be differentiated as shown in Table 3.

Table 3: Selected and participating PVC production units and their share in European ethylene dichloride, vinyl chloride monomer and polyvinyl chloride production capacity (nameplate capacity):

	Participating units data from 2013 to 2021	Participating units providing data for 2021	Coverage of production by nameplate capacity <sup>1)</sup>
<b>S-PVC</b>	17	5	73%
<b>E-PVC</b>	9	1	81%
<b>VCM</b>	12	3	68%
<b>EDC</b>	1	0	n.a.

<sup>1)</sup> Based on total installed European nameplate capacity; Source: communications with Plastics Europe, 2022

The data quality rating is considered as good (2), because the technology mix is subject to market equilibrium which is reasonably stable within the expected temporal validity.

According to the Plastics Europe LCI methodology and product category rules inputs of secondary materials (recyclate) and outputs of waste for recovery or disposal shall be noted as crossing the system boundaries. While there is no input of recyclates at all, outputs of wastes for recovery or disposal only contribute very little to the total proceedings under consideration in this Eco-profile. The following list shows the waste streams of the VCM and PVC production processes and their treatment (total amount of waste: 1.0 % related to feedstock input).

Table 4: Waste produced per kg product (foreground process) and treatment

	Unit	VCM	S-PVC	E-PVC
Hazardous waste to Landfill	kg	1.89E-04	4.95E-05	-
Hazardous waste to Recovery	kg	2.21E-03	3.11E-05	5.54E-05
Hazardous waste to Incineration	kg	9.30E-03	9.45E-05	3.67E-04
Hazardous waste to Others	kg	-	1.56E-06	7.56E-06
Non-hazardous waste to Landfill	kg	1.36E-04	9.07E-04	2.12E-03
Non-hazardous waste to Recovery	kg	6.85E-05	4.50E-04	5.79E-04
Non-hazardous waste to Incineration	kg	1.91E-05	1.65E-04	5.80E-04
Non-hazardous waste to Others	kg	-	9.20E-06	3.49E-05

## Temporal Reference

The LCI data for this Eco-profile represents the most recent available data and therefore represents the average technology in Europe. Data for EDC, VCM and PVC production was collected during an earlier Eco-profile and refers to the production year 2013. Additional primary data referring to the production year 2020 was collected during the previous Eco-profile in 2021, representing 9 plants identified by ECVM, which exhibit major changes in production or energy supply between 2013 and 2020. The present Eco-profile relies on the same primary data basis (2013 to 2020) as the previous report (Plastics Europe 2023). A small group of plants is represented by data from 2017 – 2020, since the practitioner has gained confidential and more recent information on these plants during other projects – the data could be used, since quality and system boundaries were identical to those required for the present Eco-profile. In spite of its age, the data is considered to be still valid, since – due to the high investment costs for production facilities – only small changes are expected at those plants not identified for new data collection.

The overall year of validity for this Eco-profile is 2023 with a maximum temporal validity until 2028 due to the update of all background systems including feedstock, fuels and energy supply. It seems adequate to refer to the 5-year interval that is proposed in the product category rules for polymers [Plastics Europe 2022].

The data quality rating is considered poor (4) because a significant portion of the production data is more than 10 years older than the reference year: Nevertheless, it was considered still valid by ECVM and its member companies. Data from the year 2021 were collected where the data quality of 2013 was considered as not sufficient.

## Geographical Reference

This Eco-profile refers to the average production of PVC in Europe (EU27+NO+CH+UK) with a total coverage of 68 % of installed production capacity for VCM, 73 % for S-PVC and 81 % for E-PVC. For 8 of the considered countries – Belgium, Germany, Netherlands, Norway, Portugal, Sweden, Spain, UK – the overall data coverage is 100 % or close to 100 % (related to production capacity of the participating companies). For 4 countries – Czech Republic, Hungary, Poland, Slovakia – the data coverage is 0 %, since the respective production sites were not participating in the Eco-profile. France exhibits a coverage rate of around 50 %. In total, the geographical coverage is biased towards the production from western European sites: 32 % of total European VCM production, 27 % of S-PVC production, and 19 % of E-PVC production are missing in the production quantities covered in the present ECVM Eco-profile, mainly from eastern European production sites in Czech Republic, Hungary, Poland, Slovakia as well as France.

The data quality rating is considered good (2) because the covered set of plants represents a major portion of the European VCM and PVC production, though biased towards western Europe, where ECVM membership is more established.

## Cut-off Rules

To achieve completeness, i.e. a closed mass and energy balance, any cut-off of material and energy flows have been avoided in this Eco-profile. For commodities with an input < 1 wt.-% of the total material input (additives, other compounds, etc.) generic datasets from the LCA database ecoinvent v3.11 [Ecoinvent 2024] were used. In ecoinvent datasets, waste for recycling is generally cut off. Furthermore, expenses for capital equipment were not considered in this Eco-profile.

Simplified generic processes are assumed for catalysts and a few commodities (input < 0.1 wt.-% of the precursor's output) with missing secondary production data. The process input/output relation has been determined by reaction equations from literature. The upstream production of the used metals (antimony, cobalt, manganese and palladium) and chemicals are implemented using ecoinvent v3.11 data [Ecoinvent 2024]. Thus, the potential environmental relevant metal extraction and refinement processes are included in the LCI data.

## Data Quality Requirements

### Data Sources

The LCI data used in this Eco-profile and EPD is representative of the production processes of VCM and PVC in Europe, both in terms of technology and market share. Average data representative of the respective foreground production process, both in terms of technology and market share, are used. Foreground processes comprise the production units for EDC, VCM, S-PVC and E-PVC, including water treatment and on-site energy production as part of the respective site. The primary data for the production units and the on-site energy were collected from the participating member companies (see Producer Description).

Data concerning the production of chlorine are taken from the most recent Euro Chlor Eco-profile (Chlor-alkali process) [EuroChlor 2020] of which the full dataset is known to the LCA practitioner.

Concerning HCl input, the same data as for chlorine was used. This procedure is in line with the previous version of this Eco-profile of 2023 and is based on the conservative assumption that one molecule HCl carries half the load of a Cl<sub>2</sub> molecule. The conservative assumption is chosen over the assessment of specific HCl production information, which states that a majority (> 85 %) of the imported HCl originates from MDI production (corresponding to 20 % of total chlorine input to the EDC/VCM processes modelled). This approach is justified by the fact that in the published Eco-profile for MDI/TDI [Plastics Europe 2021c] burdens are allocated by mass between the main product MDI and the by-product HCl, resulting in unreasonably high environmental loads for HCl.

Data concerning the ethylene feedstock for VCM was taken from the Plastics Europe Eco-profile of steam cracker products [Plastics Europe 2026], of which the full dataset is known to the LCA practitioner.

Oil and gas extraction datasets are taken from the Ecoinvent datasets, version 3.11 (latest available version in most LCA softwares) [Ecoinvent 2024].

- market for natural gas, high pressure [m3], country specific

- market for petroleum [RER], European mix. The mix refers to the latest information available on petroleum imports to Europe and applies ecoinvent datasets for producer specific data and transport distances.

There are some differences in the oil and gas upstream dataset of ecoinvent v3.11 compared to the datasets used in the previous Eco-profile. The sensitivity case of the previous Eco-profile applying the ESU oil and gas extraction dataset [Meili 2019a; Meili 2019b] including methane emissions according to the IEA Methane Tracker is comparable to the ecoinvent v3.11 datasets. One of the differences is the geographical reference of the dataset: The current dataset allows for the implementation of country specific oil and gas upstream processes, while the previous Eco-profile provided information on an average European basis; this includes transportation modes and distances as well as venting and flaring.

For transport processes the main data source is ecoinvent v3.11.

Electric power supply was modelled using country specific grid electricity mixes, since the environmental burdens of power production varies strongly depending on the electricity generation technology. The country-specific electricity mixes are obtained from ecoinvent v3.11 and are referring to the year 2021. The main grid electricity contributions to VCM and PVC production processes are shown in Table 5.

*Table 5: Climate change or Global Warming Potential indicator (GWP100 after EFv3.1) for the five most significant country electricity mixes, based on electricity demand of VCM and PVC production amounts reported by ECVM in 2022. Shares represent the total reported grid electricity demands for VCM and PVC in 2022.*

Country <sup>1)</sup>	2021 GWP100 (EFv3.1) [kg CO <sub>2</sub> eq/kWh]	Country significance (grid electricity demand share)
Germany	0.473	36.5%
The Netherlands	0.444	21.1%
France	0.0775	10.6%
Spain	0.203	9.4%
Belgium	0.177	8.2%
Others: Norway/Sweden/Portugal		14.2%

1) market for electricity, medium voltage [Ecoinvent 2024]

Data for the provision of on-site energy and utilities was taken from Ecoinvent v3.11, except for

- Oxygen and nitrogen supply: The air separation unit from ecoinvent was remodelled using a more recent electricity consumption factor of 0.25 kWh/kg air.

### Relevance and Representativeness

With regard to the goal and scope of this Eco-profile, the process data, i.e. data for the foreground processes, are of high relevance as the collected primary data for the VCM and PVC processes represent the best available data to describe the European landscape of PVC production. The used data reflect the current technology in Europe and the current upstream chains of feedstock relevant for production in (EU27+NO+CH+UK) member countries.

The data used for this study covers 73 % and 81 % of the installed S-PVC and E-PVC nameplate capacities, respectively, and 68 % of the installed VCM nameplate capacities in Europe (EU27.NO+CH+UK) in 2021. The background data used can be regarded as representative for the intended purpose, as these are averaged data sets, which are not in the focus of the analysis.

### Consistency

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 (e.g. allocation principles, background datasets, waste treatment) are used throughout the whole system. Those parts of the model defined as background systems according to the Plastics Europe LCI methodology [Plastics Europe 2022] have been treated with the same thoroughness as if they were foreground systems.

The data quality rating is considered very good (1) because the model is fully consistent with the methodology herein.

### **Reliability**

In the questionnaires, the site managers were encouraged to classify their data into one of the following reliability grades: measured, calculated or estimated. According to these statements, the data of foreground processes provided directly by producers were almost completely measured. Data of relevant background processes, e.g. grid electricity, is based on ifeu models that are regularly updated with statistical data, with available primary data, and with data derived from literature after it has been reviewed and checked for its quality. Thus, the overall data quality rating for reliability is considered good (2), since either verified data partly based on assumptions or non-verified data based on measurements was used.

### **Completeness**

The data collection covers relevant inputs (e.g. amount of raw materials, energy or water) and main output products (e.g. S-PVC, E-PVC, recovered energy) as well as relevant output data, covering emissions to air and water, amounts of waste, and transport information.

In general, the collected and applied data can be stated as complete, because no flows are omitted or substituted. However, for a few production sites it was not possible to obtain detailed emission data due to site-specific measurement and recording practices. In order to compensate for missing information on certain important inputs and outputs, average values (calculated based on the data reported by other production sites of the same process type weighted by product output) are used. This procedure avoids missing information to be treated as "zero" in the calculation of average values. This procedure is applied to the following substances/process flows:

- emissions to air from VCM process: NMVOC, NO<sub>x</sub>, dioxins and furans, tetrachloromethane, trichloromethane, Ethylene, HCl
- emissions to air from PVC processes: ammonia, dust
- emissions to water from VCM process: total nitrogen, total phosphorus, VCM, dioxins and furans, TOC, chlorides
- emissions to water from PVC processes: total nitrogen, total phosphorus, VCM, TOC, suspended matter

In case of missing information about the fuel mix (natural gas, fuel oil, coal, etc.) used for on-site energy production, the average fuel mix of all participating sites is assumed. This method is also applied for thermal or electrical efficiencies of on-site energy installations as well as for means and distances of raw materials and wastes.

The data quality rating is considered good (2) because cut-offs are smaller than 1 %.

### **Precision and Accuracy**

The relevant foreground data consist of primary data or modelled data based on primary information sources of the owner of the technology, such that the best possible precision has been achieved within this

goal and scope. The accuracy of results with respect to systematic errors can be considered very high due to the high level of detail within both, input data and model.

The overall qualitative assessment of data accuracy is as follows (overall data quality rating: 2):

- There is a high accuracy of relevant material flows, especially of feedstock input and product outputs within the production system
- There is good accuracy for energy flows and combustion related air emissions (CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, CH<sub>4</sub>)
- There is satisfactory accuracy for other air emissions and emissions to water bodies.

### **Reproducibility**

All data and information used are either documented in this report or are available from the mathematical model of the processes and process plans designed within the UMBERTO 11 software [Umberto 11]. 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 – full reproducibility in any degree of detail may not be available for confidentiality reasons. However, experienced experts would be able to easily recalculate and reproduce parts of the system or key indicators.

### **Data Validation**

Data on EDC, VCM and PVC production were collected from Plastics Europe members in an iterative process with several feedback steps if necessary. The collected data were validated using existing data from published sources or expert knowledge.

The relevant background information from those sources mentioned under 'data sources' has been validated and is regularly updated by the LCA practitioner.

### **Life Cycle Model**

The investigated product system is modelled in UMBERTO 11 [Umberto 11], a standard software tool for LCA. Figure 3 gives an overview of the model in a simplified manner. The associated database integrates ISO 14040/44 [ISO 14040: 2006, ISO 14044: 2006] requirements. Due to confidentiality reasons, details on software modelling and applied methods cannot be given within the framework of this report. Data for production processes have been transferred to the model after successful validation.

The model applied in this Eco-profile comprises extraction and refinery of crude oil for the ethylene production, salt recovery and chlorine electrolysis, as well as production of ethylene dichloride, the production of vinyl chloride monomer and the final polymerisation yielding PVC. The modelled polymer production process includes suspension process and emulsion process. Impacts related to abnormal process conditions (e.g. accidents) are not considered in this study.

Fuel and energy inputs in the system reflect site specific conditions wherever applicable. Only in cases site specific information was missing, average European values have been used. Therefore, the study results are intended to be applicable within EU27+NO+CH+UK boundaries. In order to be applied in other regions, adjustments might be required. PVC products imported into Europe are not considered in this Eco-profile.

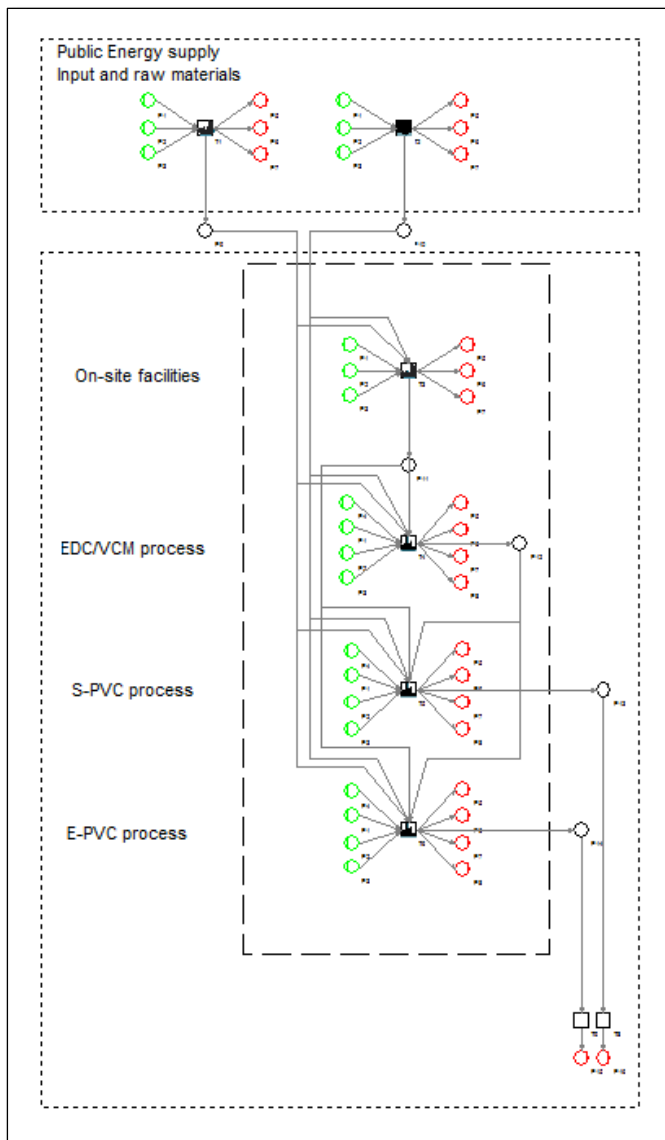


Figure 6: A simplified flow chart of the Life cycle model for the production of polyvinyl chloride (PVC) in Europe in the UMBERTO software. Here, only one production site is shown (inside the dashed box), connected to the prechains of public energy, input materials and raw materials. For the complete model, additional production sites were inserted in adjacent columns

## Calculation Rules

### Horizontal/Vertical Averaging

On the larger scale, horizontal averages were calculated to model and calculate average Eco-profiles from the collected individual LCI datasets. This means that monomer feedstock and other raw material input to each plant (chlorine, ethylene) was modelled representing average European production based on the EuroChlor and Plastics Europe Eco-profiles of chlorine, steam cracker and refinery products.

However, each VCM and polymerisation plant was modelled in a way that individual site-specific parameters like fuel mix and efficiency of on-site energy supply as well as on-site production of supply materials like pressurised air, nitrogen, or process water, transport of input materials and waste, waste treatment, and wastewater treatment are considered. Similarly, national electricity mixes were used to calculate the grid electricity supply.

## Allocation Rules

Production processes in the chemical and plastics industry are usually multi-functional systems, i.e. they exhibit not one but several valuable product and co-product outputs. Wherever possible, and according to Plastics Europe's LCI methodology [Plastics Europe 2022], allocation should be avoided by expanding the system to include the additional functions related to the co-products. To achieve this, a generic process with the same function (product) can be introduced such that the examined system receives credits for the associated burdens avoided elsewhere («avoidance allocation»). System expansion should only be used where there is a dominant, identifiable displaced product, and if there is a dominant, identifiable production path for the displaced product.

Often, however, avoiding allocation is not feasible in technical reality; stand-alone processes do not exist in reality to serve as alternatives, or alternative technologies exhibit completely different technical performances and product qualities. 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.

The vinyl chloride and the polyvinyl chloride production processes themselves are regarded as single-output processes with certain exceptions. Generally, each plant features one main product, which is either EDC, VCM, S-PVC, or E-PVC, according to the main purpose of the facility.

Additionally, an installation may yield minor amounts of certain by-products, e.g. excess of EDC from a combined EDC/VCM unit, or low-grade PVC products from either S- or E-PVC units. These other or lower grade products (together with recovered material) are in the order of 0.01 % of overall VCM production (ethyl chloride production), 0.08 % of S-PVC production, and 0.48 % of E-PVC production. In total PVC, about 19 % of this material is made up of "recovered PVC" (20 % for S-PVC and 17 % for E-PVC). In these cases of recovered material and/or additional products with an assigned value burdens were allocated by economic factors describing the relative price of the products related to the price of PVC. The economic allocation factors for each product are shown in Table 6. Each production unit declaring an output stream of recovered and low-grade PVC was asked to provide a relative price of this product compared to PVC. Low grade products were classified into three grades with similar relative prices (<15 %, 15–35 %, >35 % relative value). For each grade, the economic allocation factor was calculated as the weighted average (by mass) of the relative prices. Relative prices of EDC and VCM were provided by ECVM. In spite of the fact that market prices tend to be subject to changes, this method was chosen due to the inappropriateness of physical allocation between high value products and low-grade by-products.

Table 6: Economic allocation factors for valuable products (based information supplied by ECVM and companies).

Product	Average price in EUR/t	Economic allocation factor
PVC	1,229	1.000
Low grade PVC (<15 % rel. value)	n/a	0.082
Low grade PVC (15-35 % rel. value)	n/a	0.209
Low grade PVC (>35 % rel. value)	n/a	0.400
VCM	638	0.520
EDC	451	0.367
Ethylchloride	150% of VCM	0.780

Some further products, e.g. monomers being recycled to the cracker or distillation, or hydrocarbons being used thermally, are treated as internal flows replacing the respective input materials (i.e. monomers or energy carriers). Hence, no allocation is needed in these cases. A similar approach was chosen for excess HCl from cracking of EDC: to avoid allocation excess HCl is sent to the input side of the model where it replaces the equivalent amount of HCl or chlorine input.

The allocation rule for waste management is the following: process waste with a recycling potential (e.g. catalysts) leaving the system (<0.5 wt.-% of the total output) does not receive any burdens or credits (Cut-Off). Other process waste is treated within the system.

## Life Cycle Inventory (LCI) Results

### Delivery and Formats of LCI Dataset

This Eco-profile comprises

- a report in PDF format and
- a dataset in ILCD format (<http://lct.jrc.ec.europa.eu>) according to the last version at the date of publication of the Eco-profile and including the reviewer (internal and external) input.

Please note that values may not exactly add up to the respective sum reported in the same table. Minor deviations may be caused by rounding of values.

### Energy Demand

The **primary energy demand** (system input) in 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).

The **energy content of the product** 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), in MJ/kg.

The difference ( $\Delta$ ) between primary energy input and energy content in polymer precursor 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 7: Primary energy demand (system boundary level) per 1 kg of product.

Primary Energy Demand	VCM	S-PVC	E-PVC
Energy content in product [MJ] (energy recovery potential, quantified as gross calorific value)	17.5	20.0 <sup>a)</sup>	20.0 <sup>a)</sup>
Process energy [MJ] (quantified as difference between primary energy demand and energy content of product)	32.1	38.6	46.2
<b>Total primary energy demand [MJ UHV]</b>	<b>49.6</b>	<b>58.6</b>	<b>66.2</b>

<sup>a)</sup> Communications with ECVM, value for PVC resin

## Water use (withdrawal) foreground (gate to gate)

The following tables show the values for water use (=withdrawal) of the VCM and PVC production processes (gate-to-gate level).

Table 8: Water use and source per 1 kg of product (gate-to-gate).

Source	Unit	VCM	S-PVC	E-PVC
<u>from River or Lake:</u>				
Cooling water	kg	26.8	4.9	14.4
Process and Boiler Feed Water	kg	0.3	1.6	0.5
<u>from Groundwater:</u>				
Cooling water	kg	0.1	3.1	12.8
Process Water	kg	0.4	1.7	1.4
<u>from Sea/Ocean:</u>				
Cooling water	kg	0.0	0.0	0.0
Process Water	kg	0.0	0.0	0.0
<u>unspecified:</u>				
Cooling water	kg	2.6	2.6	3.6
Process Water	kg	0.5	0.3	1.7
<b>Total</b>	<b>kg</b>	<b>30.6</b>	<b>14.2</b>	<b>34.3</b>

The water demands as reported directly by the participating production sites yield the following picture: The production average water demand of the...

- EDC/VCM process is 26.7 kg/kg EDC+VCM for cooling and 1.9 kg/kg EDC+VCM for process, boiler feed and in heat products.
- S-PVC process is 8.0 kg/kg S-PVC for cooling and 3.9 kg/kg S-PVC for process, boiler feed and in heat products.
- E-PVC process is 27.2 kg/kg E-PVC for cooling and 5.1 kg/kg E-PVC for process, boiler feed and in heat products.

These values refer to the water demands of the plants without allocation in contrast to the values in Table 8, which represent water demands allocated to the products VCM and PVC, considering EDC and VCM as well as lower grade PVC products via economic allocation.

VCM plants use about 60 % direct cooling and 40 % cooling tower; direct cooling involves a significant share of river water sent to the ocean. S-PVC plants on average use about 90 % direct cooling and 10 % cooling tower, while E-PVC plants have reported almost 100 % direct cooling.

The following tables show the further handling/processing of the water output of the VCM and PVC production processes (gate-to-gate level and allocated to products).

Table 9: Treatment of Water Output per 1 kg of product (gate-to-gate).

Treatment	Unit	VCM	S-PVC	E-PVC
<u>to River or Lake:</u>				
Cooling Water*	kg	0.4	4.5	20.6
Process Water**	kg	0.1	2.4	2.0
<u>to Sea/Ocean:</u>				
Cooling Water*	kg	13.3	1.0	3.0
Process Water**	kg	0.1	0.9	0.4
<u>unspecified:</u>				
Cooling Water*	kg	2.2	4.8	6.9
Process Water**	kg	0.5	0.3	1.1
Water Vapour	kg	14.0	0.3	0.2
<b>Totals</b>	<b>kg</b>	<b>30.6</b>	<b>14.2</b>	<b>34.3</b>

\* untreated; \*\* after WWTP

### Water consumption foreground (gate to gate)

The following tables show the water consumption, i.e. water not fed back to the same water body (gate-to-gate level). Water from the ocean or sea is not considered consumed. Water consumption is given when an amount of water is not returned to the water body it was taken from (e.g. evaporation, use in products or flow of river water to sea/ocean). VCM water consumption for cooling is high due to the use of cooling towers (evaporation) and river water released to the ocean. For E-PVC there is a significant share of groundwater (wells) for cooling returned to river or unspecified destinations.

Table 10: Water consumption per 1 kg of product (gate to gate). Sea water withdrawal and turbined water not included.

Consumption	Unit	VCM	S-PVC	E-PVC
Process	kg	0.5	1.7	2.0
Cooling	kg	26.9	3.5	12.8
<b>Total water consumption (kg)</b>	<b>kg</b>	<b>27.4</b>	<b>5.2</b>	<b>14.7</b>

## Water use (withdrawal) cradle to gate

The following table shows the values for water use of the complete supply chain (cradle-to-gate level).

Table 11: Water use (withdrawal) per source per 1 kg of product (cradle to gate).

Source/Use	Unit	VCM	S-PVC	E-PVC
Cooling				
Lake	kg	0.00	0.00	0.00
River	kg	26.80	4.90	14.40
Well	kg	0.10	3.10	12.80
Ocean	kg	0.00	0.00	0.00
Unspecified	kg	123.18	165.54	177.67
<b>Total cooling</b>	<b>kg</b>	<b>150.08</b>	<b>173.54</b>	<b>204.87</b>
Process				
Lake	kg	0.01	0.08	0.14
River	kg	2.53	5.54	5.68
Well	kg	1.43	3.56	2.38
Ocean	kg	997.32	1392.67	1468.07
Unspecified	kg	9.61	12.42	13.58
<b>Total process</b>	<b>kg</b>	<b>1010.91</b>	<b>1414.27</b>	<b>1489.85</b>
Turbine use	kg	4382.06	5305.86	6846.78
<b>Total (excl. Turbine)</b>	<b>kg</b>	<b>1160.99</b>	<b>1587.81</b>	<b>1694.72</b>

## Water consumption cradle to gate

Table 12: Water consumption per 1 kg of product (cradle to gate). Sea water withdrawal and turbined water not included.

	Unit	VCM	S-PVC	E-PVC
<b>Total water consumption</b>	kg	45.01	47.97	50.93

## Life Cycle Impact Assessment (LCIA) Results

For Life Cycle Impact Assessment the set of impact categories and methodologies was used according to the rules for Product Environmental Footprint using the latest available characterization factors (EFv3.1) from EC-JRC/ILCD [EC-JRC 2023, ILCD 2010]. However, to allow the Eco-profile to be comparable to older versions of Eco-profiles, the results for the impact categories using the same methodology as in the previous Eco-profile are shown as well (EFv3.0) [Fazio 2018]. The following list gives an overview of the applied methodology for each impact category.

Please note that values may not exactly add up to the respective sum reported in the same table. Minor deviations may be caused by rounding of values.

### **Disclaimer:**

GWP results are based on an LCA calculation using the current dataset for oil and gas production (European averages for oil and country specific for natural gas), including unintended methane losses from oil and gas exploration, production and processing. This case resembles the sources of methane emissions considered in the sensitivity case ESU with IEA Methane Tracker emissions of the previous Eco-profile of 2023.

The following LCIA methods are recommended by JRC but the results of these environmental impact indicators shall be used with care as the uncertainties on these results are high or as there is limited experienced with the indicator (recommendation level III, [Fazio 2018]):

- Ecotoxicity freshwater
- Human toxicity, cancer
- Human toxicity, non-cancer
- Land use
- Resource use, fossils (or Abiotic Depletion Potential, fossil)
- Resource use, elements (or Abiotic Depletion Potential, mineral)
- Water use

Results for land use are underestimated as no information was available on area occupation of polymerization plants.

Table 13: List of impact categories and methodologies used for LCIA in the present Eco-profile (EF 3.1).

Eco-profile Impact Categories and Methodology (ELCD/PEF)		
Impact Category	Methodology	Unit
Acidification	Accumulated Exceedance; [Seppälä 2006], [Posch 2008]	mol H <sup>+</sup> eq
Climate change	Baseline model of 100 years of the IPCC (based on IPCC 2021)	kg CO <sub>2</sub> eq
Ecotoxicity, freshwater	USEtox model [Rosenbaum 2008]	CTUe
Particulate Matter	PM method recommended by UNEP [UNEP 2016]	disease incidence
Eutrophication marine	EUTREND-model, [Struijs 2009], as in [ReCiPe 2008]	kg N eq
Eutrophication, freshwater	EUTREND-model, [Struijs 2009], as in [ReCiPe 2008]	kg P eq
Eutrophication, terrestrial	Accumulated Exceedance (AE); [Seppälä 2006], [Posch 2008]	mol N eq
Human toxicity, cancer	USEtox model [Rosenbaum 2008]	CTUh
Human toxicity, non-cancer	USEtox model [Rosenbaum 2008]	CTUh
Ionising radiation, human health	Human health model; [Dreicer 1995], [Frischknecht 2000]	kg U235 eq
Land use	Soil quality index based on LANCA [Beck 2010] and [Bos 2016]	-
Ozone depletion	EDIP model over an infinite time horizon. [WMO 2014] (excl. N <sub>2</sub> O)	kg CFC11 eq
Photochemical ozone formation - human health	LOTOS-EUROS, [Van Zelm 2008], as in ReCiPe	kg NMVOC eq
Resource use, fossils	CML [Guinée 2002] and [Van Oers 2002].	MJ (LHV)
Resource use, minerals and metals	CML [Guinée 2002] and [Van Oers 2002].	kg Sb eq
Water use	Available WAter REMaining (AWARE) as recommended by [UNEP 2016]	m <sup>3</sup> world eq

In the following tables the LCIA results are shown for each of the considered products using the ELCD method (EFv3.1) as recommended by Plastics Europe [Plastics Europe 2022].

Table 14: LCIA results for the products of the VCM and PVC production using the ELCD/PEF (EFv3.1) methodology according to [Plastics Europe 2022].

Impact Category	Unit	VCM	S-PVC	E-PVC
Climate change <b>GWP</b>	kg CO <sub>2</sub> eq	1.64	2.08	2.45
Acidification <b>AP</b>	mol H <sup>+</sup> eq	3.8E-03	4.5E-03	5.8E-03
Eutrophication, freshwater <b>EP_FW</b>	kg P eq	5.0E-04	6.0E-04	7.6E-04
Eutrophication, marine <b>EP_MW</b>	kg N eq	9.5E-04	1.2E-03	1.4E-03
Eutrophication, terrestrial <b>EP_Terr</b>	mol N eq	9.0E-03	1.1E-02	1.6E-02
Ozone depletion <b>ODP</b>	kg CFC11 eq	8.2E-07	8.4E-07	8.6E-07
Photochemical ozone formation <b>POCP</b>	kg NMVOC eq	6.0E-03	6.9E-03	7.4E-03
Particulate Matter <b>PM10</b>	disease incidents	2.2E-08	2.6E-08	3.7E-08
Ionising radiation <b>IoRad</b>	kg U235 eq	2.2E-01	2.7E-01	3.0E-01
Human toxicity, cancer <b>HT_Ca</b>	CTUh	5.0E-09	5.1E-09	5.8E-09
Human toxicity, non-cancer <b>HT_NC</b>	CTUh	6.9E-09	8.3E-09	9.7E-09
Ecotoxicity, freshwater <b>HT_FW</b>	CTUe	8.32	9.36	11.41
Resource use, fossils <b>ADP_fos</b>	MJ (LHV)	44.3	52.1	58.8
Resource use, minerals and metals <b>ADP_min</b>	kg Sb eq	1.0E-05	1.1E-05	1.2E-05
Water use	m <sup>3</sup> world eq	1.35	1.44	1.47
Land use	-	2.76	3.36	3.40

## Dominance Analysis

The abbreviations for the ELCD impact categories in this section can be looked up in Table 14.

Table 15: Dominance analysis of impacts per 1 kg VCM

	<b>GWP</b>	<b>AP</b>	<b>EP_FW</b>	<b>EP_MW</b>	<b>EP_Terr</b>	<b>ODP</b>	<b>POCP</b>	<b>PM10</b>
	kg CO <sub>2</sub> eq	mol H <sup>+</sup> eq	kg P eq	kg N eq	mol N eq	kg CFC11 eq	kg NMVOC eq	disease incidents
EDC+VCM production	12.21%	1.93%	0.21%	4.01%	4.64%	86.98%	4.53%	0.79%
Electricity a)	2.64%	2.75%	7.03%	3.39%	3.10%	0.09%	1.37%	3.03%
Thermal energy and utilities a)	10.26%	8.10%	4.04%	9.00%	9.57%	1.92%	7.92%	6.61%
Disposal a)	1.97%	1.02%	2.10%	2.21%	1.09%	0.04%	0.63%	2.01%
<b>Subtotal Foreground process</b>	<b>27.07%</b>	<b>13.81%</b>	<b>13.38%</b>	<b>18.62%</b>	<b>18.40%</b>	<b>89.03%</b>	<b>14.46%</b>	<b>12.44%</b>
Ethylene Production	46.67%	44.44%	9.89%	45.84%	50.51%	7.00%	70.52%	47.40%
Chlorine Production	24.92%	37.98%	73.30%	33.20%	28.87%	3.82%	13.96%	35.42%
Other raw materials	1.31%	3.72%	3.37%	2.30%	2.19%	0.14%	1.05%	4.71%
Transport of precursors and other raw materials	0.02%	0.04%	0.06%	0.03%	0.03%	0.00%	0.01%	0.03%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

	<b>HT_Ca</b>	<b>HT_NC</b>	<b>ET_FW</b>	<b>IoRad</b>	<b>ADP_fos</b>	<b>ADP_min</b>	<b>WaterUse</b>	<b>LandUse</b>
	CTUh	CTUh	CTUh	kg U235 eq	MJ (LHV)	kg Sb eq	m <sup>3</sup> world eq	-
EDC+VCM production	2.50%	0.96%	17.68%	0.00%	0.00%	0.00%	44.88%	0.00%
Electricity a)	0.13%	3.67%	1.02%	14.66%	2.42%	1.16%	2.86%	7.24%
Thermal energy and utilities a)	0.73%	6.97%	2.18%	5.28%	13.34%	2.72%	10.67%	4.77%
Disposal a)	0.72%	2.04%	6.31%	0.38%	0.36%	0.90%	0.17%	1.08%
<b>Subtotal Foreground process</b>	<b>4.09%</b>	<b>13.64%</b>	<b>27.19%</b>	<b>20.32%</b>	<b>16.12%</b>	<b>4.78%</b>	<b>58.57%</b>	<b>13.10%</b>
Ethylene Production	2.05%	31.14%	12.01%	9.81%	65.64%	5.34%	28.33%	39.63%
Chlorine Production	90.61%	50.73%	57.88%	67.17%	17.43%	83.12%	12.39%	43.88%
Other raw materials	3.25%	4.46%	2.91%	2.59%	0.79%	6.75%	0.69%	3.36%
Transport of precursors and other raw materials	0.00%	0.04%	0.01%	0.10%	0.02%	0.01%	0.02%	0.04%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

a) only relating to direct input/output of the EDC/VCM production process

Table 16: Dominance analysis of impacts per 1 kg S-PVC

	<b>GWP</b>	<b>AP</b>	<b>EP_FW</b>	<b>EP_MW</b>	<b>EP_Terr</b>	<b>ODP</b>	<b>POCP</b>	<b>PM10</b>
	kg CO <sub>2</sub> eq	mol H <sup>+</sup> eq	kg P eq	kg N eq	mol N eq	kg CFC11 eq	kg NMVOC eq	disease incidents
S-PVC production	1.20%	1.69%	0.29%	2.43%	3.28%	0.11%	0.55%	2.64%
Electricity a)	3.32%	3.77%	10.49%	4.28%	4.01%	0.13%	1.91%	3.66%
Thermal energy and utilities a)	13.22%	6.76%	2.76%	7.81%	8.78%	1.50%	6.95%	5.60%
Disposal a)	0.11%	0.18%	1.08%	4.75%	0.22%	0.00%	0.09%	0.36%
<b>Subtotal Foreground process</b>	<b>17.85%</b>	<b>12.39%</b>	<b>14.62%</b>	<b>19.27%</b>	<b>16.28%</b>	<b>1.74%</b>	<b>9.50%</b>	<b>12.26%</b>
EDC+VCM production	24.39%	15.92%	14.14%	17.62%	18.19%	87.53%	14.64%	15.14%
Ethylene Production	36.71%	37.40%	8.33%	35.69%	40.56%	6.86%	61.91%	39.15%
Chlorine Production	19.61%	31.96%	61.76%	25.85%	23.19%	3.74%	12.26%	29.25%
Other raw materials	1.42%	2.30%	1.10%	1.54%	1.75%	0.12%	1.68%	4.17%
Transport of precursors and other raw materials	0.02%	0.04%	0.05%	0.02%	0.02%	0.00%	0.01%	0.02%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

	<b>HT_Ca</b>	<b>HT_NC</b>	<b>ET_FW</b>	<b>IoRad</b>	<b>ADP_fos</b>	<b>ADP_min</b>	<b>WaterUse</b>	<b>LandUse</b>
	CTUh	CTUh	CTUh	kg U235 eq	MJ (LHV)	kg Sb eq	m <sup>3</sup> world eq	-
S-PVC production	1.05%	0.83%	2.55%	0.00%	0.00%	0.00%	0.90%	0.00%
Electricity a)	0.19%	4.65%	1.50%	13.24%	2.75%	1.42%	2.23%	9.22%
Thermal energy and utilities a)	0.80%	5.31%	1.64%	3.48%	9.55%	1.99%	1.36%	3.30%
Disposal a)	0.05%	2.59%	3.45%	0.10%	0.04%	0.09%	0.05%	0.26%
<b>Subtotal Foreground process</b>	<b>2.09%</b>	<b>13.39%</b>	<b>9.14%</b>	<b>16.82%</b>	<b>12.34%</b>	<b>3.50%</b>	<b>4.55%</b>	<b>12.78%</b>
EDC+VCM production	7.43%	15.97%	26.95%	18.75%	15.82%	11.19%	55.98%	16.78%
Ethylene Production	2.00%	25.90%	10.67%	8.12%	55.79%	5.02%	26.63%	32.52%
Chlorine Production	88.18%	42.19%	51.41%	55.56%	14.81%	78.14%	11.65%	36.00%
Other raw materials	0.31%	2.53%	1.83%	0.67%	1.22%	2.14%	1.19%	1.88%
Transport of precursors and other raw materials	0.00%	0.03%	0.01%	0.09%	0.02%	0.01%	0.01%	0.03%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

a) only relating to direct input/output of the S-PVC production process

Table 17: Dominance analysis of impacts per 1 kg E-PVC

	<b>GWP</b>	<b>AP</b>	<b>EP_FW</b>	<b>EP_MW</b>	<b>EP_Terr</b>	<b>ODP</b>	<b>POCP</b>	<b>PM10</b>
	kg CO <sub>2</sub> eq	mol H <sup>+</sup> eq	kg P eq	kg N eq	mol N eq	kg CFC11 eq	kg NMVOC eq	disease incidents
E-PVC production	2.04%	14.19%	0.02%	3.14%	23.66%	0.00%	1.51%	22.21%
Electricity a)	4.23%	4.07%	19.22%	5.74%	3.48%	0.13%	2.08%	3.23%
Thermal energy and utilities a)	23.70%	11.67%	6.26%	14.53%	12.86%	3.59%	12.19%	8.70%
Disposal a)	0.17%	0.18%	0.90%	4.13%	0.19%	0.01%	0.11%	0.32%
<b>Subtotal Foreground process</b>	<b>30.14%</b>	<b>30.11%</b>	<b>26.41%</b>	<b>27.53%</b>	<b>40.20%</b>	<b>3.72%</b>	<b>15.89%</b>	<b>34.45%</b>
EDC+VCM production	19.25%	11.48%	16.84%	14.76%	11.43%	85.62%	11.78%	9.67%
Ethylene Production	31.26%	29.29%	6.54%	31.64%	28.88%	6.71%	57.30%	27.59%
Chlorine Production	16.69%	25.03%	48.48%	22.92%	16.51%	3.66%	11.34%	20.62%
Other raw materials	2.63%	4.06%	1.70%	3.13%	2.97%	0.30%	3.67%	7.66%
Transport of precursors and other raw materials	0.01%	0.03%	0.04%	0.02%	0.02%	0.00%	0.01%	0.02%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

	<b>HT_Ca</b>	<b>HT_NC</b>	<b>ET_FW</b>	<b>IoRad</b>	<b>ADP_fos</b>	<b>ADP_min</b>	<b>WaterUse</b>	<b>LandUse</b>
	CTUh	CTUh	CTUh	kg U235 eq	MJ (LHV)	kg Sb eq	m <sup>3</sup> world eq	-
E-PVC production	11.19%	2.90%	14.23%	0.00%	0.00%	0.00%	0.58%	0.00%
Electricity a)	0.24%	6.73%	2.49%	17.04%	3.46%	1.86%	2.94%	7.55%
Thermal energy and utilities a)	1.40%	12.02%	2.94%	9.65%	18.49%	5.87%	3.09%	8.45%
Disposal a)	0.08%	2.21%	3.01%	0.10%	0.05%	0.13%	0.06%	0.32%
<b>Subtotal Foreground process</b>	<b>12.91%</b>	<b>23.85%</b>	<b>22.66%</b>	<b>26.80%</b>	<b>22.00%</b>	<b>7.86%</b>	<b>6.68%</b>	<b>16.32%</b>
EDC+VCM production	6.28%	13.60%	22.47%	14.69%	12.64%	10.05%	54.10%	11.32%
Ethylene Production	1.78%	22.09%	8.78%	7.36%	49.59%	4.75%	26.03%	32.21%
Chlorine Production	78.46%	35.98%	42.33%	50.37%	13.17%	73.86%	11.39%	35.66%
Other raw materials	0.56%	4.46%	3.76%	0.71%	2.60%	3.46%	1.79%	4.45%
Transport of precursors and other raw materials	0.00%	0.03%	0.01%	0.08%	0.01%	0.01%	0.01%	0.03%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

a) only relating to direct input/output of the E-PVC production process

- GWP:** VCM has the highest contribution to the climate change indicator (47 %) from ethylene (of these emissions about half stem from steam cracking and half from the extraction of natural gas for ethylene). Chlorine is the next biggest contributor to GWP of VCM with 25 %, with chlorine GWP contribution relying more on electricity production (in part renewable) and less on the extraction and processing of fossil fuels. The category EDC+VCM covers direct emissions from incineration of fuels (for heat) within the foreground system. Average direct emissions of CO<sub>2</sub> from the EDC/VCM plants are 0.20 kg CO<sub>2</sub>/kg EDC+VCM, so that EDC+VCM contributes 12 % to the GWP category. In comparison, PVC exhibits direct emissions of 0.02 kg CO<sub>2</sub>/kg S-PVC and 0.05 kg CO<sub>2</sub>/kg E-PVC, causing lower contribution of these foreground processes to GWP.
- AP:** E-PVC shows a higher contribution (14 %) from the foreground process (E-PVC) to acidification than the S-PVC and VCM products: direct emissions of ammonia to air from six of the nine covered E-PVC plants are reported significantly higher than from any of the S-PVC plants, where no ammonia

emissions are expected. The strongest contribution to AP for VCM and PVC is based on ethylene production, i.e. the extraction and processing of natural gas.

- **EP\_FW:** Freshwater eutrophication is dominated by emissions from the chlorine production category due to the high electricity demand. Especially coal power and the related emissions contribute to freshwater eutrophication.
- **EP\_MW:** Marine water eutrophication is caused to about 32–46 % by the production process of ethylene, more specifically by the extraction of natural gas as feedstock.
- **EP\_Terr:** The contribution of the E-PVC process (24 %) to terrestrial eutrophication is significantly higher than for the S-PVC and VCM products. This is mainly caused by direct emission of ammonia to air (similar to the AP indicator). Most significant contributions for all products are related to ethylene (natural gas extraction) and chlorine production.
- **ODP:** Direct emissions of halogenated hydrocarbons to the air (e.g. TCM) were reported in detail by the VCM producers, resulting in a 87 % contribution of EDC+VCM production to **ODP**. These emissions propagate to the PVC products in the VCM category.
- **POCP:** Similar to the indicators acidification and marine eutrophication, ethylene production (natural gas extraction) plays the most important role in the emission of tropospheric ozone producing chemicals.
- **PM10:** Dust and particulate matter emissions are strongly related to ethylene production, as they make up about 47 % of the overall result for VCM. The noticeable contribution (22 %) of the E-PVC foreground category to particulate matter emissions related to E-PVC is based on high direct emissions of ammonia and particulate matter to air reported by six of nine E-PVC plants (significantly higher than any of the S-PVC plants).
- **HT\_Ca:** The emissions of chemicals causing cancer (equally based on emissions of metals and organic compounds) in humans is dominated by the chlorine production category (directly related to reported dioxin emissions to water from the electrolysis process of the chlorine production).
- **HT\_NC:** The emissions of toxic chemicals other than cancer-related (HT\_Ca) is mainly related to the two feedstock materials chlorine and ethylene production: the electricity demand for chlorine production and the extraction of natural gas for ethylene. The electricity supply to the production of VCM and PVC also play a role in the emission of toxic substances with 4–7 % contribution. The indicator result for ethylene is based on emissions of metals (about 2/3) and inorganic compounds (1/3), mainly from fossil fuels extraction. Toxic emissions from chlorine production (and generally from electricity production) are mainly based on the emission of metals.
- **ET\_FW:** Chloride emissions to water from the chlorine production (electrolysis) is the main contributor to emission of substances toxic to the environment. These emissions were reported by the chlorine producers of the EuroChlor Eco-profile in 2020.
- **IoRad:** The health hazard of ionising radiation is caused by electricity demands of all process steps. The chlorine category with high electricity demands for the electrolysis process plays a major role here.
- **ADP\_fos:** A large part of the abiotic depletion related to fossil resources rely on those processes and feedstocks that are based on the extraction of fossil resources. This is especially valid for ethylene as a feedstock, with a contribution of 66 % to the VCM result of the fossil ADP indicator.
- **ADP\_min:** Abiotic depletion related to mineral resources is mainly influenced by chlorine production, more specifically by the mining of salt, be it cut and blast mining for rock salt or solution mining. Accordingly, chlorine production contributes to 83 % to the overall mineral depletion result of VCM, propagating to the PVC products.
- **WaterUse** within the ELCD methodology is a consumption indicator, covering water inputs and outputs to the environment. I.e. VCM cooling water consumption plays a strong role for WaterUse (see Table 9: high consumption caused by cooling tower evaporation and river CW released to sea/ocean).

Accordingly, the EDC+VCM production contributes 45 % to the WaterUse indicator. This contribution propagates to PVC in the VCM category.

### Scenario analysis – methane losses

Awareness has been rising in scientific literature about unwanted methane emissions during oil and gas extraction, processing and transport which are higher than assumed in previous Eco-profiles and in current LCA databases. These additional methane emissions are also reported by the International Energy Agency who built a methane tracker website<sup>3</sup>. As a base case the present Eco-profile is using an oil and gas extraction dataset which does consider these increased methane losses. However, a separate case named “Reduced methane losses” for oil and gas reflects a possible carbon footprint connected with oil and gas extraction in case the increased methane losses are not considered. These results are presented as a sensitivity analysis of the steam cracker products and polyvinyl chloride.

Table 18: Sensitivity analysis of the carbon footprint of the investigated products with reduced methane losses.

Scenario	Unit	VCM	S-PVC	E-PVC
Base case	kg CO <sub>2</sub> eq	1.64	2.08	2.45
Reduced methane losses	kg CO <sub>2</sub> eq	1.55	1.99	2.36

Table 18 shows a comparison of the Base Case (used throughout this Eco-profile) and the Reduced methane losses case on the basis of GWP.

The comparison makes clear that in case the increased methane emissions reported by IEA Methane Tracker are not considered, the GWP results of VCM and polyvinyl chloride decrease by 0.08 kg CO<sub>2</sub> eq/kg.

### Scenario analysis – steam cracker allocation method

The Eco-profiles program and methodology of Plastics Europe [Plastics Europe 2022] considers two groups of products from the steam cracker. High value products are sold on the market, while low value products are fed back to the refinery or used as internal fuels for heat production. According to the given methodology (“base case”), burdens associated with the steam cracker feedstock are allocated to all products of the steam cracker process, while all additional burdens are allocated by mass to the high value chemicals.

An alternative approach is the “**mass allocation**” of all burdens to all products of the steam cracker, including those low value chemicals used as fuels or returned to the refinery.

**Disclaimer on methodology:** Following this approach, those **chemicals fed back into the refinery must be considered with all their environmental burdens** when modelling the refinery with its feedstock mix in order to account for all burdens in this branch of the chemical industry, actively preventing greenwashing of steam cracker products and all following products including polyolefins based on ethylene and propylene. It has to be noted that this assumption could not be followed during the modelling of this scenario analysis due to data gaps. Accordingly, the feedstock mix of the refinery represent the conventional base case feedstock mix **without additional burdens** introduced via the returned low value chemicals from the steam

<sup>3</sup> <https://www.iea.org/reports/methane-tracker-2025>

cracker. The corresponding scenario results (mass allocation in Table 19) are not methodologically clean and of the same quality as the base case results: Burdens from the low value steam cracker products going to the refinery are presently neglected and do not circle back to the steam cracker products in the appropriate manner. Results for a correctly applied mass allocation to all products are expected to be significantly more similar to the base case results as soon as considering correct low value product burdens from the steam cracker returned to the refinery process.

*Table 19: Sensitivity analysis of the carbon footprint of the investigated product, allocation*

Scenario	Unit	VCM	S-PVC	E-PVC
Base case	kg CO <sub>2</sub> eq	1.64	2.08	2.45
Mass allocation to all products	kg CO <sub>2</sub> eq	1.59	2.03	2.40

Table 19 presents the GWP results for VCM and polyvinyl chloride, assuming both allocation approaches described above. Please note that the reduction of burdens on the monomer and polymers implies the increase of burdens for specific (low value) steam cracker products that are not reported in this Eco-profile.

The comparison shows the impact conscious allocation choices on the overall results. Assuming that low value chemicals should be associated with the same process burdens as high value steam cracker products can lead to a decrease of GWP results of VCM and polyvinyl chloride by 0.04 kg CO<sub>2</sub> eq/kg product.

### **Comparison of the present Eco-profile with its previous version**

Table 20 compares the present results with the previous version of the Eco-profile of 2023. This comparison is done based on the impact assessment method used in the previous Eco-profile (EFv3.0) [Fazio 2018]. The comparison is made on the basis of the 2023 sensitivity case with increased methane emissions from oil and gas extraction and processing. These emissions were not accounted for in earlier studies, while they have been widely accepted and implemented in major LCA databases by now, also as part of the base case of the present Eco-profile study.

Table 20: Comparison of the present Eco-profile of the VCM and PVC with its previous version (2022, sensitivity case ESU including IEA methane losses). Impacts were calculated with the methodology used in the previous Eco-profile report EFv3.0.

Impact Category	VCM			S-PVC			E-PVC		
	2023	2025	diff	2023	2025	diff	2023	2025	diff
Climate change [kg CO <sub>2</sub> eq]	1.90	1.69	-11%	2.22	2.14	-3%	2.37	2.52	6%
Acidification [mol H <sup>+</sup> eq]	8.7E-03	3.8E-03	-56%	9.6E-03	4.5E-03	-53%	1.1E-02	5.8E-03	-47%
Eutrophication, freshwater [kg P eq]	4.3E-04	5.0E-04	17%	5.0E-04	6.0E-04	19%	6.4E-04	7.6E-04	19%
Eutrophication, marine [kg N eq]	1.1E-03	9.5E-04	-14%	1.3E-03	1.2E-03	-7%	1.4E-03	1.4E-03	-2%
Eutrophication, terrestrial [mol N eq]	1.1E-02	9.0E-03	-19%	1.3E-02	1.1E-02	-14%	1.9E-02	1.6E-02	-17%
Ozone depletion [kg CFC11 eq]	1.4E-06	8.2E-07	-41%	1.6E-06	8.4E-07	-48%	1.1E-06	8.6E-07	-22%
Photochemical ozone formation [kg NMVOC eq]	7.1E-03	6.0E-03	-15%	7.8E-03	6.9E-03	-12%	7.9E-03	7.4E-03	-6%
Particulate Matter [disease incidents]	3.6E-08	2.2E-08	-40%	4.2E-08	2.6E-08	-38%	5.5E-08	3.7E-08	-32%
Human toxicity, cancer [CTUh]	4.9E-09	5.0E-09	1%	5.0E-09	5.1E-09	2%	5.7E-09	5.7E-09	1%
Human toxicity, non-cancer [CTUh]	1.4E-08	1.1E-08	-22%	1.5E-08	1.4E-08	-5%	1.7E-08	1.7E-08	-1%
Ecotoxicity, freshwater [CTUe]	43.0	3.3E+01	-24%	46.8	4.0E+01	-14%	48.0	4.5E+01	-6%
Ionising radiation [kg U235 eq]	2.1E-01	0.22	5%	2.5E-01	0.27	7%	3.0E-01	0.30	-2%
Resource use, fossils [MJ LHV]	48.2	44.3	-8%	53.5	52.1	-3%	56.6	58.8	4%
Resource use, minerals and metals [kg Sb eq]	3.9E-06	1.0E-05	166%	4.7E-06	1.1E-05	135%	5.4E-06	1.2E-05	117%
Water use [m <sup>3</sup> world eq]	2.02	1.35	-33%	1.81	1.44	-21%	3.71	1.47	-60%
Land use [-]	4.72	2.76	-42%	5.17	3.36	-35%	5.78	3.40	-41%

For the current study, datasets on electricity production, oil and gas extraction (and their supply mixes to European countries), refinery and steam cracking of hydrocarbons were updated to the most recent datasets. Within these, significant changes created an impact on mainly these results:

- The Climate Change indicator results decreased for VCM and S-PVC, mainly due to the decreasing climate change impact of chlorine, which is strongly affected by the most recent electricity supply with increasing shares of renewable energy carriers. Results for E-PVC have increased, mainly based on the high heat and direct fuels imports to the E-PVC process (more than twice the demand of S-PVC per kg product). These high energy demands introduce increased Climate Change burdens via the background processes of extraction and processing of oil and gas.
- Resource use of fossils (or Abiotic depletion potential (ADP), fossil) shows changes similar to Climate Change, based on similar reasoning.
- Resource use of minerals and metals (or Abiotic depletion potential (ADP), elements) increased strongly compared to the previous Eco-profile. The last Eco-profile did not consider salt as resource from ground under the category of mineral resource use. Salt is presently associated with 1.65E-5 kg Sb eq/kg NaCl.
- Acidification Potential decreased significantly, especially in the category of crude oil extraction. There was a significant change in the background dataset, where the previous Eco-profile relied on an average European crude oil mix dataset provided by ESU services [Meili 2019a, Meili 2019b], while the present dataset for crude oil is a) taken from ecoinvent v3.11 [Ecoinvent 2024] with b) a changed import mix of crude oil, i.e. significantly less oil imports to Europe from Russia, switching to Scandinavian suppliers, accompanied by a decrease in a number of environmental impact categories.

# Review Statement

## Review Details

Commissioned by:	Plastics Europe AISBL, ECVM
Prepared by:	Sabrina Ludmann, Dr.-Ing. Thomas Fröhlich ifeu Institut für Energie- und Umweltforschung Heidelberg
Reviewed by:	Matthias Schulz, Schulz Sustainability Consulting
References:	<ul style="list-style-type: none"><li>• Plastics Europe 2022: Eco-profiles program and methodology –Plastics Europe – V3.1 (2022).</li><li>• ISO 14040 (2021): Environmental Management – Life Cycle Assessment – Principles and Framework</li><li>• ISO 14044 (2021): Environmental Management – Life Cycle Assessment – Requirements and Guidelines</li></ul>

## Review Summary

As recommended in accordance with the Plastics Europe methodology version 3.1 (2022), an external independent critical review was conducted for this Eco-profile before publication of the respective dataset. The outcome of the critical review is reproduced below.

The subject of the critical review was this Eco-profile report for the following vinyl products:

- vinyl chloride (VCM),
- polyvinyl chloride from suspension polymerisation (S-PVC) and
- polyvinyl chloride from emulsion polymerisation (E-PVC).

The critical review included two iterations of the final Eco-profile report review (October 2025 and January 2026), in which the reviewer raised questions and comments and the LCA practitioners responded with clarifications and revisions in the Eco-profile report. On 11 December 2025, a web-based review meeting was held in which open issues were discussed and spot checks of data and calculations were carried out. The final version of the report was provided to the reviewer on 30 January 2026. 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 LCA practitioners to address the comments provided, as well as the open and constructive dialogue during the entire critical review process. All versions of the documentation (reports and data), including the individual reviewer's comments, questions and associated answers, are archived and can be made available upon request.

A three-pronged approach to primary data collection was used: 1) Plants exhibiting significant changes when compared to the last data collection in 2013 provided updated annual input-output data for 2021. 2) For vinyl plants with no significant changes in energy consumption or other process modifications influencing their environmental performance, the same data was used as for the last Eco-profile (reference year 2013). 3) A small group of plants is represented by data from 2017 – 2020, to which the LCA practitioner had access during other LCA projects. Primary data take into account site-specific technologies for ethylene di-chloride (EDC), VCM and PVC production. In total, data from 39 vinyl plants (EDC: 1, VCM: 12, S-PVC: 17, E-PVC: 9) were included in this study, leading to a representativeness of 68 % (VCM), 73 % (S-PVC) and 81 % (E-PVC) with regards to total European production. It should be noted that plants not considered for this Eco-

profile are mainly located in Eastern Europe. Overall, primary data quality can be considered to be good, however, data gaps exist for certain emissions to air and water, see details under 'Completeness' in the main report.

Background data for the main precursors chlorine and ethylene were taken from the most current Plastics Europe Eco-profiles (Eco-profile chlorine: EuroChlor 2022; Eco-profile ethylene: Plastics Europe 2026). The respective feedstocks oil and gas are based on a dataset prepared by ESU services and modelled with unit processes from the database Ecoinvent v3.11 [Ecoinvent 2024]. The resulting background dataset considers increased methane losses based on country-specific information for 2024. A scenario analysis in which these increased methane emissions are neglected can be found in the report.

Other background process data, e.g. for transport data, additives, surfactants, or auxiliary materials and electricity were sourced from Ecoinvent as well as specific data sources from the LCA practitioners (e.g. updated country-specific electricity grid mixes). All background datasets used for this Eco-profile are described in detail in the report and are considered appropriate for the goal and scope of this study.

Economic allocation was applied to small amounts of lower grade VCM and PVC output according to prices provided by the manufacturers. Concerning HCl input, the same data as for chlorine was used. This procedure is in line with the previous version of this Eco-profile and is based on the conservative assumption that one molecule HCl carries half the load of a Cl<sub>2</sub> molecule. Regarding the allocation approach for steam cracker products, the allocation procedures follow the recommended principles of the current Plastics Europe methodology and are transparently described and justified in the report. This Eco-profile report also includes an alternative allocation approach which considers "mass allocation" of all burdens to all products of the steam cracker, including those low value chemicals used as fuels or returned to the refinery. The prominent disclaimer of this approach as outlined in the report should be observed and is strongly supported by the reviewer.

The potential environmental impacts for VCM and PVC are quantified using the ELCD/PEF methodology (characterisation factors according to EFv3.1 [EC-JRC 2023]), as recommended in the current Plastics Europe methodology.

In general, the potential environmental impacts for VCM and PVC are dominated by the precursor products ethylene and chlorine for most environmental indicators. For VCM production, emissions of tetrachloromethane contribute significantly to the indicator Ozone Depletion Potential. Another contributor in particular to the GWP impact category are greenhouse gas emissions from the EDC/VCM plants, due to the combustion of fossil fuels for thermal energy production. A detailed results analysis can be obtained from the dominance analysis presented in Tables 15 – 17 in the report.

The Eco-profile report also includes a comparison of the results with the previous version of the VCM and PVC Eco-profile from 2023. For details, please refer to the chapter 'Comparison of the present Eco-profile with its previous version'.

The critical review included detailed result checks, comparing the different Eco-profile versions and trying to identify key reasons for respective changes. The practitioners of the Eco-profile were able to clarify all related comments and questions.

The LCA practitioners have demonstrated high levels of competence and experience, with a track record of LCA projects in the chemical and plastics industry. The critical review confirms that this Eco-profile adheres to the rules set forth in the Plastics Europe's Eco-profiles methodology version 3.1 (2022) and represents the best available data for VCM, S-PVC and E-PVC reported herein.

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