# Comparative Life Cycle Assessment (LCA) of Fossil-Based and CCU-Based EVA Copolymer

This report was written by Carbon Minds and represents the outcome of a comparative LCA commissioned by ON AG.

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# DISCLAIMER

This document includes information that has been generated based on complex calculation models established by Carbon Minds. These calculations use data from third parties and Carbon Minds to represent the product ethylene-vinyl acetate (EVA) copolymer produced via two alternative feedstock pathways: a conventional fossil-based route and a Carbon Capture and Utilization (CCU)-based route, adhering to ISO 14040 and ISO 14044 standards. The calculations for Life Cycle Assessment (LCA) incorporate secondary data from cm.chemicals database for the foreground system. For the background system, Ecoinvent and cm.chemicals are used as a standardized external database to ensure the use of reliable and widely accepted data sources.

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# 1. INTRODUCTION

This report presents a comparative cradle-to-gate Life Cycle Assessment (LCA) of fossil-based and carbon capture and utilization (CCU)-based production routes for ethylene-vinyl acetate (EVA) copolymer. The study evaluates alternative feedstock pathways under harmonized methodological assumptions within an attributional modeling framework.

The assessment is designed to provide a robust and transparent basis for data-driven decision-making in the context of material innovation, supplier engagement, and long-term sustainability strategy development.

ON AG has commissioned Carbon Minds GmbH to conduct this comparative study in accordance with ISO 14040[1] and ISO 14044[2]. The work leverages Carbon Minds' proprietary cm.chemicals database[3] and integrates literature data, industry datasets, and simplified process modeling to develop transparent and representative life cycle inventories for both pathways.

The LCA applies the Environmental Footprint (EF) 3.1 method as the basis for impact quantification. This study has been conducted in accordance with international standards:

- ISO 14040[1]: Life cycle assessment – Principles and framework.
- ISO 14044[2]: Environmental management – Life cycle assessment – Requirements and guidelines.

Following the reporting structure outlined in ISO 14040 for Life Cycle Assessment reports, Chapter 2 defines the goal and scope of the study, including system boundaries, assumptions, and limitations. Chapter 3 describes the life cycle modelling. Chapter 4 presents the description and results of each EVA copolymer pathway individually. Chapter 5 provides a comparative analysis and discussion of the results across pathways and selected impact categories. Chapter 6 focuses on the interpretation of results, including contribution analysis and sensitivity analysis. Chapter 7 summarizes the overall findings of the study.

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[1] DIN EN ISO 14040, 2021. Environmental management - Life cycle assessment – Principles and framework (ISO 14040:2006 + Amd 1:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179655
[2] DIN EN ISO 14044, 2021. Environmental management - Life cycle assessment – Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179656
[3] Carbon Minds, 2024. cm.chemicals database V2.02 – methodology document. Available online at: https://www.carbon-minds.com/wp-content/uploads/2025/09/cm_chemicals_methodology_V2.02_2024.pdf
[4] Carbon Minds
[5] ON Running

# 2. GOAL AND SCOPE DEFINITION

This chapter presents the goal and scope definition of the present comparative Life Cycle Assessment (LCA), according to ISO standards 14040[6], 14044[7]. The goal definition in Section 2.1 specifies the intended application of the study, the reasons for carrying out the assessment, the addressed target group, and whether the results will be used for public comparison.

Based on the defined goals, the scope definition in Section 2.2 determines the investigated product systems, including their functions and system boundaries, as well as a suitable functional unit. Further aspects of the scope definition include cut-off criteria, data sources and collection approach, the impact assessment method, and key assumptions and constraints applied to the modeling framework. Section 2.3 provides the data quality criteria to specify the data quality of the datasets.

The alignment of the scope with the goals is crucial to ensure that the comparative assessment is methodologically consistent. In ISO terms, the compared systems must be functionally equivalent and modeled with consistent methodological choices (functional unit, system boundary, allocation, data quality, and impact assessment method) to ensure comparability.

## 2.1 GOAL DEFINITION

The primary goal of this study is to conduct a comparative Life Cycle Assessment (LCA) of EVA copolymer production via two alternative feedstock pathways and to quantify and compare their environmental impacts under a consistent methodological framework. The study is intended as a feasibility study and exploratory innovation assessment, with the specific purpose of evaluating the potential decarbonization benefits of CCU-based pathway compared to a conventional fossil-based EVA copolymer reference case. The study also compares and discusses alternative CCU calculation approaches and evaluates how these methodological choices influence the resulting environmental performance of CCU-based EVA Copolymer pathway.

The assessment is framed as a scenario analysis and proof of concept. It is designed to validate the potential environmental performance of a future synthetic feedstock route rather than to demonstrate current operational emission reductions within the existing supply chain.

This study is conducted to achieve the following objectives:

- Internal strategic planning and alignment with regulatory requirements
- Supporting potential sustainability claims for marketing purposes in the future.

[6] DIN EN ISO 14040, 2021. Environmental management - Life cycle assessment – Principles and framework (ISO 14040:2006 + Amd 1:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179655

[7] DIN EN ISO 14044, 2021. Environmental management - Life cycle assessment – Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179656

- o Evaluating the decarbonization potential of CCU-based EVA copolymer pathway compared with industry-standard fossil-based reference data based on secondary data from the cm.chemicals database.
- o Comparing and discussing relevant CCU accounting and calculation approaches, including their implications for carbon uptake, allocation, and interpretation of comparative LCA results.
- o Identifying key environmental hotspots across both production routes, including the role of renewable energy supply in determining the environmental performance of CCU-derived materials.

The results of this study are intended for both external and internal stakeholders:

- o **External**: Including customers and local authorities, who may require insights into environmental performance.
- o **Internal**: Such as marketing, R&D, and management teams, to inform strategic planning, product development, and sustainability initiatives.

This study represents a comparative cradle-to-gate Life Cycle Assessment (LCA) of two EVA copolymer production routes. The assessment follows an attributional modeling framework. Comparative results disclosed publicly are subject to independent critical review in accordance with ISO 14044, clause §4.2.3.7[8]. The comparison reflects modeled differences under the defined system boundaries and assumptions and does not imply inherent product superiority. The study is desk-based and relies primarily on literature, secondary life cycle inventory databases, and simplified modeling assumptions where primary supplier data are not available.

This approach is aligned with the TfS Product Carbon Footprint (PCF) Guidelines[9], which allow upstream processes of purchased materials or intermediates to be excluded from the system boundary when these are supplied under defined contractual conditions. All pathways are modeled under harmonized methodological assumptions to ensure comparability. The results are intended to support internal strategic decision-making and scenario evaluation. All public-facing materials derived from this work shall include a disclaimer stating that the assessment represents the potential impact of future supply chain integration and should not be interpreted as evidence of current supply chain performance or verified product-level emission reductions.

[8] DIN EN ISO 14044, 2021. Environmental management - Life cycle assessment – Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179656

[9] Together for Sustainability (TfS) Initiative (2023). Product Carbon Footprint (PCF) Guideline. Available at: https://www.tfs-initiative.com

## 2.2 SCOPE DEFINITION

This section provides a detailed description of the scope of the present life cycle assessments. First, subsection 2.2.1 presents the function of the investigated product system and the respective functional unit. The following subsection 2.2.2 outlines the system boundaries of the main process stages of the ON Running EVA copolymer. The following subsections 2.2.3 and 2.2.4 describe applied cut-off criteria and the choice of environmental impact categories and applied methods.

### 2.2.1 Functional unit

The functional unit (FU) in a Life Cycle Assessment represents the reference quantity used to quantify the cradle-to-gate environmental impacts. The functional unit for both pathways is defined as follows:

**Production of 1 kg of unpacked EVA copolymer at the production site gate**

Functional equivalence between the pathways is assumed based on identical polymer composition, copolymer ratio, molecular weight range, and technical product specifications. Both pathways are modeled to deliver EVA copolymer with equivalent performance characteristics for identical downstream applications.

### 2.2.2 System boundaries

The system boundaries define the processes, material flows, and energy exchanges that are included within each product system. The selection of system boundaries determines which elementary flows are exchanged with the environment and which technical flows are considered internal to the modeled system.

The system boundaries for comparative LCA adopt **a cradle-to-gate approach**, covering all processes in the production of raw materials and their transformation into EVA copolymer up to the factory gate. A detailed description of included and excluded processes, including assumptions related to transportation, packaging, production waste, auxiliary materials, infrastructure, and other cut-off criteria, is provided in Section 3.4. For the CCU-based route, two alternative modeling approaches are applied to address multifunctionality: (a) credit approach and (b) a cut-off approach

From this point forward:

- The **fossil-based EVA copolymer** will be referred to as **Pathway 1**.
- The **CCU-based EVA copolymer** will be referred to as **Pathway 2.**
  a) *When modeled using* ***credit approach*** *to address multifunctionality will be referred to as* ***Pathway 2a****.*
  b) *When modeled using a* ***cut-off approach*** *will be referred to as* ***Pathway 2b****.*

Each pathway is described separately below, with specific details about processes, schematics, and unique characteristics included.

*System boundaries for Pathway 1*

Pathway 1 represents the conventional fossil-based production of EVA copolymer. This pathway is represented by an aggregated cradle-to-gate production dataset for EVA copolymer obtained from the cm.chemicals database (Version 2.02)[10]. The geographical coverage applied for this pathway is Eastern Asia, as this is the default regional representation for ON's fossil-based EVA supply chain.

The cm.chemicals dataset was selected in line with the desk-based feasibility and scenario-analysis scope of this study. As the assessment is not intended to represent a supplier-specific product carbon footprint for ON's current operational supply chain, primary foreground data for ON's existing fossil-based EVA copolymer supply chain were not collected. The Eastern Asia cm.chemicals dataset is therefore used as a representative industry-average reference case, aligned with the default regional representation of ON's fossil-based EVA supply chain.

The dataset represents the production of 1 kg of EVA copolymer at the factory gate and integrates upstream supply chains for all relevant intermediates (e.g., ethylene, vinyl acetate), energy provision, transportation, and waste treatment in accordance with the standardized life cycle inventory framework of the cm.chemicals database.

The cm.chemicals methodology applies plant-level technology modeling combined with production-weighted regional or national production mixes, including embedded allocation procedures for multifunctional processes and defined cut-off rules. The dataset is provided as an aggregated, ready-to-use cradle-to-gate inventory and does not require additional foreground process modeling within this study.

As Pathway 1 is represented by a pre-compiled dataset, no separate system boundary diagram is provided. The system boundary terminates at the factory gate of EVA copolymer production.

*System boundaries for Pathway 2*

Pathway 2 represents the production of EVA copolymer using synthetic naphtha (e-naphtha) derived from captured carbon dioxide ($CO_2$) and green hydrogen. This pathway aims to reduce reliance on fossil-derived hydrocarbon feedstocks by integrating renewable electricity–based synthetic fuels into the ethylene value chain.

**System boundaries for Pathway 2a: Credit Approach**

Figure 1 illustrates the system boundaries for Pathway 2a, representing the CCU-based EVA copolymer production modeled using credit approach. The green dashed line defines the system boundary; the following foreground unit processes are included:

- $CO_2$ capture from amine gas processing (USA)
- Synfuel production via green hydrogenation of captured $CO_2$ (USA)
- Separation of synfuels into hydrocarbon fractions, including e-naphtha (USA)

[10] Carbon Minds, 2024. cm.chemicals database V2.02 – methodology document. Available online at: https://www.carbon-minds.com/wp-content/uploads/2025/09/cm_chemicals_methodology_V2.02_2024.pdf

- Steam cracking of e-naphtha to produce ethylene (Finland)
- EVA copolymerization in an autoclave reactor (Belgium)
- Vinyl acetate production (Europe, modeled as an aggregated process)

The upper horizontal block represents the supply of energy and utilities (electricity, water, thermal energy), which feed into the respective unit processes across the value chain.

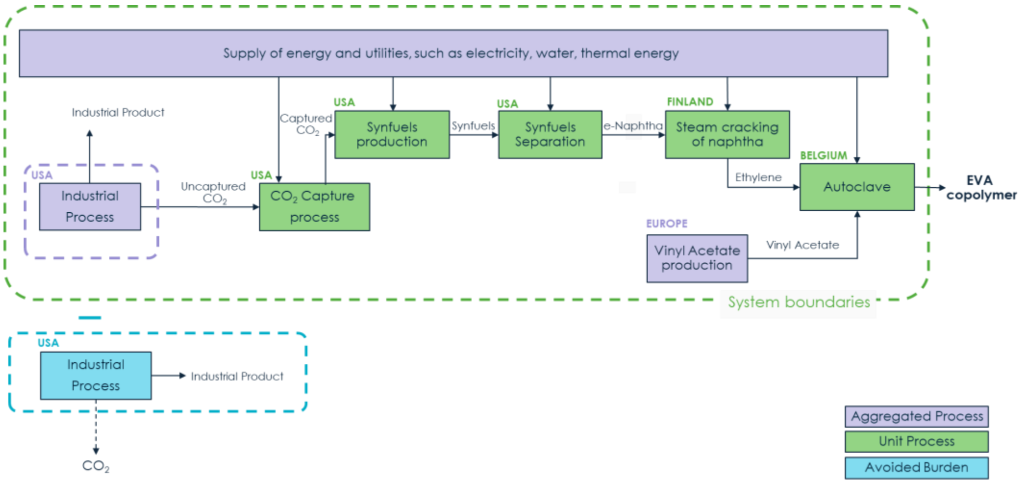


*Figure 1. System boundaries Pathway 2a. CCU-based EVA Copolymer Credit Approach.*

The blue-highlighted box in the lower section of the figure represents the avoided conventional industrial process that would otherwise produce equivalent fossil-based hydrocarbon products. These avoided processes are included within the expanded system boundary as credits.

Thus, the expanded system includes:

- Direct burdens from CCU-based production processes
- Upstream supply chains for inputs (electricity, green hydrogen, capture)
- CCU credit approach for fossil $CO_2$ utilization, applying a $CO_2$ burden to the generating process and a corresponding $CO_2$ credit to the consuming process

The system boundary terminates at the factory gate of EVA copolymer production.

Pathway 2a applies a CCU-specific credit approach for the treatment of utilized fossil $CO_2$, reflecting the bookkeeping logic described in the TfS PCF guidance[11]. Under this approach, the $CO_2$-generating process is assigned the climate burden associated with the generated $CO_2$, while the $CO_2$-consuming process receives a corresponding credit for the amount of $CO_2$ utilized as carbon feedstock. The approach is treated as a specific methodological option for CCU accounting within the context of this scenario analysis. To avoid double counting or inconsistent interpretation along the value chain, appropriate external

[11] Together for Sustainability (TfS) Initiative (2023). Product Carbon Footprint (PCF) Guideline. Available at: https://www.tfs-initiative.com

bookkeeping or certification should be considered where this approach is applied, particularly in the context of mass-balanced CCU-based materials.

**System boundaries for Pathway 2b: Cut-Off Approach**

Figure 2 illustrates the system boundaries for Pathway 2b, representing the CCU-based EVA copolymer production modeled using the Cut-Off approach. The green dashed line defines the system boundary. The following foreground unit processes are included:

- $CO_2$ capture process (USA)
- Synfuel production via green hydrogenation of captured $CO_2$ (USA)
- Separation of synfuels into e-naphtha and other hydrocarbon fractions (USA)
- Steam cracking of e-naphtha to produce ethylene (Finland)
- Vinyl acetate production (Europe, modeled as an aggregated process)
- EVA copolymerization in an autoclave reactor (Belgium)

The upper horizontal block represents the supply of energy and utilities (electricity, water, thermal energy) required across the production stages. Captured $CO_2$ is assumed to originate from an amine-based gas processing facility in the USA. The e-naphtha production site is assumed to be located near the $CO_2$ source, enabling $CO_2$ transport by pipeline. The vertical boundary labeled "Cut-off" indicates that environmental burdens associated with the upstream industrial production process are not attributed to the CCU system. In line with the TfS PCF guidance for CCU-containing systems, captured $CO_2$ is treated analogously to a recycled or secondary feedstock, and the cut-off is placed before the $CO_2$ capture process. Accordingly, $CO_2$ enters the CCU system without upstream burdens from the original $CO_2$-generating process. All burdens directly related to the CCU pathway are included within the system boundary, including $CO_2$ capture, hydrogen production, e-naphtha production, and subsequent conversion to EVA copolymer. Capture losses are considered in the modeling. The system boundary, therefore, reflects only the direct environmental burdens associated with the CCU-based production chain up to the factory gate of EVA copolymer.

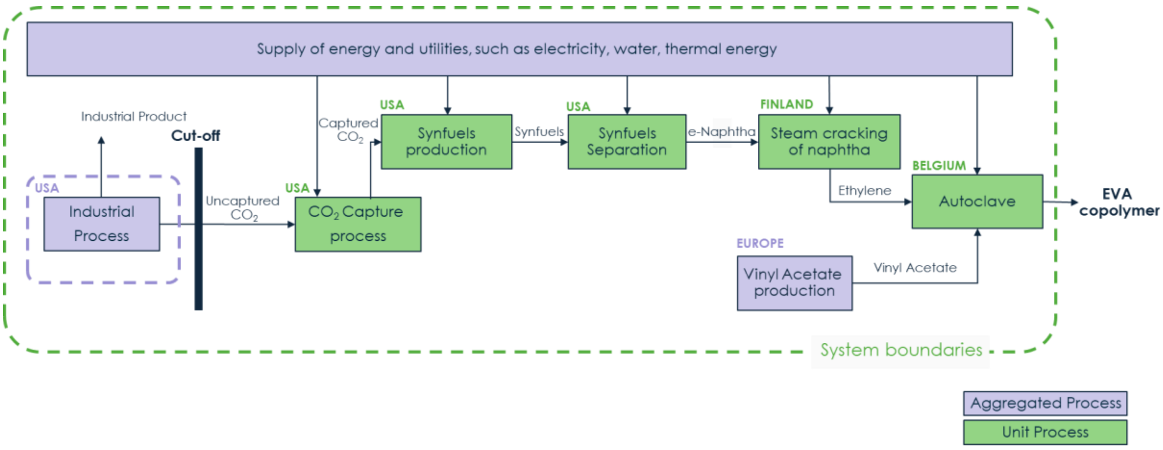


*Figure 2. System boundaries Pathway 2b. CCU-based EVA Copolymer cut-off approach.*

### 2.2.3 CUT-OFF CRITERIA

The cut-off criteria applied in this Life Cycle Assessment (LCA) ensure that the analysis captures the most significant environmental impacts while adhering to international standards, including ISO 14040[12]/14044[13]. They are applied to determine the inclusion of inputs and outputs based on their significance to the overall system. The following thresholds are used:

- Mass Cut-Off: Flows contributing less than 1% of the total input mass may be excluded, provided that the sum of all excluded flows does not exceed 3% of the total mass input.
- Energy Cut-Off: Flows contributing less than 1% of the total energy input may be excluded, if the total excluded energy remains below 3% of the total system energy input.

These thresholds ensure that all environmentally relevant flows are included, while allowing for the omission of negligible ones, in line with the completeness principle of ISO 14040[8]/14044[9].

For the foreground system, the study utilized the cm.chemicals[14] database and mass and energy balances for the unit process used data S&P Global data[15]. The inbound and outbound packaging flows were excluded from the assessment, as they fall below the defined cut-off thresholds and are not expected to significantly affect the overall results. Catalyst inputs and losses are considered where represented in the underlying datasets or available process data. Precious metal catalysts are treated separately from general cut-off assumptions due to their potentially high environmental relevance, even when used in small quantities. Therefore, Carbon Minds methodology[10], which is compatible with both ISO and TfS guidelines, was followed for cut-off criteria.

### 2.2.4 LCIA methods and categories

The climate change impact of EVA copolymer production following the two pathways was evaluated using the IPCC 2021 characterization factors, as implemented in the Carbon Minds database, in accordance with ISO standards[12].

Furthermore, the Environmental Footprint (EF) 3.1 method is used for all environmental impact categories. This method is selected due to its alignment with the European Commission's recommended life cycle impact assessment approach for product environmental footprinting, ensuring consistency, scientific robustness, and comparability across impact categories.

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[12] DIN EN ISO 14040, 2021. Environmental management - Life cycle assessment – Principles and framework (ISO 14040:2006 + Amd 1:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179655

[13] DIN EN ISO 14044, 2021. Environmental management - Life cycle assessment – Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179656

[14] Carbon Minds, 2024. cm.chemicals database V2.02 – methodology document. Available online at: https://www.carbon-minds.com/wp-content/uploads/2025/09/cm_chemicals_methodology_V2.02_2024.pdf

[15] S&P Global. *Chemical industry outlook and market trends*. Available at: https://www.spglobal.com

Table 1 lists the environmental impact categories according to the EF 3.1 Life Cycle Impact Assessment method, including a short description and robustness of each impact category[16]. It is important to note that the results represent potential environmental impacts and do not reflect safety thresholds, environmental limit values, or direct risk assessments.

*Table 1. Overview of impact categories covered by the EF 3.1 Life Cycle Impact Assessment method, including robustness of the individual impact categories. Robustness: I – High, II - Moderate, III – Low.*

| Impact Category | Description | Robustness |
|---|---|---|
| ***Climate Change – total, biogenic, fossil, LULUC*** | *Measures the potential contribution of greenhouse gas emissions to global warming, expressed in kilograms of $CO_2$ equivalents (kg $CO_2$eq). Includes direct emissions (e.g., $CO_2$, $CH_4$, $N_2O$) and indirect emissions from energy use and land-use changes, covering a 100-year time horizon.* | *I* |
| ***Ozone Depletion*** | *Assesses the potential of substances to degrade the ozone layer, expressed in kilograms of CFC-11 equivalents (kg CFC-11-eq). Considers atmospheric lifetimes and ozone-depleting potentials of substances like halons and CFCs.* | *I* |
| ***Human Toxicity, Cancer Effects*** | *Evaluates the potential for chemical emissions to cause cancer in humans, expressed in comparative toxic units for humans (CTUh). Quantifies the estimated increase in morbidity in the total human population.* | *III* |
| ***Human Toxicity, Non-Cancer Effects*** | *Assesses the potential for chemicals to cause non-cancer health effects, expressed in CTUh. Includes impacts like organ damage and respiratory issues caused by long-term exposure to harmful substances.* | *III* |
| ***Particulate Matter*** | *Measures health impacts from exposure to particulate matter (PM), expressed in disease incidence. Captures contributions of fine particulate emissions (e.g., PM2.5) to premature mortality and respiratory diseases.* | *I* |
| **Ionizing Radiation, Human Health** | Evaluates the potential health effects from exposure to ionizing radiation, expressed in kilobecquerels of uranium-235 equivalents (kBq U-235-eq). Includes contributions from natural radioactive decay and emissions from human activities like nuclear energy production. | II |
| **Photochemical Ozone Formation** | Assesses the potential for emissions to form ground-level ozone (smog), expressed in kilograms of non-methane volatile organic compounds equivalents (kg NMVOC-eq). Accounts for chemical reactions of VOCs and NOx under sunlight, harming human health and vegetation. | I |
| **Acidification** | Measures the potential of emissions to cause acidification of soils and water bodies, expressed in moles of hydrogen ion equivalents (mol H+-eq). Covers deposition of acidic compounds (e.g., $SO_2$, NOx), leading to ecosystem damage. | II |
| **Eutrophication, Terrestrial** | Assesses the potential for nutrient enrichment in terrestrial ecosystems, leading to excessive plant growth, expressed in moles of nitrogen equivalents (mol N-eq). Considers nitrogen inputs disrupting natural soil processes. | II |
| **Eutrophication, Aquatic (Freshwater)** | Evaluates the potential for nutrient enrichment in freshwater systems, leading to algal blooms and oxygen depletion, expressed in kilograms of phosphorus equivalents (kg P-eq). Focuses on phosphorus loading from agriculture and wastewater. | II |
| **Eutrophication, Aquatic (Marine)** | Assesses the potential for nutrient enrichment in marine environments, leading to harmful algal blooms and hypoxia, expressed in kilograms of nitrogen equivalents (kg N-eq). Highlights nitrogen inputs from industrial and agricultural activities impacting coastal ecosystems. | II |

[16] Andreasi Bassi, S., Biganzoli, F., Ferrara, N., Amadei, A., Valente, A., Sala, S., & Ardente, F. (2023). *Updated characterisation and normalisation factors for the Environmental Footprint 3.1 method*. Publications Office of the European Union. https://doi.org/10.2760/798894

| | | |
|---|---|---|
| **Ecotoxicity, Freshwater** | Evaluates the potential toxic effects of chemical emissions on freshwater ecosystems, expressed in comparative toxic units for ecosystems (CTUe). The unit is an expression of an estimate of the potentially affected fraction of species integrated over time and volume per unit mass of a chemical emitted. It considers emissions of metals, pesticides, and other harmful substances affecting aquatic organisms. | III |
| **Land Use** | Assesses the potential impacts of land occupation and transformation on soil quality and ecosystem services, expressed in dimensionless points. It considers effects on biotic production, erosion resistance, mechanical filtration, and groundwater recharge, reflecting the degradation of land-based ecosystems caused by human activities. | III |
| **Water Use** | Assesses the potential impacts of water consumption on freshwater availability, expressed in cubic meters of water equivalents (m3 world-eq). It considers regional water scarcity, competition for water resources, and the deprivation of water availability for humans and ecosystems in water-stressed areas. | III |
| **Resource Use** | Measures the depletion of mineral and metal resources, expressed in kilograms of antimony equivalents (kg Sb-eq). It reflects the increasing effort and environmental burden associated with extracting lower-grade ores, considering the long-term availability of these non-renewable resources. | III |

## 2.3 DATA QUALITY ASSESSMENT

This section outlines the data quality assessment applied in the study, emphasizing the role of reliable and transparent data in generating robust and consistent life cycle inventory (LCI) results. It evaluates data quality, including technological, geographical, temporal, and completeness aspects. The approach ensures that the modelled systems are based on data that meets the requirements of the intended application and complies with relevant methodological frameworks.

All datasets in this study were evaluated for data quality using the pedigree matrix from the ecoinvent framework[17]. This method assesses data quality across five indicators: technological, temporal, and geographical representativeness, reliability, and completeness, with scores ranging from 1 (best) to 5 (worst). These scores ensure that datasets align with the study's goals and scope, maintaining consistency with ISO 14040 and 14044 standards. Detailed descriptions of the scoring criteria and results are included in Appendix A Data Sources and Appendix B Data Quality.

[17] Weidema B P, Bauer C, Hischier R, Mutel C, Nemecek T, Reinhard J, Vadenbo C O, Wernet G, "Overview and Methodology of Ecoinvent", 2013.

# 3. LIFE CYCLE INVENTORY (LCI) MODELING

The life cycle inventory (LCI) phase primarily focuses on gathering data and the development of the life cycle inventory model. The Life Cycle Inventory (LCI) phase systematically quantifies all input and output flows within the system boundaries for EVA copolymer production. This section provides details about the inputs (materials and energy) and outputs (emissions and wastes) associated with each stage of the cradle-to-gate lifecycle. First, section 3.1 outlines the setup of the foreground and background system. Section 3.2 describes the application of allocation procedures to solve the multifunctionality of the process stages. Sections 3.3 and 3.4 describe modelling approach and calculations set-up as well as assumptions and justifications for cut-offs, applied within the study.

## 3.1 FOREGROUND AND BACKGROUND SYSTEM

Processes within the product system may either be categorized as part of the foreground or the background system. The foreground system consists of processes that are under the control of the decision-maker for which an LCA is carried out. In contrast, the background system is composed of processes on which no or, at best, indirect influence may be exercised by the decision-maker for which an LCA is carried out.

Foreground and background modeling follow the cm.chemicals database methodology[18], including plant-level modeling, integrated site modeling, trade-adjusted consumption mixes, and defined cut-off rules.

While all processes within the product system are described in detail below, it is important to note that specific numerical data related to certain processes cannot be disclosed in the public-facing documentation due to confidentiality restrictions. The underlying foreground modeling is based primarily on secondary data sources, including the cm.chemicals database, ecoinvent, and S&P Global data for process routes, mass and energy balances, and background life cycle inventory datasets. ON AG provided study-specific assumptions and contextual information used to define the modeled scenarios, including the geographical coverage of the fossil-based EVA reference case, the assumed source of captured $CO_2$, the assumed electricity source, geographical covergae. and the sequence of technologies considered for the CCU-based route to EVA copolymer. These inputs were used to define the scenario setup and technology pathway, while the quantitative life cycle inventory data were derived from the secondary data sources described above. For external reporting, the structure, methodology, system boundaries, assumptions, and overall process flow of the LCA are transparently presented, while detailed quantitative inventory data remain confidential to protect proprietary information and database licensing restrictions. For the independent review process, additional data and documentation were made available to TÜV under appropriate confidentiality

[18] Carbon Minds, 2024. cm.chemicals database V2.02 – methodology document. Available online at: https://www.carbon-minds.com/wp-content/uploads/2025/09/cm_chemicals_methodology_V2.02_2024.pdf

arrangements to support verification of the modeling approach, data sources, assumptions, and calculations.

**Pathway 1**

The fossil-based EVA copolymer production is represented by an aggregated cradle-to-gate dataset obtained from the cm.chemicals database. The dataset includes all relevant upstream and on-site process steps required to produce 1 kg of EVA copolymer at the factory gate.

Within the production chain, EVA copolymer is synthesized in an autoclave reactor through the copolymerization of ethylene and vinyl acetate. The process consumes ethylene and vinyl acetate as material inputs and requires electricity and cooling water as utilities. Steam is generated as a utility by-product. Multifunctionality associated with utility co-products is resolved within the underlying dataset using system expansion via the avoided burden approach, consistent with the cm.chemicals methodology. The dataset represents a cradle-to-gate inventory integrating upstream supply chains for crude oil extraction, naphtha production, steam cracking, vinyl acetate synthesis, utilities provision, transportation, and waste treatment. The geographical coverage selected for the fossil-based EVA copolymer pathway is Eastern Asia, which is used as the default regional representation of ON's fossil-based EVA supply chain within the scope of this study.

Process data are primarily derived from detailed process simulations. Regional production capacities and international trade volumes are based predominantly on primary industry data, complemented by secondary sources where necessary. Electricity supply is modeled according to country-specific grid mixes, including imports where relevant. Steam and thermal energy supplies reflect country-specific conditions whenever available; otherwise, regionally representative averages are applied.

**Pathway 2**

The CCU-based EVA copolymer pathway includes all unit processes required to convert post-industrial $CO_2$ into EVA copolymer via an intermediate e-naphtha route, spanning multiple geographical locations, as illustrated in Figure 1 and Figure 2. The system boundary covers $CO_2$ capture, synfuel production, and separation to e-naphtha in Texas, USA, followed by ethylene production in Finland, and vinyl acetate production in Europe and EVA copolymerization in Belgium.

The distinction between Pathway 2a (System Expansion) and Pathway 2b (Cut-Off) arises from the treatment of multifunctional processes and is addressed in Section 3.2.

The background system further includes all processes providing raw and auxiliary materials, purchased energy or utilities, as well as waste incineration. Waste incineration is modeled based on the Life Cycle Inventory (LCI) model developed by Doka (2003), which accounts for the composition of waste and its influence on environmental impacts. This model has been updated and adapted using primary data from hazardous waste incineration plants located in a chemical park in Germany, as documented in the cm.chemicals database V2.02[19].

Details on the applied methodologies are provided in the methodology documents of Carbon Minds, and Ecoinvent[20]. Datasets used for background modelling are covered in Appendix A Data Sources.

### 3.1.1 Foreground system

#### $CO_2$ capture process

Post-industrial $CO_2$[21] is assumed to be captured in Texas, USA, from an amine-based gas processing facility and supplied as a feedstock for synthetic fuel production. This $CO_2$ source is used in the model based on information provided by ON AG. As the $CO_2$ is captured from amine gas processing, the energy demand for $CO_2$ capture is assumed to be relatively low compared with more energy-intensive capture routes, but it is further investigated in Section 6.2 of the report.

Under this approach, the upstream burdens of the industrial process generating the $CO_2$ is excluded from the CCU-based EVA system, while $CO_2$ capture, compression, and transfer required to make the $CO_2$ available for synfuels production are included. $CO_2$ transport is assumed to occur by pipeline, as synfuels production site is assumed to be located near the $CO_2$ source. Additional compression is assumed to take place upon arrival at the synfuels production site. This additional compression is considered to have limited influence on the results due to the assumed use of wind electricity for whole process.

Capture losses are considered in the modeling at conversion rate of 80%[22], meaning that the amount of $CO_2$ generated, captured, and ultimately utilized in synfuels production is different.

The assumptions regarding $CO_2$ source, capture technology, pipeline transport, additional compression, renewable electricity use, and capture losses represent scenario assumptions and should be considered when interpreting the results.

#### Synfuels production

Captured $CO_2$ is combined with green hydrogen to produce synfuels. The life cycle inventory for synfuel production is constructed using an arithmetic average of three S&P Global process models[23] for synfuels production from $CO_2$ and green hydrogen in the United States, Gulf Coast region. All three configurations include the conversion of captured $CO_2$ and green hydrogen into liquid hydrocarbon products. Hydrogen

[19] Carbon Minds, 2024. cm.chemicals database V2.02 – methodology document. Available online at: https://www.carbon-minds.com/wp-content/uploads/2025/09/cm_chemicals_methodology_V2.02_2024.pdf

[20] ecoinvent Association (2024). ecoinvent database version 3.11. Zurich, Switzerland. Available at: https://www.ecoinvent.org

[21] Selecting $CO_2$ Sources for $CO_2$ Utilization by Environmental-Merit-Order Curves. Available at: https://pubs.acs.org/doi/full/10.1021/acs.est.5b03474?casa_token=lR-euCTEzEYAAAAA%3Akedk5vLTK4q-4A4-laxQu-Wwhmbw0CXvjUmC4QmMtZFcVKff2GLtr-LfDW8llerwyAWSc9GPmjBslCVd

[22] Gary T. Rochelle ,Amine Scrubbing for CO2 Capture.Science325,1652-1654(2009). DOI:10.1126/science.1176731

[23] S&P Global. Chemical industry outlook and market trends. Available at: https://www.spglobal.com

production is considered upstream of the synfuels production step and is modeled according to the green electricity assumptions defined for the CCU pathway. The modeled routes include reverse water-gas shift or equivalent syngas production, followed by Fischer–Tropsch or proprietary liquid fuel synthesis and, where applicable, hydroprocessing to produce synfuels. Catalyst use is not included as several process routes rely on proprietary technologies, detailed catalyst compositions are not separately specified in this study.

### Synfuels separation process

The hydroprocessed Fischer–Tropsch liquid is separated by atmospheric distillation into three product streams:

- e-naphtha (reference product),
- Middle distillates (kerosene and diesel range),
- LPG (C3–C4 fraction).

The distillation process requires steam for reboiler duty, renewable electricity for pumps and process control as defined by ON AG, cooling water for heat removal, and boiler feed water for steam makeup. No catalysts or process chemicals are consumed during this step. Minor hydrocarbon losses occur as NMVOC emissions to air, and a small wastewater stream results from cooling-water blowdown. The unit performs physical separation only; no chemical transformation occurs.

### Steam cracking process

Ethylene is produced in Finland via steam cracking of e-naphtha. The process involves high-temperature thermal cracking of hydrocarbons in the presence of dilution steam, followed by rapid quenching and downstream separation of product fractions. The process consumes: e-naphtha as feedstock; electricity; cooling water; inert gas; process water.

Dilution steam is injected into the cracking furnace to reduce hydrocarbon partial pressure and suppress coke formation. The cracked gas mixture is subsequently cooled and separated via compression, cryogenic distillation, and fractionation into ethylene, propylene, pyrolysis gasoline, hydrogen and C4 fraction. In addition to products, the process generates utility co-products in the form of steam and thermal energy through heat recovery from high-temperature process streams. Upstream production of crude oil, naphtha, and natural gas is represented by country-specific or regionally representative datasets.

### Autoclave process

EVA copolymer is produced in Belgium via high-pressure copolymerization of ethylene and vinyl acetate in an autoclave reactor. The process consumes ethylene and vinyl acetate as material inputs and requires electricity and cooling water. Steam is generated as a utility by-product. Multifunctionality associated with utility co-products is treated consistently with the selected multifunctionality approach defined in Section 3.2.

### 3.1.2 Background system

Across the pathway, upstream production of raw materials and intermediates is represented using country-specific datasets where available or regionally representative datasets where country-level resolution is not fully available. Details regarding geographical coverage are described in Appendix A Data Sources. Electricity supply is modeled using country-specific grid mixes reflecting the geographical location of each production stage. Where country-level consumption datasets are unavailable, regionally representative datasets are applied consistently. Steam and thermal energy supplies are modeled using geographically aligned datasets wherever possible; otherwise, broader regional averages are used to ensure methodological consistency.

Regarding transportation, freight transportation was considered for all internationally traded flows between countries.-For CO2 capture unit, $CO_2$ transport is assumed to occur by pipeline, as synfuels production site is assumed to be located near the $CO_2$ source.

Transport distances are determined using Searates[26], based on the most common commercial routes and modal breakdown between sea and land transport. Where precise production site locations are known, specific geographic coordinates are applied. This includes the use of representative country-to-country transport routes for internationally traded flows, combining sea transport between ports with inland road transport where applicable. In the absence of exact site information, transport modeling follows the standardized assumptions defined in the cm.chemicals[27] methodology. Emission factors and resource data were drawn from Ecoinvent database[24].

## 3.2 APPLICATION OF ALLOCATION PROCEDURES

The present life cycle assessment follows the hierarchy for allocation procedures as proposed by ISO14040[25] and ISO14044[26]. According to the allocation hierarchy physical allocation is applied where applicable, with the objective of consistently addressing multifunctionality across both the fossil-based and CCU-based EVA copolymer pathways. Where datasets are aggregated or processes yield multiple valuable outputs, allocation or system expansion approaches were applied as specified below.

### 3.2.1 Pathway 1

Pathway 1 is modeled using aggregated cm.chemicals datasets, which follow predefined allocation rules embedded in the database. The cm.chemicals framework applies to the allocation hierarchy in accordance with ISO 14044, and TfS guidelines. Where feasible, subdivision of processes is applied to avoid allocation. If subdivision is not technically possible, physical relationships (e.g., mass or energy content) are used to allocate environmental burdens among co-products. In cases where physical causality cannot be

[24] ecoinvent Association (2024). ecoinvent database version 3.11. Zurich, Switzerland. Available at: https://www.ecoinvent.org

[25] DIN EN ISO 14040, 2021. Environmental management - Life cycle assessment – Principles and framework (ISO 14040:2006 + Amd 1:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179655.

[26] DIN EN ISO 14044, 2021. Environmental management - Life cycle assessment – Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179656

adequately represented, alternative allocation approaches consistent with ISO principles are implemented within the dataset construction.

For energy-producing processes (e.g., steam cracking, refinery operations), allocation of material co-products and utility streams follow established industry methodologies integrated into the database – in accordance with TfS guidelines.

No additional allocation procedures were applied within this study for Pathway 1 beyond those already implemented in the cm.chemicals datasets.

### 3.2.2 Pathway 2

Multifunctionality arises in several unit processes within the CCU-based pathway. The allocation procedures applied at each stage are described below in accordance with the principles of the ISO 14044 allocation hierarchy. Where relevant, differences between Pathway 2a (Credit Approach) and Pathway 2b (Cut-Off) are explicitly indicated.

**$CO_2$ capture process**

At the $CO_2$ capture stage, no allocation is required, as the modeled capture process has a single functional output: captured $CO_2$ supplied to the CCU chain. Post-industrial $CO_2$ is assumed to be captured in Texas, USA, from amine gas processing, based on information provided by ON AG. This source is used as the assumed point source for the CCU pathway. Due to the nature of amine gas processing, the energy demand for $CO_2$ capture is assumed to be relatively low compared with more energy-intensive capture routes; this assumption is further assessed in Section 6.2. For the **cut-off approach**, the upstream burdens of the industrial process generating the $CO_2$ are excluded from the CCU-based EVA system, while the burdens of $CO_2$ capture, compression, and transfer required to make the $CO_2$ available for synfuels production are included. For the **credit approach**, the treatment follows the CCU bookkeeping logic described in the TfS guidance, where the $CO_2$-generating process is burdened with the generated $CO_2$, while the $CO_2$-consuming process receives a corresponding credit for the amount of $CO_2$ utilized.

**Synfuels production**

In the synfuels production step, no additional allocation is applied in either Pathway 2a or Pathway 2b, as the process data are available as partially aggregated inventory data (green hydrogen production with Fisher-Tropsch process). Embedded allocation or multifunctionality treatments from the original data source are retained. Oxygen released during the process is treated as an emission and not as a co-product.

**Synfuels separation process**

In the synfuels separation unit, hydroprocessed Fischer–Tropsch liquids are separated into e-naphtha (reference product), middle distillates, and LPG. This process represents the atmospheric distillation (product fractionation) of hydroprocessed Fischer–Tropsch (FT) liquids, energy allocation was applied following the TfS recommendation. Economic allocation was not applied as ratio between the economic values of the co-products is lower than 5. Waste streams generated within this unit are treated using the internal cm.chemicals waste modelling approach.

### Steam cracking process

In the steam cracking of naphtha, ethylene is produced alongside propylene, pyrolysis gasoline, hydrogen, and C4 fraction. Allocation of material outputs follows the Plastics Europe recommendation[27]. The main products are ethylene, propylene, pyrolysis gasoline (high value chemicals), pyrolysis gasoline (non-high value chemicals), hydrogen, and C4 fraction. As defined in the recommendation, below are allocation factors for ethylene production:

- Allocation factor for feedstock: 38.96%
- Allocation factor for energy and emissions: 42.57%

The exported steam is assumed to substitute for regionally representative conventional steam production, and exported thermal energy is assumed to substitute for regionally representative conventional thermal energy production.

### Autoclave Process (EVA Copolymer Production)

The autoclave reactor produces EVA copolymer as the main material output and co-generates steam as a utility by-product. No allocation is applied to the EVA material product, as it represents the sole material output of the process. Multifunctionality associated with the co-produced steam is resolved through system expansion via the avoided burden approach. The exported steam is assumed to substitute for regionally representative conventional steam production. This treatment is applied consistently in both Pathway 2a and Pathway 2b.

## 3.3 MODELING AND CALCULATING

The life cycle model was implemented within a structured spreadsheet-based computational framework. Inventory compilation and impact assessment calculations were performed using a matrix-based formulation consistent with ISO 14040 and ISO 14044 requirements for Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA).

The applied formulation follows the established mathematical structure of process-based LCA, in which the technology matrix (A), elementary flow matrix (B), scaling vector, and characterization matrix are used to derive inventory and impact results. This computational structure is consistent with the framework formalized by Heijungs and Suh[28] and widely adopted in ISO-conform LCA implementations as follows:

- The **technology matrix (A)** represents the interdependencies between unit processes and contains all intermediate input and output flows within the defined system boundary.

[27] PlasticsEurope recommendation on Steam Cracker allocation. Life Cycle and Sustainability working group of PlasticsEurope (2017). Available at: PlasticsEurope recommendation on Steam Cracker allocation- Juillet 2018.pdf
[28] Heijungs, R., & Suh, S. (2002). The Computational Structure of Life Cycle Assessment. Dordrecht: Kluwer Academic Publishers.

- The **functional unit vector (f)** defines the demand for 1 kg of EVA copolymer at the factory gate.
- The **scaling vector (s)** is obtained by solving the linear system

$$A \cdot s = f$$

which determines the activity levels of all processes required to fulfill the functional unit.

- The **elementary flow matrix (B)** contains all emissions to air, water, and soil, as well as resource extractions associated with each unit process.

The aggregated Life Cycle Inventory results are calculated as:

$$LCI = B \cdot s$$

For impact assessment, characterized results are obtained by multiplying the inventory results with the characterization factor matrix:

- The **characterization matrix (Q)** contains impact category–specific characterization factors (e.g., Global Warming Potential factors).

The life cycle impact assessment results are calculated as:

$$LCIA = Q \cdot B \cdot s$$

All matrix operations were implemented explicitly within the spreadsheet model to ensure transparency and traceability of intermediate calculation steps. Internal consistency checks were performed to verify mass balance closure and carbon balance integrity across all modeled pathways.

## 3.4 ASSUMPTIONS AND LIMITATIONS

The following assumptions and limitations apply to both Pathway 1 (fossil-based EVA) and Pathway 2 (CCU-based EVA):

- **Transportation modelling:** Transportation was modeled for all internationally traded intermediate flows. Transport distances were determined using representative commercial routes and modal splits (sea and land transport). Transport impacts scale proportionally with transported mass and distance.
- **Data Basis and Representativeness:** The study relies on secondary data sources. No primary or site-specific operational data are used. Mass and energy balances are derived from S&P Global[29], the cm.chemicals methodological framework, and peer-reviewed scientific literature. As a result, the outcomes reflect representative, technology-based estimates rather than plant-specific performance. Process inventories are constructed using detailed process simulations, industry production statistics, and trade-adjusted regional production mixes.

[29] S&P Global. *Chemical industry outlook and market trends*. Available at: https://www.spglobal.com

- **Treatment of $CO_2$ capture utilities:** Heat and electricity inputs associated with $CO_2$ capture are included the system boundary and the impact calculations. This modelling choice reflects the treatment of captured $CO_2$ as an externally supplied intermediate, based on an existing contractual arrangement governing $CO_2$ supply.
- **Geographical Representativeness:** Country-specific datasets were applied wherever available. In cases where country-level consumption datasets were unavailable, regionally representative or proxy datasets were used consistently across pathways to maintain comparability.
- **Electricity Modeling:** The CCU pathway assumes the use of 100% wind-based electricity. High-voltage wind electricity is transformed to medium-voltage electricity before use in the modeled industrial processes. This transformation step is simplified and represents only electricity transmission and distribution losses; no additional material inputs or elementary flows are modeled for the transformation itself. Losses are reflected through an increased electricity requirement, assuming a 5% loss for the United States based on reported electric power transmission and distribution losses as a percentage of output[30]. This electricity modeling represents a scenario assumption rather than a supplier-specific electricity supply model. It does not account for temporal matching, grid balancing, contractual procurement conditions, guarantees of origin or energy attribute certificates, curtailment, or regional variability in wind electricity supply. As electricity demand is a key driver for the CCU pathway, particularly for hydrogen and synfuels production, the results should be interpreted in light of this assumption.
- **Comparability:** The comparison between Pathway 1 and Pathways 2a/2b is subject to limitations due to differences in data structure and modeling approach. Pathway 1 is represented by an aggregated cradle-to-gate cm.chemicals dataset with embedded assumptions for upstream processes, utilities, transport, waste treatment, and multifunctionality treatment, whereas Pathways 2a and 2b are modeled using a scenario-based approach combining secondary data and study-specific assumptions for the CCU route. Therefore, differences in results may reflect not only technological differences between fossil-based and CCU-based EVA Copolymer production, but also differences in data aggregation, regional representativeness, and modeling assumptions. The results should be interpreted as a feasibility-oriented scenario comparison rather than a supplier-specific product comparison.

The following assumptions and limitations were considered for Pathway 1:

- Pathway 1 is modeled using aggregated cradle-to-gate datasets from the cm.chemicals database. Allocation procedures and treatment of multifunctionality are embedded within these datasets and follow the database's methodological framework. As the datasets are aggregated, process-level transparency is limited to

[30] World Bank. (n.d.). Electric power transmission and distribution losses (% of output) [Data set]. World Bank Open Data. Retrieved May 20, 2026, from https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS

the documentation provided by the database developer. No additional process-specific adjustments were performed within this study.

- Pathway 1 is based on an aggregated cradle-to-gate cm.chemicals dataset, whereas Pathways 2a and 2b are modeled using a more disaggregated, scenario-based approach. As a result, direct comparability is limited by differences in data aggregation, process-level transparency, embedded methodological choices, and regional representativeness. Differences in results may therefore reflect both technological differences between fossil-based and CCU-based EVA production routes and differences in modeling structure. The comparison should be interpreted as a feasibility-oriented scenario comparison rather than as a supplier-specific or fully process-level comparison.

The following assumptions and limitations were considered for Pathway 2:

- **Technological maturity and optimization potential:** Some technologies assessed, particularly within the CCU-based pathway, are at an early stage of deployment and might have significant potential for future optimization. To improve the representativeness of the results, simplified arithmetic adjustments and consistency checks were applied across the process models to ensure coherent mass and energy balances.
- **Treatment of $CO_2$ capture utilities:**
  - Pathway 2a (Credit Approach): The $CO_2$-consuming process receives a $CO_2$ bookkeeping credit for the amount of captured $CO_2$ utilized as feedstock, while the $CO_2$-generating process carries the corresponding $CO_2$ burden.
  - Pathway 2b (Cut-Off): No substitution credits are applied at the product system level. Co-products do not receive avoided burden credits beyond those embedded within background datasets.

Table 2 provides an overview of the activities that are included in and excluded from the system boundary of the study. The classification reflects the cradle-to-gate scope applied in this assessment and is intended to ensure transparency regarding the processes, inputs, and activities considered in the modelling of EVA copolymer production, as well as those excluded due to their limited relevance to the defined system boundary.

*Table 2. Included and excluded activities as defined in the system boundary.*

| Included Activities | Excluded Activities |
|---|---|
| **Production-related raw materials and intermediates required for EVA copolymer production (e.g., fossil naphtha and CCU-derived e-naphtha)** | Services such as engineering, infrastructure services, R&D activities, and business travel |
| **Energy consumption across lifecycle stages(e.g., electricity, natural gas)** | Packaging (inbound and outbound) and any packaging-related upstream processes |
| **Direct emissions from manufacturing and related on-site utilities generation** | All emissions occurring during the end-of-life phase (EoL) |

| | |
|---|---|
| **Treatment or disposal of process wastes and wastewater (operational waste)** | Production of capital goods (e.g., equipment and facilities) |
| **Utilities consumed during production (e.g, process water, cooling water)** | Use phase |

# 4. LIFE CYCLE IMPACT ASSESSMENT (LCIA) RESULTS

This chapter presents the results of the life cycle impact assessment for the functional unit, "production of 1 kg of EVA copolymer, at production site" for the 2 pathways: **fossil-based EVA copolymer pathway** and **CCU-based EVA copolymer pathway.**

It presents the life cycle assessment (LCA) results for EVA copolymer, highlighting its environmental impacts across various categories. It evaluates key factors such as climate change, human toxicity, water use, and other environmental indicators throughout the EVA copolymer production process, from raw material sourcing to final product.

## 4.1 PATHWAY 1: FOSSIL-BASED EVA COPOLYMER

The environmental impacts of 1 kg of fossil-based EVA copolymer production at the production site for ON Running are listed in Table 3.

*Table 3. Life Cycle Impact Assessment (EF3.1) and compliant with ISO 14067 based on the IPCC 2021, for Pathway 1 (Fossil-based). FU: Production of 1 kg of unpacked EVA copolymer at the production site gate.*

| Environmental impact method | Environmental impact category | Indicator | Results | Unit |
|---|---|---|---|---|
| EF v3.1 | acidification | accumulated exceedance (AE) | 1.24E-02 | mol H+-Eq |
| EF v3.1 | climate change: total | global warming potential (GWP100) | 3.12 | kg $CO_2$eq |
| EF v3.1 | climate change: biogenic | global warming potential (GWP100) | 8.63E-04 | kg $CO_2$eq |
| EF v3.1 | climate change: fossil | global warming potential (GWP100) | 3.12 | kg $CO_2$eq |
| EF v3.1 | climate change: land use and land use change | global warming potential (GWP100) | 1.08E-03 | kg $CO_2$eq |
| EF v3.1 | ecotoxicity: freshwater | comparative toxic unit for ecosystems (CTUe) | 11.80 | CTUe |
| EF v3.1 | ecotoxicity: freshwater, inorganics | comparative toxic unit for ecosystems (CTUe) | 11.44 | CTUe |
| EF v3.1 | ecotoxicity: freshwater, organics | comparative toxic unit for ecosystems (CTUe) | 0.36 | CTUe |
| EF v3.1 | eutrophication: freshwater | fraction of nutrients reaching freshwater end compartment (P) | 76.07 | kg P-Eq |
| EF v3.1 | resource use, fossils | abiotic depletion potential (ADP): fossil fuels | 6.68E-04 | MJ, net calorific value |
| EF v3.1 | eutrophication: marine | fraction of nutrients reaching marine end compartment (N) | 2.41E-03 | kg N-Eq |

| | | | | |
|---|---|---|---|---|
| EF v3.1 | eutrophication: terrestrial | accumulated exceedance (AE) | 2.46E-02 | mol N-Eq |
| EF v3.1 | human toxicity: carcinogenic | comparative toxic unit for human (CTUh) | 6.27E-10 | CTUh |
| EF v3.1 | human toxicity: carcinogenic, inorganics | comparative toxic unit for human (CTUh) | 2.22E-10 | CTUh |
| EF v3.1 | human toxicity: carcinogenic, organics | comparative toxic unit for human (CTUh) | 4.05E-10 | CTUh |
| EF v3.1 | human toxicity: non-carcinogenic | comparative toxic unit for human (CTUh) | 1.09E-08 | CTUh |
| EF v3.1 | human toxicity: non-carcinogenic, inorganics | comparative toxic unit for human (CTUh) | 9.97E-09 | CTUh |
| EF v3.1 | human toxicity: non-carcinogenic, organics | comparative toxic unit for human (CTUh) | 8.96E-10 | CTUh |
| EF v3.1 | ionising radiation: human health | human exposure efficiency relative to u235 | 1.76E-01 | kBq U235-Eq |
| EF v3.1 | land use | soil quality index | 6.14 | dimensionless |
| EF v3.1 | resource use, minerals and metals | abiotic depletion potential (ADP): elements (ultimate reserves) | 2.37E-06 | kg Sb-Eq |
| EF v3.1 | ozone depletion | ozone depletion potential (ODP) | 8.58E-08 | kg CFC-11-Eq |
| EF v3.1 | particulate matter formation | impact on human health | 1.03E-07 | disease incidence |
| EF v3.1 | photochemical oxidant formation: human health | tropospheric ozone concentration increase | 1.31E-02 | kg NMVOC-Eq |
| EF v3.1 | water use | user deprivation potential (deprivation-weighted water consumption) | 0.31 | m3 world Eq deprived |

## 4.2 PATHWAY 2A: CCU-BASED EVA COPOLYMER (CREDIT APPROACH)

The environmental impacts of 1 kg CCU-based EVA copolymer production, at the production site for ON Running, following the Credit Approach, are listed in Table 4.

*Table 4. Life Cycle Impact Assessment (EF3.1) and compliant with ISO 14067, based on the IPCC 2021, for Pathway 2a (Credit Approach). FU: Production of 1 kg of unpacked EVA copolymer at the production site gate.*

| Environmental impact method | Environmental impact category | Indicator | Results | Unit |
|---|---|---|---|---|
| EF v3.1 | acidification | accumulated exceedance (AE) | 1.83E-02 | mol H+-Eq |
| EF v3.1 | climate change: total | global warming potential (GWP100) | 0.4997 | kg $CO_2$eq |
| EF v3.1 | climate change: biogenic | global warming potential (GWP100) | 1.99E-03 | kg $CO_2$eq |
| EF v3.1 | climate change: fossil | global warming potential (GWP100) | 0.494 | kg $CO_2$eq |
| EF v3.1 | climate change: land use and land use change | global warming potential (GWP100) | 3.20E-03 | kg $CO_2$eq |
| EF v3.1 | ecotoxicity: freshwater | comparative toxic unit for ecosystems (CTUe) | 1.00E+04 | CTUe |
| EF v3.1 | ecotoxicity: freshwater, inorganics | comparative toxic unit for ecosystems (CTUe) | 27.2 | CTUe |
| EF v3.1 | ecotoxicity: freshwater, organics | comparative toxic unit for ecosystems (CTUe) | 9.99E+03 | CTUe |
| EF v3.1 | eutrophication: freshwater | fraction of nutrients reaching freshwater end compartment (P) | 40.8 | kg P-Eq |
| EF v3.1 | resource use, fossils | abiotic depletion potential (ADP): fossil fuels | 1.05E-03 | MJ, net calorific value |
| EF v3.1 | eutrophication: marine | fraction of nutrients reaching marine end compartment (N) | 2.81E-03 | kg N-Eq |
| EF v3.1 | eutrophication: terrestrial | accumulated exceedance (AE) | 3.05E-02 | mol N-Eq |
| EF v3.1 | human toxicity: carcinogenic | comparative toxic unit for human (CTUh) | 5.00E-06 | CTUh |
| EF v3.1 | human toxicity: carcinogenic, inorganics | comparative toxic unit for human (CTUh) | 2.27E-08 | CTUh |
| EF v3.1 | human toxicity: carcinogenic, organics | comparative toxic unit for human (CTUh) | 4.98E-06 | CTUh |
| EF v3.1 | human toxicity: non-carcinogenic | comparative toxic unit for human (CTUh) | 1.41E-05 | CTUh |
| EF v3.1 | human toxicity: non-carcinogenic, inorganics | comparative toxic unit for human (CTUh) | 1.42E-06 | CTUh |

| | | | | |
|---|---|---|---|---|
| EF v3.1 | human toxicity: non-carcinogenic, organics | comparative toxic unit for human (CTUh) | 1.26E-05 | CTUh |
| EF v3.1 | ionising radiation: human health | human exposure efficiency relative to u235 | 9.82 | kBq U235-Eq |
| EF v3.1 | land use | soil quality index | 12.5 | dimensionless |
| EF v3.1 | resource use, minerals and metals | abiotic depletion potential (ADP): elements (ultimate reserves) | 1.11E-04 | kg Sb-Eq |
| EF v3.1 | ozone depletion | ozone depletion potential (ODP) | 4.99E-06 | kg CFC-11-Eq |
| EF v3.1 | particulate matter formation | impact on human health | 1.39E-07 | disease incidence |
| EF v3.1 | photochemical oxidant formation: human health | tropospheric ozone concentration increase | 1.33E-02 | kg NMVOC-Eq |
| EF v3.1 | water use | user deprivation potential (deprivation-weighted water consumption) | 0.661 | m3 world Eq deprived |

## 4.3 PATHWAY 2B: CCU-BASED EVA COPOLYMER (CUT-OFF APPROACH)

The environmental impacts of 1 kg CCU-based EVA copolymer production, at the production site for ON Running, following the Cut-off Approach, are listed in Table 5.

*Table 5. Life Cycle Impact Assessment (EF3.1) and compliant with ISO 14067, based on the IPCC 2021, for Pathway 2b (Cut-off Approach). FU: Production of 1 kg of unpacked EVA copolymer at the production site gate.*

| Environmental impact method | Environmental impact category | Indicator | Results | Unit |
|---|---|---|---|---|
| EF v3.1 | acidification | accumulated exceedance (AE) | 1.83E-02 | mol H+-Eq |
| EF v3.1 | climate change: total | global warming potential (GWP100) | 4.32 | kg $CO_2$eq |
| EF v3.1 | climate change: biogenic | global warming potential (GWP100) | 1.99E-03 | kg $CO_2$eq |
| EF v3.1 | climate change: fossil | global warming potential (GWP100) | 4.32 | kg $CO_2$eq |
| EF v3.1 | climate change: land use and land use change | global warming potential (GWP100) | 3.20E-03 | kg $CO_2$eq |
| EF v3.1 | ecotoxicity: freshwater | comparative toxic unit for ecosystems (CTUe) | 1.00E+04 | CTUe |
| EF v3.1 | ecotoxicity: freshwater, inorganics | comparative toxic unit for ecosystems (CTUe) | 27.2 | CTUe |

| | | | | |
|---|---|---|---|---|
| EF v3.1 | ecotoxicity: freshwater, organics | comparative toxic unit for ecosystems (CTUe) | 9.99E+03 | CTUe |
| EF v3.1 | eutrophication: freshwater | fraction of nutrients reaching freshwater end compartment (P) | 40.8 | kg P-Eq |
| EF v3.1 | resource use, fossils | abiotic depletion potential (ADP): fossil fuels | 1.05E-03 | MJ, net calorific value |
| EF v3.1 | eutrophication: marine | fraction of nutrients reaching marine end compartment (N) | 2.81E-03 | kg N-Eq |
| EF v3.1 | eutrophication: terrestrial | accumulated exceedance (AE) | 3.05E-02 | mol N-Eq |
| EF v3.1 | human toxicity: carcinogenic | comparative toxic unit for human (CTUh) | 5.00E-06 | CTUh |
| EF v3.1 | human toxicity: carcinogenic, inorganics | comparative toxic unit for human (CTUh) | 2.27E-08 | CTUh |
| EF v3.1 | human toxicity: carcinogenic, organics | comparative toxic unit for human (CTUh) | 4.98E-06 | CTUh |
| EF v3.1 | human toxicity: non-carcinogenic | comparative toxic unit for human (CTUh) | 1.41E-05 | CTUh |
| EF v3.1 | human toxicity: non-carcinogenic, inorganics | comparative toxic unit for human (CTUh) | 1.42E-06 | CTUh |
| EF v3.1 | human toxicity: non-carcinogenic, organics | comparative toxic unit for human (CTUh) | 1.26E-05 | CTUh |
| EF v3.1 | ionising radiation: human health | human exposure efficiency relative to u235 | 9.82 | kBq U235-Eq |
| EF v3.1 | land use | soil quality index | 12.5 | dimensionless |
| EF v3.1 | resource use, minerals and metals | abiotic depletion potential (ADP): elements (ultimate reserves) | 1.11E-04 | kg Sb-Eq |
| EF v3.1 | ozone depletion | ozone depletion potential (ODP) | 4.99E-06 | kg CFC-11-Eq |
| EF v3.1 | particulate matter formation | impact on human health | 1.39E-07 | disease incidence |
| EF v3.1 | photochemical oxidant formation: human health | tropospheric ozone concentration increase | 1.33E-02 | kg NMVOC-Eq |
| EF v3.1 | water use | user deprivation potential (deprivation-weighted water consumption) | 0.661 | m3 world Eq deprived |

# 5. COMPARATIVE ASSESSMENT

This chapter presents the comparative assessment of the fossil-based (Pathway 1) and CCU-based (Pathway 2a and 2b) production routes for EVA copolymer. This chapter presents the comparative analysis of climate change impacts on a cradle-to-gate basis, based on the modelling assumptions defined in Chapters 2 and 3.

The assessment compares carbon emissions for the climate change category, identifying differences between the modeled pathways. First, Section 5.1 provides an overview of total climate change results, differentiated into fossil, biogenic, and land-use and land-use change emissions. Section 5.2 analyzes the contribution of life cycle stages to the climate change impact to identify the main drivers of the comparative results.

## 5.1 OVERVIEW OF CLIMATE CHANGE RESULTS

This section presents the cradle-to-gate climate change impacts (GWP100, IPCC 100-year time horizon) per functional unit (1 kg of unpacked EVA copolymer at the production site gate) for all assessed pathways. Results are summarized in Table 6, and illustrated in Figure 3.

*Table 6. Climate change - global warming potential (GWP100) for all pathways. FU: Production of 1 kg of unpacked EVA copolymer at the production site gate.*

| Scenario | Carbon Source | Biogenic | Fossil | Land use and land use change | Total |
|---|---|---|---|---|---|
| **Pathway 1** | Fossil | 8.63E-04 | 3.12 | 1.08E-03 | 3.12 |
| **Pathway 2a** | Captured $CO_2$ | 1.99E-03 | 0.494 | 3.20E-03 | 0.4997 |
| **Pathway 2b** | Captured $CO_2$ | 1.99E-03 | 4.32 | 3.20E-03 | 4.32 |

Figure 3 illustrates the climate change results for the three pathways. The total impacts amount to 3.12 kg $CO_2$eq/kg EVA for Pathway 1, 0.4997 kg $CO_2$eq/kg EVA for Pathway 2a, and 4.32 kg $CO_2$eq/kg EVA for Pathway 2b. The results indicate that fossil-related emissions dominate the total impact in all cases. Contributions from biogenic carbon and land-use change are negligible across all pathways. The substantial difference between Pathway 2a and Pathway 2b reflects the methodological treatment of multifunctionality, specifically the application of credit approach and associated substitution in Pathway 2a.

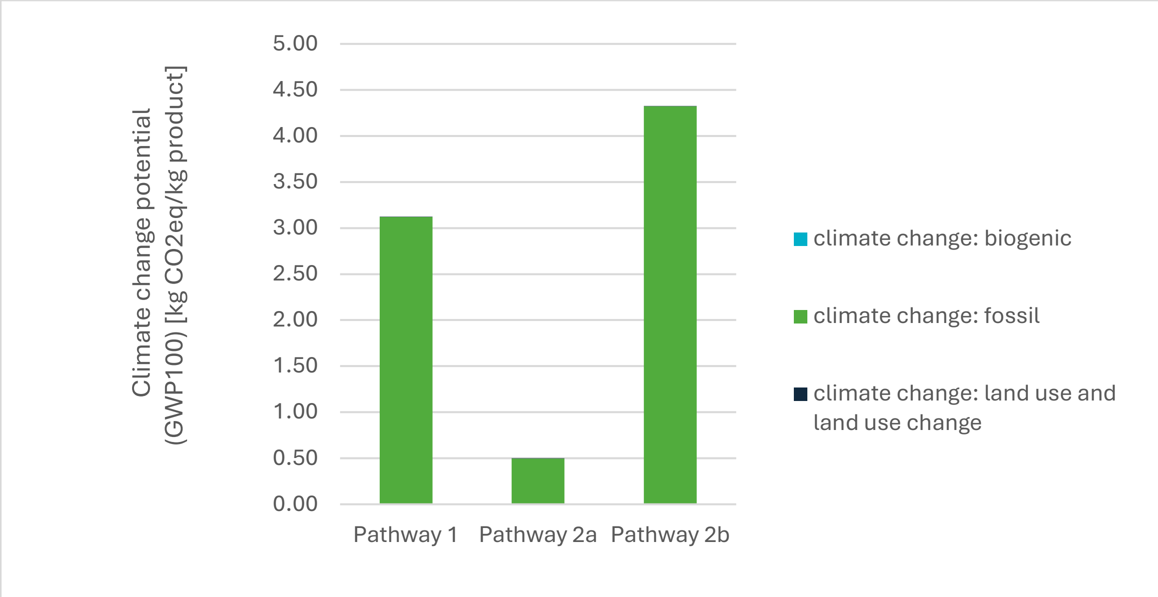


*Figure 3. Climate change - Global Warming Potential (GWP100) results for the modeled pathways.*

Across all pathways, fossil-related emissions constitute the dominant share of total GWP. Contributions from biogenic carbon and land-use change are negligible (<0.1%) and do not materially influence the comparative outcome. Under the assumptions defined in this cradle-to-gate comparative LCA, Pathway 2a achieves a reduction of approximately 84% climate change impact compared to Pathway 1, and Pathway 2b achieves an increase of approximately 38% climate change impact compared to Pathway 1. Results are sensitive to the electricity mix, green hydrogen carbon intensity, and allocation methodology.

For Pathway 1, the climate change impact of 3.12 kg $CO_2$eq. per kg of EVA copolymer is almost entirely attributable to fossil emissions, reflecting the upstream extraction and processing of fossil feedstocks.

In contrast, Pathway 2a exhibits a lower total climate change impact of 0.4997 kg $CO_2$eq. per kg of EVA copolymer. At the carbon-origin level, fossil feedstock emissions are nearly eliminated, and remaining impact is primarily driven by indirect emissions from electricity consumption, particularly associated with green hydrogen production and synfuel production.

For Pathway 2b, the total climate change impact of 4.32 kg $CO_2$eq. per kg of EVA copolymer. Although captured $CO_2$ replaces fossil naphtha at the feedstock stage, fossil-origin emissions remain dominant due to electricity-related emissions. In contrast to Pathway 2a, the absence of credit approach and associated substitution credits leads to a higher overall impact.

Across all pathways, contributions from biogenic carbon and land-use change remain negligible and do not influence comparative assessment.

## 5.2 COMPARISON OF PATHWAYS WITHIN THE PRODUCTION SYSTEM BOUNDARY

This section disaggregates the total climate change impact by comparing how the climate change impacts are generated across the production system for each pathway. The analysis breaks down contributions across process categories to identify where emissions originate and how they shift when fossil feedstocks are replaced. The applied categories represent aggregated process steps within the system boundary, enabling a consistent interpretation of emission drivers across pathways as follows:

- **Feedstock supply** reflects the upstream raw material production required for EVA production.
- **Energy supply** reflects the provision of electricity and thermal energy (including steam and other heat utilities) consumed across all process stages.
- **Direct emissions** correspond to process-level emissions within conversion steps, as well as emissions associated with on-site energy recovery and waste treatment processes attributed to the production system.
- **Transportation** reflects inter-process logistics between production stages, including freight transport of intermediates and raw materials between geographically distinct production stages.
- **Others** reflect auxiliary flows supporting these operations, such as process water, cooling water, inert gases, and other operational support flows.

The terminology used in this section refers to a disaggregation of contributions within the raw material production and processing system boundary, rather than across a full product life cycle.

Figure 4 illustrates the transition from fossil-carbon-driven emissions (Pathway 1) toward electricity-driven emissions (Pathway 2a and 2b), with the comparative outcome strongly influenced by the applied credit approach/cut-off approach and the carbon intensity of electricity. Feedstock supply dominates in Pathway 1, whereas energy supply constitutes the largest share in both Pathway 2 variants. In Pathway 2a, a negative contribution appears in the category of direct emissions due to applied credit approach.

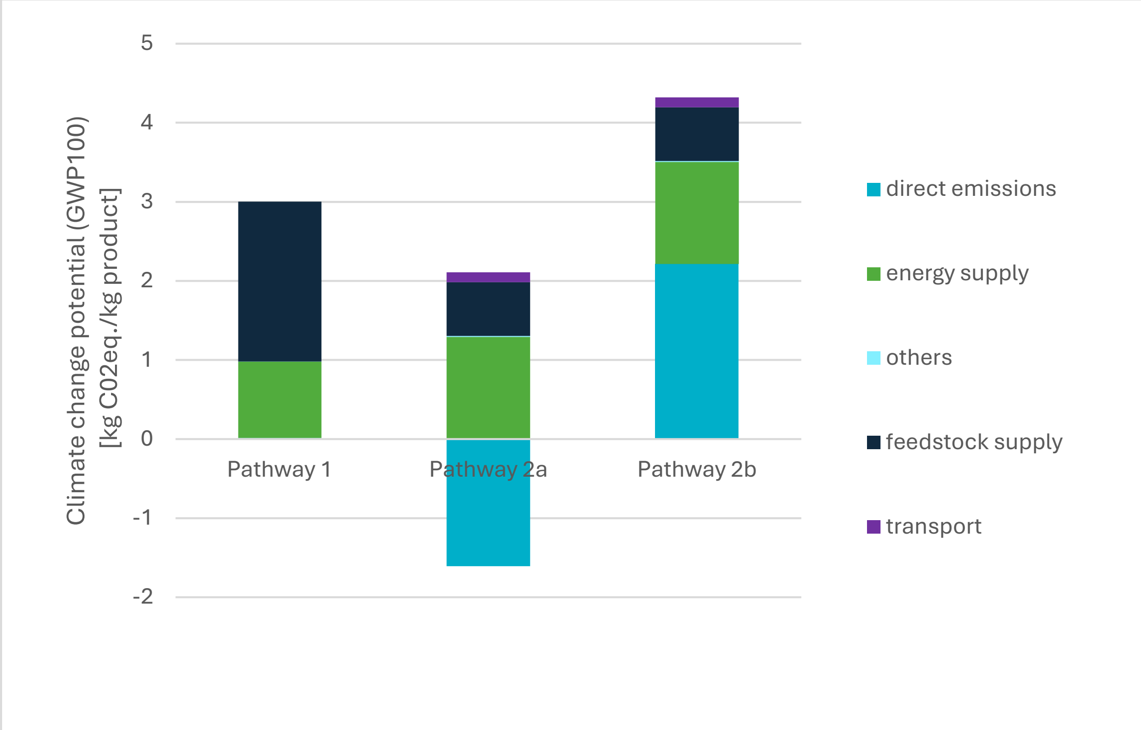


*Figure 4. Climate Change - Global Warming Potential (GWP100) Comparison Analysis for the Modeled Pathways.*

In Pathway 1 (3.12 kg $CO_2$eq./kg EVA copolymer), the largest contribution originates from feedstock supply *(72%)*, reflecting emissions embedded in fossil resource extraction, refining, and subsequent steam cracking. Energy supply contributes 26%, primarily driven by electricity consumption, while direct emissions account for 1% of the total impact. Transport and other utilities are negligible. Overall, the fossil pathway is structurally driven by primary fossil carbon inputs upstream of polymerization, indicating that the majority of emissions are embedded in upstream fossil resource supply chains rather than generated within the process-level operations of the production system.

In Pathway 2, the contribution profile shifts fundamentally. Feedstock-related emissions decrease relative to Pathway 1 due to the replacement of fossil naphtha with $CO_2$-derived intermediates. In parallel, energy supply becomes the dominant contributor, driven by the substantial electricity demand associated with green hydrogen production and synfuel synthesis. This emission profile reflects a structural shift from fossil carbon-embedded emissions in upstream feedstock provision to electricity-driven emissions across process operations.

Pathway 2a (0.4997 kg $CO_2$eq/kg EVA), the energy supply represents 61% of the total impact, indicating strong dependence on electricity-intensive green hydrogen and synfuel production. Feedstock-related emissions account for 32%; however, this positive contribution is offset by a -76% contribution from direct emissions, resulting from applied credit approach. Transport and other contributions remain negligible.

Pathway 2b (4.32 kg $CO_2$eq./kg EVA copolymer) exhibits the highest direct emissions contribution among the three pathways, accounting for 51% of the total impact. At the process level, the largest contributions originate from ethylene production (~ 26%) and synfuel production (~19%). Energy supply contributes 30%, primarily driven by electricity consumption, and feedstock supply contributes with 16%, mostly correlated with the use of vinyl acetate. Compared to Pathway 1, feedstock-related emissions are reduced; however, this reduction is partially offset by increased electricity demand and the absence credit approach. The overall comparative performance of the CCU pathway is therefore strongly contingent upon the carbon intensity of electricity used in green hydrogen and synfuel production, a parameter further examined in the sensitivity analysis (Section 6.2).

To complement the aggregated contribution analysis, Sankey diagrams are provided to visualize the distribution of climate change impacts across individual process steps and their linkage to the defined contribution categories.

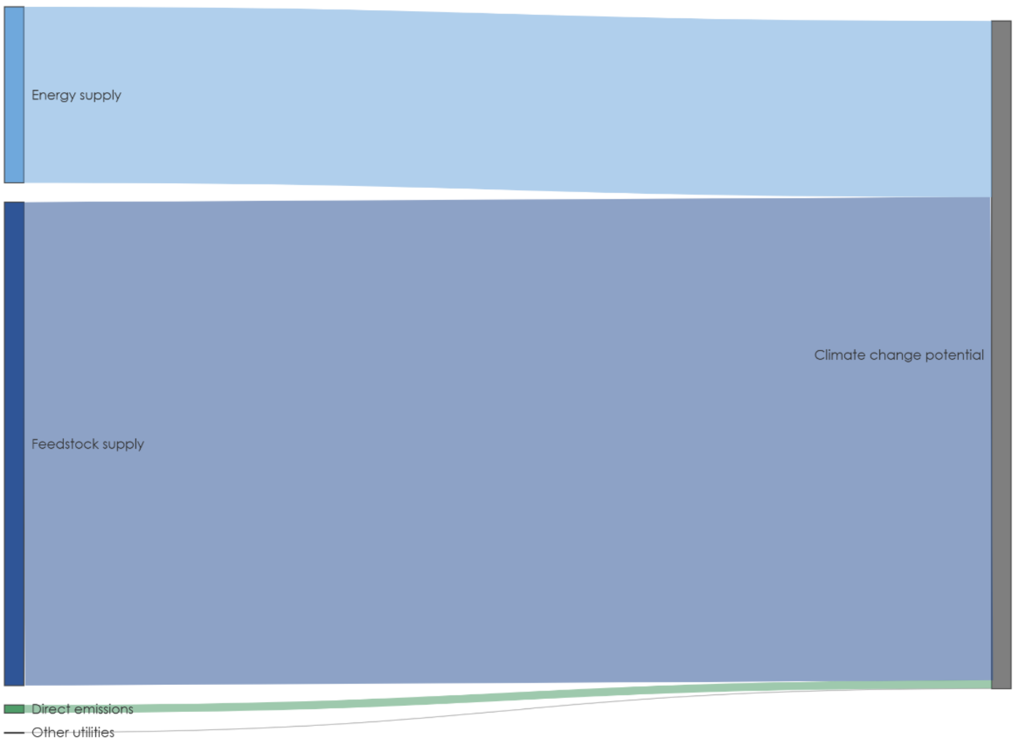


*Figure 5. Sankey diagram Pathway 1.*

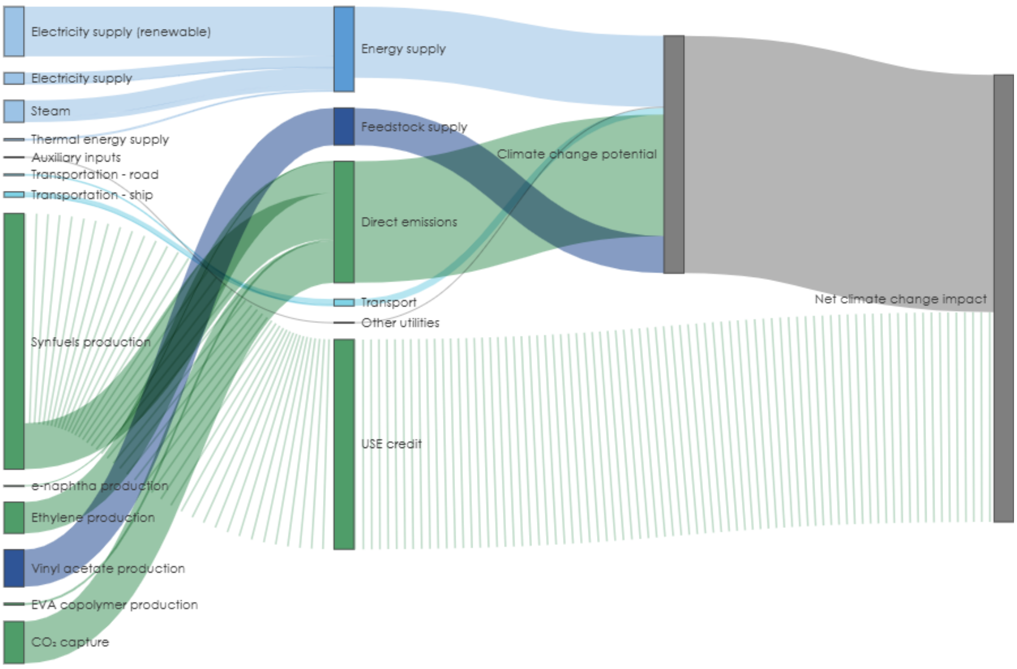


*Figure 6. Sankey diagram Pathway 2a.*

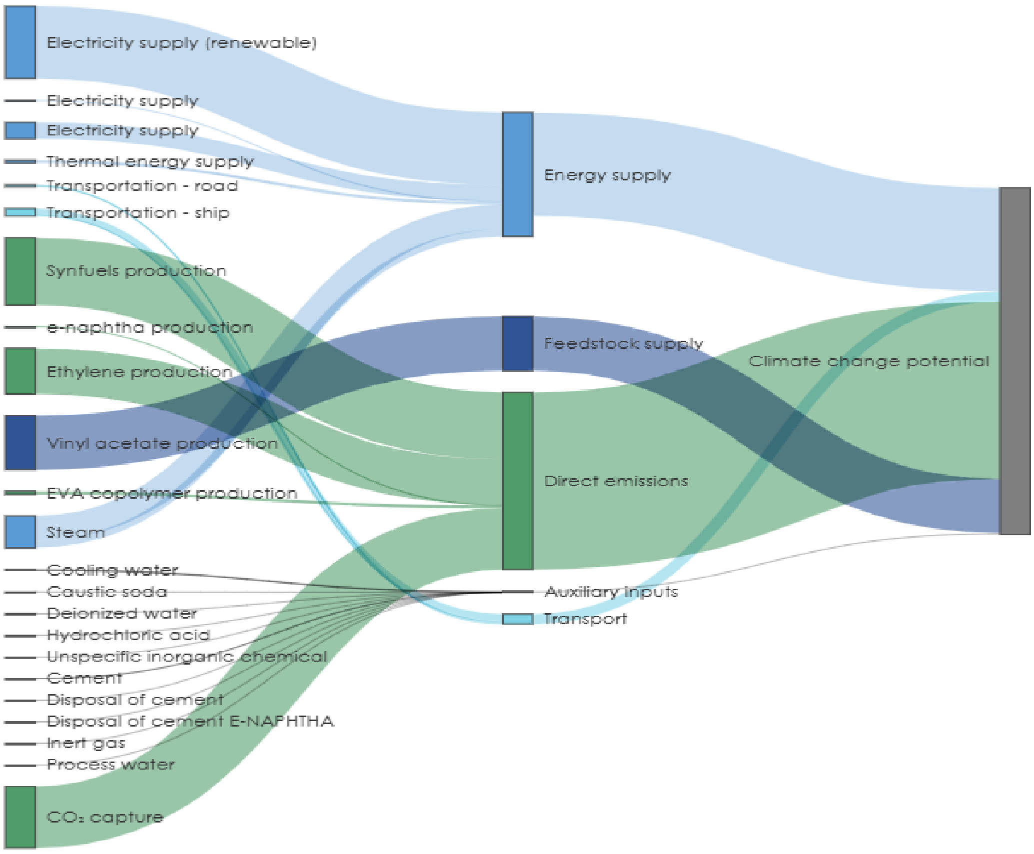


*Figure 7. Sankey diagram Pathway 2b.*

# 6. INTERPRETATION

The interpretation phase in a life cycle assessment includes a thorough analysis of the results to ensure their reliability and relevance. This chapter covers completeness checks to verify data consistency, contribution analysis to identify key drivers of environmental impacts, sensitivity analysis to assess the robustness of findings, and a compliance review to ensure alignment with relevant standards.

The interpretation phase also addresses the limitations of the study, highlighting uncertainties and constraints that may affect the results. Additionally, it provides an outlook, suggesting areas for future assessments, data improvements, and potential refinements to enhance the robustness and applicability of the findings.

Section 6.1 describes the contribution analysis for processes to the overall environmental impacts. Section 6.2 provides sensitivity analysis for methodological approaches.

## 6.1 CONTRIBUTION ANALYSIS

The contribution analysis evaluates the environmental performance of the assessed pathways across the selected impact categories to identify dominant drivers, structural differences, and potential burden-shifting effects. In accordance with ISO 14044, the objective of this analysis is not only to determine which processes contribute most to each impact category, but also to assess whether improvements in one environmental dimension are accompanied by trade-offs in others.

This section first presents the results for the complete set of EF v3.1 impact categories. Subsequently, a detailed evaluation is provided for the key decision-relevant impact categories summarized in Table 7.

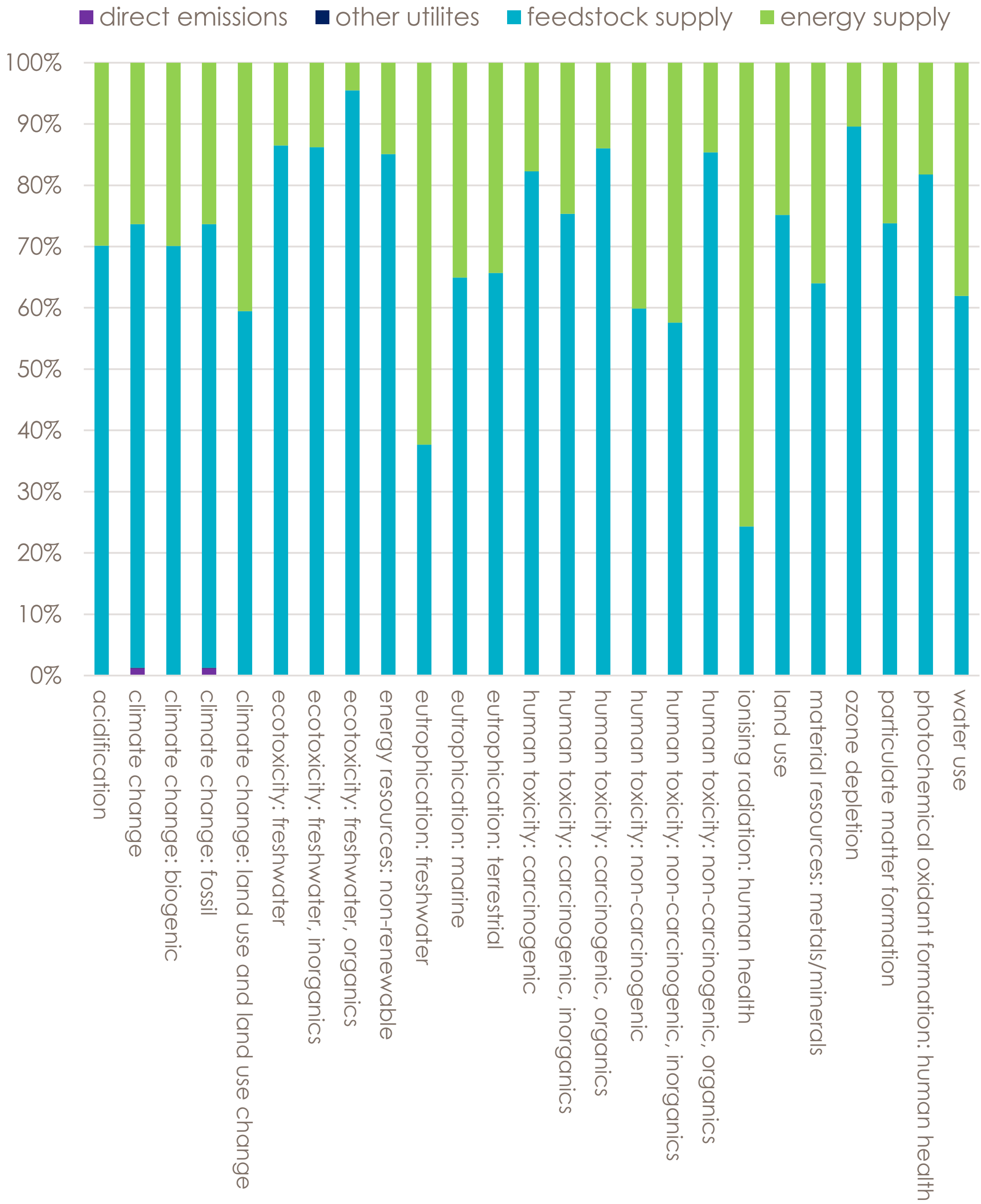


*Figure 8. Contribution Analysis following the EF3.1 methodology and compliant with ISO 14067, based on the IPCC 2021, for Pathway 1 (Fossil-based).*

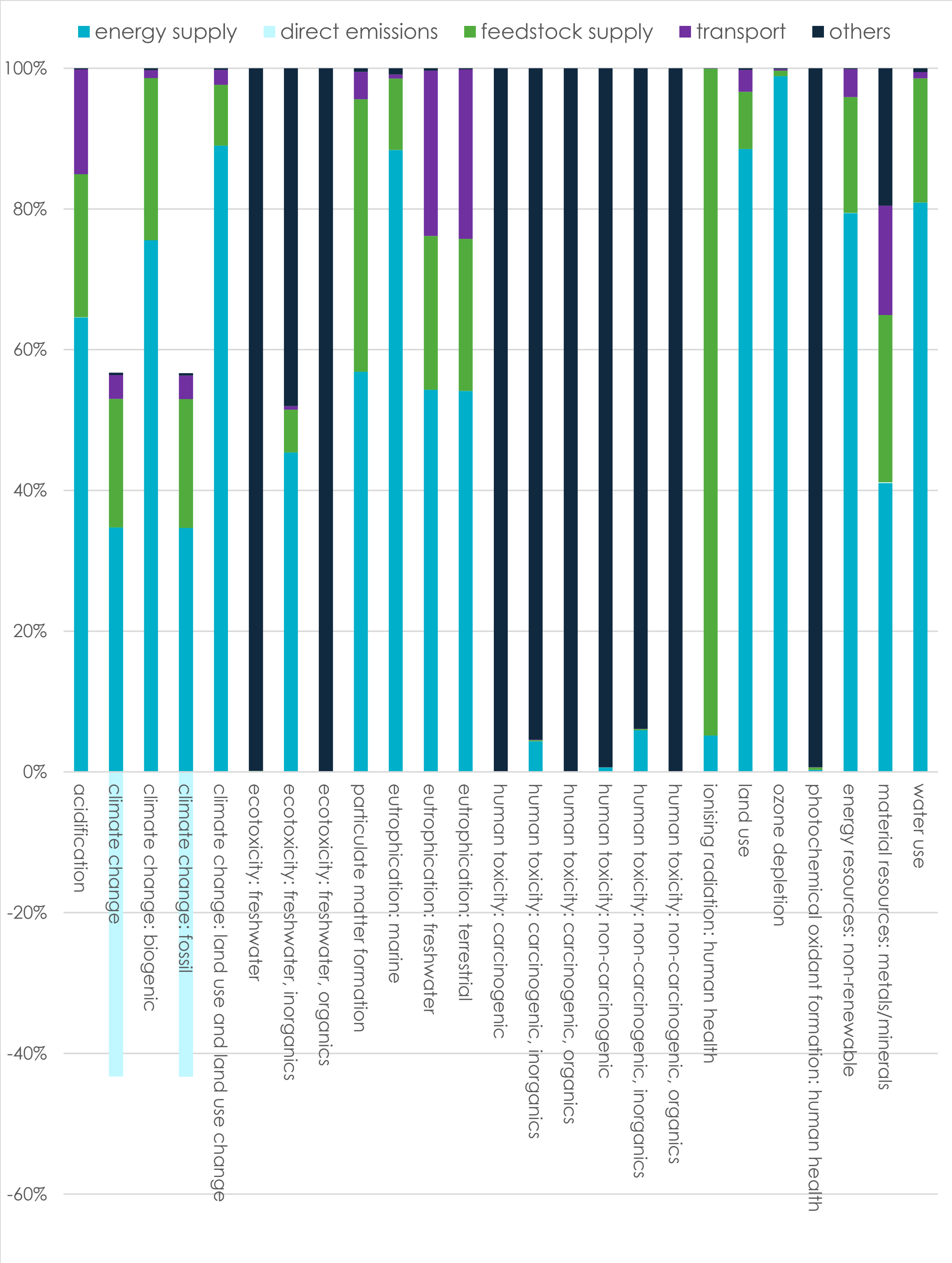


*Figure 9. Contribution Analysis following the EF3.1 methodology and compliant with ISO 14067, based on the IPCC 2021, for Pathway 2a Credit Approach).*

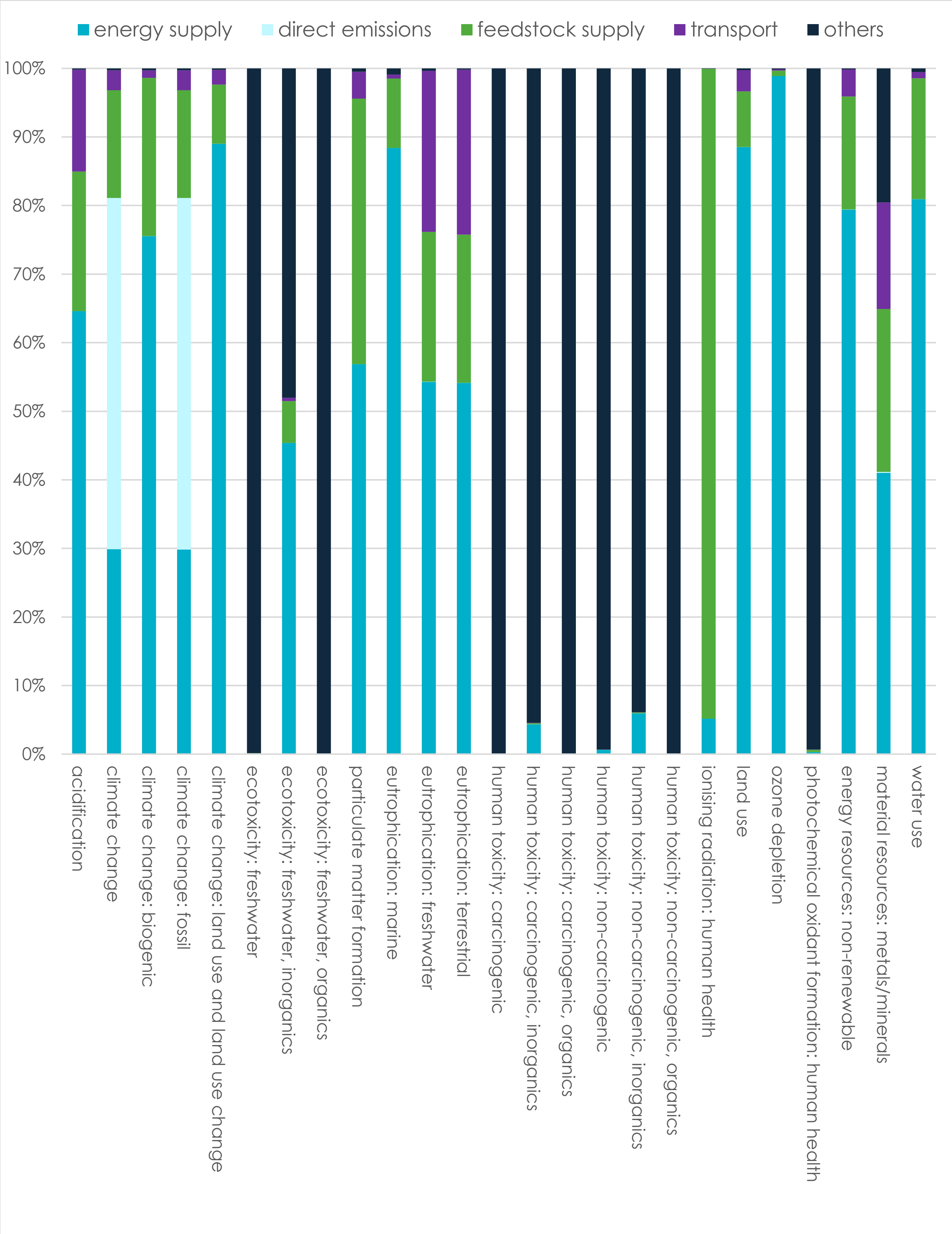


*Figure 10. Contribution Analysis following the EF3.1 methodology and compliant with ISO 14067, based on the IPCC 2021, for Pathway 2b (Cut-off approach).*

For this assessment, five environmental impacts were analyzed in detail due to their relevance for chemical production systems and energy-intensive processes using the Environmental Footprint method (EF v3.1)[31], as per Table 7. These categories were selected due to their relevance for chemical production systems and energy-intensive processes and allow for a joint evaluation of climate performance, fossil resource dependency, mineral resource depletion, and potential burden shifting toward water and land-related impacts.

*Table 7. Comparative contribution analysis for impact categories of interest.*

| Environmental impact method | Environmental impact category | Indicator | Pathway 1 | Pathway 2a | Pathway 2b | Unit |
|---|---|---|---|---|---|---|
| EF v3.1 | climate change | global warming potential (GWP100) | 3.12 | 0.4997 | 4.32 | kg $CO_2$eq |
| EF v3.1 | energy resources: non-renewable | abiotic depletion potential (ADP): fossil fuels | 76.07 | 40.78 | 40.78 | MJ, net calorific value |
| EF v3.1 | material resources: metals/minerals | abiotic depletion potential (ADP): elements (ultimate reserves) | 2.37E-06 | 1.11E-04 | 1.11E-04 | kg Sb-Eq |
| EF v3.1 | water use | user deprivation potential (deprivation-weighted water consumption) | 0.31 | 0.66 | 0.66 | $m^3$ world Eq deprived |
| EF v3.1 | land use | soil quality index | 6.14 | 12.47 | 12.47 | dimensionless |

### Climate change (Global Warming Potential, GWP100):

This category quantifies radiative forcing effects of greenhouse gas emissions over a 100-year time horizon, expressed in kg $CO_2$eq. It captures contributions from fossil, biogenic, and land-use-related carbon emissions. As shown previously, Pathway 2a achieves the lowest climate change impact (0.4997 kg $CO_2$eq./kg EVA copolymer), followed by Pathway 1 (3.12 kg $CO_2$eq./kg EVA copolymer), while Pathway 2b exhibits the highest value (4.32 kg $CO_2$eq./kg EVA copolymer).

### Energy resources: non-renewable (Abiotic Depletion Potential – fossil fuels):

This indicator quantifies the depletion of non-renewable fossil energy resources, expressed in MJ net calorific value. It reflects cumulative fossil energy demand embedded in the life

[31] Environmental Footprint (EF) version 3.1. Available at: European Platform on LCA | EPLCA

cycle. A substantial reduction in fossil energy demand is observed for both CCU pathways. Pathway 1 requires 76.07 MJ per kg EVA copolymer, while both Pathway 2a and 2b require 40.78 MJ per kg EVA copolymer, corresponding to a substantial reduction. The CCU-based pathway reduces dependence on primary fossil resources at the system level. The values for Pathway 2a and 2b are identical in this category; this indicates that the different methodological approach does not influence this impact category.

**Material resources: metals/minerals (Abiotic Depletion Potential – elements, ultimate reserves):**

This category evaluates the depletion of mineral and metal resources based on ultimate reserve estimates, expressed in kg Sb-equivalents. It indicates long-term pressure on non-energy abiotic resource stocks. Although absolute values are low, differences between pathways are observable. Pathway 1 results in 2.37E-06 kg Sb-eq per kg EVA copolymer, primarily driven by hydrocarbon extraction and refining, which are more intensive in fossil resource use than in metal inputs.

While both Pathway 2a and Pathway 2b result in 1.11E-04 kg Sb-eq per kg EVA copolymer. The higher values observed the contribution of metal-intensive upstream processes. While the CCU-based routes (Pathway 2a and Pathway 2b) reduce reliance on fossil resource extraction, they introduce a dependence on infrastructure and energy conversion systems, particularly associated with green hydrogen production, synfuel synthesis, and $CO_2$ conversion. These contributions arise from the cumulative demand for metals embedded in background processes, including catalyst use such as palladium in vinyl acetate production, as well as metals associated with energy and process infrastructure.

**Water use (User Deprivation Potential):**

This category assesses water consumption considering regional water scarcity, expressed in $m^3$ world-equivalent deprived. It accounts for both the quantity of water consumed and its relative scarcity in the region of extraction. Pathway 1 results in 0.31 $m^3$ world-eq deprived, while both Pathway 2a and 2b result in 0.66 $m^3$ world-eq deprived. This increase is attributable to the high-water demand associated with electricity generation and green hydrogen production processes. The values for Pathway 2a and 2b are identical in this category; this indicates that the different methodological approach does not influence this impact category.

**Land use (Soil Quality Index):**

This category quantifies impacts on soil quality due to land occupation and transformation. It reflects potential degradation of ecosystem services associated with land use over time. Pathway 1 results in a soil quality index of 6.14, while both CCU pathways reach 12.47, corresponding to nearly a fourfold increase. This increase reflects the upstream land occupation associated with electricity generation infrastructure and related supply chains. The values for Pathway 2a and 2b are identical in this category; this indicates that the different methodological approach does not influence this impact category.

## 6.2 SENSITIVITY ANALYSIS

Sensitivity analysis was performed to evaluate the robustness of the CCU-based pathways (Pathway 2a and Pathway 2b) with respect to variations in electricity supply and $CO_2$ capture heat assumptions. As identified in the contribution analysis (Section 6.1), electricity demand associated with $CO_2$ capture and green hydrogen production via electrolysis constitutes the dominant hotspot of the CCU system. Consequently, the carbon intensity and resource profile of electricity are expected to significantly influence the environmental performance of these pathways. Two electricity supply scenarios were assessed: A fully renewable electricity consumption mix and a regional grid mix representing the Texas region. In addition, a conventional MEA-based $CO_2$ capture[32] was evaluated to include thermal energy requirements for solvent regeneration based on literature values for MEA systems.

The fossil-based pathway (Pathway 1) was not subjected to sensitivity analysis, as it does not rely structurally on electricity-driven green hydrogen production and represents an established industrial configuration with comparatively lower variability related to electricity sourcing.

**Electricity carbon intensity:**

Under the wind electricity scenario, climate change impacts amount to 0.4997 kg $CO_2$eq/kg EVA copolymer for Pathway 2a (Credit Approach) and 4.32 kg $CO_2$eq/kg EVA copolymer for Pathway 2b (Cut-off Approach). When the US-TRE grid electricity dataset is applied, the impacts increase to 17.78 kg $CO_2$eq/kg EVA (Pathway 2a) and 21.60 kg $CO_2$eq/kg EVA (Pathway 2b).

This means that the result for Pathway 2a is now around 35.6 times higher than before, while the result for Pathway 2b is now around 5 times higher. The magnitude of change demonstrates that the climate performance of the CCU-based EVA system is highly sensitive to the carbon intensity of electricity. The result is directly attributable to the fossil energy embedded in the regional electricity mix.

**$CO_2$ capture heat demand:**

Under the current $CO_2$ capture-process configuration, a MEA-based capture scenario including the solvent regeneration heat demand of 3.7 MJ/kg $CO_2$ captured[33], the impacts increase to 1.11 kg $CO_2$eq/kg EVA copolymer for Pathway 2a and 4.93 kg $CO_2$eq/kg EVA copolomer for Pathway 2b. Relative to the default capture-process configuration, this represents an increase by 0.66 kg $CO_2$eq/kg EVA copolymer for Pathway 2a and 0.61 kg $CO_2$eq/kg EVA for Pathway 2b.

[32] Comparative evaluation of amine-based solvents for post-combustion $CO_2$ capture: Energy consumption, regeneration performance, and process optimization. Results in Engineering, 20, 101404. Available at: https://doi.org/10.1016/j.rineng.2023.101404

[33] Comparative evaluation of amine-based solvents for post-combustion $CO_2$ capture: Energy consumption, regeneration performance, and process optimization. Results in Engineering, 20, 101404. Available at: https://doi.org/10.1016/j.rineng.2023.101404

**Energy resources: non-renewable (Abiotic Depletion Potential – fossil fuels):**
Fossil resource depletion increases from 40.78 MJ/kg EVA under wind electricity to 317.92 MJ/kg EVA under the US grid scenario. This represents an increase by a factor greater than seven.

**Water use (User Deprivation Potential):**
Water use increase from 0.66 $m^3$ world-eq deprived under wind electricity to 2.46 $m^3$ world-eq deprived under the US grid scenario. This is relative to the operational water consumption difference from wind electricity and US-TRE grid which includes large contributions from thermoelectric generation technologies that require cooling water.

**Land use (Soil Quality Index):**
Land use impacts increase slightly from 12.5 (soil quality index) under wind electricity to 16.1 under the US grid scenario. This increase reflects the land occupation associated with wind electricity infrastructure compared to the regional grid mix. This impact is primarily attributable to the upstream infrastructure and resource extraction activities associated with the US grid electricity mix, including fossil fuel extraction, fuel processing, and thermoelectric power generation systems.

## 6.3 COMPLETENESS CHECK

The completeness check ensures that all relevant data and processes within the defined system boundaries have been included, in accordance with ISO 14040[34], ISO 14044[35]. This includes verifying that the required 95% coverage of mass and energy flows has been met, with no significant omissions that could compromise the results. All data sets used have been cross-checked for consistency and appropriateness to maintain compliance with these frameworks, ensuring the study's reliability and robustness.

[34] DIN EN ISO 14040, 2021. Environmental management - Life cycle assessment – Principles and framework (ISO 14040:2006 + Amd 1:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179655.
[35] DIN EN ISO 14044, 2021. Environmental management - Life cycle assessment – Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179656

# 7. SUMMARY

This study presents a comparative cradle-to-gate Life Cycle Assessment (LCA) of ethylene-vinyl acetate (EVA) copolymer production, evaluating two alternative production routes: a conventional fossil-based pathway and a Carbon Capture and Utilization (CCU)-based pathway. The assessment compares three modeled scenarios:

- **Pathway 1:** Conventional fossil-based production route
- **Pathway 2:** Carbon Capture and Utilization (CCU)-based production route
  - **Pathway 2a:** *Credit Approach*
  - **Pathway 2b:** *Cut-Off Approach*

The functional unit is defined as:

**Production of 1 kg of unpacked EVA copolymer at the production site gate.**

All pathways are modeled under harmonized methodological assumptions to ensure comparability in accordance with ISO 14040 and ISO 14044. Environmental impacts were quantified using the EF 3.1 method. For the climate change category, total results amount to **3.12 kg $CO_2$eq per kg EVA for Pathway 1**, **0.4997 kg $CO_2$eq per kg EVA for Pathway 2a**, and **4.35 kg $CO_2$eq per kg EVA for Pathway 2b**. Across all pathways, fossil-related emissions are the dominant contributor, while biogenic and land-use-related contributions are minor and do not affect the comparative conclusion for the climate change category.

The study relies on secondary data. For Pathway 1, the fossil-based EVA route is represented by an aggregated cradle-to-gate dataset from the cm.chemicals database. For Pathway 2, the modelling combines Carbon Minds datasets, Ecoinvent datasets, and S&P Global for mass and energy balances, and peer-reviewed literature, where required. The report states explicitly that no primary or site-specific operational data were used, and that results therefore represent technology-based estimates rather than plant-specific performance. Background modelling further includes country-specific or regionally representative datasets for electricity, steam, thermal energy, raw materials, transport, and waste treatment. Data quality was assessed using the pedigree matrix; this approach assesses technological, temporal, and geographical representativeness, reliability, and completeness, each scored from 1 to 5. The pedigree matrix was used at the dataset level as a descriptive data quality characterization, rather than as a basis for quantitative uncertainty propagation.

Allocation procedures follow the hierarchy outlined by ISO 14044 and are stated in the report to be aligned with TfS guidance where relevant. For Pathway 1, no additional allocation procedures were applied within the study because allocation rules are already embedded in the aggregated cm.chemicals datasets. For Pathway 2, multifunctionality is resolved at the process level. Cut-off criteria were defined to exclude only negligible flows. Material or energy flows contributing less than 1% of total input may be excluded, provided the sum of excluded flows remains below 3% of total mass or energy input.

The model was implemented in a structured spreadsheet-based framework. The report states that inventory compilation and impact assessment calculations were carried out explicitly in Excel using a matrix-based process LCA formulation, including the technology matrix, elementary flow matrix, scaling vector, and characterization matrix.

## Key findings

**Identification of dominant contributors:**

- Relative climate change performance differences between fossil and CCU routes:
  - **Fossil-origin emissions dominate in all pathways**, even in the CCU scenarios, due to the fossil intensity of electricity supply.
  - **Biogenic and land-use-related contributions are negligible** and do not materially influence comparative conclusions.
- The major difference between Pathway 2a and Pathway 2b is not the carbon origin at the molecular level, but methodological approach.
- The CCU pathway reduces direct fossil feedstock extraction, but total fossil-origin emissions remain strongly dependent on the electricity system.

**Sensitivity to electricity supply:**

- Sensitivity analysis demonstrates that **the carbon intensity of the electricity source is the dominant parameter influencing CCU performance.**
- Under renewable electricity assumptions, climate change impacts remain substantially lower than the fossil reference. However, when regional grid electricity (US-TRE) is applied, climate change impacts increase significantly, exceeding those of the fossil pathway.
- Similarly, fossil resource depletion increases substantially under grid electricity, while water use and land occupation decrease relative to the renewable scenario.

# Appendix A Data Sources

*Table 8. Overview of the datasets used in the background system of the present life cycle assessments. The table lists the process name and the abbreviation of the process name used in the LCI modelling, Ecoinvent dataset.*

| Chemical / Process name | Process name in the database | Region | Source | Time Period | Reference year |
|---|---|---|---|---|---|
| electricity, medium voltage | market for electricity, medium voltage | US-TRE | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| electricity, medium voltage | market for electricity, medium voltage | Finland (FI) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| electricity, medium voltage | market for electricity, medium voltage | Belgium (BE) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| electricity, high voltage, wind energy | electricity, high voltage, wind energy | US | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| steam, in chemical industry | steam production, in chemical industry | Rest of the World (RoW) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| steam, in chemical industry | steam production, in chemical industry | Rest of Europe (RER) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| heat, district or industrial, natural gas | market group for heat, district or industrial, natural gas | Rest of Europe (RER) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| heat, district or industrial, natural gas | market group for heat, district or industrial, natural gas | Rest of the World (RoW) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| carbon dioxide, in chemical industry | market for carbon dioxide, in chemical industry | Global (GLO) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| water, deionised | water production, deionised | Rest of the World (RoW) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| water, decarbonised | market for water, decarbonised | Rest of the World (RoW) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| nitrogen, liquid | market for nitrogen, liquid | Rest of Europe (RER) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| oxygen, liquid | market for oxygen, liquid | Rest of Europe (RER) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| oxygen, liquid | market for oxygen, liquid | Rest of the World (RoW) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |

| | | | | | |
|---|---|---|---|---|---|
| metal catalyst for catalytic converter | palladium to the generic market for metal catalyst for catalytic converter | Global (GLO) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| hydrochloric acid, without water, in 30% solution state | market for hydrochloric acid, without water, in 30% solution state | Rest of the World (RoW) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| chemical, inorganic | market for chemical, inorganic | Global (GLO) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| cement, unspecified | cement, all types to generic market for cement, unspecified | US | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| cement, unspecified | cement, all types to generic market for cement, unspecified | Europe without Switzerland | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| waste cement in concrete and mortar | treatment of waste cement in concrete and mortar, collection for final disposal | Rest of the World (RoW) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| transport, freight, sea, tanker for liquid goods other than petroleum and liquefied natural gas, heavy fuel oil | market for transport, freight, sea, tanker for liquid goods other than petroleum and liquefied natural gas, HFO | Global (GLO) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |
| transport, freight, lorry, diesel, unspecified | market for transport, freight, lorry, unspecified | Rest of Europe (RER) | Ecoinvent V3.11 | 2021 – 2023 | 2024 |

*Table 9. Overview of the datasets used in the background system of the present both life cycle assessments. The table lists the process name and the abbreviation of the process name used in the LCI modelling. Carbon Minds dataset.*

| Chemical / Process name | Process name in the database | Region | Source | Reference period | Reference year |
|---|---|---|---|---|---|
| cooling water | production mix for cooling water | US | cm.chemicals methodology document V2.01 2024 | 2022-2026 | 2024 |
| cooling water | production mix for cooling water | BE | cm.chemicals methodology document V2.01 2024 | 2022-2026 | 2024 |

| | | | | | |
|---|---|---|---|---|---|
| cooling water | production mix for cooling water | FI | cm.chemicals methodology document V2.01 2024 | 2022-2026 | 2024 |
| caustic soda (50%) | consumption mix for caustic soda (50%) | US | cm.chemicals methodology document V2.01 2024 | 2022-2026 | 2024 |
| acetic acid | consumption mix for acetic acid (Belgium) | BE | cm.chemicals methodology document V2.01 2024 | 2022-2026 | 2024 |
| **vinyl acetate** | consumption mix for vinyl acetate (EU-27 Member States) | EU-27 | cm.chemicals methodology document V2.01 2024 | 2022-2026 | 2024 |

# Appendix B Data Quality

All datasets in this study were evaluated for data quality using the pedigree matrix from the ecoinvent framework[36]. This method assesses data quality across five indicators: technological, temporal, and geographical representativeness, reliability, and completeness, with scores ranging from 1 (best) to 5 (worst). These scores ensure that the datasets align with the study's goals and scope, maintaining consistency with ISO 14040[37] and 14044[38] standards.

*Table 10. Pedigree matrix, for data quality assessment according to ecoinvent.*

| Indicator | 1 (best) | 2 | 3 | 4 | 5 (worst) |
|---|---|---|---|---|---|
| **Reliability** | Verified data based on measurements | Verified data partly based on assumptions or non-verified data based on measurements | Non-verified data partly based on qualified estimates | Qualified estimate (e.g., by industrial expert) | Non-qualified estimate |
| **Completeness** | Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations | Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations | Representative data from only some sites (<50%) relevant for the market considered or >50% of sites but from shorter periods | Representative data from only one site relevant for the market considered or some sites but from shorter periods | Representativeness unknown or data from a small number of sites and from shorter periods |
| **Temporal correlation** | Less than 3 years of difference to the time period of the dataset | Less than 6 years of difference to the time period of the dataset | Less than 10 years of difference to the time period of the dataset | Less than 15 years of difference to the time period of the dataset | Age of data unknown or more than 15 years of difference to the time period of the dataset |
| **Geographical correlation** | Data from area under study | Average data from larger area in which the area under study is included | Data from area with similar production conditions | Data from area with slightly similar production conditions | Data from unknown or distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia) |

[36] Weidema B P, Bauer C, Hischier R, Mutel C, Nemecek T, Reinhard J, Vadenbo C O, Wernet G, "Overview and Methodology of Ecoinvent".
[37] DIN EN ISO 14040, 2021. Environmental management - Life cycle assessment – Principles and framework (ISO 14040:2006 + Amd 1:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179655.
[38] DIN EN ISO 14044, 2021. Environmental management - Life cycle assessment – Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179656

| | | | | | |
|---|---|---|---|---|---|
| **Further technological correlation** | Data from enterprises, processes and materials under study | Data from processes and materials under study (i.e., identical technology) but from different enterprises | Data on related processes or materials | Data on related processes on laboratory scale or from different technology | Data on related processes on laboratory scale or from different technology |

Based on the pedigree matrix the data used in this study was assessed using a simplified aggregation of the indicators. Given that this study does not include quantitative uncertainty propagation or Monte Carlo simulation, the pedigree matrix was applied at the dataset level as a descriptive quality characterization rather than at the individual parameter level. This evaluation was conducted to characterize dominant data quality attributes. In line with ISO 14044[39]

*Table 11. Data quality assessment in accordance to Pedigree matrix.*

| Process name | Data type | Region | Technological correlation | Temporal correlation | Geographical correlation | Completeness | Reliability |
|---|---|---|---|---|---|---|---|
| **Wind electricity** | Secondary data | US | 2 | 2 | 1 | 3 | 2 |
| **electricity** | Secondary data | Finland | 1 | 1 | 1 | 2 | 2 |
| **electricity** | Secondary data | Belgium | 1 | 1 | 1 | 2 | 2 |
| **electricity** | Secondary data | US-TRE | 1 | 1 | 1 | 2 | 1 |
| **steam** | Secondary data | RoW | 1 | 1 | 1 | 2 | 2 |
| **steam** | Secondary data | RER | 1 | 1 | 1 | 2 | 2 |
| **thermal energy** | Secondary data | GLO | 1 | 1 | 1 | 2 | 2 |
| **thermal energy** | Secondary data | RER | 1 | 1 | 1 | 2 | 2 |

[39] DIN EN ISO 14044, 2021. Environmental management - Life cycle assessment – Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). *Section 4.2.3.6*. German Version. Beuth. Available online at https://dx.doi.org/10.31030/3179656

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **cooling water** | Secondary data | US | 1 | 1 | 1 | 2 | 2 |
| **cooling water** | Secondary data | Finland | 1 | 1 | 1 | 2 | 2 |
| **cooling water** | Secondary data | Belgium | 1 | 1 | 1 | 2 | 2 |
| **caustic soda** | Secondary data | US | 1 | 1 | 1 | 2 | 2 |
| **deionized water** | Secondary data | RoW | 1 | 1 | 3 | 2 | 2 |
| **oxygen** | Secondary data | RoW | 1 | 1 | 3 | 2 | 2 |
| **hydrochloric acid** | Secondary data | RoW | 1 | 1 | 3 | 2 | 2 |
| **unspecific inorganic chemical** | Secondary data | GLO | 1 | 1 | 3 | 2 | 2 |
| **cement** | Secondary data | US | 1 | 1 | 1 | 2 | 2 |
| **cement** | Secondary data | (Europe without Switzerland) | 1 | 1 | 2 | 2 | 2 |
| **disposal of cement** | Secondary data | RoW | 1 | 1 | 3 | 2 | 2 |
| **inert gas** | Secondary data | RER | 1 | 1 | 2 | 2 | 2 |
| **process water** | Secondary data | RoW | 1 | 1 | 3 | 2 | 2 |
| **acetic acid production** | Secondary data | Belgium | 1 | 1 | 1 | 2 | 2 |
| **oxygen** | Secondary data | RER | 1 | 1 | 2 | 2 | 2 |
| **catalyst palladium** | Secondary data | GLO | 1 | 1 | 3 | 2 | 2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Transportation - road** | Secondary data | US | 1 | 1 | 3 | 2 | 2 |
| **Transportation - ship** | Secondary data | Finland | 1 | 1 | 3 | 2 | 2 |
| **Transportation - road** | Secondary data | Finland | 1 | 1 | 3 | 2 | 2 |
| **Transportation - ship** | Secondary data | Belgium | 1 | 1 | 3 | 2 | 2 |
| **$CO_2$ capture process** | Secondary data | US | 1 | 1 | 1 | 3 | 3 |
| **synfuels production from captured $CO_2$ and $H_2$** | Secondary data | US | 3 | 1 | 1 | 3 | 2 |
| **e-naphtha production** | Secondary data | US | 1 | 1 | 1 | 2 | 2 |
| **ethylene production** | Secondary data | Finland | 1 | 1 | 1 | 1 | 1 |
| **vinyl acetate production** | Secondary data | Europe | 1 | 1 | 1 | 1 | 1 |
| **EVA copolymer production** | Secondary data | Belgium | 1 | 1 | 1 | 1 | 1 |