

Life Cycle Assessment for Polyester

Virgin and recycled
production systems

**Title: Life Cycle Assessment for Polyester
(Virgin and recycled production systems)**

On behalf of SCS Consulting Services

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Textile Exchange is a global non-profit driving beneficial impacts on climate and nature across the fashion, textile, and apparel industry. We guide a growing community of brands, manufacturers, and farmers towards more purposeful production from the very start of the supply chain.

At the heart of our organizational strategy, Climate+, is the goal to help the industry reduce greenhouse gas emissions from fiber and raw material production by 45% by 2030, aligned with the 1.5°C pathway of the Paris Agreement. But our approach goes further, maintaining a holistic and interconnected perspective that aims to improve freshwater, soil health, and biodiversity.

Given Textile Exchange's role and reach in the industry, we believe that we are well-positioned to facilitate the development of Life Cycle Assessment (LCA) studies in a robust and impartial manner, helping to address key data gaps related to the environmental impacts of raw materials and fibers. By engaging stakeholders across and beyond our membership base, we can ensure that different supply chain actors are involved and considered within the LCA development process. Additionally, our LCA+ approach complements LCA results with qualitative insights on biodiversity, soil health, water use, animal welfare, and livelihoods, providing a more complete understanding of material impacts.

In 2022, Textile Exchange launched a series of LCA studies to support the industry in filling key LCA data gaps. Priority studies were identified based on the following criteria: total volume of a fiber or material used by the industry; current availability of impact data; and quality of available impact data.

As a result, seven priority LCA studies were identified: Cotton, Polyester, Leather (hide production), Responsible Wool Standard (RWS) Wool, Responsible Mohair Standard (RMS) Mohair, Nylon, and Cashmere. Each of these studies focuses on the pre-spin stage, or equivalent, impacts of the fiber or material.

For more information on Textile Exchange's position on LCA, please refer to our *Ensuring Integrity in the Use of Life Cycle Assessment Data* paper.

To ensure the LCA studies facilitated by Textile Exchange are robust and credible, we engage with multiple stakeholder groups throughout the study development process:

- **Data collection partners:**

For example, organizations, schemes, and programs that support the collection and delivery of primary and secondary data.

- **Project sponsors forming a Project Advisory Group:**

Brands and suppliers that financially support the improvement of LCA data and provide an industry perspective on the LCA needs for a given fiber or material.

- **Material and technical experts forming a Technical Advisory Group:**

Subject matter experts reviewing initial project outputs ahead of the formal critical review process—helping ensure a robust, transparent, and inclusive review process.

- **Critical reviewers:**

Independent third-party reviewers assessing the study's alignment with the principles and requirements of the relevant ISO standards.

- **Peer reviewers:**

For the animal fiber and material LCA studies, peer-reviewed journal articles will be developed to validate and communicate findings.

LCA results are intended to support:	LCA data should <u>not</u> be used for:
✓ Environmental impact reduction strategies ✓ Scope 3 reporting and target-setting ✓ Default or “proxy” data for internal or supply chain-specific LCA studies ✓ Benchmarking and validation within supply chains ✓ Inclusion in LCA databases (for example, Higg MSI, Quantis WALDB) ✓ Holistic understanding of impacts, including social factors	✗ Public or marketing claims (including on-product labels) ✗ Country-based sourcing or production decisions based solely on LCA averages ✗ Comparisons between fibers or materials. Textile Exchange LCA studies are not comparative studies. They should not be used to investigate the differences in impacts between or within fiber or material types.

When reviewing the Life Cycle Assessment (LCA) results and reports, Textile Exchange advises that the scope of the studies, methodologies applied, and carbon accounting approaches utilized are carefully considered, in particular, biogenic carbon accounting and how this differs between natural and synthetic fibers and materials.

LCA studies assess only those environmental impacts that are anthropogenic in origin, meaning impacts that are caused by human activity.

For example, in the case of polyester, the LCA boundary begins at the extraction of crude oil, as this marks the point at which human intervention initiates environmental impacts. The geological formation of crude oil itself is not considered within the scope, as it is a natural process not attributable to human activity. The emissions associated with the fossil carbon contained in the oil and therefore the fiber are usually considered at the end-of-life (EoL) stage of the product.

For natural fibers, the starting point of the assessment differs. For animal-based fibers, it begins with animal rearing; for plant-based fibers, it begins with crop cultivation. All upstream activities related to feed and fertilizer production are also included.

In all cases, the associated impacts are allocated across the multiple outputs of the system, a process known as allocation in LCA methodology.

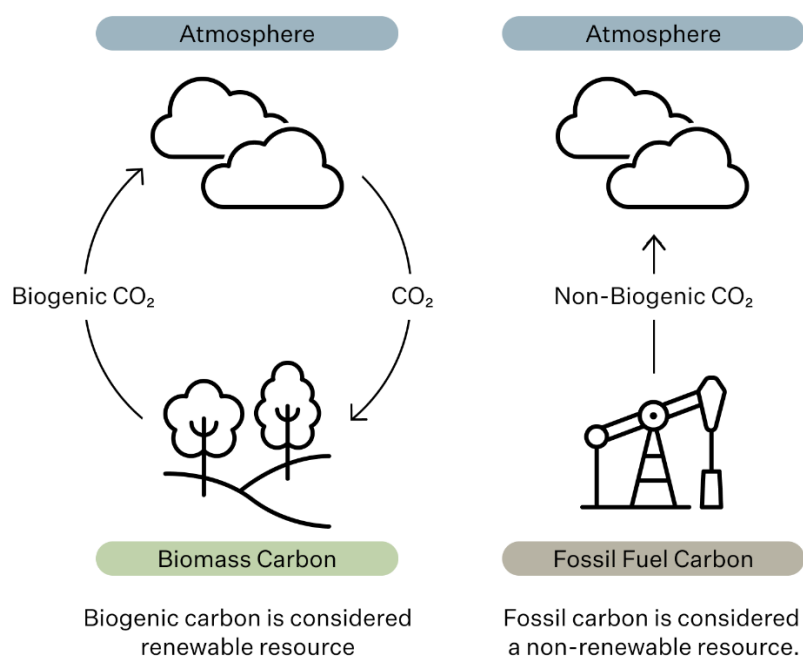
Natural fibers also contain biogenic carbon. Biogenic carbon is absorbed from the atmosphere by plants as they grow and can be released back into the atmosphere later when the plants burn or break down. This is different to fossil carbon that is from fossilized sources in the earth’s crust that has formed over millions of years. New fossil material is not formed in natural conditions, so, for example, the incineration of fossil fuels or materials reduces fossil carbon stock and increases atmospheric carbon (never the opposite). Biogenic carbon is considered renewable and fossil carbon is non-renewable. There are several approaches for accounting for biogenic carbon. Its treatment is a critical consideration when comparing fiber types, as inconsistent inclusion or exclusion can lead to misleading or unfair comparisons between biobased and synthetic (fossil-based) materials.

Textile Exchange conducts LCA studies using a cradle-to-gate approach. This means that the studies assess impacts from raw material extraction through to fiber formation. The use phase and EoL stages are not included. However, if EoL were to be included, it would be essential to distinguish between the emissions profiles of biobased and fossil-based materials. For example, synthetic fibers may result in additional greenhouse gas impacts at EoL (for example, due to emissions of fossil carbon from incineration), whereas the emissions occurring from biobased materials are typically considered carbon-neutral at EoL since the emitted carbon was previously absorbed from the atmosphere. See the illustrative example below.

It is important to recognize that the challenge of accounting for biogenic carbon emissions and removals goes beyond carbon stored in the product, and different methods exist for accounting for biogenic carbon. For further guidance, please refer to Textile Exchange's *Biogenic Carbon* guidelines, which outlines recommended practices and considerations for incorporating biogenic carbon into LCA studies. For fossil-based carbon, there are established and standardized accounting methodologies such as the GHG Protocol and ISO guidelines. These methodologies require that emissions and resource use are directly attributable to human activity.

Accounting for Greenhouse Gas (GHG) emissions and the differences between natural and synthetic material production systems is an evolving area with ongoing research and methodology development. Textile Exchange continues to track developments in this area and relevance for its impact data and measurement work.

Illustrative example of natural (crop) vs. synthetic fiber production and the associated carbon cycle:



This study has been led by Textile Exchange in partnership with SCS Consulting Services.

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Contents

List of Acronyms	10
Glossary	11
List of Tables	13
List of Figures	19
Executive Summary	22
Introduction	22
Scope and methodology	23
Summary of results	25
Chemical recycling	25
Thermomechanical recycling	26
Virgin polyester production	28
Sensitivity analyses	30
Electricity sensitivity analysis results	30
Transport sensitivity analysis results	32
Chemical sensitivity analysis results	33
Limitations and data quality	35
Conclusion and recommendations	36
LCA methodology recommendations	36
LCA insights for business action	37
1. Introduction	38
1.1. Background on polyester production	40
1.1.1 Virgin polyethylene terephthalate (PET) production	40
1.1.2 Types of PET waste	41
1.1.3 Thermomechanical recycling	41
1.1.4 Chemical recycling	41
1.2. Goals of the study	44
1.3. Scope of the study	45
1.4. Intended use of this report	45
1.5. LCA data challenges and common criticisms	47
2. Methodology	51
2.1. Life cycle assessment	51
2.2. Functional unit	52
2.3. System boundary	52
2.4. Modeling approach	54
2.4.1. Data collection and validation	54
2.4.2. Value choices and optional elements	55

2.4.3. Cut-off criteria	55
2.5. Allocation procedures	56
2.6. Impact indicators and categories.....	56
2.7. Data quality assessment methodology.....	61
2.8. Critical reviewers and technical advisory group.....	66
3. Chemical Recycling Product Systems	67
3.1. System boundary.....	67
3.2. Product system description	69
3.2.1. Data provider C1	69
3.2.2. Data provider C2	72
3.2.3. Data provider C3.....	74
3.3 Summary of assumptions	75
3.4. Life cycle inventory	77
3.4.1. Data collection and modeling.....	77
3.4.2. Data quality assessment	79
3.5. Life cycle impact assessment (LCIA) results	80
3.5.1. Data provider C1	80
3.5.2. Data provider C2	84
3.5.3. Data provider C3.....	86
3.6 Key takeaways.....	91
4. Thermomechanical Recycling Product Systems	93
4.1. System boundary	94
4.2. Product system description	97
4.2.1. Data provider M1	97
4.2.2. Data provider M2	98
4.2.3. Data provider M3	99
4.3. Summary of assumptions	103
4.4. Life cycle inventory	104
4.4.1. Data collection and sources	104
4.4.2. Data quality assessment.....	107
4.5. Life cycle impact assessment (LCIA) results	107
4.5.1. Data provider M1	108
4.5.2. Data provider M2	114
4.5.3. Data provider M3.....	117
4.6. Key takeaways.....	123
5. Virgin Production Product Systems	125
5.1. System boundary.....	126
5.2. Product system description	129
5.2.1. Staple fiber products (SF1, SF2, SF3)	129
5.2.2. Partially oriented yarn (black POY)	134

5.2.3. Drawn textured yarn (white DTY)	137
5.3. Summary of assumptions	139
5.4. Life cycle inventory	140
5.4.1. Data collection and sources	140
5.4.2. Data quality assessment	142
5.5. Life cycle impact assessment (LCIA) results	143
5.5.1. Staple fiber (SF1, SF2, SF3)	143
5.5.2. Partially oriented yarn (black POY)	152
5.5.3. Drawn textured yarn (white DTY)	155
5.6. Key takeaways	158
6. Sensitivity Analyses	159
6.1. Electricity scenarios.....	159
6.1.1. Chemical recycling electricity analysis	162
6.1.2. Thermomechanical recycling electricity analysis	168
6.1.3. Virgin production of polyester electricity analysis	176
6.2. Truck transport scenarios.....	184
6.2.1. Chemical recycling transport analysis	187
6.2.2. Thermomechanical recycling transport analysis	195
6.3. Upstream chemical production scenarios	204
6.3.1. Chemical recycling analysis (ethylene glycol, methanol)	204
6.3.2. Virgin production analysis (purified terephthalic acid, monoethylene glycol)	215
7. Limitations.....	225
7.1. Limitations in the study scope.....	225
7.2. Limitations in the life cycle impact assessment phase	226
8. Conclusions and Recommendations	227
8.1. Chemical recycling results.....	227
8.2. Thermomechanical recycling results	228
8.3. Virgin production results	228
8.4. Sensitivity analyses	229
8.4.1. Electricity sensitivity analysis results	229
8.4.2. Transport sensitivity analysis results	229
8.4.3. Chemical sensitivity analysis results	230
8.5. Recommendations	230
8.5.1. LCA methodology recommendations	230
8.5.2. LCA insights for business action.....	230
Appendix A—Circular Footprint Formula	233
A.1 Background and history	233
A.2 Other recycling allocation approaches.....	234
A.3 The circular footprint formula	236
A.4 Application of the circular footprint formula.....	239

A.5 Circular footprint formula results	241
A.6 Discussion of results	251
Appendix B—Examining Human Rights Impacts in Polyester Production: Social Assessment for Polyester	252
B.1 About this appendix	252
B.2 Definitions	253
B.3 Introduction	255
B.4 Scope	256
B.5 Methodology	257
B5.1 Virgin polyester	257
B5.2 Recycled polyester	258
B5.3 Questionnaire	258
B5.4 Expert consultations	259
B5.5 Limitations	260
B.6 Findings	261
B6.1 Human rights impacts associated with the extraction of crude oil for virgin PET	261
B6.2 Human rights impacts associated with feedstock sourcing for recycled PET	264
B6.3 Human rights impacts associated with processing of polyester feedstock and production of polyester chip and staple fiber	269
B.7 Recommendations	272
B7.1 Recommendations for brands, retailers, and manufacturers	272
B7.2 Recommendations for the textile industry as a whole	273
B.8 Conclusion	273
B.9 Primary data questionnaire for recyclers	275
1. General information	275
2. Feedstock sourcing	276
3. Human and labor rights	277
4. Stakeholder engagement	283
5. Chemical management	284
6. Grievance mechanisms	286
B.10 Matrix of common human rights impacts in polyester chip, staple fiber, and yarn production	288
Appendix C: Critical Review Statement	290
The Scope of the Critical Review	290
Critical Review Process	291
General Evaluation	291
Remaining Concerns	291
Conclusion	291
References	292

List of Acronyms

CH ₄	Methane
CML	Institute of Environmental Sciences at Leiden University
CML-IA	Impact assessment methodology from CML
CO ₂	Carbon dioxide
CO ₂ e	Carbon dioxide equivalents
CtEG	Coal-to-ethylene glycol
DMT	Dimethyl terephthalate
DQR	Data quality rating
DTY	Drawn textured yarn
Eq	Equivalent
GHG	Greenhouse gas
FPIC	Free prior informed consent
GWP	Global warming potential
ISO	International Organization for Standardization
kg	kilogram
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
m	Meters
m ²	Square meters
m ³	Cubic meters
MEG	Monoethylene glycol
MJ	Megajoule
Higg MSI	Higg Material Sustainability Index
O ₃	Ozone
PET	Polyethylene terephthalate
POY	Partially oriented yarn
PTA	Purified terephthalic acid
SCS	SCS Consulting Services
SF	Staple fiber

Glossary

Allocation

The process of partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (ISO 14040: 2006a).

Characterization factor

A factor derived from a characterization model, which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator (ISO 14040: 2006a).

Chemical recycling

Polyester chemical recycling refers to technologies that use either solvents, heat, enzymes, or other chemicals to purify or break down polyester (either complete depolymerization or partial depolymerization) to create polymers, monomers, oligomers, or hydrocarbon products so that they can re-enter manufacturing supply chains and be repolymerized, instead of going to landfill.

Circular economy/circularity

A systems-oriented framework focused on decoupling economic activity from the consumption of finite resources, while designing waste out of the system. In a circular economy, products and materials are kept in circulation through processes like regeneration, maintenance, reuse, refurbishment, remanufacture, recycling, and composting (Textile Exchange, 2024b).

Functional unit

A functional unit represents the quantified performance of a product system for use as a reference unit (ISO 14040: 2006). It includes both the quantity and function of the product in a defined context of use (ISO 14040: 2006).

Impact category

A class representing environmental issues of concern (such as climate change, acidification, etc.) to which life cycle inventory (LCI) results are assigned.

Impact indicator

A quantifiable representation of an impact category, chosen to reflect the potential environmental impact.

Life cycle assessment (LCA)

A life cycle assessment is the systematic study of environmental and human health impacts over all stages of a product, including raw material extraction, manufacturing, transportation, use and maintenance, and disposal.

Life cycle impact assessment (LCIA)

LCA phase, where inventory data is translated into potential environmental impacts using characterization factors.

Life cycle inventory (LCI)

An inventory that captures all the input and output flows needed to produce the functional unit.

Post-consumer waste

Material generated by households or by commercial, industrial, and institutional facilities in their role as end users of the product that can no longer be used for its intended purpose. This includes returns of materials from the distribution chain (ISO 14021:2016, 2016).

Post-industrial waste

Material diverted from the waste stream during the manufacturing process. Excluded is the reutilization of materials such as rework, regrind, or scrap generated in a process and capable of being reclaimed within the same process that generated it (ISO 14021:2016, 2016).

Pre-commercial

Pre-commercial scale refers to the stage in technology or product development where a system, process, or product has moved beyond laboratory and pilot testing but has not yet reached full commercial production.

Primary data

Data collected directly from an activity, such as data from a facility, transportation, or farming activities.

Secondary data

Secondary data refers to data obtained from sources that are not directly performing or overseeing the activity being assessed—such as databases, literature, or academic studies.

Solvolysis/solvolytic method

A chemical reaction where a solvent participates as a reactant, breaking a bond in a molecule.

System boundary

A system boundary defines the scope of processes and stages included in an LCA analysis, specifying which inputs, outputs, and impacts are considered, and which are excluded.

Thermomechanical recycling

Thermomechanical recycling involves physically processing plastic waste to create new products without significantly altering the plastic's chemical structure. It involves mechanical processes like sorting, washing, drying and grinding, and the use of heat.

List of Tables

Table E-1: Data providers included in this study	24
Table E-2: Climate change results—chemical recycling	26
Table E-3: Climate change results—climate change—thermomechanical recycling	27
Table E-4: Climate change results—virgin staple fiber products	29
Table E-5: Climate change results— virgin partially oriented yarn (85 denier, 34 filaments)	29
Table E-6: Climate change results—virgin drawn textured yarn (150 denier, 34 filaments)	29
Table 1: Strengths and limitations of virgin and recycled polyester production technologies	43
Table 2: Strengths and limitations of different chemical recycling technologies	43
Table 3: Scope of the LCA study	45
Table 4: LCA data challenges—positioning and outlook	47
Table 5: Scoping of polyester LCA data providers.....	51
Table 6: Primary data collected from data providers and secondary data examples for this study.....	54
Table 7: Electricity grid mix sources for LCA modeling.....	55
Table 8: Impact categories and indicators included in the main body of this report.	58
Table 9: Description of impact categories used in the main body of this report.	58
Table 10: Description of impact categories required by EF 3.1.	59
Table 11: Example table for step 1 of adapted PEF DQR methodology.	62
Table 12: Example table for step 2 of adapted PEF DQR methodology.....	62
Table 13: Example table for step 3 of adapted PEF DQR methodology	63
Table 14: DQR assessment criteria for datasets with company-specific information (primary data)	64
Table 15: DQR criteria for secondary datasets.....	65
Table 16: Overall data quality level according to achieved data quality rating (DQR)	65
Table 17: Technical advisory group members	66
Table 18: Critical review panel	66
Table 19: Summary of chemical recycling product systems.....	67
Table 20: Electricity mix—Chinese data provider C1	70
Table 21: Electricity mix—Chinese data provider C2.....	74
Table 22: Electricity mix—European data provider C3	75
Table 23: LCI datasets from ecoinvent 3.11 (2024)—LCA modeling for chemical recycling	77
Table 24: Data quality assessment for chemical recycling product systems	79
Table 25: Chemical recycling key inputs.....	80
Table 26: C1—LCIA results for 1 kg chemically recycled chip—100% post-industrial textile waste.....	81
Table 27: C1—EF 3.1 LCIA results for 1 kg of chemically recycled PET chip—100% post-industrial textile waste	82
Table 28: C2—LCIA results for 1 kg chemically recycled chip—93% post-industrial, 7% post-consumer textile waste.....	84

Table 29: C2—EF 3.1 LCIA results for 1 kg chemically recycled chip—93% post-industrial, 7% post-consumer textile waste	84
Table 30: C3—LCIA results for 1 kg chemically recycled chip—100% post-consumer textile waste	86
Table 31: C3—LCIA results for 1 kg chemically recycled chip—100% post-industrial textile waste	87
Table 32: C3—EF 3.1 LCIA results for 1 kg of chemically recycled chip—100% post-consumer textile waste ...	88
Table 33: C3—EF 3.1 LCIA results for 1 kg of chemically recycled chip—100% post-industrial textile waste ..	88
Table 34: Summary of thermomechanical recycling product systems	93
Table 35: Electricity grid mix—United States data provider M1.....	97
Table 36: Electricity mix—Chinese data provider M2	98
Table 37: Electricity mix—chip production—Southeast Asian data provider M3	100
Table 38: Electricity mix—staple fiber production—Southeast Asian data provider M3.....	100
Table 39: Life cycle inventory data for 1 kg chip produced at M3.....	101
Table 40: Life cycle inventory data for 1 kg staple fiber produced at M3	102
Table 41: LCI datasets from ecoinvent 3.11 (2024)—LCA modeling for thermomechanical recycling	104
Table 42: Data quality assessment for thermomechanical recycling product systems.....	107
Table 43: Thermomechanical key inputs.....	108
Table 44: M1—LCIA results for 1 kg thermomechanically recycled post-consumer chip	108
Table 45: M1—LCIA results for 1 kg thermomechanically recycled 50-50 blended chip	109
Table 46: M1—EF 3.1 LCIA results for 1 kg of thermomechanically recycled post-consumer chip	110
Table 47: M1—EF 3.1 LCIA results for 1 kg of thermomechanically recycled 50-50 blended chip	111
Table 48: M2—LCIA results for 1 kg thermomechanically recycled chip	114
Table 49: M2—EF 3.1 LCIA results for 1 kg of thermomechanically recycled PET chip.....	115
Table 50: M3—LCIA results for 1 kg thermomechanically recycled chip	117
Table 51: M3—LCIA results for 1 kg thermomechanically recycled staple fiber	118
Table 52: M3—EF 3.1 LCIA results for 1 kg of thermomechanically recycled PET chip.....	119
Table 53: M3—EF 3.1 LCIA results for 1 kg of thermomechanically recycled staple fiber	120
Table 54: Summary of virgin PET product systems.....	125
Table 55: Electricity mix used for SF1 and SF2—Facility 1— Southeast Asia	130
Table 56: Electricity mix used for SF3—Facility 2—Southeast Asia	131
Table 57: Life cycle inventory data for 1 kg SF1 produced at Facility 1	131
Table 58: Life cycle inventory data for 1 kg SF2 produced at Facility 1	132
Table 59: Life cycle inventory data for 1 kg SF3 produced at Facility 2	133
Table 60: Electricity mix used for black POY production—Facility 2— Southeast Asia	135
Table 61: Life cycle inventory data for 1 kg POY produced at Facility 2.....	136
Table 62: Electricity mix used for white DTY production—Facility 2—Southeast Asia	137
Table 63: Life cycle inventory data for 1 kg DTY produced at Facility 2.....	138
Table 64: LCI datasets from ecoinvent 3.11 (2024)—LCA modeling for virgin production	140
Table 65: Data quality assessment for virgin product systems	142
Table 66: Virgin PET production key inputs.....	143
Table 67: Cradle-to-gate LCIA results for 1 kg virgin PET staple fiber products (average, SF1, SF2, SF3)	143

Table 68: LCIA results for 1 kg black virgin staple fiber SF1.....	144
Table 69: LCIA results for 1 kg white virgin staple fiber SF2	144
Table 70: LCIA results for white virgin staple fiber SF3	144
Table 71: EF 3.1 LCIA results for black virgin staple fiber SF1.....	147
Table 72: EF 3.1 LCIA results for white virgin staple fiber SF2	147
Table 73: EF 3.1 LCIA results for white virgin staple fiber SF3	148
Table 74: LCIA results for black virgin POY	152
Table 75: EF 3.1 LCIA results for black virgin POY	153
Table 76: LCIA results for white virgin DTY.....	155
Table 77: EF 3.1 LCIA results for white virgin DTY	156
Table 78: Abbreviations used for impact categories.....	159
Table 79: Baseline electricity mixes for the Chinese data providers (C1, C2, M2)	160
Table 80: Baseline grid mix for the European data provider (C3)	160
Table 81: Baseline grid mix for the United States data provider (M1)	160
Table 82: Baseline electricity mixes for the Southeast Asian data provider (M3)	161
Table 83: Baseline electricity mixes for the Southeast Asian data provider (V1)	161
Table 84: C1—chemically recycled chip—Scenario "Electricity—Renewable"	163
Table 85: C1—chemically recycled chip—Scenario "Electricity—Coal"	164
Table 86: C2—chemically recycled chip—Scenario "Electricity—Renewable".....	164
Table 87: C2—chemically recycled chip—Scenario "Electricity—Coal".....	165
Table 88: C3—chemically recycled post-consumer chip—Scenario "Electricity—Renewable"	165
Table 89: C3—chemically recycled post-consumer chip—Scenario "Electricity—Coal"	166
Table 90: C3—chemically recycled post-industrial chip—Scenario "Electricity—Renewable"	167
Table 91: C3—chemically recycled post-industrial chip—Scenario "Electricity—Coal"	167
Table 92: M1—thermomechanically recycled post-consumer chip—Scenario "Electricity—Renewable"	170
Table 93: M1—thermomechanically recycled post-consumer chip±—Scenario "Electricity—Coal"	170
Table 94: M1—thermomechanically recycled 50-50 blended chip—Scenario "Electricity—Renewable"	171
Table 95: M1—thermomechanically recycled 50-50 blended chip—Scenario "Electricity—Coal"	172
Table 96: M2—thermomechanically recycled chip—Scenario "Electricity—Renewable"	172
Table 97: M2—thermomechanically recycled chip—Scenario "Electricity—Coal"	173
Table 98: M3—thermomechanically recycled chip—Scenario "Electricity—Renewable"	174
Table 99: M3—thermomechanically recycled chip—Scenario "Electricity—Coal"	174
Table 100: M3—thermomechanically recycled staple fiber—Scenario "Electricity—Renewable"	175
Table 101: M3—thermomechanically recycled staple fiber—Scenario "Electricity—Coal"	175
Table 102: Virgin staple fiber SF1—Scenario "Electricity—Renewable"	178
Table 103: Virgin staple fiber SF1—Scenario "Electricity—Coal"	178
Table 104: Virgin staple fiber SF2—Scenario "Electricity—Renewable"	179
Table 105: Virgin staple fiber SF2—Scenario "Electricity—Coal"	179
Table 106: Virgin staple fiber SF3—Scenario "Electricity—Renewable"	180
Table 107: Virgin staple fiber SF3—Scenario "Electricity—Coal"	181

Table 108: Black virgin POY—Scenario "Electricity—Renewable"	181
Table 109: Black virgin POY—Scenario "Electricity—Coal"	182
Table 110: White virgin DTY—Scenario "Electricity—Renewable"	183
Table 111: White virgin DTY—Scenario "Electricity—Coal"	183
Table 112: Parameters for transport scenarios	186
Table 113: Change (%) in environmental impacts per kg-km of truck transport compared to EURO 4 emission standard (European and Rest-of-World datasets)	189
Table 114: Top contributing elementary flows to freshwater ecotoxicity (as % of total impact per kg-km truck transport)	189
Table 115: C1—chemically recycled chip—Scenario "Transport—Low Intensity"	189
Table 116: C1—chemically recycled chip—Scenario "Transport—High Intensity"	190
Table 117: C2—chemically recycled chip—Scenario "Transport—Low Intensity"	191
Table 118: C2—chemically recycled chip—Scenario "Transport—High Intensity"	191
Table 119: C3—chemically recycled post-consumer chip—Scenario "Transport—Low Intensity"	192
Table 120: C3—chemically recycled post-consumer chip—Scenario "Transport—High Intensity"	193
Table 121: C3—chemically recycled post-industrial chip—Scenario "Transport—Low Intensity"	193
Table 122: C3—chemically recycled post-industrial chip—Scenario "Transport—High Intensity"	194
Table 123: Change (%) in environmental impacts per kg-km of truck transport compared to EURO 4 emission standard	196
Table 124: Top contributing elementary flows to freshwater ecotoxicity (as % of total impact per kg-km truck transport)	196
Table 125: M1—thermomechanically recycled post-consumer chip—Scenario "Transport—Low Intensity"	196
Table 126: M1—thermomechanically recycled post-consumer chip—Scenario "Transport—High Intensity"	197
Table 127: M1—thermomechanically recycled 50-50 blended chip—Scenario "Transport—Low Intensity"	198
Table 128: M1—thermomechanically recycled 50-50 blended chip—Scenario "Transport—High Intensity"	198
Table 129: M2—thermomechanically recycled chip—Scenario "Transport—Low Intensity"	199
Table 130: M2—thermomechanically recycled chip—Scenario "Transport—High Intensity"	199
Table 131: M3—thermomechanically recycled chip—Scenario "Transport—Low Intensity"	201
Table 132: M3—thermomechanically recycled chip—Scenario "Transport—High Intensity"	201
Table 133: M3—thermomechanically recycled staple fiber—Scenario "Transport—Low Intensity"	202
Table 134: M3—thermomechanically recycled staple fiber—Scenario "Transport—High Intensity"	202
Table 135: LCIA percent differences from 1 kg EG sensitivity scenarios (C1 and C2 baselines)	206
Table 136: LCIA percent differences for 1 kg EG sensitivity scenarios (C3 baseline)	206
Table 137: LCIA percent differences for 1 kg methanol sensitivity scenarios (C1 and C2 baselines)	207
Table 138: Sensitivity scenario data sources for chemical recycling product systems	207
Table 139: C1—chemically recycled chip—Scenario "Chemicals—Low Intensity"	208
Table 140: C1—chemically recycled chip—Scenario "Chemicals—High Intensity"	209
Table 141: C1—chemically recycled chip—Scenario "Chemicals—Coal"	209
Table 142: C2—chemically recycled chip—Scenario "Chemicals—Low Intensity"	210
Table 143: C2—chemically recycled chip—Scenario "Chemicals—High Intensity"	210
Table 144: C2—chemically recycled chip—Scenario "Chemicals—Coal"	211

Table 145: C3—chemically recycled post-consumer chip—Scenario "Chemicals—Low Intensity"	211
Table 146: C3—chemically recycled post-consumer chip—Scenario "Chemicals—High Intensity"	212
Table 147: C3—chemically recycled post-consumer chip—Scenario "Chemicals—Coal"	212
Table 148: C3—chemically recycled post-industrial chip—Scenario "Chemicals—Low Intensity"	213
Table 149: C3—chemically recycled post-industrial chip—Scenario "Chemicals—High Intensity"	213
Table 150: C3—chemically recycled post-industrial chip—Scenario "Chemicals—Coal"	214
Table 151: LCIA percent differences for 1 kg PTA sensitivity scenarios (V1 baseline)	215
Table 152: LCIA percent differences from 1 kg MEG sensitivity scenarios	216
Table 153: Sensitivity scenario data sources for virgin PET production	216
Table 154: Virgin staple fiber SF1—Scenario "Chemicals—Low Intensity"	217
Table 155: Virgin staple fiber SF1—Scenario "Chemicals—High Intensity"	218
Table 156: Virgin staple fiber SF1—Scenario "Chemicals—Coal"	218
Table 157: Virgin staple fiber SF2—Scenario "Chemicals—Low Intensity"	219
Table 158: Virgin staple fiber SF2—Scenario "Chemicals—High Intensity"	219
Table 159: Virgin staple fiber SF2—Scenario "Chemicals—Coal"	219
Table 160: Virgin staple fiber SF3—Scenario "Chemicals—Low Intensity"	220
Table 161: Virgin staple fiber SF3—Scenario "Chemicals—High Intensity"	220
Table 162: Virgin staple fiber SF3—Scenario "Chemicals—Coal"	221
Table 163: Black virgin POY—Scenario "Chemicals—Low Intensity"	222
Table 164: Black virgin POY—Scenario "Chemicals—High Intensity"	222
Table 165: Black virgin POY—Scenario "Chemicals—Coal"	222
Table 166: White virgin DTY—Scenario "Chemicals—Low Intensity"	223
Table 167: White virgin DTY—Scenario "Chemicals—High Intensity"	223
Table 168: White virgin DTY—Scenario "Chemicals—Coal"	224

Table A-1: 2025 Apparel and Footwear PEFCR “A”, “Q _{sin} ”, and “Q _p ” values.....	240
Table A-2: C1—chemically recycled chip Higg MSI results calculated using the CFF	241
Table A-3: C1—chemically recycled chip EF 3.1 results calculated using the CFF	241
Table A-4: C2—chemically recycled Higg chip MSI results calculated using the CFF	242
Table A-5: C2—chemically recycled chip EF 3.1 results calculated using the CFF	242
Table A-6: C3—100% post-consumer chemically recycled chip Higg MSI results calculated using the CFF	243
Table A-7: C3—100% post-consumer chemically recycled chip EF 3.1 results calculated using the CFF	243
Table A-8: C3—100% post-industrial chemically recycled chip Higg MSI results calculated using the CFF	244
Table A-9: C3—100% post-industrial chemically recycled chip EF 3.1 results calculated using the CFF	244
Table A-10: M1—100% post-consumer thermomechanically recycled chip Higg MSI results calculated using the CFF	245
Table A-11: M1—100% post-consumer thermomechanically recycled chip EF 3.1 results calculated using the CFF	245
Table A-12: M1—50-50 blended thermomechanically recycled chip Higg MSI results calculated using the CFF	246

Table A-13: M1—50-50 blended thermomechanically recycled chip EF 3.1 results calculated using the CFF	247
Table A-14: M2—thermomechanically recycled chip Higg MSI results calculated using the CFF	247
Table A-15: M2—thermomechanically recycled chip EF 3.1 results calculated using the CFF	248
Table A-16: M3—thermomechanically recycled chip Higg MSI results calculated using the CFF	248
Table A-17: M3—thermomechanically recycled chip EF 3.1 results calculated using the CFF	249
Table A-18: M3—thermomechanically recycled staple fiber Higg MSI results calculated using the CFF	250
Table A-19: M3—thermomechanically recycled staple fiber EF 3.1 results calculated using the CFF	250
Table B-1: Overview of data providers (recyclers) by region, technology type, and feedstock	259
Table B-2: Human rights impacts associated with extraction of crude oil for virgin PET	262
Table B-3: Human rights impacts associated with informal sourcing of feedstock for recycled PET	267
Table B-4: Human rights impacts associated with formal sourcing of feedstock for recycled PET	268
Table B-5: Common impacts associated with processing polyester	269

List of Figures

Figure E-1: Process-level contribution—climate change—chemical recycling	26
Figure E-2: Process-level contribution—climate change—thermomechanical recycling	28
Figure E-3: Process-level contribution—climate change—virgin PET production	30
Figure E-4: Electricity sensitivity analysis—climate change—chemical and thermomechanical recycling	31
Figure E-5: Electricity sensitivity analysis—climate change—virgin PET production	31
Figure E-6: Transport sensitivity analysis—climate change—chemical and thermomechanical recycling	33
Figure E-7: Chemical sensitivity analysis—climate change—chemical recycling	34
Figure E-8: Chemical sensitivity analysis—climate change—virgin PET production	35
Figure 1: Life cycle assessment framework, adapted from ISO 14040:2006	51
Figure 2: Example system boundary diagram for a cradle-to-gate life cycle assessment.	53
Figure 3: DQR calculation formula	61
Figure 4: System boundary diagram for chemically recycled chip	68
Figure 5: C1—contribution by life cycle stage	81
Figure 6: C1—process-level contribution	83
Figure 7: C2—process-level contribution	86
Figure 8: C3—contribution by life cycle stage—100% post-consumer (PC) chip and 100% post-industrial (PI) chip	87
Figure 9: C3—process-level contribution—100% post-consumer textile waste	90
Figure 10: C3—process-level contribution—100% post-industrial textile waste	91
Figure 11: System boundary diagram for thermomechanically recycled chip	95
Figure 12: System boundary diagram for thermomechanically recycled staple fiber	96
Figure 13: M1—contribution by life cycle stage—100% post-consumer chip	109
Figure 14: M1—contribution by life cycle stage—50-50 blended chip	110
Figure 15: M1—process-level contribution—100% post-consumer chip	113
Figure 16: M1—process-level contribution—50-50 blended chip	114
Figure 17: M2—contribution by life cycle stage	115
Figure 18: M2—process-level contribution	117
Figure 19: M3—contribution by life cycle stage—PET chip	118
Figure 20: M3—contribution by life cycle stage—PET staple fiber	119
Figure 21: M3—process-level contribution—PET chip	122
Figure 22: M3—process-level contribution—PET staple fiber	123
Figure 23: System boundary diagram for continuously polymerized virgin PET staple fiber	127
Figure 24: System boundary diagram for batch polymerized virgin PET POY	128
Figure 25: System boundary diagram for continuously polymerized virgin PET DTY	129
Figure 26: Contribution by life cycle stage—virgin staple fiber SF1–SF3	146
Figure 27: Process-level contribution—virgin staple fiber SF1	150

Figure 28: Process-level contribution—virgin staple fiber SF2	151
Figure 29: Process-level contribution—virgin staple fiber SF3	152
Figure 30: Contribution by life cycle stage—black virgin POY	153
Figure 31: Process-level contribution—black virgin POY	155
Figure 32: Contribution by life cycle stage for white virgin DTY	156
Figure 33: Process-level contribution—white virgin DTY	158
Figure 34: Comparison of electricity scenarios for chemically recycled chip produced by data provider C1 .	164
Figure 35: Comparison of electricity scenarios for chemically recycled chip produced by data provider C2 .	165
Figure 36: Comparison of electricity scenarios for chemically recycled post-consumer chip produced by data provider C3	167
Figure 37: Comparison of electricity scenarios for chemically recycled post-industrial chip produced by data provider C3	168
Figure 38: Comparison of electricity scenarios for thermomechanically recycled post-consumer chip produced by data provider M1	171
Figure 39: Comparison of electricity scenarios for thermomechanically recycled 50-50 blended chip produced by data provider M1	172
Figure 40: Comparison of electricity scenarios for thermomechanically recycled chip produced by data provider M2	173
Figure 41: Comparison of electricity scenarios for thermomechanically recycled chip produced by data provider M3	175
Figure 42: Comparison of electricity scenarios for thermomechanically recycled staple fiber produced by data provider M3	176
Figure 43: Comparison of electricity scenarios for virgin staple fiber SF1	179
Figure 44: Comparison of electricity scenarios for virgin staple fiber SF2	180
Figure 45: Comparison of electricity scenarios for virgin staple fiber SF3	181
Figure 46: Comparison of electricity scenarios for black virgin POY	182
Figure 47: Comparison of electricity scenarios for white virgin DTY	184
Figure 48: Comparison of transport scenarios for chemically recycled chip produced by data provider C1 ...	191
Figure 49: Comparison of transport scenarios for chemically recycled chip produced by data provider C2 ...	192
Figure 50: Comparison of transport scenarios for chemically recycled post-consumer chip produced by data provider C3	193
Figure 51: Comparison of transport scenarios for chemically recycled post-industrial chip produced by data provider C3	194
Figure 52: Comparison of transport scenarios for thermomechanically recycled post-consumer chip produced by data provider M1	197
Figure 53: Comparison of transport scenarios for thermomechanically recycled 50-50 blended chip produced by data provider M1	199
Figure 54: Comparison of transport scenarios for thermomechanically recycled chip produced by data provider M2	200
Figure 55: Comparison of transport scenarios for thermomechanically recycled chip produced by data provider M3	202
Figure 56: Comparison of transport scenarios for thermomechanically recycled staple fiber produced by data provider M3	203
Figure 57: Comparison of chemical scenarios for chemically recycled chip produced by data provider C1 ...	210

Figure 58: Comparison of chemical scenarios for chemically recycled chip produced by data provider C2 ...	211
Figure 59: Comparison of chemical scenarios for chemically recycled post-consumer chip produced by data provider C3	213
Figure 60: Comparison of chemical scenarios for chemically recycled post-industrial chip produced by data provider C3	214
Figure 61: Comparison of chemical scenarios for virgin staple fiber SF1	218
Figure 62: Comparison of chemical scenarios for virgin staple fiber SF2	220
Figure 63: Comparison of chemical scenarios for virgin staple fiber SF3	221
Figure 64: Comparison of chemical scenarios for black virgin POY	223
Figure 65: Comparison of chemical scenarios for white virgin DTY	224
Figure A-1. Recycled cut-off and avoided burden flow diagram	235
Figure A-2. PEF Circular Footprint Formula flow diagram	237
Figure B-1: Supply chains stages of PET production in scope of this study	256
Figure B-2: Methodology for virgin polyester	257
Figure B-3: Methodology for recycled polyester	258
Figure B-4: Types of feedstock for recycled PET—estimated proportion of formal versus informal sources.	264
Figure B-5: An example supply-chain map for a polyester recycler, showing the numerous sub-levels and complexity involved	266

Executive Summary

Introduction

Polyester is the most used fiber globally due to its low cost (United Nations Regional Information Centre for Western Europe, 2024), durability, versatility (Wankai Global 2024c), moisture resistance (Wankai Global, 2024a; Wankai Global, 2024c), and color retention (Wankai Global, 2024a; Wankai Global, 2024c), making up 57% of the global fiber market (Textile Exchange, 2024a). It is used widely in clothing, accessories, home furnishings, and footwear (Textile Exchange, 2025). While the word polyester can refer to a group of polymers with specific repeating chemical bonds, in the context of the textile, apparel, and fashion industry, polyester refers to a fiber that is made from polyethylene terephthalate (PET), which is currently the predominant polyester used in the industry (Palacios-Mateo et al., 2021). Both polyester and PET are used interchangeably within this report.

Polyester's advantages come with some environmental and social costs. The production of polyester involves the extraction and consumption of crude oil and natural gas, leading to environmental impacts such as air and water pollution, ocean acidification, and habitat destruction (Bertrand, 2021). Polyester is also not inherently biodegradable and so can persist in the environment for decades (Palacios-Mateo et al., 2021), creating extended environmental and social impacts related to its waste. Textile garments made from polyester also contribute to microplastic pollution, which affects marine life and human health (European Environment Agency, 2022). While a small percentage of textile waste is reused or recycled, most of it is incinerated or landfilled (European Parliament, 2020). A large portion of collected textiles are exported to communities in the Global South, where they often end up as waste due to their low resale value (Burke, 2015; Kokutse, 2024). Since polyester is the most widely used fiber in the world, (Textile Exchange, 2024a), it comprises a significant portion of this textile waste.

Recycling is one important solution to help mitigate these impacts, (World Economic Forum, 2023; US Government Accountability Office, 2024), along with other key actions, including finding ways to reduce overproduction and overconsumption, and designing for circularity. Designing materials for circularity, by making products that can be easily repaired and recycled, keeps materials in use for longer and helps reduce the use of virgin materials. For the use of polyester within the textile industry, this means reducing both PET waste and the need for virgin PET production, thus conserving finite fossil resources and reducing environmental impacts (Joseph et al., 2024). However, current recycling methods have limitations around the removal of contaminants and the types of feedstock they can handle. Currently, a majority of PET waste is thermomechanically recycled (Nageler-Petriz, 2023), with 98% of recycled polyester produced using post-consumer bottles (Textile Exchange, 2024a). While using post-consumer bottles to produce textiles diverts bottle waste from landfills, it also diverts feedstock from the bottle industry, reducing this industry's ability to produce new bottles from its own waste, and it does not help in reducing the textile industry's waste issues (Textile Exchange, 2024a). New recycling technologies are being developed to tackle some of these limitations and improve textile-to-textile recycling.

Life cycle assessments (LCAs) are one of the most widely used methodologies to assess different types of environmental impacts from the production of different materials, however the accuracy of an LCA is only as good as the quality of data on which it is based. Currently, there is no publicly available data for virgin PET production in Asia, where the majority of virgin PET is produced (Coherent Market Insights, 2025; Research and Markets, 2023; Intel Market Research, 2025). There is also limited data on the production of mechanically and chemically recycled PET across the world, and especially in Asia.

While the life cycle assessment (LCA) methodology captures impacts related to the environment, it does not cover impacts on people, such as those that may affect workers' and communities' human rights. Textile Exchange as well as its project partners believe it is important to understand both of these impact areas when sourcing and using polyester. Because of this, an additional component referred to as "LCA+", which is based on a social risk survey completed by participating data providers, and a literature review on the current state of polyester production, has been conducted and added to appendix B of this LCA study. This "LCA+" assessment does not aim to provide a comprehensive analysis on the social footprint of polyester. Rather, this assessment aims to highlight the importance of understanding the social impacts alongside the environmental impacts and provide readers with a foundational understanding of key human rights risk areas related to this production system.

This study was led by Textile Exchange, in partnership with SCS Consulting Services, to provide the textile industry, as well as LCA practitioners, with up-to-date impact data related to polyester production. Production data from 2022 to 2024 was collected from five different PET producers utilizing a variety of thermomechanical recycling, chemical recycling, and virgin production technologies in Europe, the United States, Southeast (SE) Asia, and China. To help contextualize these results, this report also includes important qualitative findings gathered through numerous industry and social expert interviews and a literature review.

Scope and methodology

This report examines the production of virgin PET chip, staple fiber, partially oriented yarn and drawn textured yarn, thermomechanically recycled PET chip and staple fiber, and chemically recycled PET chip, from five data providers across four regions (Table E-1). For this study, a cradle-to-gate system boundary is considered. This boundary includes all inputs and outputs required to produce these PET products, and accounts for the impact of raw material extraction and production, including the extraction of crude oil and natural gas, all transport, and all processes required to transform these raw materials into the PET products considered in this study. The packaging of the final product is excluded, as the focus of these LCAs is on the virgin and recycled polyester production processes.

The choice of methods and impact indicators used in the assessment is based on the requirements of ISO 1404 (ISO 14044:2006, 2006) and the Higg Materials Sustainability Index (MSI), (Cascale, 2024). Additionally, impact indicators recommended in the EF 3.1 reference package (European Commission, 2025a) are also included in this study. Ecoinvent v3.11 (Ecoinvent, 2024a) datasets were used to model all primary and secondary life cycle inventory data in openLCA 2.4 (Cilleruelo, 2025). These datasets were selected based on how recently the data was collected, and how closely they match the actual technology used and the location in which the actual process occurred, if known. Except where noted, they are considered to be representative of the processes for which primary data was not available. However, they are not perfect matches to the actual operations that they represent.

Within this study, the recycled content method (also known as the 100-0 method or cut-off method) is used to determine how the benefit of using recycled materials and producing materials that can be recycled are accounted for. This means that any waste that is used as feedstock enters the system burden-free, and only the impacts related to processing and recycling the feedstock are included. Any impacts related to the processes that originally created the waste are not included. Additionally, the results for all impact categories have been recalculated using the PEF circular footprint formula, presented in appendix A (European Commission, n.d.–a).

In addition to the LCA, this study also included an assessment of social impacts related to the production of polyester, to provide readers with a core understanding of important human rights risks associated with polyester production; this assessment can be found in appendix B.

Table E-1: Data providers included in this study

Data provider	Region of operation	Feedstock	Data collection period	Functional unit
Chemical recycler 1 (C1)	China	Post-industrial textile waste	August 2023–January 2024	1 kg chemically recycled PET chip
Chemical recycler 2 (C2)	China	93% post-industrial textile waste and 7% post-consumer textile waste	January–October 2024	1 kg chemically recycled PET chip
Chemical recycler 3 (C3)	Europe (pre-commercial operation)*	100% post-industrial and separately, 100% post-consumer textile waste	October 2022*	1 kg of post-industrial chemically recycled chip; 1 kg of post-consumer chemically recycled PET chip
Thermomechanical recycler 1 (M1)	United States	Post-consumer bottle waste (100%); A 50-50 blend of post-industrial textile waste and post-consumer bottle waste for their blended chip	January–December 2023	1 kg of post-consumer thermomechanically recycled PET chip, 1 kg thermomechanically recycled 50-50 blended PET chip
Thermomechanical recycler 2 (M2)	China	Post-consumer bottle waste (100%)	January–December 2023	1 kg of thermomechanically recycled PET chip
Thermomechanical recycler 3 (M3)	Southeast Asia	Post-consumer bottle waste (100%)	January–December 2022	1 kg of thermomechanically recycled PET chip; 1 kg of thermomechanically recycled staple fiber
Virgin producer 1 (V1)	Southeast Asia	Virgin chemicals	January–December 2022	1 kg of black virgin staple fiber, 1 kg of white virgin staple fiber, 1 kg of virgin partially oriented yarn (POY), 1 kg of virgin drawn textured yarn (DTY)

* Chemical recycler 3 (C3) has not yet reached commercial operations and is not currently producing a sellable product. Its input and output data is based on detailed mass and energy balances based on testing conducted at a pilot plant. This engineering study was completed in October 2022.

Summary of results

The sections below provide a brief description of the different PET production technologies assessed in this study, along with the climate change impact results calculated using the IPCC 2021 (AR6) global warming potentials. However, it is important to understand how these production processes affect a broad range of environmental impact categories, not just climate change, and it is recommended to explore these other results, which can be found in sections 3.5, 4.5, and 5.5 of the main body of the report.

Chemical recycling

Polyester chemical recycling refers to technologies that use either solvents, heat, enzymes, or other chemicals to purify or break down polyester to create polymers, monomers, oligomers, or hydrocarbon products so that they can re-enter manufacturing supply chains, instead of being disposed (Closed Loop Partners, 2023). Chemical recycling can be employed for both post-industrial and post-consumer textile waste feedstock. It supports textile-to-textile recycling and helps secure a consistent supply of recycled PET chip produced from waste textiles, which can reduce reliance on waste PET bottles. This also allows the stock of waste PET bottles to be used by the packaging industry, where demand for PET bottle waste has continued to rise.

In this study, three chemical recyclers were evaluated, using different types of solvolytic chemical recycling technologies. Solvolytic processes involve the breaking down of polymer bonds using a solvent. These recycling processes can remove contaminants, dyes, and other chemical additives, and hence expand the types of polyester waste that they can recycle (Closed Loop Partners, 2023). An input of ethylene glycol and/or methanol is required as part of the chemical recycling process. Ethylene glycol (EG) generally refers to monoethylene glycol (MEG), although EG can also describe other ethylene glycols such as diethylene glycol and triethylene glycol. In this report, EG refers specifically to MEG. The terminology aligns with usage by the chemical recyclers that provided the data.

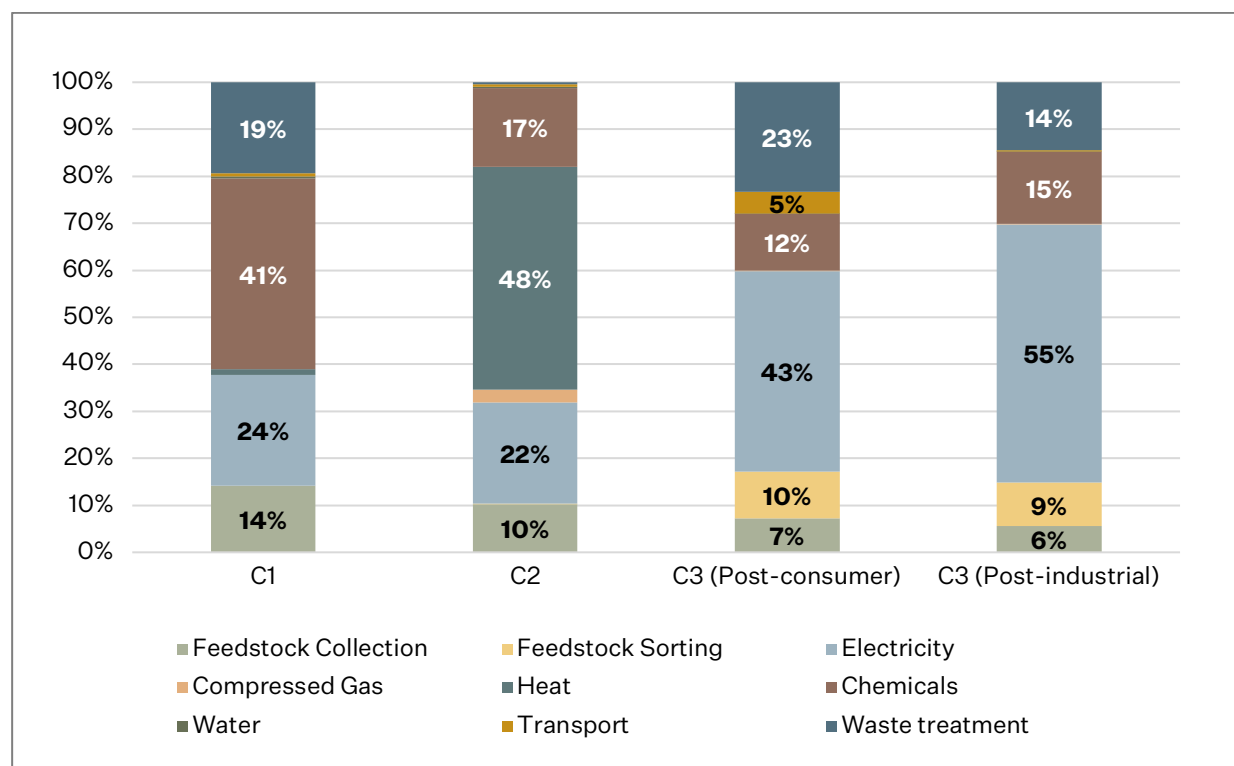
The chemically recycled PET chip they produce is equivalent in quality to virgin PET chip. These three chemical recyclers (denoted as C1, C2, and C3) recycle a mix of post-industrial and post-consumer textile waste. Post-industrial textile waste—such as fabric offcuts and trimmings, selvaige waste (edges of a woven fabric that are often trimmed off during production), and scraps from garment assembly—are cleaner, more homogeneous, and require less sorting, and pre-treatment than post-consumer textile waste, which can be any type of finished product discarded by a consumer. C1 and C2 are located in China and operate at a commercial scale. C3 is located in Europe and is not yet at a commercial scale, referred to as pre-commercial throughout this report. C3's life cycle inventory data is taken from an engineering study for a planned commercial plant and was validated using detailed mass and heat balances based on testing at a pilot plant; as this data does not represent commercial operation, it should be interpreted with caution. In addition, while both commercial chemical recyclers (C1 and C2) claim their technology can be used to recycle post-consumer waste, C1 recycled <1% post-consumer waste during the data collection period and C2 recycled approximately 7%.

Energy consumption (including electricity and heat) and the use of chemicals are the two largest hotspots for climate change impacts associated with the chemical recycling of polyester by data providers C1 and C2. For data provider C3, electricity consumption is the largest contributor to climate change, followed by the treatment of waste and the use of chemicals. Apart from these contributors, the combined impacts of the transport required to collect the feedstock and electricity used to sort it are the next largest hotspots. The distance transported and the amount of electricity consumed vary greatly for each data provider depending on the chemical recycling technology used and the region of operation.

Table E-2: Climate change results—chemical recycling

Data provider	Technology	Cradle-to-textile shred		Textile shred-to-chip		Total	Unit
C1 (post-industrial)	Two-stage depolymerization (glycolysis then methanolysis)	0.304	17%	1.46	83%	1.77	kg CO ₂ eq
C2* (93% post-industrial, 7% post-consumer)	Two-stage depolymerization (glycolysis then methanolysis)	N/A	N/A	N/A	N/A	2.24	kg CO ₂ eq
C3 (post-consumer)	Partial glycolysis	0.522	59%	0.364	41%	0.885	kg CO ₂ eq
C3 (post-industrial)	Partial glycolysis	0.426	62%	0.257	38%	0.683	kg CO ₂ eq

* Chemical recycler 2 (C2) was unable to provide input and output data subdivided between the two life cycle stages shown in this table. Therefore, only the total impact from cradle-to-chip is shown.

Figure E-1: Process-level contribution—climate change—chemical recycling

Thermomechanical recycling

Thermomechanical recycling uses physical processes (sorting, washing, shredding, melting, and extruding) to recycle plastic waste into new products. Currently, 98% of recycled polyester is made from recycled plastic bottles; however, homogeneous, high quality textile waste can also be thermomechanically recycled (Textile Exchange, 2024a). Thermomechanical recycling is unable to remove contaminants or additives within PET and so it is unable to decolor waste PET (Textile Exchange, 2024c); recycled chip or staple fiber matches the color of the waste used.

Thermomechanical recycling can only recycle PET waste a limited number of times before the PET becomes too degraded for further thermomechanical recycling (Patel et al., 2024).

In this study, three thermomechanical recyclers were evaluated (indicated as M1, M2, and M3), with their facilities located in three different regions (United States, China, and Southeast Asia, respectively). M1 produces two types of PET chip, the first uses only post-consumer PET bottles, while the second utilizes 50% post-consumer PET bottles and 50% post-industrial textile waste, referred to as 50-50 blended chip. M2 and M3 only use post-consumer PET bottles. While all three data providers produce recycled PET chip, M3 also produces recycled staple fiber directly from flake.

The production of thermomechanically recycled PET chip typically involves two main stages: cradle-to-flake production and flake-to-chip. Flake production includes the collection of post-consumer PET bottles, and post-industrial PET waste textile, in the case of M1's 50-50 blended chip. Post-consumer PET bottles are crushed, baled, and transported to a facility where they are sorted, cleaned, and mechanically shredded into flake. The flake is then either moved to a different processing line within the same facility or is transported to a different facility where it is melted and extruded into recycled PET chip. The post-industrial textile waste used by M1 is shredded and mixed with the flake, then extruded into chip.

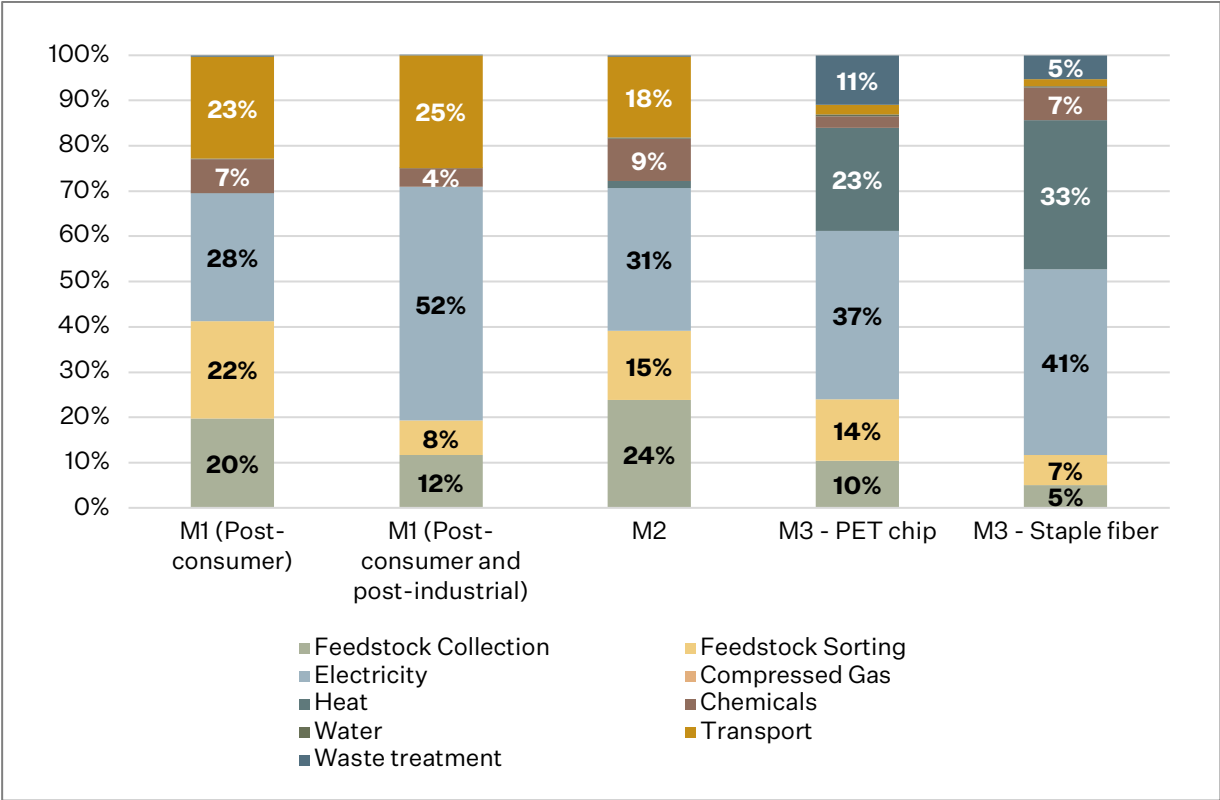
The production of thermomechanically recycled PET staple fiber, produced by M3, also involves two stages: cradle-to-flake and flake-to-staple fiber. The cradle-to-flake stage is identical to the one used for chip production. Flake-to-staple fiber production involves melting, spinning, drawing, annealing, crimping, drying, and, finally, cutting the resulting fiber into the desired staple lengths.

The electricity consumed by thermomechanical recycling is the primary driver of climate change impacts for the production of chip and staple fiber. Across all thermomechanical data providers, feedstock collection and sorting together is another key driver of climate change impact in chip production. For M1 and M2, transport of materials and chemicals to the recycling facilities also contribute significantly to climate change. For M3, coal-based heat used at the manufacturing site is another major driver.

Table E-3: Climate change results—climate change—thermomechanical recycling

Data provider—PET Chip	Cradle-to-flake		Flake-to-chip		Total	Unit
M1 (post-consumer bottles)	0.716	75%	0.243	25%	0.959	kg CO ₂ eq
M1 (50-50 blended chip)	0.367	34%	0.708	66%	1.07	kg CO ₂ eq
M2 (post-consumer bottles)	0.879	73%	0.321	27%	1.20	kg CO ₂ eq
M3 (post-consumer bottles)	0.897	68%	0.416	32%	1.31	kg CO ₂ eq
Data provider—staple fiber	Cradle-to-flake		Flake-to-staple fiber		Total	Unit
M3 (post-consumer bottles)	1.01	33%	2.03	67%	3.04	kg CO ₂ eq

Figure E-2: Process-level contribution—climate change—thermomechanical recycling



Virgin polyester production

Virgin PET is produced by a chemical reaction involving monoethylene glycol (MEG) and either purified terephthalic acid (PTA) or dimethyl terephthalate (DMT), all derived from petrochemical sources (UNFCCC, 2021). This process, known as polymerization, forms long chains of repeating molecules linked by chemical bonds. While both PTA and DMT are used with MEG, PTA is much more widely used as it has lower production costs, better reaction efficiency, and reduced environmental impacts when compared to DMT (IHS Markit, 2019; Environmental Protection Agency, 1991). This is further supported by the fact that between 2017 and 2022, the consumption of PTA grew at 5% per year, and DMT has been declining at a rate of 1% per year (S&P Global, 2023).

MEG is often produced via the ethylene oxide pathway (Zhang et al., 2024), in which ethylene oxide is derived from petroleum, natural gas, or other sources. MEG can also be produced from coal syngas through the dimethyl oxalate route (Qian et al., 2022) referred to in this report as coal-to-ethylene glycol (coal-to-EG). This coal-to-EG process is conducted in China (Qian et al., 2022). In this study, MEG production is modeled using the ethylene oxide pathway available in ecoinvent (Ecoinvent, 2024b), however, a sensitivity analysis was conducted to explore how using MEG produced from the coal-to-EG pathway affects the results.

Data provider V1 produces PET staple fiber, partially oriented yarn (POY), and drawn and textured yarn (DTY) using two different production pathways: batch production or continuous polymerization. Batch production, used for small-scale specialty orders, creates PET chip as an intermediate output and is used to produce V1’s POY. Continuous polymerization, which is used for the majority of its production, is a continuous reaction process which produces PET melt as an intermediate output and is used to produce its three staple fiber products and DTY. Both pathways polymerize PET using MEG and PTA. The system boundary for V1 was extended to include all of the inputs and outputs required to produce these products.

The results shown below account for all cradle-to-gate impacts of the production of virgin PET, including the impacts associated with the extraction and processing of fossil fuels such as crude oil and natural gas. These fossil fuels are processed to produce the chemicals used in the virgin PET polymerization process, PTA and MEG. The production of PTA and MEG are the largest contributors to the climate change results for all virgin products studied. Energy (electricity and heat combined) is another major contributor. The contribution of other chemicals to climate change impacts for the black staple fiber product is larger than it is for the two white staple fiber products. This is primarily due to the black masterbatch—a black coloring agent containing carbon black and PET carrier resin—used to color the staple fiber.

As far as the authors are aware, V1's life cycle inventory data and their LCIA results represent the first known publicly available data on virgin PET chip, melt, and staple fiber production in Southeast Asia; PET chip, melt, and staple fiber are used to produce all subsequent polyester products. As Asia accounts for more than half of the world's PET production (Coherent Market Insights, 2025; Research and Markets, 2023; Intel Market Research, 2025), this data will greatly improve the accuracy of future LCAs on any virgin polyester product that has its origins in Asia.

Table E-4: Climate change results—virgin staple fiber products

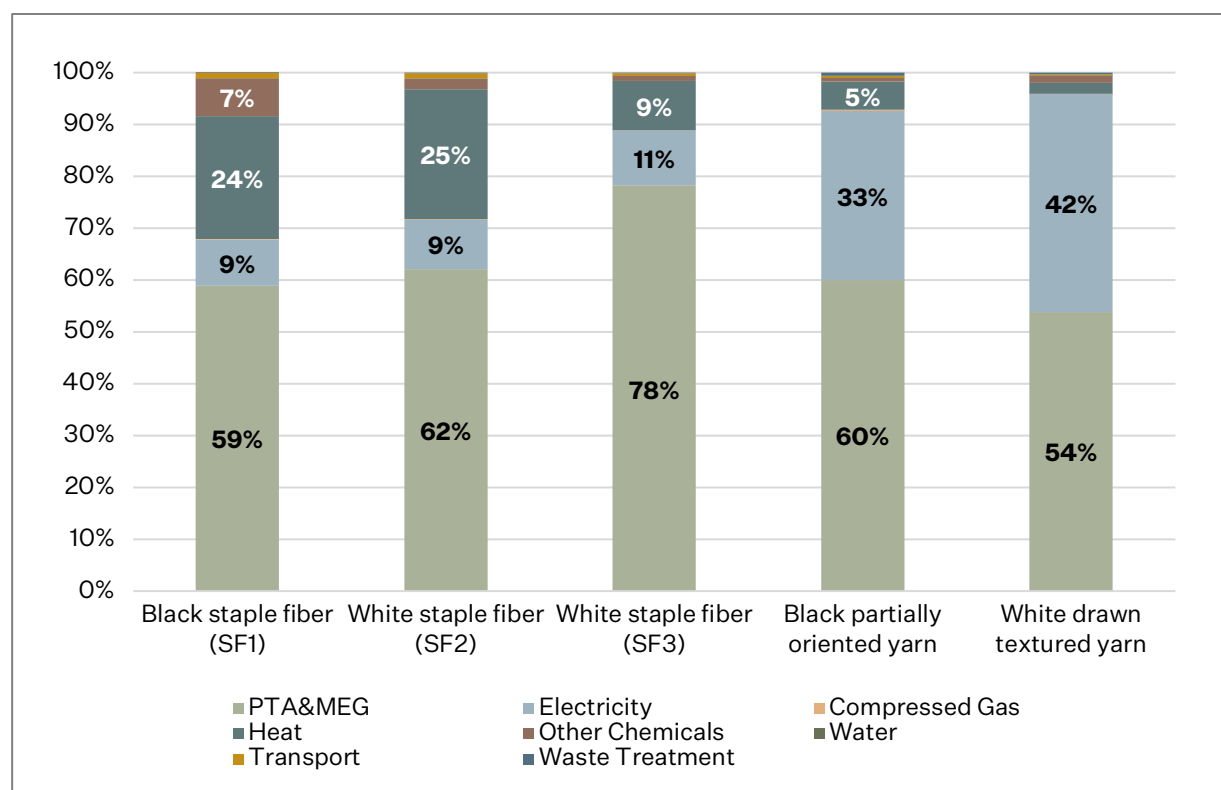
Product	Cradle-to-melt		Melt-to-staple fiber		Total	Unit
Black staple fiber (SF1)	3.41	72%	1.34	28%	4.74	kg CO ₂ eq
White staple fiber (SF2)	3.74	76%	1.19	24%	4.93	kg CO ₂ eq
White staple fiber (SF3)	3.39	86%	0.573	14%	3.96	kg CO ₂ eq
Average staple fiber	3.51	77%	1.03	23%	4.55	kg CO ₂ eq

Table E-5: Climate change results— virgin partially oriented yarn (85 denier, 34 filaments)

Product	Cradle-to-chip		Chip-to-POY		Total	Unit
Black partially oriented yarn	3.56	66%	1.87	34%	5.44	kg CO ₂ eq

Table E-6: Climate change results—virgin drawn textured yarn (150 denier, 34 filaments)

Product	Cradle-to-melt		Melt-to-POY		POY-to-DTY		Total	Unit
White drawn textured yarn	3.43	59%	0.719	12%	1.68	29%	5.83	kg CO ₂ eq

Figure E-3: Process-level contribution—climate change—virgin PET production

Sensitivity analyses

Sensitivity analyses explore how responsive LCA results are to parameter changes within an LCA model. Given that recycling technologies can be deployed in any part of the world, there will be variations in the source of electricity used and emissions associated with the transport to collect PET waste; both electricity and feedstock collection were hotspots across several PET producers. Therefore, three scenarios were created to explore how variations in the electricity mix, truck transport intensity (transport distance and fuel combustion emissions), and chemical production pathways and markets affected the results.

Electricity sensitivity analysis results

For each data provider, two electricity scenarios were designed—the use of 100% coal electricity and 100% renewable electricity (with a 50-50 split of wind and solar energy). These scenarios are in addition to the mix of electricity actually used by the data providers, referred to as the baseline. These additional scenarios were chosen to represent the minimum and maximum range of environmental impacts possible due to the use of electricity. Electricity generated by burning coal is widely considered one of the most environmentally impactful sources of energy, and certainly the most impactful from a climate change perspective. Coal power is still used by 108 countries (Global Energy Monitor, 2025), including all the countries in which these data providers are located. Conversely, electricity generated using renewable wind and solar are considered among the cleanest sources of electricity (United Nations Economic Commission for Europe, 2021) and are increasing in use across the world, especially in Asia (International Renewable Energy Agency, 2025). China, for example, contributed 64% of the total global renewable capacity added in 2024 (International Renewable Energy Agency, 2025).

Figure E-4: Electricity sensitivity analysis—climate change—chemical and thermomechanical recycling

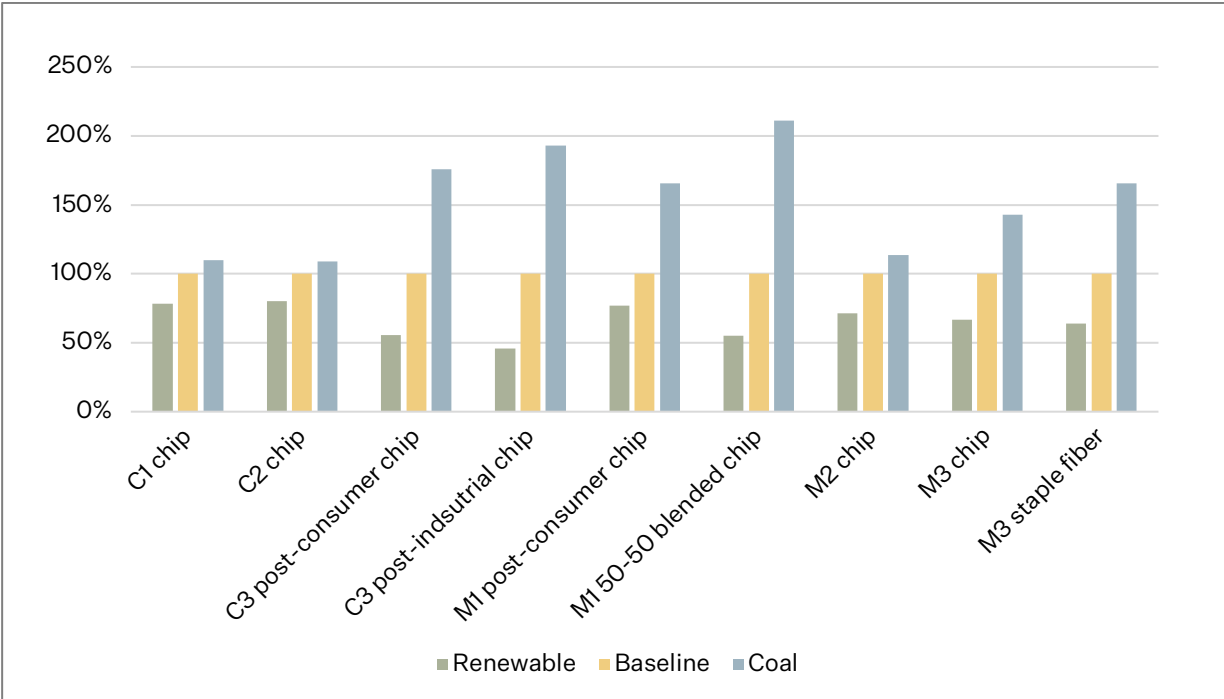
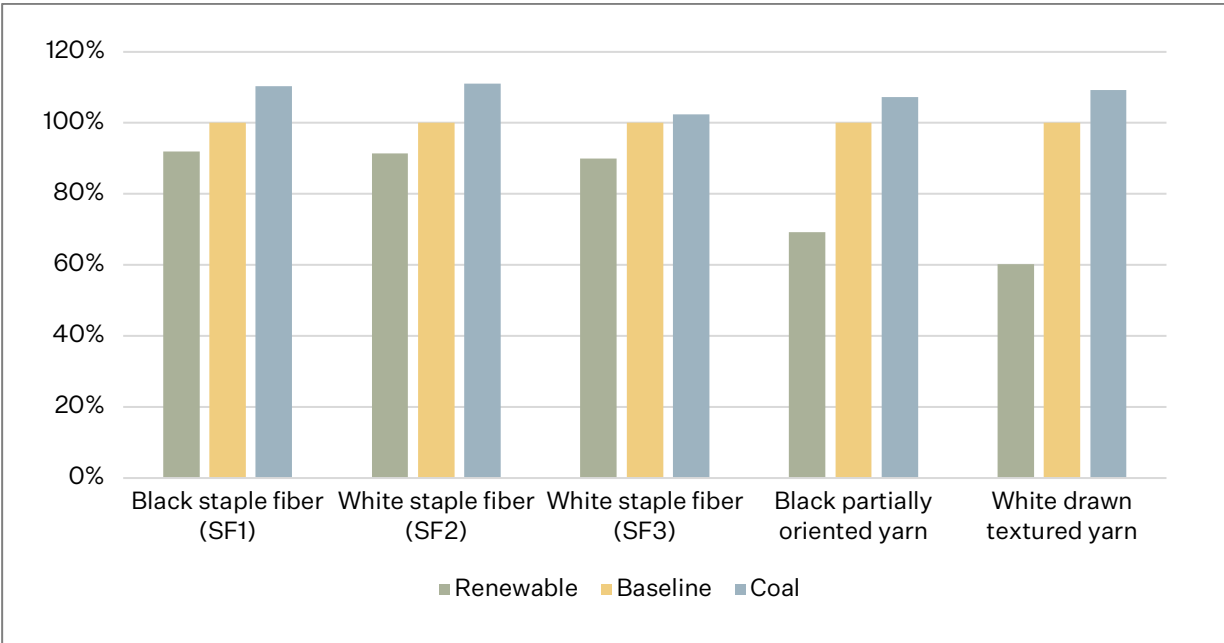


Figure E-5: Electricity sensitivity analysis—climate change—virgin PET production



The results of the electricity sensitivity analysis showed that changing the source of electricity used by a manufacturing facility will affect the overall environmental climate change impact, sometimes substantially. The magnitude of change is dependent upon the amount of coal or renewables used in the baseline electricity mix, as well as the amount of electricity used by the PET production process. This analysis highlights that using renewable energy reduces the impact from electricity production. Companies looking to set up new recycling facilities should look for regions with large amounts of renewable energy in the grid mix, consider entering into contracts

with renewable energy producers, or install onsite renewable energy to see lower environmental impacts. Similarly, textile brands should source PET chip from producers who use large amounts of renewable energy in their production process.

Transport sensitivity analysis results

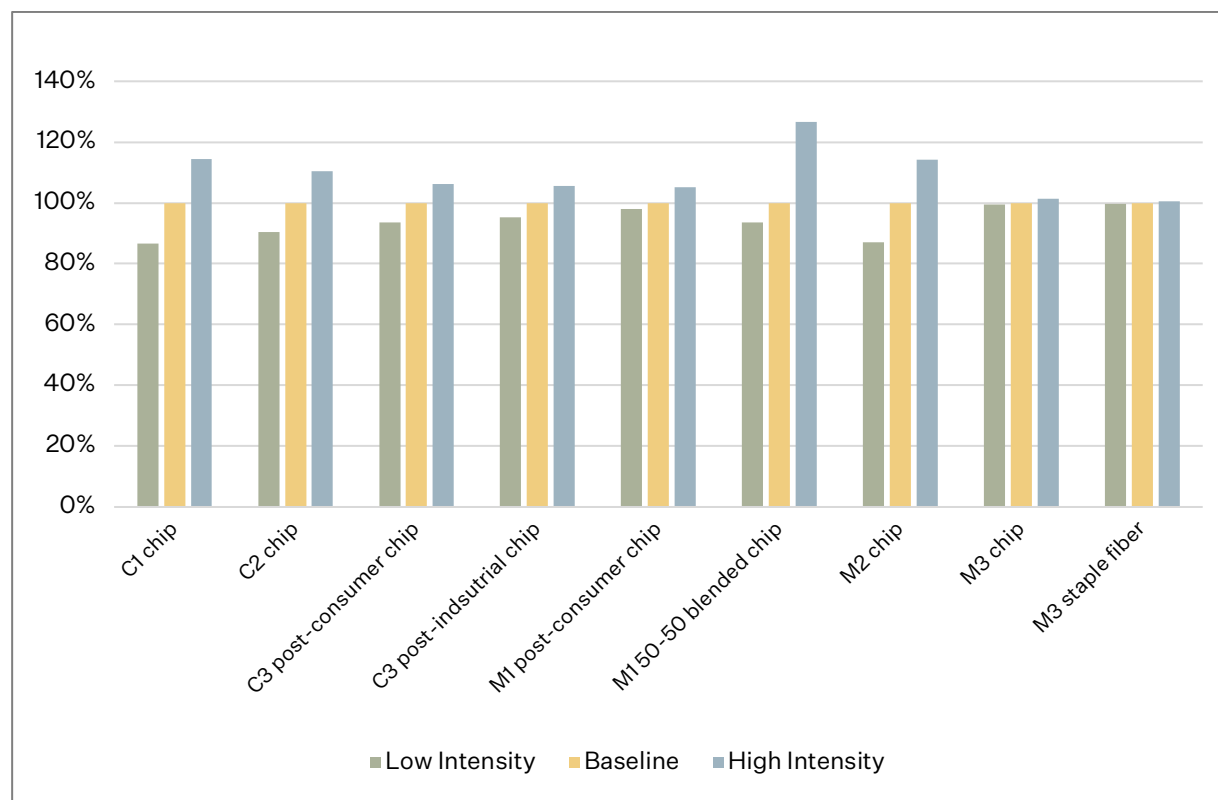
For each recycler included in the study, there are two legs of transport: feedstock collection and raw material transport. Feedstock collection covers the gathering of waste feedstock, while raw material transport refers to moving the collected waste to the recycling facility.

For waste bottles, feedstock collection involves acquiring the waste bottles for processing, and raw material transport moves the collected bottles to the recycling facility. For post-consumer textile waste, feedstock collection includes acquiring of waste textiles, and raw material transport delivers the collected textile waste to the recycling facility. In the transport sensitivity analyses, only the feedstock collection stage was tested due to uncertainties in transport distances. The raw material transport was excluded from testing because its distances were provided by data providers.

For each chemical and thermomechanical recycler, a high- and low-truck transport scenario was modeled, which varied the distance required to collect PET waste and the intensity of the emissions from the combustion of the fuel used by the trucks. Similar to the electricity scenarios, these transport scenarios were created to understand how the likely minimum and maximum environmental impact from upstream PET waste transport could affect the results, with the high-intensity scenario representing the worst environmental impact and the low-intensity scenario representing the opposite. Each data provider had its own high- and low-intensity scenarios, which were based on the emission regulations within the area they operate, and the baseline transport distance modeled.

For each data provider, the low intensity transport scenario assumed a transport distance of 32–50 km for upstream feedstock collection, and a low intensity emission standard. For the high-intensity scenario, the baseline upstream collection distance was doubled, and a high-intensity emission standard was used.

Truck transport was the sole focus of this scenario. While ship transport can be part of the upstream supply chain, it is not relevant for the data providers in this project, as truck transport contributes substantially more to environmental impact per ton-kilometer; ships can transport significantly more mass using less fuel than trucks. The transport scenario varies the cleanliness of truck engines and the resulting emissions from fuel combustion, in addition to changes in the distance required to collect PET waste. The transport scenario only focuses on recycling technologies. Virgin production of PET is excluded from this sensitivity analysis, as transport of raw materials was a negligible contribution to total impact.

Figure E-6: Transport sensitivity analysis—climate change—chemical and thermomechanical recycling

Overall, the transport sensitivity analysis shows that changes in truck transport intensity can greatly affect the climate change results. Longer transport distances and less stringent emission standards both increase impacts, while shorter distances and more stringent emission standards reduce them. Among the two, transport distance has a stronger influence on the climate change impact. More stringent emission standards help reduce specific pollutant-related impacts (for other impact categories such as acidification, eutrophication, and freshwater ecotoxicity), but reductions in transport distances—such as through local sourcing—yield broader and more significant reductions. Therefore, both emission standards and transport distance should be considered, but the latter remains the dominant factor when assessing the environmental performance of upstream transport for recycled PET chip.

Chemical sensitivity analysis results

Chemical sensitivity analyses were performed to address uncertainty regarding the origin and production methods of key chemicals used in chemical recycling (ethylene glycol and methanol) and virgin PET production (purified terephthalic acid and monoethylene glycol). These chemicals contribute significantly to the overall environmental impacts of both processes. Although the names and locations of chemical suppliers were provided by data providers, it is unclear whether these sites were manufacturing plants, warehouses, distribution centers, or other non-production facilities.

The ecoinvent database contains multiple production datasets for the same chemical, differentiated by manufacturing location and technology, as well as market-average datasets (for example, global, European, Asian) representing average production within a given region. Production in different regions uses varying technologies and electricity mixes, which lead to different environmental impacts. In the baseline results presented in sections 3.5, 4.5, and 5.5,

either a global average dataset or a regional dataset corresponding to the reported production location was used.

For the sensitivity analysis, ecoinvent market datasets with the lowest and highest environmental impacts for methanol, ethylene glycol, and purified terephthalic acid were selected, in order to establish the minimum–maximum range of impacts and assess how this variability influences the overall results for chemical recycling and virgin PET production; when impact results across different impact categories did not show a consistent pattern, the climate change impact was used to guide which dataset was chosen as the minimum or maximum.

In addition to using ecoinvent market datasets for ethylene glycol (also referred to as monoethylene glycol), LCIA data taken from a published journal article on the impacts of coal-to-ethylene glycol production was used; ecoinvent does not contain any data on coal-to-ethylene glycol (CtEG) production. Ethylene glycol (EG) is commonly produced through the direct hydration of ethylene oxide (Zhang et al., 2024), which is ultimately derived from oil or natural gas. This pathway is the standard practice globally and is reflected in the ecoinvent EG datasets (Ecoinvent, 2024b). However, EG can also be produced using a more energy-intensive process that utilizes coal instead of oil or gas as the feedstock. This CtEG process is used in China, along with the traditional EG production route. The climate change results of the chemical sensitivity analysis are shown below in figure E-7 and figure E-8.

Figure E-7: Chemical sensitivity analysis—climate change—chemical recycling

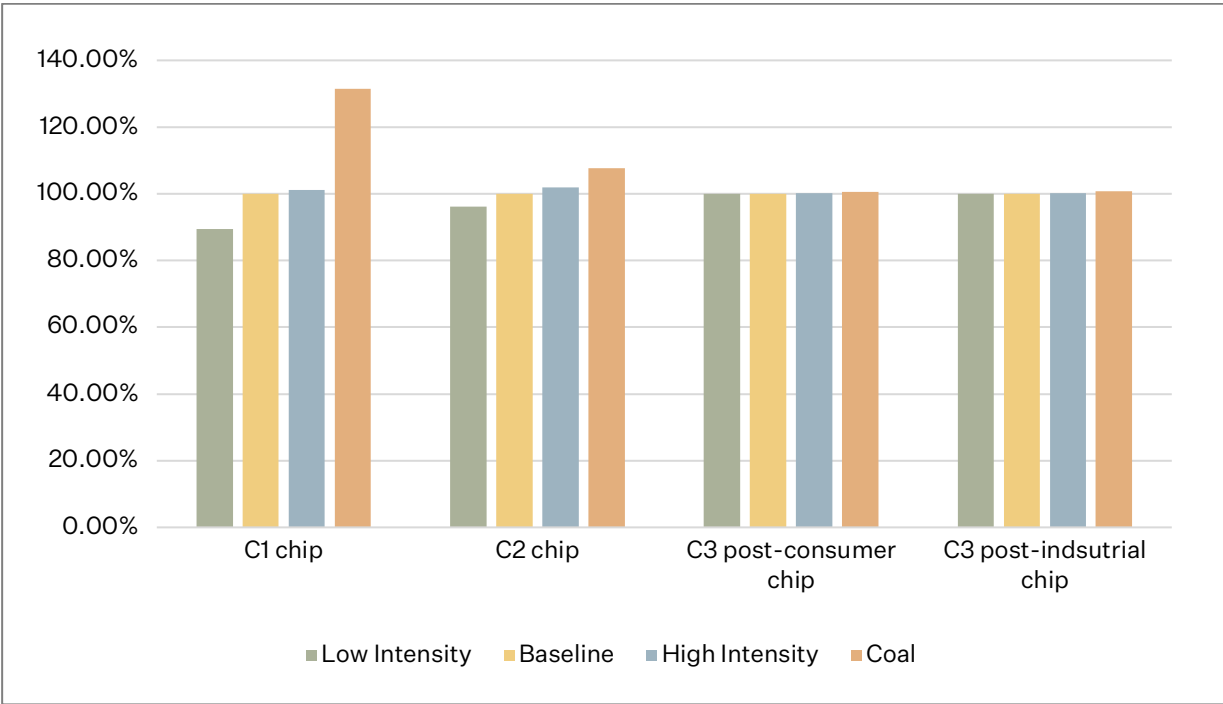
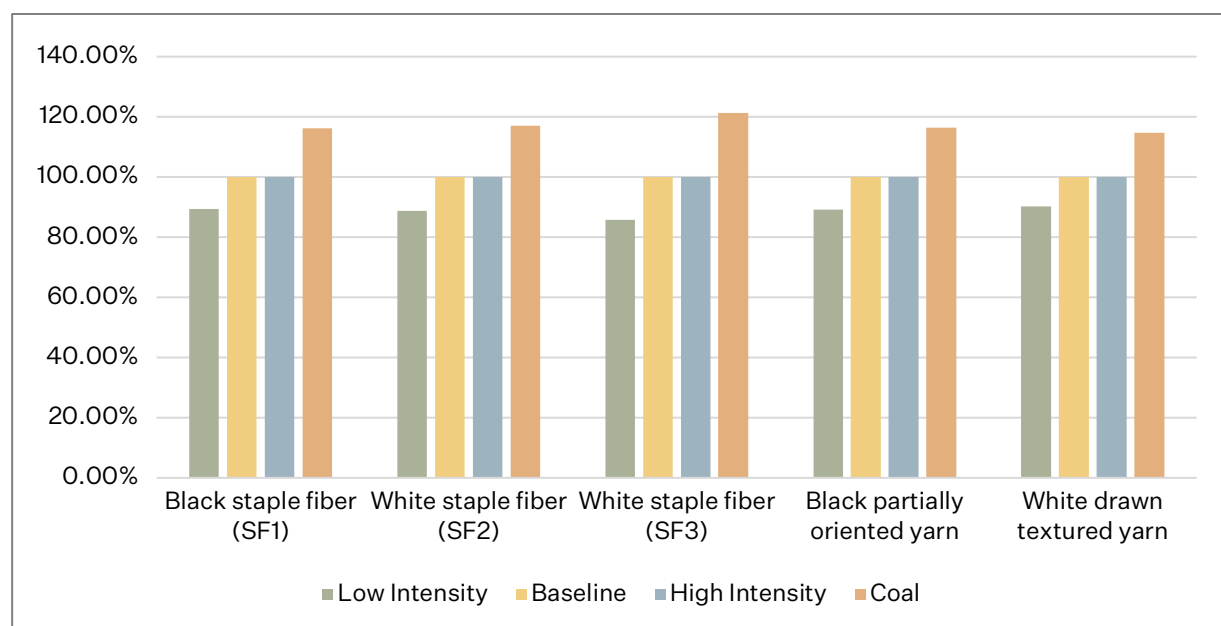


Figure E-8: Chemical sensitivity analysis—climate change—virgin PET production

The results of the sensitivity analysis show that variation in chemical datasets can affect outcomes, particularly for systems that rely more heavily on virgin chemical inputs. For chemical recycling, C1 and C2 are sensitive to differences in ethylene glycol and methanol, with changes to climate change impacts ranging from decreases of 4–11% when lower impact datasets are applied, to increases of 8%–32% when CtEG ethylene glycol and coal-based methanol are used. By contrast, C3 uses only small quantities of EG, contributing less than 1% of total impacts, and, therefore, shows minimal variation across dataset choices.

For virgin PET, substituting alternative datasets for PTA and MEG leads to decreases in climate change impacts of about 10–14% in lower-impact cases, and increases of about 15–21% when CtEG MEG and higher impact PTA are modeled. These findings confirm that upstream chemical production is a key driver of overall results, with ethylene glycol and methanol determining sensitivity for chemical recycling, and PTA and MEG dominating virgin PET production. While this study relies on the most recent ecoinvent datasets, obtaining supplier-specific information on chemical production routes would allow further refinement of future assessments.

Limitations and data quality

Several important limitations should be considered to ensure the results are interpreted appropriately. The system boundary for this study is cradle-to-chip or cradle-to-staple fiber for all recycled products, while for virgin production, cradle-to-partially oriented yarn and drawn textured yarn are also considered. Therefore, the downstream applications of the PET chip, staple fiber, and filament yarn are not considered. While the recycled products in this study have been confirmed to be functionally equivalent to their virgin PET counterparts, it was not possible to determine whether differences exist within later stages of the supply chain, such as for dyeing and finishing.

Other limitations arise due to the lack of certain data, including upstream waste collection distances, the confidential organic catalysts and additives used by chemical recycler C1, the proprietary solvent used by chemical recycler C3, and the upstream agricultural processes involved in the bagasse-based bioenergy used by thermomechanical recycler M3 and virgin producer V1. Additionally, data provider C3's LCI data is not from commercial operations, but instead from detailed mass and heat balances based on testing conducted at a pilot plant

combined with detailed engineering plans. As such, this data does not represent commercial-scale operation and caution should be used when interpreting C3's LCA results. Given the use of specific facility modeling choices and the variability between suppliers, the LCA results reported here should not be used to extrapolate to an industry average for these types of processes, if better data is available. These facilities may represent better-than-average scenarios.

Finally, the characterization methodologies used to estimate the different environmental impact categories all include a level of uncertainty due to the underlying model within each methodology; these are discussed at length in the literature (Cascale, 2024; Wolf et al., 2010; European Committee for Standardization, 2019).

Conclusion and recommendations

Polyester is widely used in the fashion industry due to its physical advantages, such as durability and low cost, but it can also have harmful environmental and social impacts, especially related to its waste, which are explored in this study. Recycling technologies are one solution to help address textile waste. The LCA methodology is an important tool to help understand the environmental impacts associated with different recycling methods, and to better understand the impacts associated with virgin production of PET. However, the lack of data on the production of virgin PET from Asia, which produces over half of the world's PET (Coherent Market Insights, 2025; Research and Markets, 2023; Intel Market Research, 2025), and on different recycling technologies, especially chemical recycling, reduces the accuracy and usefulness of LCAs. This study conducted a non-comparative LCA of five different data providers, utilizing a variety of thermomechanical, chemical, and virgin production technologies to help address these data gaps.

As far as the authors are aware, this study includes the first known, publicly available, LCI data and LCIA results on virgin production of PET melt, chip, and staple fiber produced from Southeast Asia, as well as new LCIA results on thermomechanical and chemical recycling technologies. The results of the LCAs revealed that electricity and chemical use were hotspots within both the virgin and recycled PET product systems included in this study. These are intended to serve as default values only when more specific data is not available. Collection of waste feedstock was also a significant contributor of impact to the chemical and thermomechanical recyclers; however, it played a larger role for thermomechanical recyclers that almost exclusively recycled post-consumer PET bottles. Post-consumer waste was generally more widely dispersed than post-industrial waste and, thus, required more transport. The findings of the sensitivity analyses show that the source of electricity used (for example, renewables or coal), and the distance required to collect waste feedstock, need to be considered, as variations in either parameter can substantially change the results.

The results presented in this study should only be used when they are geographically, temporally, and technologically representative of the product system being modeled, or when better data is not available.

In addition to the quantitative findings discussed above, recommendations to improve future LCAs on this topic and to help businesses tackle challenges related to the production, use, and recycling of polyester are discussed below.

LCA methodology recommendations

- Improve traceability of post-industrial and post-consumer textile waste sorting and collection to greatly improve the availability of data for facilitating better accuracy of future LCAs.
- Build upon existing relationships with recyclers and their supply chains to continue to improve data availability.

LCA insights for business action

- Collaborate with recyclers to innovate together in tackling post-consumer textile waste recycling and invest in better sorting technologies to improve the viability of post-consumer textile waste recycling. Better sorting would enable the separation of different fibers in blended fabrics, and the removal of contaminants before the recycling process, leading to better quality and environmental outcomes.
- Use renewable energy at recycling facilities and source textile products from recyclers who use high amounts of renewable energy to significantly reduce environmental impacts. Companies should consider their source of electricity when designing and choosing locations for recycling facilities and consider contracts with renewable energy producers. Textile brands should support waste recyclers with transitioning to renewable energy sources, especially post-consumer recyclers, to counteract the increased energy needed for the additional processing of post-consumer waste.
- Find ways to decrease truck transport emissions, especially those associated with the collection of waste feedstock, to further reduce impacts. Establishing recycling facilities near sources of textile waste, sourcing waste locally, and using cleaner (train or electric truck) or more efficient (ship) forms of transport will all lower environmental impacts when other sources of emissions are constant.
- Consider tradeoffs between chemical and thermomechanical recycling methods, each with distinct advantages and limitations. Thermomechanical recycling is generally less environmentally intensive but is limited to clean, high-quality waste (Patel et al., 2024) and is, at present, mostly used to recycle post-consumer PET bottles. In contrast, chemical recycling is more flexible and can process a wider range of waste, including post-consumer textiles with dyes and contaminants, though it generally has a higher environmental impact (Closed Loop Partners, 2023).

1. Introduction

Polyester's low cost (United Nations Regional Information Centre for Western Europe, 2024), durability, versatility (Wankai Global, 2024c) moisture resistance, (Wankai Global, 2024a; Wankai Global, 2024c), and color retention (Wankai Global, 2024a; Wankai Global, 2024c), have made it the most popular fiber in the world, making up 57% of the global fiber market (Textile Exchange, 2024a). While the word polyester can refer to a group of polymers with specific repeating chemical bonds, in the context of the textile, apparel, and fashion industry, polyester refers to a fiber that is made from polyethylene terephthalate (PET), which is currently the predominant polyester used in the industry (Palacios-Mateo et al., 2021). Both polyester and PET are used interchangeably within this report.

Polyester's advantages, along with the global economy's push to overconsume, have led to serious environmental and social costs. The durability of polyester allows it to persist for decades before it biodegrades (Palacios-Mateo et al., 2021). Fast fashion, a growing trend within producer and consumer textile culture, prioritizes the rapid production of trendy, affordable clothing, and encourages overconsumption and waste (Baloyi et al., 2024). This has led to increased consumption and shorter usage cycles for clothing (Reichart and Drew, 2019). In the European Union (EU), less than half of clothes are collected for reuse at the end of their life, and only 1% of clothes are recycled (European Parliament, 2020). Instead, the majority of textile waste (87%) is incinerated or landfilled (European Parliament, 2020). Of the <50% of textiles collected for reuse or recycling, only 30% are resold in domestic markets, with the vast majority (70%) ending up in countries in the Global South, like Africa (Burke, 2015; Kokutse, 2024). While second-hand clothing markets in African countries once supported large sections of their economy, the decreasing cost and value of clothing, and corresponding increase in consumption and waste generation, have substantially reduced the resale value of these second-hand textiles (Burke, 2015). In Kenya, half of the imported clothing is too low in value for resale. Kenya receives over 140,000 metric tons of used clothing each year, meaning that over 70,000 tons are discarded (Burke, 2015). Many of the communities located in the Global South lack the infrastructure to properly dispose of these waste garments, and they are forced to dump them in the environment or burn them in open pits (Kokutse, 2024).

It's not only the waste from textiles that leads to negative environmental impacts. The extraction and consumption of crude oil and natural gas used to create the chemical components of PET have significant environmental impacts, including air and water pollution, greenhouse gas emissions, and habitat destruction (Bertrand, 2021). Since fossil fuels are non-renewable, their use for PET also depletes these finite resources. The washing of polyester garments and the fragmentation of waste textiles, including polyester, in open landfills, and due to weathering, can eventually lead to the release of any harmful additives used during production, as well as microplastics (European Environment Agency, 2022; European Parliament, 2020). Between 200,000 and 500,000 metric tons of microplastics enter the ocean every year, out of which 16–35% are estimated to be from synthetic textiles (European Environment Agency, 2022). While the environmental and health impacts of microplastics are still being studied, they've been linked to physical harm, reduced feeding, and impaired growth and breeding in marine animals (Plastic Soup Foundation, 2021). In humans, studies suggest that microplastics lead to respiratory issues and inflammation, along with other impacts related to the numerous chemicals within the plastic (Plastic Soup Foundation, 2021; Stanford University, 2025).

Recycling is one important solution to help reduce these impacts (World Economic Forum, 2023; US Government Accountability Office, 2024), along with other key actions, including finding ways to reduce overproduction and overconsumption, and designing for circularity. Increasing the percentage of PET waste textiles that are recycled each year would keep materials in circulation for longer, and delay or reduce the incineration and landfilling of waste PET. It could also lessen the

amount of waste textiles exported to developing countries and, potentially, displace the production of new, or virgin, PET. Displacing virgin production would both slow the use of finite fossil resources and reduce climate change, as well as other environmental impacts of PET production (Joseph et al., 2024). However, as the pressure to increase textile recycling grows, it's important to understand the strengths and weaknesses of current and near-commercial PET textile recycling methods—both from logistical and environmental perspectives.

Life cycle assessment (LCA) is one of the most widely used methodologies to assess environmental impacts from the production of materials, including the impacts associated with the extraction and processing of crude oil and natural gas, manufacturing activities, and transportation. However, the accuracy of an LCA is only as good as the quality of data on which it is based. As of the writing of this report, there is no data on the production of PET chip, resin, or staple fiber from Asia; these intermediate PET products are used to produce all other polyester textiles. While exact numbers are not available, it is clear that Asia produces over half of the world's PET, with China producing more PET than any other country globally (Coherent Market Insights, 2025; Research and Markets, 2023; Intel Market Research, 2025). Instead, data from the production of PET in Europe or the United States is commonly used to represent other countries' PET production (Holding, 2024). Another issue is the use of outdated data (typically data >10 years old). These data gaps not only lead to less accurate assessments but also hinder government and stakeholder trust in using LCAs to determine environmental impacts (Haugsrud and Klepp, 2025).

In addition to the lack of data on existing PET recycling methods, a new category of chemical recycling technologies is being developed to improve the ability of textile-to-textile recycling. Currently, the majority of recycled PET waste is thermomechanically recycled (Nageler-Petritz, 2023), with 98% of recycled polyester produced using post-consumer bottles (Textile Exchange, 2024a). While using post-consumer bottles to produce textiles diverts bottle waste away from landfills and incineration, it also diverts feedstock away from the bottle industry, reducing this industry's ability to produce new bottles from its own waste. Additionally, this practice does not address the growing volume of PET textile waste that continues to be landfilled, incinerated, or released into the environment (Wenzel, 2024). Thermomechanical recycling is limited to using high-quality, homogenous wastes that have limited amounts of chemical contaminants and additives. Post-consumer textile waste, on the other hand, is composed of many different materials, is typically dyed, contains additional components (such as zippers), and usually has a variety of additives mixed into the PET to enhance different performance characteristics. These new chemical recycling technologies hope to address some, if not all, of these issues.

To help close the data gaps described above and better understand the environmental impacts of thermomechanical and chemical recycling methods, this study collected 2022–2024 production data from five different PET producers, utilizing a variety of thermomechanical recycling, chemical recycling, and virgin production technologies in Europe, the United States, Southeast (SE) Asia, and China. Secondary data, primarily from the ecoinvent 3.11 database, was selected based on how recently the data was collected, as well as its technological and geographical representativeness; where possible, secondary data less than 10 years old was used. Both waste textile (post-consumer and post-industrial) and post-consumer waste bottle feedstocks were studied. Extensive interviews were conducted with these data providers, and many others who ultimately did not participate in this project, to understand their recycling markets, the types of waste PET they are able to recycle, and any limitations associated with the products they produce. These interviews were instrumental in the definition of the scope and system boundary of the study, and key takeaways from these interviews have been included in this report as qualitative findings, in addition to the life cycle impact assessment results.

While the life cycle assessment (LCA) methodology captures impacts related to the environment, it does not cover impacts on people, such as those that may affect workers' and communities' human rights. The production of all materials, including polyester garments, has been linked to

labor exploitation, poor wages and working conditions for factory workers, and causes detrimental pollution to communities located close to production facilities or landfills (United Nations Regional Information Centre for Western Europe, 2024). Textile Exchange and its project partners believe it is important to understand these social impact areas when sourcing and using polyester. Because of this, an additional component referred to as “LCA+,” which is based on a social risk survey completed by participating data providers, and a literature review on the current state of polyester production, has been added to appendix B of this LCA study. This “LCA+” assessment does not aim to provide a comprehensive analysis of the social footprint of polyester. Rather, this assessment aims to highlight the importance of understanding the social impacts alongside the environmental impacts and provide readers with a foundational understanding of key human rights risk areas related to this production system.

While this LCA+ study serves an important goal, it is essential to note that there are other serious issues related to the textile industry that this assessment does not address, such as overproduction and overconsumption of textiles, microplastic pollution, material efficiency, and the effect that different types of recycling technologies have on the weaving, dyeing, and finishing stages of the textile supply chain.

This study was led by Textile Exchange, in partnership with SCS Consulting Services (SCS). Textile Exchange is a global non-profit driving beneficial impacts on climate and nature across the fashion, textile, and apparel industry. It guides a growing community of brands, manufacturers, and farmers towards more purposeful production, right from the start of the supply chain. SCS Consulting was launched in 2019 and provides industry-leading climate, nature, and sustainability advisory solutions. SCS Consulting advises companies, NGOs, government agencies, and other stakeholders worldwide to identify and develop market-driven sustainable outcomes and policies that advance the goals of sustainable development and give innovators a competitive advantage.

For nearly 35 years, the SCS LCA team has been completing LCAs for major industries, NGOs, and governments.

1.1. Background on polyester production

1.1.1 Virgin polyethylene terephthalate (PET) production

Polyethylene terephthalate (PET) is a type of plastic that is commonly used in many different industries: packaging, consumer goods, medical applications, automotive industry, construction, and, of course, textiles. It is a polymer built from repeating units of monomers (small molecules) that are connected with ester bonds. An ester bond is a carbon-oxygen double bond and a single bond to another oxygen atom, $-C(=O)-O-$. PET is produced by a chemical reaction involving monoethylene glycol (MEG) and either purified terephthalic acid (PTA) or dimethyl terephthalate (DMT), all derived from petrochemical sources (UNFCCC, 2021). This process, known as polymerization, forms long chains of repeating molecules linked by ester bonds.

MEG and PTA are both produced using key raw materials derived from crude oil and natural gas. Crude oil and natural gas are extracted from underground reservoirs using drilling rigs (Wankai Global, 2024b). Crude oil is refined by distillation into several fractions, or chemical products of distillation, such as naphtha, which is a key feedstock for petrochemicals (Wankai Global, 2024b). Natural gas is processed to produce gases like ethane, methane, and propane (Wankai Global, 2024b). Ethylene for MEG production is most often produced by steam cracking of naphtha or ethane (which are derived from crude oil and natural gas), or other suitable feedstocks, and then oxidized to ethylene oxide and combined with water to produce MEG (Wankai Global, 2024b). This process is known as the ethylene oxide hydration pathway, referred to in this report as the ethylene oxide pathway. Naphtha can also be used to produce paraxylene, which can be oxidized to produce PTA (Wankai Global, 2024b).

In addition to the ethylene oxide pathway, MEG can also be produced from coal syngas through the dimethyl oxalate route (Qian et al., 2022). This process, referred to as coal-to-ethylene glycol (coal-to-EG) in this report, is used in China (Qian et al., 2022). For this study, MEG production is modeled using the ethylene oxide pathway available in ecoinvent (Ecoinvent, 2024b).

1.1.2 Types of PET waste

As noted in the introduction, it is imperative that we improve our ability to recycle PET waste textiles. Waste textiles for recycling are often divided into two categories: post-industrial and post-consumer. Post-industrial waste is produced by production facilities at different stages of a supply chain before the material has been used by a consumer. Because of this, it generally represents less processed, cleaner, homogenous waste, which is much easier to recycle as it requires less sorting, disassembling, and cleaning. There is typically more knowledge about what the post-industrial waste consists of, as it is bought and sold from waste generators and recyclers. For textiles, post-industrial waste is off-cuts, trimmings, and materials that fall below quality control standards. In contrast, post-consumer waste is generated by consumers after they have used it. Post-consumer waste usually comprises finished products made of many different materials and chemicals. It can be contaminated by consumer use and have different levels of wear and damage. Post-consumer waste is often unsorted and can include a wide variety of products and components, as well as blended materials. For textiles, post-consumer waste includes shoes, clothing, linens, and carpets, among other things.

1.1.3 Thermomechanical recycling

The majority of PET waste is recycled thermomechanically (Textile Exchange, 2024a), which is a recycling method that involves physical processes (cleaning, grinding, shredding, and melting) to turn plastic waste into new products. Currently, 98% of recycled polyester is made using recycled plastic bottles (Textile Exchange, 2024a). Thermomechanical recycling is an effective way to recycle PET bottle waste; however, it has limitations. The physical processes used by thermomechanical recycling do not affect the chemical structure of the PET. This leaves the polymer intact and does not remove colors, additives, or contaminants that have been added or become embedded within the PET (Neste, 2025). This forces thermomechanical recyclers to use relatively high-quality, uncontaminated bottle waste and leads to a PET product that has a similar color to the bottles being recycled. During the thermomechanical recycling process, the waste feedstock is subjected to high heat and high shear forces, which lead to a decreased quality of final products over time. This limits the number of times PET can be recycled before it must be downcycled or used for a different product that has lower quality requirements (Patel et al., 2024). Sometimes, virgin PET is mixed into the recycling process to improve yields and quality (UNEP—Basel Convention, 2020), although this wasn't the case for the thermomechanical recyclers included in this study. Relying on high-quality, post-consumer bottles for recycled textiles does not address textile waste and can lead to shortages of feedstock, as demand grows for using post-consumer bottles to produce recycled goods in a variety of industries (Textile Exchange, 2024a).

1.1.4 Chemical recycling

In contrast to thermomechanical recycling, chemical recycling is a relatively new process that can accept a wide variety of waste, including post-industrial and post-consumer textiles. Chemical recycling either fully or partially depolymerizes PET polymers, breaking them down into smaller molecules, such as monomers or oligomers, which can then be repolymerized to create new plastic products (Closed Loop Partners, 2023). Oligomers are small polymer chains that consist of a few monomer units. Depolymerization allows for chemical additives (such as finishes and performance enhancers), contaminants, and, often, colors to be removed from the PET, which increases the types of PET wastes that can be accepted. While chemical recycling can produce high-quality PET products that are not limited in the number of times they can be recycled, it does still typically rely on virgin chemicals (such as ethylene glycol and purified terephthalic acid) to maintain the quality of its recycled products. In some cases, biobased ethylene glycol or recycled purified terephthalic

acid may be used instead of virgin chemicals. In addition, chemical recycling is generally a more intensive process that requires more energy and chemicals than thermomechanical recycling.

A significant challenge for textile recycling is the complexity of post-consumer textiles. Finished textiles are often made with blends of different fibers (for example, cotton, polyester, nylon, elastane, and viscose). Current PET chemical recycling technologies can only accept small amounts (<4–15%)¹ of some of these materials, which usually must first be separated and then individually recycled (Loo et al., 2023). The interwoven, multi-layer design of many textiles make it challenging to automate the sorting and pre-processing/de-trimming processes, while reliance on manual sorting and pre-processing greatly increases the economic costs of recycling. New sorting technologies are being developed to address this challenge, but have yet to be adopted at a commercial level. At present, most commercial chemical recyclers focus on post-industrial waste to avoid the technological and economic challenges of dealing with post-consumer waste. Overall, the PET chemical recycling space is still in its early stages, with new technologies continuously being developed and tested for commercial viability. These emerging solutions are also being specialized to handle specific types of post-industrial and post-consumer waste. The descriptions below capture only some of these technologies.

One of the most common types of chemical recycling is solvolysis, a chemical reaction that breaks down chemical bonds with the use of solvents. Commonly used solvents include glycols, methanol, and water (Bengtsson et al., 2022). All three chemical recyclers included in this study use solvolysis.

- Glycolysis, which uses ethylene glycol to break PET bonds, is one of the oldest methods of chemical recycling (Babaei et al., 2024) used industrially, due to mild reaction conditions such as low operating temperature and pressure (Shirazimoghaddam et al., 2023). However, it produces a limited yield of bis(2-hydroxyethyl) terephthalate (BHET), the intermediate product that can be purified and used to make new PET (Shirazimoghaddam et al., 2023).
- Methanolysis, another type of solvolysis, uses methanol at high temperatures and pressures to break down PET into dimethyl terephthalate (DMT) and ethylene glycol. This method can handle waste feedstock with high levels of contaminants; however, it results in a complex mixture of many chemicals apart from the two main products (Payne and Jones, 2021). The separation of DMT from other products requires more electricity and produces more waste (Payne and Jones, 2021).
- Hydrolysis is the process of breaking down PET bonds using water or steam. This chemical recycling method can process highly contaminated waste streams but needs to be operated at high temperatures and pressures (Payne and Jones, 2021). It also yields terephthalic acid with low purity, which requires further processing before it can be polymerized back into PET (Payne and Jones, 2021).

Several chemical recycling technologies do not use solvents, including conversion technologies like pyrolysis and gasification.

- Pyrolysis is the process of depolymerizing PET using heat in the absence of oxygen. However, the application of this technology for plastic recycling is new, with a few commercial-scale plants starting operations recently and several others still under development (Jeswani et al., 2021; Tullo, 2022).
- Gasification converts used plastics to carbon monoxide and hydrogen (collectively called syngas), which can then be used to produce PET. Gasification can process a wide variety of plastic feedstocks that do not need to be separated. However, the syngas produced would

¹ Based on primary data from data providers included in this study.

then need to be converted into monomers, and then into PET, requiring more resources (Trapp and Murphy, 2021). Gasification of waste plastics has only been conducted at lab and pilot scales (Afzal et al., 2023).

A summary of the strengths and limitations of different polyester production technologies are shown in Table 1 below. The strengths and limitations of various chemical recycling technologies are shown in Table 2.

Table 1: Strengths and limitations of virgin and recycled polyester production technologies

Production method	Strengths	Limitations	Feedstock/types of accepted waste
Virgin production	Low cost to produce (United Nations Regional Information Centre for Western Europe, 2024) High efficiency of manufacturing process (Wankai Global, 2024c)	Reliance on finite, fossil-based raw materials (Joseph et al., 2024) High environmental and social impacts related to production and waste (Joseph et al., 2024)	Petrochemical compounds (MEG and PTA) (Wenzel, 2024)
Thermomechanical recycling	Low cost and efficient to operate (Alliance to End Plastic Waste, 2025) Widely applied and mature technology (TotalEnergies, 2025)	Requires high quality, uncontaminated feedstock (Total Energies, 2025) Does not remove colors or additives in the waste feedstock (Neste, 2025) Limited in the number of times PET can be recycled before it must be downcycled (Patel et al., 2024) - Does not address the problem of textile waste	Clean PET bottles and containers (Neste, 2025) Homogeneous, post-industrial textile waste
Chemical recycling	Can accept various types of post-industrial and post-consumer textile waste Some chemical recycling technologies can decolor the waste they process Supports textile-to-textile recycling	High costs due to complex processes (Paramount Global, 2024) High energy and resource use (Paramount Global, 2024) Higher environmental impact from more intensive recycling process (Paramount Global, 2024)	Post-industrial and post-consumer textile waste Mixed plastics (Trapp and Murphy, 2021)

Table 2: Strengths and limitations of different chemical recycling technologies

Recycling method	Technology description	Strengths	Limitations
Hydrolysis	Process of breaking down PET bonds using water or steam Monomers produced are terephthalic acid and ethylene glycol (Payne and Jones, 2021)	Processes highly contaminated waste streams (Payne and Jones, 2021)	Requires high temperatures and pressures (Payne and Jones, 2021) Yields low purity terephthalic acid (Payne and Jones, 2021)

Recycling method	Technology description	Strengths	Limitations
Methanolysis	Process of breaking down PET at high temperatures and pressures into dimethyl terephthalate (DMT) and ethylene glycol (Payne and Jones, 2021)	Processes highly contaminated waste streams (Payne and Jones, 2021)	Produces complex mixture requiring more electricity to purify and more waste (Payne and Jones, 2021)
Glycolysis	Process of using ethylene glycol to break PET bonds Produces bis(2-hydroxyethyl) terephthalate (BHET) as the primary monomer (Babaei et al., 2024)	Mild reaction conditions (low temperature and pressure) (Shirazimoghaddam et al., 2023)	Limited yield of BHET, (Payne and Jones, 2021), the intermediate product that is polymerized back to PET
Pyrolysis	Depolymerization of PET using heat in the absence of oxygen Produces a complex mix of chemical compounds (Jeswani et al., 2021)	Can handle a wide range of plastic feedstocks (Jeswani et al., 2021)	Still under development; not widely operated commercially (Jeswani et al., 2021)
Gasification	Conversion of used plastics to carbon monoxide and hydrogen (collectively called syngas) (Trapp and Murphy, 2021)	Can handle a wide range of plastic feedstocks (Trapp and Murphy, 2021)	Requires conversion of syngas into PET monomers and then into PET, needing more resources (Trapp and Murphy, 2021) Not widely commercialized (Afzal et al., 2023)

1.2. Goals of the study

The goals of the study are to:

- **Create a publicly available, non-comparative LCA report** for the various virgin production, thermomechanical, and chemical recycling technologies for which data was able to be collected.
- **Include an assessment of the social impacts** involved with the production of virgin and recycled PET chip and staple fiber, which is added as appendix B within this report. While the LCA was critically reviewed by a panel of LCA experts in conformance with ISO 14044, this social assessment was not reviewed.
- **Generate robust LCA datasets** for polyester production using consistent and transparent methods aligned with the ISO 14040 and ISO 14044 standards. These datasets will reflect actual production conditions and practices in selected countries and systems.
- **Support credible Scope 3 reporting** and environmental-impact accounting by providing supply chain actors with reliable default inventory data, especially where supply chain-specific data is unavailable or no longer fit for purpose.
- **Fill critical data gaps** identified in existing LCA literature and datasets, particularly regarding different polyester production technologies.
- **Inform future improvements and updates** by establishing a methodological framework that can be refined over time, supporting the ongoing development of life cycle inventory data in a dynamic and evolving industry.

1.3. Scope of the study

This report examines the production of virgin PET, thermomechanically recycled PET chip, and chemically recycled PET chip from five data providers across four regions. All three chemical recyclers use solvolytic processes for depolymerization of the waste feedstock. More details on the technology used by them, and other data providers, are provided in sections 3.2, 4.2 and 5.2.

Table 3: Scope of the LCA study

Data provider	Region of operation	Feedstock	Data collection period	Functional unit
Chemical recycler 1 (C1)	China	Post-industrial textile waste	August 2023–January 2024	1 kg chemically recycled PET chip
Chemical recycler 2 (C2)	China	93% post-industrial textile waste and 7% post-consumer textile waste	January–October 2024	1 kg chemically recycled PET chip
Chemical recycler 3 (C3)	Europe (pre-commercial operation)*	100% post-industrial and separately, 100% post-consumer textile waste	October 2022*	1 kg of post-industrial chemically recycled chip; 1 kg of post-consumer chemically recycled PET chip
Thermomechanical recycler 1 (M1)	United States	Post-consumer bottle waste (100%); A 50-50 blend of post-industrial textile waste and post-consumer bottle waste for their blended chip	January–December 2023	1 kg of post-consumer thermomechanically recycled PET chip, 1 kg thermomechanically recycled 50-50 blended PET chip
Thermomechanical recycler 2 (M2)	China	Post-consumer bottle waste (100%)	January–December 2023	1 kg of thermomechanically recycled PET chip
Thermomechanical recycler 3 (M3)	Southeast Asia	Post-consumer bottle waste (100%)	January–December 2022	1 kg of thermomechanically recycled PET chip; 1 kg of thermomechanically recycled staple fiber
Virgin producer 1 (V1)	Southeast Asia	Virgin chemicals	January–December 2022	1 kg of black virgin staple fiber, 1 kg of white virgin staple fiber, 1 kg of virgin partially oriented yarn (POY), 1 kg of virgin drawn textured yarn (DTY)

*Chemical recycler 3 (C3) has not yet begun commercial operations and does not currently produce a sellable product. Its input and output data is based on detailed mass and energy balances based on testing conducted at a pilot plant. This engineering study was completed in October 2022.

1.4. Intended use of this report

The LCA results of this study, and any shared inventory data, **are not intended to be used for comparative purposes**. Comparing the results of different LCA studies is only possible if the system boundaries, functional units, and overall methods of each study are equivalent. ISO 14044 (ISO 14044:2006, 2006), the ISO standard that prescribes requirements for LCA studies, has additional requirements for any comparative assertions that are intended to be disclosed to the public. This LCA study does not conform to these requirements.

The technologies examined in this report are varied, with different operating conditions, data quality, regions of operation, and scale of commercialization. The different recycling technologies included also accept different types of feedstocks. Some technologies can only accept post-industrial waste, others can accept up to 30% post-consumer waste, while a new pre-commercial chemical recycling technology can accept all types of post-consumer textile waste. In addition, while all types of PET chip modeled are suitable for textile applications, some are decolored and some are not, which changes the type of textiles they can be used in (for example, yarn for clothing versus down-like fiber for stuffing). These nuances preclude the ability to compare these technologies.

All Textile Exchange LCAs are designed as cradle-to-gate studies. Users are encouraged to integrate this data into broader cradle-to-grave assessments where use-phase and end-of-life impacts are relevant to their goals. Textile Exchange plans to continue its effort to improve the raw material-impact data available for the textile industry. In addition, the results presented in this study should only be used when they are geographically, temporally, and technologically representative of the product system being modeled, or when better data is not available. When these conditions are met, the LCA report may be used in the following ways:

- To analyze the environmental impact of commercial and pre-commercial recycling technologies included in this assessment, including gaining an understanding of which life cycle stages, inputs, and processes contribute the greatest amount of impact to each technology type.
- For scope 3 reporting and target setting, using the LCIA results and life cycle inventory data of virgin and recycled PET chip production shared in this report.
- As a source of default inventory data for internal or supply chain-specific assessments.
- For submission to LCA databases, such as Higg MSI, WALDB, ecoinvent, and other databases.
- For scenario analysis.
- To promote holistic considerations of impact, including social impacts.

Data should not be used for the following:

- Public claims, marketing claims (including on product labels) or any form of comparison:
- based on the comparison of the LCI or LCIA results of this LCA study
- based on comparing the results of this LCA study to other studies
- about differences between geographies and/or production technologies
- Production or sourcing decision-making based solely on LCA results. Implementing reduction measures in high-impact regions is more environmentally beneficial than shifting sourcing, and social impacts deriving from changing sourcing strategy require careful evaluation.²

² Shifting sourcing to low-carbon geographies is discouraged as well by SBTi FLAG guidance section 3.3.7, which emphasizes engagement and improvement in existing supply regions to avoid leakage and promote long-term sustainability outcomes (Science Based Targets initiative, 2026).

1.5. LCA data challenges and common criticisms

LCA is a widely used tool for quantifying the environmental impacts of textile materials, including polyester production. However, LCA applications in this context have drawn recurring concerns around data quality, methodological consistency, and the way results are communicated and interpreted—especially in relation to product claims and global fiber comparisons.

This section reviews common criticisms of LCA data use in the polyester and fashion, textile, and apparel industry. These concerns were collected through stakeholder feedback, the 2021 report *Identifying Low Carbon Sources of Cotton and Polyester Fibers by the Fashion Industry Charter for Climate Action* (UNFCCC, 2021), and recent publications that have critically examined LCA methodologies and their use in sustainability communication (Kassatly and Baumann-Pauly, 2021). Table 4: LCA data challenges—positioning and outlook presents a selection of these concerns alongside the study’s response or position.

Table 4: LCA data challenges—positioning and outlook

LCA challenge/ Criticism	Criticism description	How this study addresses the challenge	Relevant sections
Inconsistent and non-standardized methodologies	LCA results are highly sensitive to assumptions, and LCA methods vary (system boundaries, allocation, functional units), making comparisons unreliable (wide ranges in GHG estimates reflect inconsistent methods more than real-world differences).	The widely adopted ISO 14044 standard was used, which standardizes elements of the goal and scope, life cycle inventory analysis, life cycle impact assessment, and interpretation. In addition, the commonly utilized recycled cut-off approach was incorporated, and the ecoinvent 3.11 database was used for nearly all secondary data, another commonly employed LCA resource. The choice of methods and impact indicators used in the assessment are based on the requirements of the Higg Materials Sustainability Index (MSI), and also include the Environmental Footprint (EF) 3.1 acidification indicator for consistency with other Textile Exchange LCA studies. Additionally, indicators recommended in the EF 3.1 reference package (European Commission, 2025a) are included. All included impact indicators conform to ISO 14044. By adhering to this framework, the study ensures consistency with widely accepted modeling approaches.	2.6 Impact indicators and categories
Misuse of LCA results for simplistic rankings or claims	LCA results are oversimplified into scores or rankings that mislead consumers and mask nuance.	The study clearly outlines its intended use and limitations, emphasizing that LCA results are context-dependent and not suited for simplified product comparisons. The results of this study should not be used for consumer-facing claims. In addition, no weighting or other value-based choices are made. Instead, the life cycle impact assessment was conducted using widely accepted impact indicators required by the Higg MSI and PEF (EF 3.1 indicators).	1.4 Intended use of this report 2.6 Impact indicators and categories 7. Limitations
Lack of transparency and public access to data	LCA data and assumptions are often not publicly	This study ensures a high degree of transparency by publishing the inventory data used in the LCA modeling, along with comprehensive documentation of the data sources, system	2. Methodology

LCA challenge/ Criticism	Criticism description	How this study addresses the challenge	Relevant sections
	available, making claims unverifiable.	boundaries, and modeling assumptions. Limitations in data quality are explicitly communicated, including the requirement requested by participating data providers to keep their company name and specific facility location anonymous. Certain chemicals and locations of raw materials, while included in the model, are also kept anonymous. All key assumptions are clearly stated and accompanied by sensitivity or scenario assessments to evaluate their influence on results. A DQR approach was applied to assess the quality of data for each system.	3.3, 4.3, 5.3 Summary of assumptions 3.4, 4.4, 5.4 Life cycle inventory
Use of outdated or non-representative data	Many LCAs rely on data 10–20 years old, not reflecting current practices or technologies.	The goal of this study is to use the most recent and representative data available. Primary data was collected directly from polyester production systems, primarily covering 2022–2024. Secondary data was selected based on how recently the data was collected, as well as its technological and geographical representativeness. Where possible, data less than 10 years old was used. The DQR of the study considers time representativeness and all data providers have data rated as “good” or “very good” (section 2.7, Table 16).	1.Introduction 3.4.2., 4.4.2, 5.4.2 Data quality assessment
Data collection bias and small sample sizes	Small, unrepresentative samples and vested-interest data collection skew LCA outcomes.	The study recognizes the importance of ensuring representative primary data to support robust and credible results. While high representativeness in the data compiled for this study could not always be achieved due to practical constraints, the intention to capture representative data guided the evaluation of data quality. However, the intention of this study is to contribute high-quality, transparent data to help address the lack of data available on the recycling of PET and on virgin production of PET within Asia. To support transparency, the study includes a detailed assessment of representativeness for each dataset, in alignment with established statistical approaches. This enables users to understand the extent to which results can be generalized. Representativeness is formally considered within the DQR framework, ensuring that any related limitations are communicated and factored into the interpretation of results.	2.7 Data quality assessment methodology 3.4.2, 4.4.2, 5.4.2 Data quality assessment
Regional and practice-based variability ignored	Global averages mask local variation in polyester production impacts, leading to inaccurate conclusions.	This study addresses this challenge by providing new, transparent data on the recycling of PET waste (bottle and textile waste), as well as virgin PET collected from five different companies operating in different countries around the world. While this data is not intended to be used to represent country-level production, as the sample size of data providers included is too small, it still provides LCA practitioners with data that can be tied to specific production practices in specific regions and countries. It also helps move closer to producing	1.4 Intended use of this report 2. Methodology

LCA challenge/ Criticism	Criticism description	How this study addresses the challenge	Relevant sections
		country or regional datasets by providing more data to be incorporated into these larger datasets. More detailed (for example, supply chain-specific) studies are encouraged, and this study provides a transparent foundation that can support such follow-up analyses. Where regional LCA data exists that aligns with a brand or user's sourcing regions, its use is strongly recommended and should be prioritized over the use of national averages, to ensure the representativeness of results.	
Cherry-picking data to support pre-set narratives	Selective data use to favor certain fibers undermines credibility of comparative results.	This study does not support or encourage comparative assertions between different production systems (or with other fibers). Its focus is on generating transparent and high-quality inventory data for polyester production systems. To further safeguard against bias or pre-set narratives (for example, on different recycling technologies), the study was guided by a multi-stakeholder Technical Advisory Group (TAG) and underwent external review by an ISO 14044 critical review panel that represented different views in the polyester sector. These structures were designed to ensure that diverse perspectives were considered.	1.4 Intended use of this report 2. Methodology
Scope: Lack of use-phase and end-of-life consideration; functional performance not considered	Cradle-to-gate LCAs exclude garment use and disposal, skewing fiber impact comparisons. Garment durability or wear count are ignored, undervaluing long-lasting natural fibers.	This is a question of scope. All Textile Exchange LCAs are designed as cradle-to-gate studies. Users are encouraged to integrate this data into broader cradle-to-grave assessments where use-phase and end-of-life impacts are relevant to their goals.	2. Methodology
Poor representation of different polyester recycling technologies	Certain polyester recycling technologies often omitted due to lack of data, underestimating mitigation potential.	This study focuses heavily on recycled polyester production practices, with all five data providers producing either chemically or thermomechanically recycled PET chip and staple fiber, across China, Europe, the US, and Southeast Asia. While not every type of recycling technology is assessed, the study enhances the overall picture of the environmental impact of different PET production pathways in different regions.	1.3 Scope of the study 2. Methodology
Exclusion of key emission sources	Key emission sources excluded from LCA modeling, obscuring hotspots.	This study follows the ISO 14044 standard (ISO 14044:2006, 2006). No arbitrary cut-offs were applied, and all relevant inputs were accounted for. All upstream processes, including the impacts related to the extraction of crude oil and natural gas, are also included.	2. Methodology

LCA challenge/ Criticism	Criticism description	How this study addresses the challenge	Relevant sections
LCA's are not comprehensive measures of sustainability	LCA's measure only environmental impacts, not social or economic factors; cannot support broad "sustainable" claims on their own.	This study is designed as an environmental Life Cycle Assessment and does not claim to capture the full spectrum of impact areas relevant to polyester production. Following Textile Exchange's LCA+ approach, additional impacts beyond conventional LCA metrics are considered. For example, a review of potential social impacts is included, though relevant limitations apply in this area as well. Economic dimensions remain outside the scope of this assessment. Users are advised not to interpret the results as comprehensive sustainability ratings. Instead, the findings are intended to inform decision-making as one element within a broader assessment framework.	1.4 Intended use of this report 2. Methodology, Appendix B
Concerns over industry-led studies	Private corporations should not unilaterally determine the environmental impact of materials; independent oversight and public accountability are necessary.	This study was supported by a formal ISO 14044 critical review process and, in addition, guided by a multi-stakeholder Technical Advisory Group (TAG) composed of independent experts to ensure independent verification. These measures follow—and through the addition of the TAG, go beyond—the requirements set out in international standards, such as ISO 14044 for third-party reviewed LCAs. While the study was industry-funded and conducted by a private consultancy, these third-party verification structures were implemented to ensure transparency, methodological integrity, and overall credibility. The study acknowledges that greater independence in data collection and verification, particularly by public or academic institutions, would significantly strengthen the credibility and robustness of LCA results. However, public investment in such efforts has so far been limited. In this context, the aim of this study is to work transparently with the best available data, ensure stakeholder engagement and external review, and make results accessible for broader scrutiny and discussion. This approach is intended as a constructive step forward, while recognizing the need for more publicly governed holistic assessments in the future.	1.4 Intended use of this report 2. Methodology

2. Methodology

The development of this report included two phases: a scoping phase and a life cycle assessment phase. The scoping phase involved extensive interviews with the textile brand project sponsors and potential stakeholders to better understand the recycling market and technologies and confirm participating data providers. Table 5, below, shows the number of polyester producers contacted and confirmed. The life cycle assessment phase included the collection and validation of data, the creation and iteration of LCA models, writing the report, results analysis, including interpretation, and a series of internal and external reviews, including an ISO 14044 (ISO 14044:2006, 2006) and Higg MSI (Cascale, 2024) conformant critical review conducted by a panel of experts. A detailed methodology of the LCA phase is shown in the sections below.

Table 5: Scoping of polyester LCA data providers

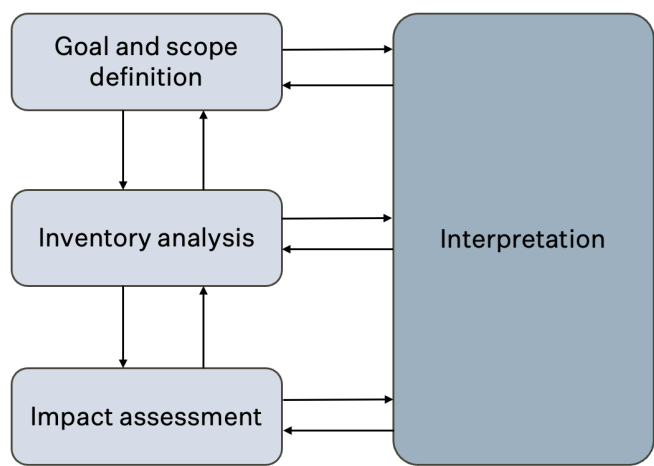
Outreach stages	Number of data providers
Textile Exchange contacts	29
Responses from	21
Meetings conducted with Textile Exchange	18
Meetings conducted with SCS	12
Organizations included in the LCA	5

2.1. Life cycle assessment

ISO 14044 (ISO 14044:2006, 2006) is an international standard that prescribes the methodology for conducting life cycle assessments (LCAs). This study conforms to ISO 14044.

An LCA is the systematic study of environmental and human health impacts over all life cycle stages of a product, including raw material extraction, manufacturing, transportation, use and maintenance, and disposal. It includes four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation (European Commission, n.d.–b). Figure 1, below, shows the life cycle assessment framework.

Figure 1: Life cycle assessment framework, adapted from ISO 14040:2006



After the aim and the scope of an LCA study are defined, a life cycle inventory (LCI) is built. This inventory captures all the input and output flows needed to produce the functional unit. The functional unit represents a quantitative unit of the product or process being studied. The functional unit also describes the function of the product or process (for example, 1 kg of PET chip for use in textile production). Once the LCI is built, each flow is connected to a characterization factor that translates the physical quantity of the flow into a quantifiable environmental impact (for example, the conversion of greenhouse gas emissions from the production of a product into a climate change impact using global warming values, the characterization factors). This step is called life cycle impact assessment (LCIA) and is used to create an environmental impact for all included impact categories using specific impact indicators (section 2.4). Each impact indicator has its own methodology, which determines which LCI output flows should be characterized into an impact for that indicator, and what the characterization factors are. After the LCIA, the results are interpreted, and sensitivity analyses are run to test areas of the model that are uncertain. Finally, conclusions are drawn.

2.2. Functional unit

A functional unit is a key concept used in LCA studies and represents the quantified performance of a product system for use as a reference unit (ISO 14040: 2006, 2006). In other words, it defines the quantity, performance characteristics, and the intended use of the desired output, for example, 1 kg of PET chip for use in textile applications, in a way that allows for meaningful comparisons (Sala et al., 2016), and as the basis for calculating the environmental impacts associated with it. A reference flow is the measure of output(s) of a product system required to fulfill the functional unit. So, for instance, a functional unit could be 1 m² of drywall to a certain construction specification, while the reference flow would be the quantity of drywall required to fulfill the functional unit, which could be different. In the case of all of the product systems included within this report, the functional unit and reference flow are the same.

The functional units for each type of technology explored in this study are shown below and also described in detail in the individual results sections (sections 3.5, 4.5, and 5.5) later in this report. These include:

- 1 kg of PET chip for use in textile applications
- 1 kg of staple fiber for use in textile applications
- 1 kg of partially oriented yarn (POY) for use in textile applications
- 1 kg of drawn texturized yarn (DTY) for use in textile applications

These are all products used in the fashion, textile, and apparel industry. PET chips are small, granulated particles of PET that are used as the starting material for producing fiber and yarn. A staple fiber is a textile fiber, usually between 10 and 400 millimeters in length, that can be spun into yarn or used as the fill for certain products (for example, stuffed animals and pillows). POY is an intermediate type of yarn that is partially stretched and is primarily used in making textured yarn. DTY is a finished yarn product that is used in knitting and weaving.

2.3. System boundary

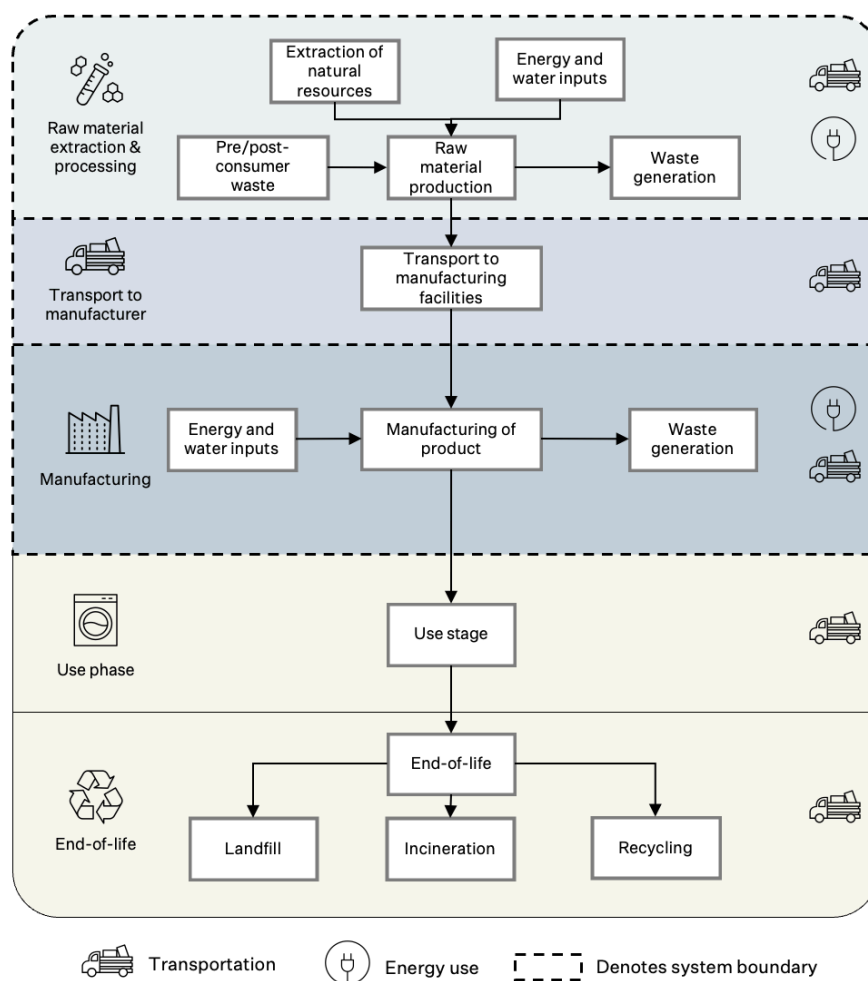
In a life cycle assessment (LCA), the system boundary defines the scope of processes and stages included in the analysis, specifying which inputs, outputs, and impacts are considered, and which are excluded. Different studies may employ various types of system boundaries, such as cradle-to-gate and cradle-to-grave. A cradle-to-grave system boundary includes the impacts of a product across its entire life cycle, from raw material extraction to its disposal.

For this study, a cradle-to-gate system boundary is considered. This boundary includes the impacts of a product from raw material extraction up to the point where it leaves the factory gate where it was produced. Any downstream applications and packaging are excluded. PET products can be packaged differently at different recycling facilities and can often contribute significantly to the impact associated with a PET product. Packaging was excluded to ensure only the impact related to the PET product itself was considered, and to provide uniformity across different data providers and regions.

Within this study, the recycled content method (also known as the 100-0 method or cut-off method) is used to determine how the benefits of using recycled materials and producing materials that can be recycled are accounted for. This means that any waste that is used as feedstock enters the system burden-free, and only the impacts related to processing and recycling the feedstock are included. Any impacts related to the processes that originally created the waste are allocated to the product system that generated the waste and not the product system that uses it as a feedstock. No credit is applied to a product system that produces a material that can be recycled. The system boundary includes the impacts related to the treatment of feedstock materials that are rejected by the recyclers (for example, labels, caps, heavily contaminated bottles or textile waste).

The figure below shows an example of processes and life cycle stages that are included in a cradle-to-gate study. Green areas indicate life cycle stages that are included in the system boundary, and grey areas represent stages that are excluded.

Figure 2: Example system boundary diagram for a cradle-to-gate life cycle assessment.



2.4. Modeling approach

2.4.1. Data collection and validation

LCA studies involve collecting data on each stage associated with the production of any material or chemical. In this study, data collected directly from a facility is referred to as primary data. In contrast, information obtained from external sources not directly involved in the process—such as academic journals on sorting post-consumer bottles or life cycle inventory databases like ecoinvent—is considered secondary data.

Primary data collected from data providers’ recycling facilities includes all inputs and outputs required to produce the functional unit. Primary data was not collected from many upstream facilities in the supply chain, such as petrochemical refineries that produce purified terephthalic acid (PTA) and monoethylene glycol (MEG)—the two key chemicals used to polymerize PET—nor any data upstream of the recycling facilities. Since there was no visibility into the data providers’ suppliers, there was no access to their manufacturing data. Instead, for processes upstream of each data provider—including the extraction and refining of oil and natural gas—secondary data from ecoinvent was used.

For each data provider, data validation was performed to ensure the data collected was plausible and accurate. Inventory data was benchmarked against literature sources or previous internal projects, and mass balance checks were performed to ensure that the inputs and outputs for a particular product system were accurate. Additionally, completeness and consistency checks were performed for each data provider during data collection. The completeness checks verified that all relevant data and information required by the goal and scope of the LCA were included, ensuring that the life cycle impact assessment had all necessary elements, and that there was no missing data that could significantly affect the results or conclusions. The consistency checks validated that the methodological choices (for example, system boundaries, allocation rules) were applied consistently, and that data sources and impact assessment methods were compatible. This data validation was done in conjunction with a data quality assessment, which can be found in section 2.7.

Table 6, below, shows the key inputs and outputs on which data was collected from the data providers, and common types of secondary data needed to fill data gaps.

Table 6: Primary data collected from data providers and secondary data examples for this study

Flows	Primary data	Secondary data
Inputs		
Raw material extraction	Type, mass, or volume of raw materials (for example, chemicals) consumed	Inputs and outputs needed to produce the raw materials
Utilities consumed	Quantity of electricity, water, steam, and fuel consumed	Upstream processes related to the production of a specific facility (for example, coal mining)
Transport	Mode of transport (truck, ship, rail) and distance inputs are transported to the recycling facility	Upstream processes related to the production of a vehicle or fuel; upstream transport distances for raw materials used
Outputs		
Wastes generated	Quantity of hazardous and non-hazardous solid and liquid waste generated at the facility	Processes related to the treatment of the waste

Flows	Primary data	Secondary data
Air and water emissions	Air and water emissions released from the manufacturing facility that are unrelated to fuel combustion	Air or water emissions from upstream or downstream processes not occurring directly at the manufacturing facility

2.4.1.1. Electricity grid modeling

For each data provider, the electricity consumed at their facilities was modeled using ecoinvent electricity datasets, which were modified to represent the actual generation sources used (for example, solar, wind, coal, natural gas). To achieve this, ecoinvent high-voltage datasets—representing the production mix of each country, or of an eGRID sub-region in the United States—were adjusted so that the contribution of each generation type matched the percentages reported in the data sources shown in Table 7, below. In addition, low-voltage generation sources, primarily solar photovoltaic, were included where applicable. Note that only the overall share of each generation type was adjusted; the specific technologies within each category (for example, natural gas cogeneration vs. conventional power plants, or lignite vs. hard coal) were not modified. The generation mixes applied to each data provider are detailed in sections 3.2, 4.2, and 5.2.

Table 7: Electricity grid mix sources for LCA modeling

Data provider	Electricity grid mix source	Region	Data source year
C1	International Energy Agency (IEA) (International Energy Agency, 2024a)	China	2022
C2	International Energy Agency (IEA) (International Energy Agency, 2024a)	China	2022
C3	International Energy Agency (IEA) (International Energy Agency, 2024b)	Europe	2022
M1	United States eGRID (Environmental Protection Agency, 2025a)	United States (confidential sub-region)	2023
M2	International Energy Agency (IEA) (International Energy Agency, 2024a)	China	2022
M3	International Energy Agency (IEA) (International Energy Agency, 2024c)	Southeast Asia (confidential country)	2022
V1	International Energy Agency (IEA) (International Energy Agency, 2024c)	Southeast Asia (confidential country)	2022

2.4.2. Value choices and optional elements

The study avoids the use of value choices in the assessment, as described in ISO 14044, such as normalization, weighting, or grouping of indicator results. The study includes a data quality assessment as required by ISO 14044.

2.4.3. Cut-off criteria

The cut-off criteria for including or excluding materials, energy, and emissions data from the study are listed below:

- All inputs and outputs to a unit process are included in the LCA calculation for which data is available. Any data gaps are filled with representative data, primarily from the ecoinvent 3.11 database. Assumptions used for filling data gaps are documented in each individual section.

- Where there is a data gap or insufficient data, the criteria for exclusion of inputs and outputs are 1% of primary energy usage (renewable and non-renewable energy) and 1% on a mass basis for the specific unit process. The maximum criteria for exclusion of inputs and outputs are 5% of primary energy usage and mass across a single product system.
- If a flow meets the above criteria for exclusion but is considered to have a significant potential environmental impact, it is included.
- Processes excluded from the system boundary are shown below. The exclusion of these processes is permitted because they are not expected to significantly change the overall conclusions of the study.
 - Construction activities, capital equipment, and infrastructure
 - Maintenance and operation of capital equipment
 - Personnel travel and resource use
 - Research and development activities
 - Secondary packaging
- There are no other known exclusions.

2.5. Allocation procedures

No allocation between co-products was required. While data provider C1 does produce two valuable by-products—dimethyl terephthalate (DMT) waste block and a polyol mixture—the combined economic value of these by-products is less than 1% of the economic value of their recycled PET chip. Therefore, they were excluded (cut off) from the product system.

However, allocation was required to partition the impacts between the primary producer of a waste that is able to be recycled (for example, PET bottles) and the recycler of that waste into a valuable product (for example, the mechanical recycler of PET bottles who produces recycled PET chip).

In this study, the recycled content method (also referred to as the 100-0 method or cut-off approach) was applied to account for the use of recycled materials and the production of recyclable materials. Under this approach, any waste used as feedstock enters the system burden-free; only the impacts associated with its recycling (for example, collection, pre-treatment, and reprocessing) are included. The impacts of producing the original material that becomes waste are excluded. In other words, the method captures only the benefits of using recycled materials (i.e., zero burden from prior life cycles), while assigning the impacts of recycling processes to the product system that makes use of the recycled material. No substitution credits are given to either the generator of the waste or the user of the recycled material.

The recycled content method was selected because it is required by both the Higg MSI and the PEF methodology for cradle-to-gate studies (European Commission, 2021b). To provide additional perspective, all impact categories were also recalculated using the PEF Circular Footprint Formula (CFF), with results presented in appendix A. This offers a complementary scenario in line with PEF requirements.

2.6. Impact indicators and categories

An impact indicator is a quantitative measure that represents the potential environmental impact of a product, process, or service within a specific impact category. An impact category is a class of environmental issues of concern—such as climate change, acidification, or human toxicity—to which life cycle inventory (LCI) results are assigned. LCI data is the quantified inputs from and outputs to the environment required to fulfill the functional unit, which is compiled from both primary and secondary data sources.

In a life cycle assessment (LCA), multiple impact categories are evaluated to provide a holistic understanding of potential environmental consequences and to identify trade-offs among different products or production methods. Impact indicator results are calculated using defined characterization methodologies, and several indicators may exist for the same impact category. For example, the acidification impact category can be quantified using different indicators and models, two of which are:

- Acidification potential (SO₂ equivalents), based on the CML methodology, or
- Acidification (accumulated exceedance), based on the AE method

These methods can differ in their geographic scope, the substances they include, the fate and transport modeling parameters they use, and the time period when they were developed. For this study, the choice of methods and indicators follows the requirements of the Higg Materials Sustainability Index (Higg MSI), and also incorporates the Environmental Footprint (EF) 3.1 acidification potential indicator, to ensure consistency with other Textile Exchange LCA studies. However, all 16 indicators recommended in the EF 3.1 reference package are also included (European Commission, 2025a).

The EF methods were developed by the European Commission to provide standardized guidance for modeling, calculating, and reporting the life cycle environmental impacts of products and organizations (European Commission, n.d.–a). EF 3.1 refers to the most recent update of the EF method, at the time this report was written, which includes revised characterization factors for multiple impact categories such as climate change, acidification, ecotoxicity, photochemical ozone formation, and human toxicity (European Commission, 2025a).

All included impact indicators in this study conform to ISO 14044 and align with the goal and scope of the LCA. The selection of these indicators is consistent with ISO requirements, as they represent all relevant environmental impacts associated with PET production.

To calculate life cycle impact assessment (LCIA) results, LCI data is used to build an LCA model, which calculates elementary flows (for example, emissions to air, water, soil, and resource extractions). These flows are then assigned to the relevant impact categories. Next, impact indicators are applied to quantify the potential impacts in each category. Each indicator includes a set of characterization factors, which convert the various elementary flows into a common equivalence unit, allowing results to be summed and compared. For instance, in the climate change category, greenhouse gases such as methane (CH₄) and nitrous oxide (N₂O) are multiplied by their respective global warming potentials (GWPs) to express their impacts in a single, common unit—kilograms of carbon dioxide equivalents (kg CO₂e).

Within the LCIA, characterization can be performed at different points along the environmental mechanism—the cause-and-effect chain linking an elementary flow to its final impact. Two main approaches are used: midpoint and endpoint. Midpoint characterization uses problem-oriented indicators that occur at an intermediate stage in the cause-and-effect chain, prior to damage to areas of protection. Examples include climate change (expressed as mass of greenhouse gases converted to CO₂ equivalents), eutrophication (mass of nutrients released to land, freshwater, or marine systems), and ozone depletion (mass of ozone depleting substances emitted to the atmosphere). Endpoint characterization models the impacts through to the damage-oriented indicators at the end of the cause-and-effect chain, representing effects on areas of protection such as human health, ecosystem quality, and resource availability.

Because endpoint modeling requires more complex cause-effect modeling and more assumptions, and, therefore, introduces greater uncertainty, most LCAs focus on midpoint characterization. Different LCIA methods may provide midpoint indicators, endpoint indicators, or both. This study assesses impacts at the midpoint level.

Finally, it should be noted that the LCIA results presented below are relative expressions and do not predict impacts on category endpoints, exceedance of thresholds, safety margins, or risks associated with the product system. The impact categories included in the assessment are described in Table 8 and Table 9, below. Additional impact categories required by EF 3.1 are shown in Table 10.

Table 8: Impact categories and indicators included in the main body of this report.

Impact category	Unit	Impact indicator characterization method
Climate change*	kg CO ₂ eq	IPCC 2021 GWP 100a (IPCC, 2021a)
Acidification	mol H ⁺ eq	Accumulated exceedance (Damiani et al., 2022)
Eutrophication	kg PO ₄ eq	CML-IA baseline (Leiden University, 2016)
Abiotic depletion, fossil fuels	MJ	CML-IA baseline (Leiden University, 2016)
Freshwater ecotoxicity	PAF/m ³ /day	USEtox 2 (recommended characterization factors only) (Rosenbaum et al., 2008)
Water scarcity	m ³ world eq	AWARE 1.2 (openLCA implementation) (WULCA, n.d.; Serafini and Ciroth, 2024)
Freshwater consumption	m ³	LCI results

*(includes land use change)

Table 9: Description of impact categories used in the main body of this report.

Impact category	Impact category and environmental mechanism
Climate change	Anthropogenic emissions of greenhouse gases, including short-lived climate forcers, have led to increased radiative forcing, which has, in turn, increased the global mean temperature by above 0.99°C since pre-industrial times. All Intergovernmental Panel on Climate Change (IPCC) scenarios project an increase to 1.5°C in the near term, occurring between 2021–2040. The projection for the SSP2–4.5 scenario estimates an increase of 2.0°C occurring between 2041–2060, with 2.7°C occurring between 2081–2100 (IPCC, 2021c). As global mean temperatures continue to climb, global climate change will result. Some of the predicted impacts include reductions in food and water supplies, and sea level rise (IPCC, 2021b)
Acidification	Acidification is the increasing concentration of hydrogen ion (H ⁺) within the local environment and occurs as a result of adding acids, such as nitric acid and sulphuric acids, into the environment (AgImpacts, 2025). Acid precursor emissions transport in the atmosphere and deposit as acids. These acids may deposit in soils that are sensitive, or insensitive, to the increased acid burden; sensitivity can depend on a number of factors (AgImpacts, 2025). In acid-sensitive soils, the deposition can decrease the soil pH (acidification) and increase the mobility of heavy metals in the environment, such as aluminum. This acidification can affect the pH of local soils and freshwater bodies, by increasing local hydrogen ion concentrations, causing endpoints such as tree die-offs and dead lakes (AgImpacts, 2025). Emissions of sulphur dioxide and nitrogen oxides from the combustion of fossil fuels have been the greatest contributors to acid rain (Environmental Protection Agency, 2025b).
Eutrophication	Eutrophication is the build-up of a concentration of chemical nutrients in an ecosystem, which leads to abnormal productivity. In some regions, emissions of excess nutrients (including phosphorus and nitrogen) into water can lead to increased algal blooms (National Oceanic and Atmospheric Administration, 2024). These blooms can reach such a severity that waterways become choked, with no other plant life able to establish. If algal blooms are intense enough, the decaying algae consumes dissolved oxygen in the water column starving other organisms of needed oxygen. Whereas

Impact category	Impact category and environmental mechanism
	phosphorous is mainly responsible for eutrophication in freshwater systems, nitrogen is mainly responsible for eutrophication in ocean water bodies (National Research Council, 2000). Emissions of ammonia, nitrates, nitrogen oxides, and phosphorous to air or water all have an impact on eutrophication.
Abiotic Depletion, Fossil Fuels	This impact category refers to the consumption of fossil fuels. The value of the abiotic resource consumption of a substance (for example, lignite or coal) is a measure of the amount of resources consumed on an energy basis. It is measured in megajoules (MJ) of fossil fuels. (Road and Hydraulic Engineering Institute, 2002).
Freshwater Ecotoxicity	Toxicity indicators for human health effects and ecosystem quality are necessary both for comparative risk assessment and for LCAs applied to chemicals and emission scenarios. USEtox provides characterization factors for human toxicity and freshwater ecotoxicity (Rosenbaum et al., 2008). Assessing the toxicological effects of a chemical emitted into the environment implies a cause-effect chain that links emissions to impacts through three steps: environmental fate, exposure and effects linking these, and a systematic framework for toxic impacts. Modeling based on matrix algebra was developed within the OMNIITOX project and peer reviewed in a United Nations Environment Programme (UNEP) and Society for Environmental Toxicology and Chemistry (SETAC) workshop by an independent expert panel, who recommended the framework for further developments within the Life Cycle Initiative, where it was then adopted for USEtox (Rosenbaum et al., 2008).
Water Scarcity	AWARE is a water use midpoint indicator representing the relative available water remaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met (WULCA, n.d.). It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water available per area, the more likely another user will be deprived (WULCA, n.d.).
Freshwater Consumption	The results of this impact category are based on the net use (water consumed and not discharged) of freshwater and are calculated by summing the inputs of freshwater flows and subtracting the outputs of freshwater flows.

Table 10: Description of impact categories required by EF 3.1.

This table is adapted from the JRC Technical Report on PEF (Damiani et al., 2022).

EF 3.1 Impact category	Unit	Characterization method	Description
Acidification	mol H ⁺ eq	Accumulated exceedance (Seppälä et al., 2006; Posch et al., 2008)	Acidification from air, water, and soil emissions (primarily sulfur compounds) mainly due to combustion processes in electricity
Climate change	kg CO ₂ eq	Bern model—global warming potential (GWP) over a 100-year time horizon based on IPCC 2021 (Forster et al., 2021)	Increase in the average global temperature resulting from greenhouse gas emissions (GHG)
Climate change (biogenic)	kg CO ₂ eq	Bern model—global warming potential (GWP) over a 100-year time horizon based on IPCC 2021 (Forster et al., 2021)	
Climate change (fossil)	kg CO ₂ eq	Bern model—global warming potential (GWP) over a 100-year time horizon based on IPCC 2021 (Forster et al., 2021)	

EF 3.1 Impact category	Unit	Characterization method	Description
Climate change (land use)	kg CO ₂ eq	Bern model—global warming potential (GWP) over a 100-year time horizon based on IPCC 2021 (Forster et al., 2021)	
Ecotoxicity freshwater	CTUe	Based on USEtox2.1 model (Saouter et al., 2018)	Impact of toxic substances on freshwater ecosystems
Ecotoxicity freshwater (inorganics)	CTUe	Based on USEtox2.1 model (Saouter et al., 2018)	
Ecotoxicity freshwater (organics)	CTUe	Based on USEtox2.1 model (Saouter et al., 2018)	
Eutrophication freshwater	kg P eq	EUTREND model (Goedkoop et al., 2009)	Eutrophication and potential impact on ecosystems caused by nitrogen and phosphorous emissions mainly due to fertilizers, combustion, and sewage systems
Eutrophication marine	kg N eq	EUTREND model (Goedkoop et al., 2009)	
Eutrophication terrestrial	mol N eq	Accumulated exceedance (Seppälä et al., 2006; Posch et al., 2008)	
Human toxicity cancer	CTUh	Based on USEtox2.1 model (Saouter et al., 2018)	Impact on human health caused by absorbing substances through the air, water, and soil. Direct effects of products on humans are not measured
Human toxicity cancer (inorganics)	CTUh	Based on USEtox2.1 model (Saouter et al., 2018)	
Human toxicity cancer (organics)	CTUh	Based on USEtox2.1 model (Saouter et al., 2018)	
Human toxicity non-cancer	CTUh	Based on USEtox2.1 model (Saouter et al., 2018)	
Human toxicity non-cancer (inorganics)	CTUh	Based on USEtox2.1 model (Saouter et al., 2018)	
Human toxicity non-cancer (organics)	CTUh	Based on USEtox2.1 model (Saouter et al., 2018)	
Ionizing radiation (human health)	kBq U235 eq	Human health effect model (Frischknecht et al., 2000)	Impact of exposure to ionizing radiations on human health
Land use	dimensionless (pt)	Soil quality index based on LANCA model (De Laurentiis et al., 2019) and on the LANCA CF version 2.5 (Horn and Maier, 2018)	Transformation and use of land for agriculture, roads, housing, mining, or other purposes. The impact can include loss of species, organic matter, soil, filtration capacity, and permeability
Ozone depletion	kg CFC11 eq	EDIP model based on the ODPs of the World Meteorological Organization (WMO) over an infinite time horizon (WMO 2014 + integrations)	Depletion of the stratospheric ozone layer protecting from hazardous ultraviolet radiation

EF 3.1 Impact category	Unit	Characterization method	Description
Particulate matter	disease incidence	PM model (UNEP, 2016)	Impact on human health caused by particulate matter emissions and its precursors (e.g. sulfur and nitrogen oxides)
Photochemical ozone formation (human health)	kg NMVOC eq	LOTOS-EUROS model as applied in ReCiPe 2008 (Goedkoop et al., 2009)	Potential of harmful tropospheric ozone formation (“summer smog”) from air emissions
Resource use fossils	MJ (net calorific)	van Oers et al., 2002 as in CML 2002 method, v.4.8 (Leiden University, 2016)	Depletion of non-renewable resources and deprivation for future generations
Resource use minerals and metals	kg Sb eq	van Oers et al., 2002 as in CML 2002 method, v.4.8 (Leiden University, 2016)	
Water use	m³ world eq	Available Water REmaining (AWARE) model (Boulay et al., 2018; UNEP, 2016)	Depletion of available water depending on local water scarcity and water needs for human activities and ecosystem integrity

2.7. Data quality assessment methodology

Data quality assessments are an important indicator of an LCA study’s reliability and accuracy. For this report, the data quality was assessed for each product system based on an adapted version of the data quality rating (DQR) approach in the Product Environmental Footprint Category Rules (PEFCR) for Apparel and Footwear (European Commission, 2025b) methodology, referred to here as the “adapted PEF DQR.”

The PEF DQR methodology requires identifying which processes drive the environmental profile of a product, also known as the most relevant processes. Once these processes are identified, they are ranked in order of their contribution to the overall environmental impact. Each process is evaluated on a scale of 1 to 5, based on the quality of the data used, and involves four parameters: TeR (Technological Representativeness), GR (Geographical Representativeness), TiR (Time Representativeness), and P (Precision/uncertainty). All four parameters are assessed for primary data, and only TiR, TeR, and GR are assessed for secondary data. The overall data quality is calculated as a weighted average using the formula shown below, where the assigned weights are the process contributions identified previously.

Figure 3: DQR calculation formula

$$DQR = \frac{TeR + GR + TiR + P}{4}$$

The PEF DQR method, as it exists, is not a good fit for this study and was adapted due to some limitations associated with the original methodology. The PEF method requires only one DQR to be calculated for each product, based on the ranking of processes in order of environmental impact. However, the drawback here is that the rank of processes based on their contribution to environmental impact may be different for each impact category. Arriving at one DQR would mean using value judgments to prioritize one impact category over another, which would be challenging to do without a specific framework. It would also mean that certain important processes that

contribute significantly to a certain impact category may not be adequately represented in the DQR calculation if an impact category in which they are not a significant contributor is chosen for ranking processes.

Additionally, this report only discusses and interprets in detail the Higg MSI impact category results and the EF 3.1 acidification potential indicator and does not follow PEF methodology rules for allocation. Hence, it would not be appropriate to use the PEF DQR method in its entirety. The adapted PEF DQR method is explained below.

- **Step 1:** For all product systems, a process-level contribution analysis was performed that included all relevant impact categories identified in Table 9. These key processes included processes such as feedstock collection, electricity use, heat, and chemical production. These processes were kept consistent across the different product systems. Fourteen tables were created, one for each product system, with the key processes contribution for all impact categories included. An example of this table is shown below in Table 11. This approach allowed for the identification of the key data involved in the model (for example, data related to feedstocks, electricity, chemicals, etc.), which contributed the majority of impacts for each impact category. These process-level contribution analyses are shown in sections 3.5, 4.5, and 5.5.

Table 11: Example table for step 1 of adapted PEF DQR methodology.

Impact Category	Feedstock	Electricity	Chemicals	Water	Transport	Waste treatment
Climate change	45%	15%	10%	5%	10%	15%
Acidification	15%	40%	40%	2%	2%	1%
Eutrophication	2%	4%	84%	0%	0%	0%
Abiotic depletion, fossil fuels	20%	18%	50%	0%	1%	1%
Freshwater ecotoxicity	20%	10%	60%	4%	3%	3%
Water scarcity	5%	25%	45%	23%	0%	2%
Freshwater consumption	5%	15%	50%	22%	5%	3%

- **Step 2:** The data associated with each key process for each product system (for example, data related to chemicals, transport, electricity use) was rated between 1 to 5 for each data quality indicator (TeR, GR, TiR, P), where 1 was the highest quality and 5 was the lowest quality. Primary data was assessed for all four data quality indicators (TeR, GR, TiR, P), and secondary data was assessed only for TiR, GR, and TeR, in accordance with the PEFCR for Apparel and Footwear methodology (European Commission, 2025b). These ratings were based on the modified DQR assessment criteria set out in the PEF methodology for primary and secondary data, shown in Table 14 and Table 15. For TiR, GR, and TeR, which included calculations of both primary and secondary data, a simple average of the ratings for primary and secondary data was calculated. The data ratings were summed and averaged (see Figure 3) to produce an average DQR for each key process. This resulted in 14 tables, one for each product. An example is shown in Table 12, below.

Table 12: Example table for step 2 of adapted PEF DQR methodology

	Feedstock	Electricity	Chemicals	Water	Transport	Waste treatment
TiR—primary	2	2	2	1	1	2

	Feedstock	Electricity	Chemicals	Water	Transport	Waste treatment
TiR—secondary	1	2	2	2	1	1
GR—primary	1	2	1	2	1	1
GR—secondary	3	1	1	1	2	3
TeR—primary	1	2	1	2	2	1
TeR—secondary	2	1	1	2	0	2
TiR avg	1.5	2	2	1.5	1	1.5
P	3	0	2	2	2	2
GR avg	2	1.5	1	1.5	1.5	2
TeR avg	1.5	1.5	1	2	1	1.5
Avg DQR	2.00	1.25	1.50	1.75	1.38	1.75

- **Step 3:** The tables created in Step 1 were multiplied by the tables created in Step 2 to produce 14 new tables. The product from this matrix multiplication was then summed for each impact category, producing the final DQR value. Table 13, below, shows an example.

Table 13: Example table for step 3 of adapted PEF DQR methodology

Impact category	Feedstock	Electricity	Chemicals	Water	Transport	Waste treatment	Weighted avg DQR
Climate change	0.90	0.19	0.15	0.09	0.14	0.26	1.73
Acidification	0.30	0.50	0.60	0.04	0.03	0.02	1.48
Eutrophication	0.04	0.05	1.26	0.00	0.00	0.00	1.35
Abiotic depletion, fossil fuels	0.40	0.23	0.75	0.00	0.01	0.02	1.41
Freshwater ecotoxicity	0.40	0.13	0.90	0.07	0.04	0.05	1.59
Water scarcity	0.10	0.31	0.68	0.40	0.00	0.04	1.53
Freshwater consumption	0.10	0.19	0.75	0.39	0.07	0.05	1.54

- **Step 4:** These final DQRs were consolidated into three tables, one for each category of PET production (Table 24, Table 42, and Table 65).

In addition to the changes described above, the PEF criteria for the TiR data quality indicators for both primary and secondary data were adapted to better fit the datasets used in this study, as well as to capture the effect that the length of time over which facility-level primary data was measured has on data quality. These changes are described below.

- **Primary data:** In addition to the PEF criteria for the TiR rating of primary data, the duration of time over which primary data was measured was also considered. For any production system, there may be fluctuation over time in the inputs required and outputs generated at a facility. By collecting data over large periods of time, the influence that outliers can have on the results is minimized. In general, LCI data is collected for a period of 1 year or more to minimize these outliers. The shorter the span of time over which data is collected, the higher the risk that the

data collected is not representative of normal operations. The effect that the length of time over which data was collected has on the TiR rating is shown in Table 14.

- **Secondary data:** The original PEF criteria for the TiR rating of secondary data were also modified. In the original PEF DQR, the TiR criteria is based on the publication date of the study in question compared to the validity period of the dataset used. For this LCA+ study, we have modified this language to instead compare the period of time for which each product's LCA is representative (for instance, C1 provided data of its operations from August 2023 to January 2024) against the validity period listed within the documentation of each ecoinvent dataset. For secondary data used from the literature or other databases (for example, the International Energy Administration), which does not provide a validity period, we instead compare the period of time for which each product's LCA is representative against the period of time over which the data used by the literature or database was gathered. This ensures that we are assessing the underlying data and not just the publication date of the study (Table 15).

The criteria used to determine the rating of each key process included in this study are shown below.

Table 14: DQR assessment criteria for datasets with company-specific information (primary data)

(European Commission, 2025b)

Rating	P	TiR*	TeR	GR
1	Measured/calculated and externally verified	Data are collected for a duration of at least 1 year; the data refers to the most recent year with respect to the report publication date	The elementary flows and the activity data exactly match the technology of the newly developed dataset	The activity data and elementary flows reflect the exact geography where the process modeled in the newly created dataset takes place
2	Measured/calculated and internally verified, plausibility checked by reviewer	Data are collected for a period between 6–12 months; the data refers to maximum 2 years with respect to the report publication date	The elementary flows and the activity data are a proxy of the technology of the newly developed dataset	The activity data and elementary flows) partly reflects the geography where the process modeled in the newly created dataset takes place
3	Measured/calculated/literature and plausibility not checked by reviewer OR Qualified estimate based on calculations plausibility checked by reviewer	Data are collected for less than 3 months; the data refers to maximum three years with respect to the report publication date	Not applicable	Not applicable
4-5	Not applicable	Not applicable	Not applicable	Not applicable

*For this TiR criterion, OR logic is used for the length of the data collection period and the recency. For example, if the data is either collected for less than 3 months, or if the data is three years old compared to the report publication date, a TiR score of 3 is given.

Table 15: DQR criteria for secondary datasets*(European Commission, 2025b)*

Rating	TiR	TeR	GR
1	The time validity, or period of time over which the secondary data was collected, matches the period of time over which primary data was collected.	The technology used in the EF study is exactly the same as the one in scope of the dataset	The process modeled in the EF study takes place in the country the dataset is valid for
2	The time validity, or period of time over which the secondary data was collected, is less than 2 years from when the primary data was collected.	The technologies used in the EF study is included in the mix of technologies in scope of the dataset	The process modeled in the EF study takes place in the geographical region (e.g. Europe) the dataset is valid for
3	The time validity, or period of time over which the secondary data was collected, is less than 4 years from when the primary data was collected.	The technologies used in the EF study are only partly included in the scope of the dataset	The process modeled in the EF study takes place in one of the geographical regions the dataset is valid for
4	The time validity, or period of time over which the secondary data was collected, is less than 6 years from when the primary data was collected.	The technologies used in the EF study are similar to those included in the scope of the dataset	The process modeled in the EF study takes place in a country that is not included in the geographical region(s) the dataset is valid for, but sufficient similarities are estimated based on expert judgement
5	The time validity, or period of time over which the secondary data was collected, was collected more than 6 years from when the primary data was collected.	The technologies used in the EF study are different from those included in the scope of the dataset	The process modeled in the EF study takes place in a different country than the one the dataset is valid for

Adapted PEF DQR tables are shown for each type of technology and each product system in sections 3.4.2, 4.4.2, and 5.4.2. Any limitations associated with data quality are discussed in the limitations' sections for each type of technology (sections 3.3, 4.3, and 5.3). Table 16, below, presents the data quality ratings and their corresponding data quality levels.

Table 16: Overall data quality level according to achieved data quality rating (DQR)*(European Commission, 2021a)*

Overall DQR	Overall data quality level
$DQR \leq 1.5$	Excellent quality
$1.5 < DQR \leq 2.0$	Very good quality
$2.0 < DQR \leq 3.0$	Good quality
$3.0 < DQR \leq 4.0$	Fair quality
$DQR > 4$	Poor quality

2.8. Critical reviewers and technical advisory group

This LCA report went through two separate review processes. The first was conducted by Textile Exchange, the project sponsors, and an external four-person group of technical advisors, referred to as the technical advisory group (TAG). This process ensured that the report would be accessible to a wider audience, that any nuances related to the polyester industry would be captured, and that the methodology and results could be validated by experts with deep knowledge on the subject.

Table 17: Technical advisory group members

Name	Affiliation
James Cooper	WSP
Luca Mosca	Quantis
Simon Hann	Eunomia
Irene Giacchetto	Fashion for Good

Next, the report was externally reviewed by a panel of four independent LCA experts for conformance to ISO 14044, which recommends a critical review whenever the results of an LCA are communicated to the public. This critical review was conducted to ensure the accuracy, reliability, and transparency of the study's methodology and results, as well as conformance with ISO 14044. The critical review statement has been added to appendix C.

Table 18: Critical review panel

Name	Affiliation
Dr. Roland Geyer (chair)	Industrial Ecologist, University of California at Santa Barbara
Dr. Ashley Holding	Principal Consultant, Circuvate
Joel Mertens	Director, Cascale
Dr. Matthias Stratmann	Head of Department, nova Institute

3. Chemical Recycling Product Systems

In this study, three chemical recyclers were evaluated, who all use solvolytic chemical recycling technologies. These three chemical recyclers (denoted as C1, C2, and C3) recycle a mix of post-industrial and post-consumer textile waste (Table 19). Post-industrial textile waste is cleaner and more homogeneous than post-consumer textile waste and requires less sorting and pre-treatment. A detailed description of each data provider's product system is shown in section 3.2.

Table 19: Summary of chemical recycling product systems

Chemical Recycler	Region of Operation	Feedstock Recycled	Data Collection Period	Functional Unit
C1	China	Post-industrial textile waste	August 2023–January 2024	1 kg chemically recycled PET chip
C2	China	Post-industrial (93%) and post-consumer (7%) textile waste	January–October 2024	1 kg chemically recycled PET chip
C3	Europe	Post-industrial (100%) and separately, post-consumer (100%) textile waste	October 2022*	1 kg of post-consumer chemically recycled PET chip; 1 kg of post-industrial chemically recycled chip

* Chemical recycler 3 (C3) has not yet begun commercial operations and does not currently produce a sellable product. Its input and output data is based on detailed mass and energy balances based on testing conducted at a pilot plant. This engineering study was completed in October 2022.

3.1. System boundary

The chemically recycled PET chip system boundary is cradle-to-manufacturing-gate, covering all processes from the collection and pre-treatment of waste textile feedstocks to the production of chemically recycled PET chips.

The functional unit is defined as 1 kg of chemically recycled PET chip. All required inputs and generated outputs are scaled to the production of this functional unit. The function of chemically recycled PET chip is as a feedstock to produce staple fiber, which can be subsequently used to produce a wide range of textile products. These recycled PET chips can be used as drop-in replacements for virgin chips for staple fiber production (i.e., they have the same functional equivalency as virgin PET chips for staple fiber production). Assessing the difference in the ability to apply pigments and other finishes, and the durability of a finished textile garment, between the chip produced by these types of chemical recycling technology and chip produced by other technologies (virgin, thermomechanical recycling, other types of chemical recycling) is outside the scope of this project.

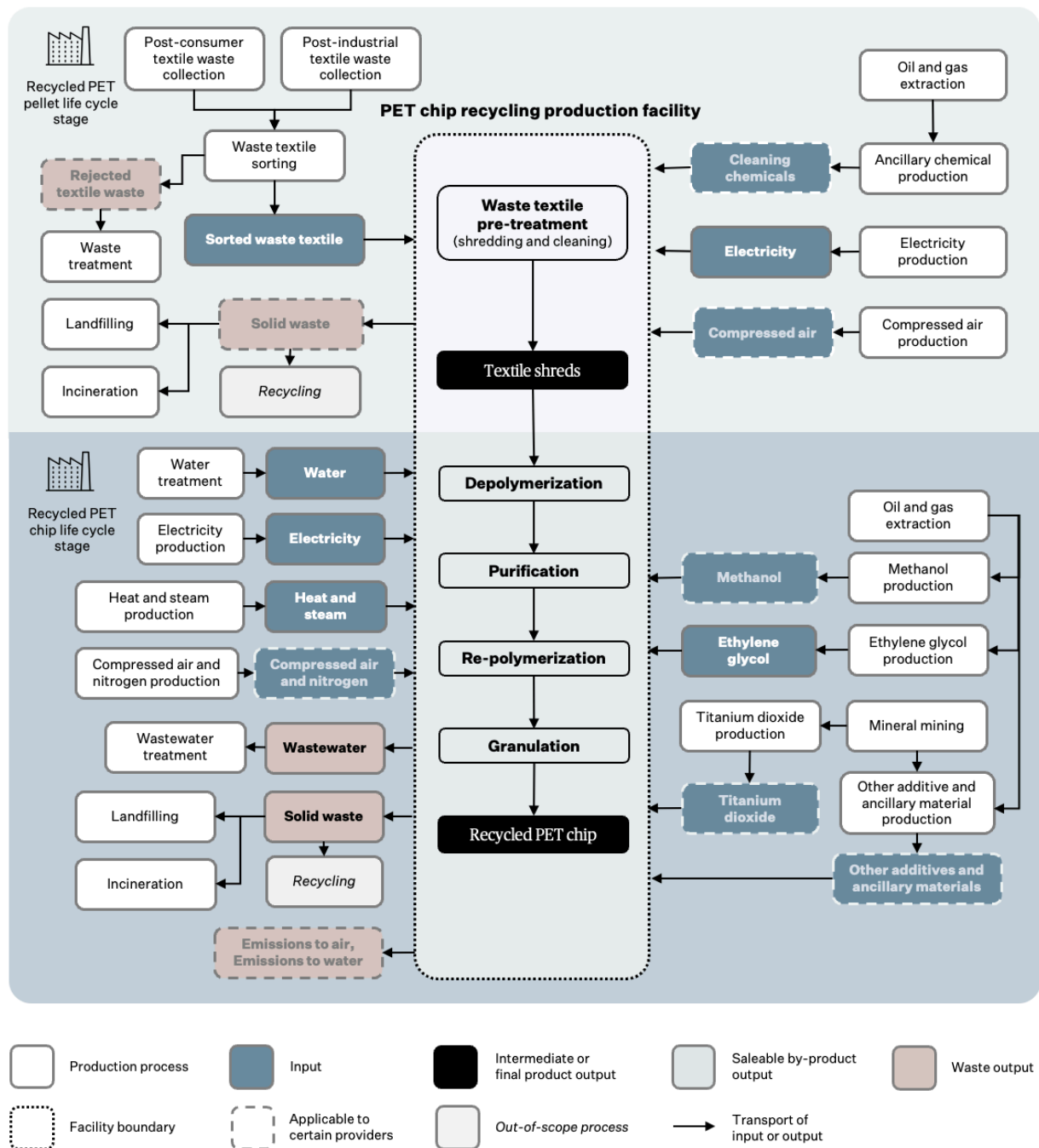
There are multiple steps that occur to turn post-industrial and post-consumer PET textile waste into a PET chip (Figure 4), and where possible, these steps have been divided into two life cycle stages (cradle-to-textile shreds and textile shreds-to-chip). However, for data provider C2, the collected input and output data (or life cycle inventory data) was not available by life cycle stage, so the results are reported for one aggregated life cycle stage (cradle-to-chip).

Ethylene glycol (EG), used by all three chemical recyclers included in this study, was modeled using the ethylene oxide production route available in the ecoinvent database. EG is commonly produced through the direct hydration of ethylene oxide (Zhang et al., 2024), which is typically derived from oil or natural gas. This pathway is the standard practice globally and is reflected in the ecoinvent EG datasets (Ecoinvent, 2024b). However, EG can also be produced using a

different and more energy-intensive process that utilizes coal syngas. This coal-to-ethylene glycol (CtEG) process is conducted in China along with the traditional EG production route (Qian et al., 2022). This route was not included in the LCA model due to the unavailability of LCI data. However, the impact of using EG produced using the CtEG process is tested in a sensitivity analysis later in this report (section 6.3).

Figure 4, below, shows the detailed product system for chemically recycled chip. For data providers C1 and C2, decoloring occurs in the depolymerization and purification stages, whereas, for data provider C3, decoloring using a solvent takes place before depolymerization, during the shredding stage, which is then followed by depolymerization.

Figure 4: System boundary diagram for chemically recycled chip



3.2. Product system description

3.2.1. Data provider C1

3.2.1.1. Background

Data provider C1 chemically recycles textile waste into bright, semi-dull, and full-dull PET chips at commercial scale using a two-stage depolymerization process.

In the first stage, glycolysis—a type of solvolytic depolymerization—is used to break down shredded PET textile into bis(2-hydroxyethyl) terephthalate (BHET). This reaction requires ethylene glycol (EG), heat, and catalysts. A portion of the EG is recovered and reused in subsequent cycles. In the second stage, transesterification with methanol (methanolysis)—a chemical reaction where the alcohol group of an ester is swapped with another alcohol—is applied to further break down the BHET into dimethyl terephthalate (DMT) and ethylene glycol. This methanolysis reaction uses methanol, heat, and catalysts, and generates EG as a by-product that is used in subsequent steps. Part of the methanol is also recovered for reuse. This step is performed to facilitate contaminant removal and produce highly purified monomers.

The resulting DMT and EG are then repolymerized into BHET through another transesterification reaction, which uses EG, heat, and catalysts and generates methanol as a by-product that is, again, captured and reused. The BHET is subjected to melt polycondensation under vacuum in the presence of catalysts and additives to form virgin-grade PET, which is extruded into PET chips. During the extrusion process, titanium dioxide is added to reduce the luster of the chips.

Although both EG and methanol are recovered and recycled during the recycling process, fresh inputs of these reagents are still required to maintain reaction efficiency and material balance within each cycle.

Primary data (i.e., data collected from manufacturing facilities) represents production between August 2023 and January 2024. The data provider is located in China.

3.2.1.2. Feedstock composition and restrictions

C1 states that its recycling process can accept both post-industrial and post-consumer textile waste, and the proportions can be adjusted to meet customer requirements; however, during the data collection period, this company almost exclusively recycled post-industrial textile waste (>99.99%) as opposed to post-consumer textile waste. Types of post-industrial textile waste recycled include fabric scraps from apparel, footwear, and home textile manufacturing. This recycling process is able to decolor waste PET, and so it can accept waste of any color. However, the waste feedstock must contain at least 85% PET. The feedstock can contain up to 10% nylon, cotton, or spandex, while all other material components must be less than 5%. Textiles with surface coatings or waterproof finishes are not accepted. Given that the majority of the feedstock is post-industrial textile waste, it does not require sorting.

All feedstock is sourced domestically from within China, in accordance with the national ban on solid waste imports implemented in January 2021.

3.2.1.3. Manufacturing process

The post-industrial textile waste is mechanically shredded and broken down into small fragments, referred to as textile shreds. The textile shreds are fed into a chemical reactor, where glycolysis and methanolysis of BHET take place to depolymerize the PET. After depolymerization, the chemical mixture is purified to remove solvents and impurities. Once purified, the monomers (dimethyl terephthalate and ethylene glycol) enter the repolymerization phase. This involves transesterification, where these two monomers form intermediate compounds, followed by

polycondensation, which further links these intermediate compounds together to form long PET polymer chains. These chemical steps rebuild the PET structure, which is extruded as PET chips.

The process requires chemicals, electricity, heat, and water, and generates waste. Waste information is confidential; based on communication with C1, it was modeled as a combination of reuse, landfill, and incineration. No co-products or by-products are reported. A small portion (3%) of electricity is supplied by onsite solar generation with the other 97% sourced from the local grid. Due to the lack of data on the sub-regional grid mix of China, the national China grid mix taken from the International Energy Agency (IEA) data for 2022 electricity generation (International Energy Agency, 2024a) which was the most recent and verifiable source available at the time of this project, was used to model grid electricity. The corresponding electricity mix used at the facility is presented in Table 20.

Input-output data was available for textile shreds (intermediate) and recycled PET chip separately; allocation was not used.

Table 20: Electricity mix—Chinese data provider C1

Type of energy	Percentage
On-site electricity—solar	3%
Grid electricity—coal	60%
Grid electricity—oil	0%
Grid electricity—natural gas	3%
Grid electricity—biofuels	2%
Grid electricity—waste	0%
Grid electricity—nuclear	5%
Grid electricity—hydro	15%
Grid electricity—solar PV	5%
Grid electricity—wind	9%
Grid electricity—other sources	0%

Due to rounding, values may not sum exactly to 100%.

A note on C1's energy usage

During the ISO 14044 critical review, the reviewers observed that C1's reported energy consumption appeared lower than expected for the chemically recycled production of recycled PET chip, especially the energy used for heating (steam and natural gas). In response, C1's life-cycle inventory (LCI) data was revalidated by reconfirming the accuracy of the initially supplied energy figures and by conducting an additional literature review.

C1 uses a two-stage depolymerization process. Glycolysis is initially used to break down PET into bis (2-hydroxyethyl) terephthalate (BHET), an oligomer, then a methanolysis-based transesterification reaction is used to further depolymerize the BHET into dimethyl terephthalate (DMT) and ethylene glycol (EG) monomers.

Although glycolysis is the most common and oldest form of chemical recycling (Ghosal and Nayak, 2022), and the most widely studied chemical depolymerization method for PET (Bohre et al., 2023) there remains a notable lack of published LCI data in the scientific literature. Two distinct data sources were identified, both derived from a combination of patents, engineering plans, and chemical process models. Uekert et al. (2023) reported slightly lower process-energy for the

glycolysis system they analyzed than C1, where “process-energy” refers to the operational energy required to depolymerize sufficient waste PET to produce one kilogram of recycled PET chip. Golkaram and Heemskerk (2022) reported substantially lower process-energy requirements. Uekert et al. (2023) also found glycolysis to have the lowest climate-change impacts among the chemical-recycling pathways they evaluated (methanolysis, dissolution, enzymatic hydrolysis, and glycolysis), and markedly lower overall environmental impacts than virgin PET production.

The variation in reported process-energy values among data providers C1 and C2 (which also utilize catalyst-assisted glycolysis) and literature sources can likely be attributed, in part, to the wide diversity of catalysts available for the glycolysis reaction. Catalysts lower the required reaction temperature and improve the yield of bis(2-hydroxyethyl) terephthalate (BHET), the target depolymerization product (Ghosal and Nayak, 2022; Bohre et al., 2023). Glycolysis is typically conducted in a closed system and does not require externally applied pressure; instead, pressure develops naturally within the reactor as the mixture is heated (i.e., under autogenous pressure) (Ghosal and Nayak, 2022; Bohre et al., 2023).

While catalyst-free glycolysis routes exist, catalytic systems remain the most widely used and industrially recognized approaches due to their effectiveness, low cost, and availability (Ghosal and Nayak, 2022; Bohre et al., 2023). Current catalysts can be grouped into several categories—metal-salt-based, heterogeneous, nanostructured, and ionic-liquid systems—each encompassing multiple specific catalysts (Ghosal and Nayak, 2022; Bohre et al., 2023). Reported reaction temperatures for glycolysis range from approximately 100°C to 300°C, depending on the catalyst and reaction conditions (Ghosal and Nayak, 2022; Bohre et al., 2023; Uekert et al., 2023). However, research and development efforts continue to focus on discovering catalysts that are more efficient and economically viable. Unfortunately, data provider C1 was unwilling to provide the specific type and mass of the catalyst(s) used and instead only informed us as to what portions of the catalyst were inorganic and organic chemicals.

No public unit-process LCI data was found for the transesterification of BHET with methanol to DMT and EG. Therefore, energy use was approximated from methanolysis of PET bottle waste from Raheem et al. (2024), and adjusted qualitatively based on Brivio and Tollini (2022) and Uekert et al. (2023). While the full methanolysis of PET requires high temperatures (>200°C) and pressures (2–4 MPa) (Babaei et al., 2024), the depolymerization of BHET using methanol can be done at ambient pressure and much lower temperatures (60–150°C) (Boaz and Stapleton, 2025; Mu et al., 2025). Using a simple energy-balance calculation for heating and methanol distillation, we estimate energy requirements that are similar or slightly higher to that reported by C1.

Based on additional discussions with C1, its confirmation of the reported data, and our literature review, we conclude that the relatively low energy requirements, including energy for heat, of its process are not implausible, though they are notable compared with data provider C2 and other systems observed by the critical review panel.

C1’s catalyst and chemical additive assumptions

Data provider C1 was unable to disclose the specific types and quantities of catalysts and additives used in its chemical recycling process due to confidentiality restrictions. It did indicate, however, that the majority of its catalysts are classified as organic chemicals, with a smaller portion being inorganic. In addition, two additives are used in the process—one organic and one inorganic.

To estimate catalyst demand, we reviewed the published literature and drew on proprietary knowledge of similar chemical recycling systems. Reported catalyst loadings for PET glycolysis vary widely (approximately 0.1–6% by weight), depending on the catalyst class (for example, metal-salt systems, heterogeneous catalysts, nanostructured catalysts, or ionic-liquid formulations) (Ghosal and Nayak, 2022; Golkaram and Heemskerk, 2022; Gabrič et al., 2025). A similar range is reported for methanol-based transesterification (approximately 0.5–5% by

weight) used to convert BHET into DMT and EG (Babaei et al., 2024). Repolymerization reactions typically require substantially lower catalyst quantities, generally around 0.01–1% by weight (Jadhav et al., 2020; Duh, 2002).

Lower catalyst dosages in the literature are typically associated with novel or highly engineered catalytic systems, while the upper end of these ranges reflects aggressive laboratory conditions that are not representative of commercial operation (Guo et al., 2025). Considering these ranges—together with proprietary data from analogous chemical recycling processes—we assume a total catalyst use of 0.03 kg per functional unit (1 kg of chemically recycled PET chip). Of this amount, 80% is assumed to be organic and 20% inorganic, modeled in openLCA using the appropriate ecoinvent datasets for generic organic and inorganic chemicals.

Based on discussions with data providers C1 and C2, chemical additives are used only during repolymerization and in trace quantities (approximately 0.01–0.02% by weight). For C1, we therefore assume 0.002 kg of additives per functional unit, modeled as a 50/50 split between organic and inorganic chemicals, again using the corresponding generic ecoinvent datasets.

While the additives used end up in the PET chip, the catalysts are either recovered or disposed of. Catalyst recovery rates vary widely depending on the class of catalyst used. For instance, metal-salt catalysts are considered challenging to recover as they fully dissolve during depolymerization (Babaei et al., 2024), while more novel catalysts can be recovered and reused multiple times in laboratory settings (Enache et al., 2024; Wang et al., 2021). Due to the lack of information on the type of catalyst used by C1, and the small mass estimated to be used, we assume that 100% of the catalyst is recovered.

These data gaps are not considered a significant limitation for any impact categories except eutrophication and freshwater ecotoxicity, where the ecoinvent organic chemical dataset accounts for 14% of C1's eutrophication and 73% of C1's freshwater ecotoxicity impact. For all other impact categories, the organic and inorganic chemical datasets used to represent the catalyst and chemical additive production contribute <10% to the total impact.

3.2.2. Data provider C2

3.2.2.1. Background

Data provider C2 chemically recycles post-industrial and post-consumer textile waste into PET chip at commercial scale using a two-stage depolymerization process.

In the first stage, glycolysis—a type of solvolytic depolymerization—is used to break down shredded PET textiles into bis(2-hydroxyethyl) terephthalate (BHET). This reaction requires ethylene glycol (EG), heat, and catalysts. A portion of the EG is recovered and reused in subsequent cycles. In the second stage, transesterification with methanol (methanolysis)—a chemical reaction where the alcohol group of an ester is swapped with another alcohol—is applied to further break down the BHET into dimethyl terephthalate (DMT) and ethylene glycol. This methanolysis uses methanol, heat, and catalysts, and generates EG as a by-product that is used in subsequent steps. Part of the methanol is recovered for reuse. This step is performed to facilitate contaminant removal and produce highly purified monomers.

The resulting DMT and EG are then repolymerized into BHET through another transesterification reaction, which uses EG, heat, and catalysts and generates methanol as a by-product that is captured and reused. Finally, the BHET is subjected to melt polycondensation under vacuum in the presence of catalysts and additives to form virgin-grade PET.

Although both EG and methanol are recovered and recycled during the process, fresh inputs of these reagents are still required to maintain reaction efficiency and material balance within each cycle.

The collected primary data represents production between January 2024 and October 2024. The region of operation is China.

3.2.2.2. Feedstock composition and restrictions

C2 states that its facility can recycle both post-industrial and post-consumer waste; however, during the data collection period, its recycled feedstock consisted of approximately 93% post-industrial textile waste and 7% post-consumer textile waste. The post-industrial waste mainly includes fabric scraps from yarn, fabric, and garment manufacturers. This waste is relatively consistent and often comes from industrial polyester-based production processes. C2 requires that the total PET content of the feedstock reaches at least 90%. The remaining 10% may include non-PET components such as nylon, cotton, and spandex. The post-consumer portion includes discarded garments and household textiles, such as polyester curtains, bedsheets, and duvet covers. These items vary widely in color and composition. Like data provider C1, the color of the waste feedstock does not matter as the recycling process removes any dyes in the feedstock.

All feedstock is sourced domestically from within China, in accordance with the national ban on solid waste imports implemented in January 2021.

3.2.2.3. Manufacturing process

The production process begins with sorting and mechanical shredding of the textile feedstock into small fragments, referred to as textile shreds. These fragments then undergo glycolysis, methanolysis of BHET, and repolymerization (transesterification and polycondensation). These chemical steps rebuild the PET structure, which is extruded as PET chips.

The results in this study are representative of a mix of recycled PET chips manufactured at the facility during the data collection period (January to October 2024). Semi-dull chips account for approximately 80%, full-dull chips 16%, bright chips 3%, cationic chips 1%, and other developmental products less than 1%.

By-products (such as DMT blocks and polyols) are generated during this production process and sold on the domestic market, but they have much lower economic values than the primary product, recycled PET chip. Since these outputs share the same manufacturing process, and the life cycle inventory (LCI) data could not be separated, allocation would typically be considered. However, economic allocation was not conducted because the by-products represent less than 1% of the total economic value based on annual procurement bidding prices. These by-products are, instead, treated as recycled waste, reflecting their low value and secondary role in the process. For more information, refer to section 2.5.

The recycling process requires chemicals, electricity, heat, and water, and generates non-hazardous and hazardous waste, along with a liquid waste stream that is recycled. The non-hazardous waste is a sludge; the recycler was unable to provide additional information on this waste. The hazardous waste includes solid process residues, used oil residues, and laboratory waste. A portion of the methanol and ethylene glycol is internally reused within each batch of the production process. A small portion of electricity (3%) is supplied by onsite solar generation, with the other 97% sourced from the local grid. The Chinese national grid mix was used to model electricity sourced from the grid due to the lack of data on the Chinese sub-region grid mixes; this grid mix was obtained from the International Energy Agency (IEA) data for 2022 electricity generation (International Energy Agency, 2024a), which was the most recent and verifiable source available at the time of this project. The corresponding electricity mix used at the facility is presented in Table 21.

Table 21: Electricity mix—Chinese data provider C2

Type of Energy	Percentage
On-site electricity—solar	3%
Grid electricity—coal	60%
Grid electricity—oil	0%
Grid electricity—natural gas	3%
Grid electricity—biofuels	2%
Grid electricity—waste	0%
Grid electricity—nuclear	5%
Grid electricity—hydro	15%
Grid electricity—solar PV	5%
Grid electricity—wind	9%
Grid electricity—other sources	0%

Due to rounding, values may not sum exactly to 100%.

3.2.3. Data provider C3

3.2.3.1. Background

Data provider C3 operates on a pre-commercial scale and uses partial glycolysis technology for depolymerization. Since this company does not currently have a commercially operating plant, its life cycle inventory (LCI) data was developed using an engineering study for a planned commercial plant and validated using detailed mass and heat balances based on testing at a pilot plant. The quality of this life cycle inventory (input-output data) is lower than that for a commercially operating facility due to the uncertainty in engineering plans, which are estimates. The actual input and output data for a commercially operating plant can be different than in the engineering study, and the LCA results for this data provider should be interpreted with this in mind.

The primary data consists of the inputs and outputs calculated based on the engineering study, which concluded in October 2022. C3's facility is assumed to be located in a specific country within Europe; however, the exact country of operation has not been included for confidentiality.

3.2.3.2. Feedstock composition and restrictions

Data provider C3 plans to produce recycled PET chip from two types of waste feedstock: either post-industrial or post-consumer polyester textile waste. Both PET chips are textile-grade and can be used for textile applications. The post-industrial waste feedstock comes from sources such as mattress production facilities, and straps for shipping, and is assumed to be 95.95% PET after sorting. The post-consumer waste, which requires more sorting than post-industrial waste, is estimated to contain a mixture of different types of textiles, such as polyester, cotton, wool, and textile blends. It is assumed to be 91.95% PET after sorting. This recycling process is able to decolor the waste PET. No other information on feedstock limitations was provided.

3.2.3.3. Manufacturing process

After collecting and sorting of the waste textile, it is sent to the feedstock preparation plant. For the collection and sorting of waste, data was collected through a third-party waste collection and sorting company. A limitation of the data is that the treatment of non-target materials is not included in the LCI due to a lack of data. At the feedstock preparation plant, waste textile is shredded into textile shreds and colorants are removed using a proprietary solvent. This

decolorized material is then melted, partially depolymerized, filtered, and then re-polymerized into recycled PET chips. Any waste generated is incinerated off-site.

Allocation was not used to model this product system as input-output data was available for each product separately.

The process requires electricity, compressed gas, water, and chemicals (proprietary solvent and ethylene glycol), and generates non-hazardous waste, which consists of the used proprietary solvent and contaminants removed from the waste. Since this process is operated in Europe, the electricity grid is modeled for the specific (confidential) country that the facility is located in. The grid mix for the (confidential) country is based on IEA data for 2022 (International Energy Agency, 2024b). The ecoinvent dataset for this country is used as the basis and was modified using this IEA data. This ecoinvent dataset includes imported electricity, which accounts for 20% of the total electricity in the dataset. The corresponding electricity mix used at the facility is presented in Table 22. While the grid mix for the (confidential) European country is used as a baseline in this study, the data provider aims to use 100% renewable energy for its planned commercial scale plant, and states that it will require any user of its technology to do the same.

Table 22: Electricity mix—European data provider C3

Type of energy	Percentage
European country grid mix	80%
Coal	11%
Oil	1%
Natural gas	31%
Biofuels	5%
Waste	2%
Nuclear	2%
Hydro	0%
Solar PV	11%
Wind	14%
Other sources	1%
Imported electricity	20%

Due to rounding, values may not sum exactly to 100%.

3.3 Summary of assumptions

The study relies on several assumptions, which are described below:

- Ecoinvent v3.11 datasets were used to model all life cycle inventory data. While primary data was available for quantities of inputs and outputs used at each facility, ecoinvent data was used to model the production of those inputs, treatment of wastes, and all transport. Ecoinvent datasets were selected based on temporal, geographic, and technological representativeness. Except where noted, they are considered to be representative of the actual production, waste treatment, and transport processes for which primary data was not available.
- A large portion of the recycled textile waste is provided by intermediary waste suppliers that may not be the first to collect the waste. A small portion is directly sourced from industry, as seen in data providers C2 and C3. Where information on this transport was available, it was

used in the model. However, no data on the collection of waste upstream of the data providers' suppliers was available. Therefore, the following assumptions are made:

- Data provider C1 was only able to provide a general area from which post-industrial waste was collected. The transport distance modeled is estimated, based on this information.
 - Data provider C2 was only able to provide a general area from which post-industrial waste was collected and the transport distance is estimated based on this information.
 - Data provider C2 was unable to provide the exact distance required to collect the post-consumer textile waste. Instead, a list of all post-consumer waste suppliers used by C2 was provided. The farthest known post-consumer textile waste supplier location (1,200 km) was used as a conservative estimate. Given that post-consumer textile waste represents only 7% of the feedstock, its impact on the overall process is limited.
 - For data provider C3, the upstream transport distance of waste post-consumer textile is modeled using secondary data from a European recycling company that collects and sorts textile waste. The distance is estimated from the (confidential) carbon footprint of the collection of one metric ton of textile waste by this company, which is 310 km. The upstream transport distance for post-industrial textile waste is modeled as 200 km, which is a reasonable assumption based on data provider C3's experience.
 - The sensitivity of the results to the transport distance required to collect post-consumer and post-industrial textile waste is tested in a scenario analysis in section 6.2.1.
- Data provider C1 was unable to provide the mass or specific type of catalyst and chemical additives used in its recycling process due to confidentiality concerns. Instead, it informed us that the majority of its catalysts are classified as organic chemicals, with the remaining inorganic. It also shared that two additives are used, one of which is organic and the other inorganic. Based on this information, it was assumed that 80% of the catalysts are organic, with the remaining 20% inorganic. The additives were assumed to be a 50-50 split of organic and inorganic. The mass of catalysts and additives was estimated as 0.03 kg and 0.002 kg respectively, which was based on a literature review and by examining data collected from similar chemical recycling processes. It is assumed that 100% of catalysts are recovered at end-of-life and that all of the additives remain in the PET chip until its end-of-life.
 - For data provider C2, manual sorting takes place at its suppliers. As no primary data was available, this post-consumer textile waste sorting process is modeled based on Nørup et al. (2019), which provided life cycle inventory data for the manual sorting of textiles at a European sorting facility. The electricity grid mix is adjusted to reflect the Chinese 2022 grid mix, which is based on the IEA 2022 database.
 - Several ancillary chemicals used in chemical recycling were not available in ecoinvent, including antimony glycolate, trimethyl phosphate, sodium acetate, and manganese acetate. Instead, proxy chemical production datasets were used (see section 3.4.1 for details). These proxy datasets are not considered a significant limitation as these ancillary chemicals are used in very small quantities (<0.1% by mass of all inputs required per kilogram of product).
 - Data provider C3 uses a confidential solvent during its shredding process, which it did not provide information on. A proxy dataset for the production of a mix of organic chemicals from ecoinvent was used to represent this solvent and likely does not accurately represent the actual impacts of producing this solvent. A sensitivity analysis to test this was not deemed appropriate as there was no information available to create reasonable scenarios to test.
 - All truck transport is modeled using the ecoinvent dataset for truck transport using the EURO 4 emission standard for vehicles in the 16–32 metric ton weight class. This weight class is used to represent typical heavy-duty freight transport in industrial supply chains. A discussion of EURO transport standards is provided in section 6.2.
 - A distance of 32 km is assumed for the transport of all manufacturing waste generated during recycling from the point of generation to a treatment facility and is based on the US

Environmental Protection Agency (EPA) Waste Reduction Model (WARM) (Environmental Protection Agency, 2004).

3.4. Life cycle inventory

3.4.1. Data collection and modeling

Primary data was collected from all three data providers' recycling facilities, including all inputs and outputs required to produce the functional unit. Secondary data taken from literature studies (described above in section 3.3) on textile waste recycling was used to model post-industrial and post-consumer textile waste collection.

These inputs and outputs were modeled in open LCA v2.4 software, using datasets from the ecoinvent v3.11 database (Ecoinvent, 2024a). Ecoinvent datasets with the greatest degree of technological, geographic, and temporal representativeness were chosen; a data quality assessment is provided in section 3.4.2. Detailed descriptions of these ecoinvent datasets can be found in the accompanying ecoinvent documentation (Ecoinvent, 2024a). The LCI datasets used in the model to represent unit processes in the cradle-to-gate LCA are provided below.

Table 23: LCI datasets from ecoinvent 3.11 (2024)—LCA modeling for chemical recycling

Note: To protect the confidentiality of the data providers, the geography of the ecoinvent datasets (chosen for the specific area in which the recyclers operate) has been removed. The word "proxy" has been added to certain datasets, and is used to denote an instance when the chosen dataset is either similar or the best match to a process flow when specific data is unavailable or unsuitable, serving as a substitute for the actual data.

Flow	Geography	Dataset
Raw material and chemical inputs		
Post-industrial waste textile feedstock	Global/ Rest-of-World	Market for transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 cutoff, U
Post-consumer waste textile feedstock	Global/ Rest-of-World/ China	Market for transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 cutoff, U (feedstock collection) Market for electricity, medium voltage electricity, medium voltage cutoff, U - China 2022 (IEA 2024) (Environmental Protection Agency, 2025a) Market for heat, district or industrial, natural gas heat, district or industrial, natural gas cutoff, U Market for polyethylene terephthalate, granulate, amorphous polyethylene terephthalate, granulate, amorphous cutoff, U (packaging) Market for extrusion, plastic film extrusion, plastic film cutoff, U (packaging) Market for tap water tap water cutoff, U Market for inert waste, for final disposal inert waste, for final disposal cutoff, U (disposal to landfill) Treatment of waste textile, soiled, municipal incineration waste textile, soiled cutoff, U Market for transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 cutoff, U (rejected waste textile transport)
Solvent (confidential, proxy)	Global	Market for chemical, organic chemical, organic cutoff, U
Ethylene glycol	Europe	Market for ethylene glycol ethylene glycol cutoff, U

Flow	Geography	Dataset
Ethylene glycol	Rest-of-World	Market for ethylene glycol ethylene glycol cutoff, U
Methanol	China	Market for methanol methanol cutoff, U
Catalyst (confidential)	Global	Market for chemical, inorganic chemical, inorganic cutoff, U Market for chemical, organic chemical, organic cutoff, U (proxy)
Catalyst	Global	Market for potassium carbonate potassium carbonate cutoff, U
Titanium dioxide	Rest-of-World	Market for titanium dioxide titanium dioxide cutoff, U
Catalyst	Global/Rest-of-World	Market for antimony antimony cutoff, U (proxy) Market for ethylene glycol ethylene glycol cutoff, U (proxy)
Catalyst	Global	Market for acetic acid acetic acid cutoff, U (proxy)
Additive (confidential)	Global	Market for chemical, organic chemical, organic cutoff, U (proxy)
Additive (confidential)	Global	Market for chemical, inorganic chemical, inorganic cutoff, U (proxy)
Additive	Rest-of-World	Market for dimethyl sulfate dimethyl sulfate cutoff, U (proxy)
Electricity and utilities		
Grid electricity	Europe	Market for electricity, medium voltage electricity, medium voltage cutoff, U - Modified using IEA 2022 grid data (International Energy Agency, 2024b)
Grid electricity	China	Market for electricity, medium voltage electricity, medium voltage cutoff, U - - custom grid mix for China 2022 (IEA 2024)
Solar electricity	China	Electricity production, photovoltaic, 570kWp open ground installation, multi-Si electricity, low voltage cutoff, U—China sub-region (confidential)
Natural gas	Rest-of-World	Market for heat, district or industrial, natural gas heat, district or industrial, natural gas cutoff, U
Steam	Rest-of-World	Market for steam, in chemical industry steam, in chemical industry cutoff, U
Compressed air	Europe	Market for compressed air, 600kPa gauge compressed air, 600kPa gauge cutoff, U
Nitrogen	Europe	Market for nitrogen, liquid nitrogen, liquid cutoff, U
Nitrogen	Rest-of-World	Market for nitrogen, liquid nitrogen, liquid cutoff, U
Water	Europe	Market for water, deionized water, deionized cutoff, U
Water	Rest-of-World	Market for tap water tap water cutoff, U
Recycled water	China	Water, unspecified natural origin (proxy, no associated environmental impact)
Transport		
Truck transport	Europe	Transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 cutoff, U
Truck transport	Rest-of-World	Market for transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 cutoff, U

Flow	Geography	Dataset
Waste treatment		
Incineration of hazardous waste	Europe	Treatment of hazardous waste, hazardous waste incineration, with energy recovery hazardous waste, for incineration cutoff, U
Incineration of hazardous waste	Rest-of-World	Market for hazardous waste, for incineration hazardous waste, for incineration cutoff, U
Incineration of hazardous waste (solvent)	Europe	Treatment of spent solvent mixture, hazardous waste incineration, with energy recovery spent solvent mixture cutoff, U
Incineration of waste metals	Europe	Treatment of waste steel, municipal incineration waste steel cutoff, U
Incineration of waste plastics	Europe	Treatment of waste plastic, mixture, municipal incineration FAE waste plastic, mixture cutoff, U
Incineration of waste PET	Europe	Treatment of waste polyethylene terephthalate, municipal incineration FAE waste polyethylene terephthalate cutoff, U
Treatment of sludge	Rest-of-World	Market for raw sewage sludge raw sewage sludge cutoff, U (sewage sludge drying and incineration)
Treatment of inert waste	Rest-of-World	Market for inert waste, for final disposal inert waste, for final disposal cutoff, U (disposal to landfill)
Wastewater treatment	Rest-of-World	Market for wastewater, average wastewater, average cutoff, U
Wastewater treatment	Europe	Treatment of wastewater, average, wastewater treatment wastewater, average cutoff, U

3.4.2. Data quality assessment

A data quality assessment, based on the adapted PEF DQR methodology explained in section 2.7, was conducted for all chemically recycled products. This data quality assessment is shown in Table 24.

The color gradient is applied to highlight relative variation within the observed range, not to represent fixed rating categories across the full 1–5 DQR range; the greenest shade is assigned to the minimum and the reddest shade to the maximum. C1 and C2's data quality ratings fall within 1.5–2.0 and are rated as “very good quality.” C3, which does not currently have a commercially operating facility, was only able to provide data based on an engineering study. This data is less certain and its scores fall between 2.0–2.3 but are still rated as “good quality” (section 2.7, Table 16).

Table 24: Data quality assessment for chemical recycling product systems

Impact category	C1—PET chip	C2—PET chip	C3—post-consumer chip	C3—post-industrial chip
Climate change	1.76	1.66	2.06	2.07
Acidification	1.74	1.65	2.06	2.12
Eutrophication	1.86	1.74	2.21	2.24
Abiotic depletion, fossil fuels	1.80	1.67	2.08	2.12
Freshwater ecotoxicity	1.86	1.73	2.26	2.24

Impact category	C1—PET chip	C2—PET chip	C3—post-consumer chip	C3—post-industrial chip
Water scarcity	1.72	1.59	2.06	2.10
Freshwater consumption	1.73	1.59	1.96	2.06

3.5. Life cycle impact assessment (LCIA) results

The cradle-to-gate life cycle impact results for each chemical recycler are given below in sections 3.5.1–3.5.3. Each section includes the Higg MSI and EF 3.1 acidification results, along with a process-level contribution analysis; a detailed analysis of these results are explored below. In addition, the results for the EF 3.1 indicators are also included; however, no process-level contribution analysis or detailed analysis of the results was conducted for these indicators.

For data providers C1 and C3, results are split by life cycle stage. For C2, LCI data was not available by life cycle stage, and results are presented for the total cradle-to-gate system boundary.

Contribution analysis by process explores how the different inputs and processes involved in each chemical recycler's operations contribute to each impact category. The contribution to the total impact of the inputs required, and treatment of waste generated from each recycling process, were assessed and are shown below. A description of the input, and any additional processes involved in the production of that input, are shown in Table 25, below.

Table 25: Chemical recycling key inputs

Key inputs	Description
Feedstock collection	Collection of waste feedstock, which enters the system burden free. Includes transport that occurs only upstream of the data provider's suppliers
Feedstock sorting	Sorting of collected waste
Electricity	Electricity used at the recycling facility
Compressed gas	Compressed air and nitrogen used at the recycling facility
Heat	Heat or steam used at the recycling facility
Chemicals	Production of chemicals used at the recycling facility
Water	Accounts for net water use (the output of treated wastewater released back to the environment subtracted from the water input) in the recycling process of each facility
Transport	Inbound truck and ship transport from the data provider's suppliers to the recycling facility, and outbound truck transport to waste treatment
Waste treatment	On-site direct emissions and off-site treatment and disposal of solid and liquid waste

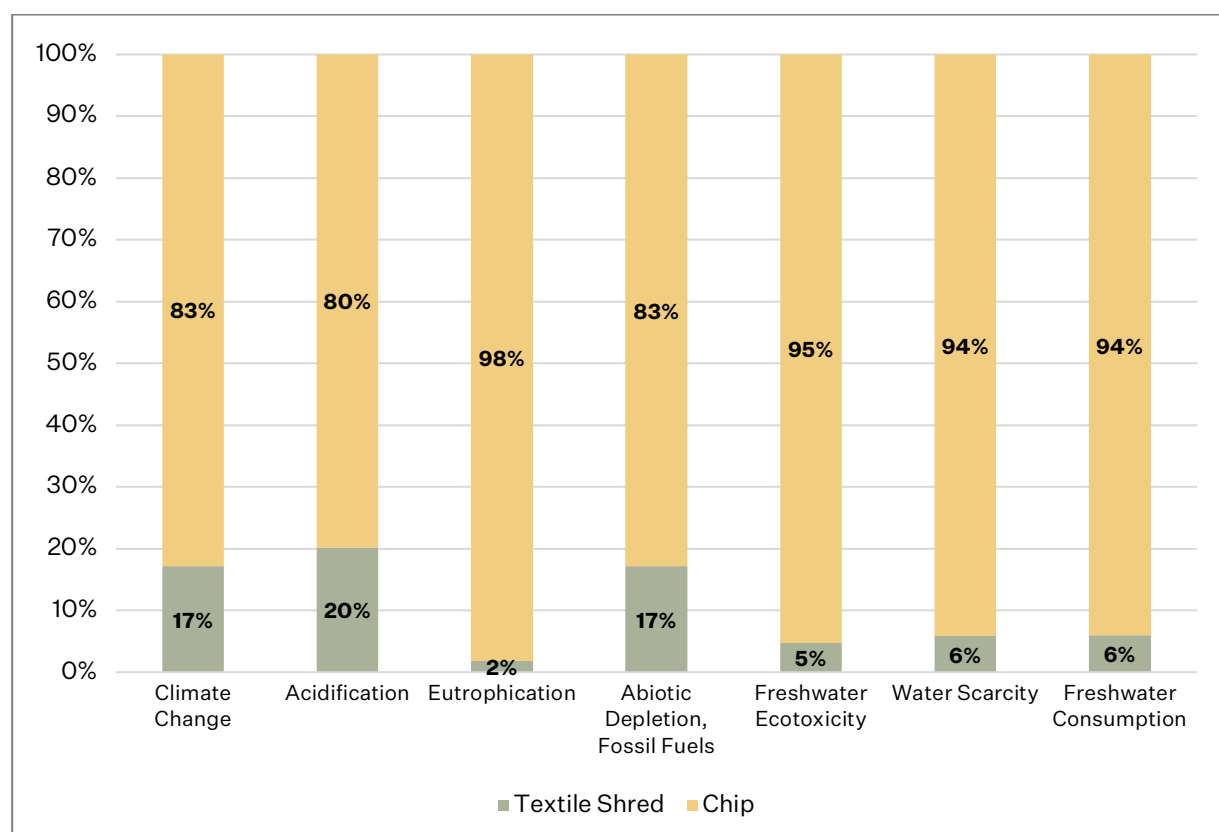
3.5.1. Data provider C1

3.5.1.1. Higg MSI and EF 3.1 acidification results

The LCIA results, including both total values and breakdowns by life cycle stage, are presented in Table 26. Figure 5 visualizes the relative contributions by life cycle stage based on 3-8. For data provider C1, the textile shreds-to-chip life cycle stage is the most impactful of all impact categories ($\geq 80\%$).

Table 26: C1—LCIA results for 1 kg chemically recycled chip—100% post-industrial textile waste

Impact category	Cradle-to-textile shreds		Textile shreds-to-chip		Total
Climate change (kg CO ₂ eq)	0.304	17%	1.46	83%	1.77
Acidification (mol H ⁺ eq)	1.36x10 ⁻³	20%	5.37x10 ⁻³	80%	6.73x10 ⁻³
Eutrophication (kg PO ₄ eq)	4.12x10 ⁻⁴	2%	2.25x10 ⁻²	98%	2.29x10 ⁻²
Abiotic depletion, fossil fuels (MJ)	3.96	17%	19.1	83%	23.0
Freshwater ecotoxicity (PAF m ³ day)	2.51x10 ⁻⁴	5%	5.10x10 ⁻³	95%	5.35x10 ⁻³
Water scarcity (m ³ world eq)	2.86x10 ⁻²	6%	0.458	94%	0.487
Freshwater consumption (m ³)	6.66x10 ⁻⁴	6%	1.05x10 ⁻²	94%	1.12x10 ⁻²

Figure 5: C1—contribution by life cycle stage

3.5.1.2. EF 3.1 results**Table 27: C1—EF 3.1 LCIA results for 1 kg of chemically recycled PET chip—100% post-industrial textile waste**

Impact category	Cradle-to-textile shreds		Textile shreds-to-chip		Total
Acidification (mol H ⁺ eq)	1.36x10 ⁻³	20%	5.37x10 ⁻³	80%	6.73x10 ⁻³
Climate change (kg CO ₂ eq)	0.304	17%	1.46	83%	1.77
Climate change (biogenic) (kg CO ₂ eq)	8.94x10 ⁻⁵	7%	1.14x10 ⁻³	93%	1.23x10 ⁻³
Climate change (fossil) (kg CO ₂ eq)	0.304	17%	1.46	83%	1.76
Climate change (land use) (kg CO ₂ eq)	2.84x10 ⁻⁴	12%	2.05x10 ⁻³	88%	2.33x10 ⁻³
Ecotoxicity freshwater (CTUe)	0.782	6%	11.9	94%	12.7
Ecotoxicity freshwater (inorganics) (CTUe)	0.766	6%	11.8	94%	12.6
Ecotoxicity freshwater (organics) (CTUe)	1.58x10 ⁻²	13%	0.104	87%	0.120
Eutrophication freshwater (kg P eq)	3.69x10 ⁻⁵	9%	3.62x10 ⁻⁴	91%	3.99x10 ⁻⁴
Eutrophication marine (kg N eq)	4.46x10 ⁻⁴	28%	1.13x10 ⁻³	72%	1.57x10 ⁻³
Eutrophication terrestrial (mol N eq)	4.86x10 ⁻³	29%	1.20x10 ⁻²	71%	1.68x10 ⁻²
Human toxicity cancer (CTUh)	4.54x10 ⁻¹¹	8%	5.43x10 ⁻¹⁰	92%	5.89x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	1.96x10 ⁻¹¹	8%	2.33x10 ⁻¹⁰	92%	2.53x10 ⁻¹⁰
Human toxicity cancer (organics) (CTUh)	2.57x10 ⁻¹¹	8%	3.10x10 ⁻¹⁰	92%	3.36x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	2.17x10 ⁻⁹	22%	7.57x10 ⁻⁹	78%	9.74x10 ⁻⁹
Human toxicity non-cancer (inorganics) (CTUh)	2.02x10 ⁻⁹	22%	7.07x10 ⁻⁹	78%	9.08x10 ⁻⁹
Human toxicity non-cancer (organics) (CTUh)	1.52x10 ⁻¹⁰	23%	5.04x10 ⁻¹⁰	77%	6.56x10 ⁻¹⁰
Ionizing radiation (human health) (kBq U235 eq)	5.94x10 ⁻³	9%	5.97x10 ⁻²	91%	6.56x10 ⁻²
Land use (dimensionless (pt))	2.34	36%	4.17	64%	6.52
Ozone depletion (kg CFC11 eq)	3.63x10 ⁻⁹	14%	2.18x10 ⁻⁸	86%	2.54x10 ⁻⁸
Particulate matter (disease incidence)	2.08x10 ⁻⁸	24%	6.64x10 ⁻⁸	76%	8.71x10 ⁻⁸
Photochemical ozone formation (human health) (kg NMVOC eq)	1.63x10 ⁻³	26%	4.57x10 ⁻³	74%	6.21x10 ⁻³
Resource use fossils (MJ (net calorific))	4.08	17%	20.3	83%	24.4
Resource use minerals and metals (kg Sb eq)	9.06x10 ⁻⁷	15%	5.28x10 ⁻⁶	85%	6.18x10 ⁻⁶
Water use (m ³ world eq)	2.86x10 ⁻²	6%	0.458	94%	0.487

3.5.1.3. Contribution analysis by process

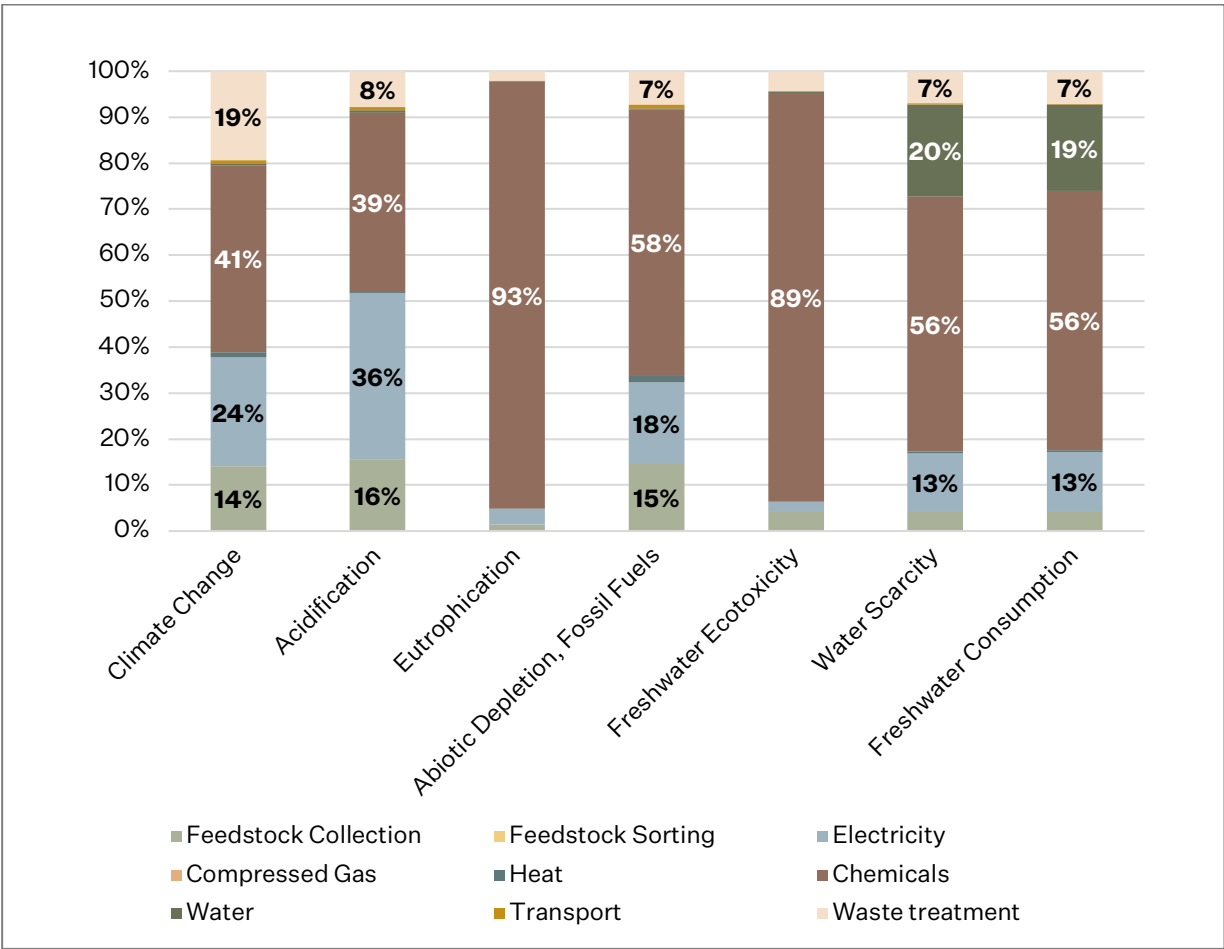
The use of chemicals is the dominant contributing input to each impact category for data provider C1. Overall, chemicals account for 39–93% across all impact categories (Figure 6). For climate change, chemicals contribute 41%. Virgin ethylene glycol and methanol drive most of the impacts because of their consumption volumes, energy-intensive production, fossil-based origins, and associated emissions. While these two chemicals are major contributors to most impact categories, their role in freshwater ecotoxicity is smaller but still considerable. The generic organic chemical dataset used to model catalysts and additives accounts for 73% of cradle-to-gate freshwater ecotoxicity and is noted as a limitation of the study.

Electricity use is also a significant contributor, especially for climate change, acidification, and abiotic depletion of fossil fuels (18–36%). Electricity’s contribution to eutrophication is relatively low (3%) as eutrophication is almost entirely driven by chemical use (93%).

The collection of the post-industrial feedstock and waste treatment are also notable contributors. Feedstock collection accounts for 14–16% of the climate change, acidification, and abiotic depletion of fossil fuels impacts (Figure 6), which is unsurprising given the large distance required to collect the post-industrial waste (967 km). Waste treatment contributes 19% to climate change, primarily from emissions generated during incineration.

The water scarcity and freshwater consumption impact categories are driven mostly by the production of chemicals used in the recycling process (56%). Water used at the recycling facility adds approximately 20% to these impacts.

Figure 6: C1—process-level contribution



Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

3.5.2. Data provider C2

3.5.2.1. Higg MSI and EF 3.1 acidification results

As mentioned previously, data collected for C2 was not able to be subdivided between the cradle-to-textile shreds and textile shreds-to-chip stages. The cradle-to-chip results are presented in Table 28.

Table 28: C2—LCIA results for 1 kg chemically recycled chip—93% post-industrial, 7% post-consumer textile waste

Impact category	Cradle-to-chip total
Climate change (kg CO ₂ eq)	2.24
Acidification (mol H ⁺ eq)	8.63x10 ⁻³
Eutrophication (kg PO ₄ eq)	2.81x10 ⁻²
Abiotic depletion, fossil fuels (MJ)	28.9
Freshwater ecotoxicity (PAF m ³ day)	1.67x10 ⁻³
Water scarcity (m ³ world eq)	0.468
Freshwater consumption (m ³)	1.07x10 ⁻²

Data was not available by life cycle stage; only total results are presented.

3.5.2.2. EF 3.1 results

Table 29: C2—EF 3.1 LCIA results for 1 kg chemically recycled chip—93% post-industrial, 7% post-consumer textile waste

Impact category	Cradle-to-chip
Acidification (mol H ⁺ eq)	8.63x10 ⁻³
Climate change (kg CO ₂ eq)	2.24
Climate change (biogenic) (kg CO ₂ eq)	1.17x10 ⁻³
Climate change (fossil) (kg CO ₂ eq)	2.24
Climate change (land use) (kg CO ₂ eq)	2.42x10 ⁻³
Ecotoxicity freshwater (CTUe)	11.1
Ecotoxicity freshwater (inorganics) (CTUe)	11.0
Ecotoxicity freshwater (organics) (CTUe)	0.105
Eutrophication freshwater (kg P eq)	3.62x10 ⁻⁴
Eutrophication marine (kg N eq)	1.91x10 ⁻³
Eutrophication terrestrial (mol N eq)	2.05x10 ⁻²
Human toxicity cancer (CTUh)	6.18x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	1.22x10 ⁻¹⁰
Human toxicity cancer (organics) (CTUh)	4.95x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	1.14x10 ⁻⁸
Human toxicity non-cancer (inorganics) (CTUh)	9.89x10 ⁻⁹
Human toxicity non-cancer (organics) (CTUh)	1.47x10 ⁻⁹
Ionizing radiation (human health) (kBq U235 eq)	6.54x10 ⁻²

Impact category	Cradle-to-chip
Land use (dimensionless (pt))	6.56
Ozone depletion (kg CFC11 eq)	3.24×10^{-8}
Particulate matter (disease incidence)	1.14×10^{-7}
Photochemical ozone formation (human health) (kg NMVOC eq)	7.76×10^{-3}
Resource use fossils (MJ (net calorific))	30.5
Resource use minerals and metals (kg Sb eq)	3.47×10^{-4}
Water use (m ³ world eq)	0.467

Data was not available by life cycle stage; only total results are presented.

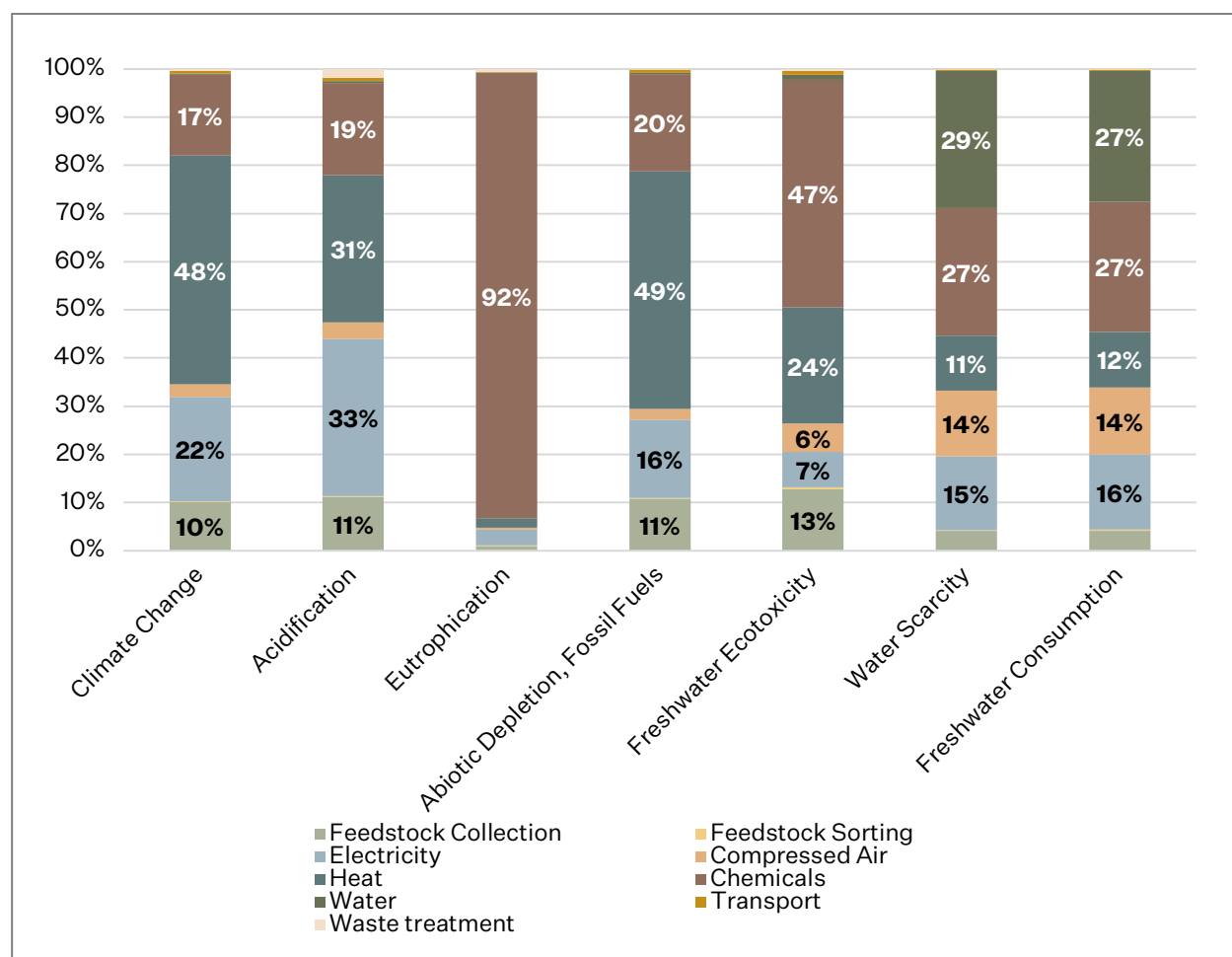
3.5.2.3. Contribution analysis by process

Energy use, which includes heat and electricity use, is the largest contributor across several impact categories (Figure 7). Heat is the largest driver of climate change (48%) and abiotic depletion of fossil fuels (49%), while electricity contributes most to acidification (33%). Combined, heat and electricity account for the majority of impacts in climate change (70%), abiotic depletion of fossil fuels (65%), and acidification (64%).

Chemicals are another major contributor, dominating eutrophication (92%) and nearly half of freshwater ecotoxicity (47%). They also contribute to climate change (17%), acidification (19%), water scarcity (27%), and freshwater consumption (27%). Ethylene glycol and methanol are notable drivers due to their consumption volumes, fossil-based origins, energy-intensive production, and associated emissions. While these two chemicals are major contributors to several impact categories, their role in freshwater ecotoxicity is smaller but still considerable. The catalyst used in glycolysis and methanolysis of BHET is a larger driver of freshwater ecotoxicity.

Collection of post-industrial and post-consumer textile waste has a smaller role, contributing 10–13% across climate change (10%), acidification (11%), abiotic depletion of fossil fuels (11%), and freshwater ecotoxicity (13%). These impacts arise primarily from transport, as collection involves long distances of 818 km for post-industrial textile waste and 1,200 km for post-consumer textile waste.

For water scarcity and freshwater consumption, direct water use at the recycling facility is the single largest contributor, accounting for 29% and 27%, respectively. The upstream production of chemicals (27%) and electricity use (15–16%) are also notable, followed by nitrogen production (14%) and heat and steam production (11–12%).

Figure 7: C2—process-level contribution

Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

3.5.3. Data provider C3

Data provider C3 operates at a pre-commercial level, and its manufacturing data is based on an engineering study for a planned commercial plant and validated using detailed mass and heat balances based on testing at a pilot plant. However, this data may not reflect commercial operations, and these results should be interpreted with caution. This data provider plans to produce two types of chip, one from post-industrial textile waste and one from post-consumer textile waste. The chip produced from post-industrial textile waste has a lower impact than that from post-consumer textile waste. This difference is driven by the fact that post-industrial textile waste has fewer contaminants than post-consumer textile waste and, therefore, requires fewer resources to sort and clean. For both types of chips, the cradle-to-textile shreds stage has a higher impact than the textile shreds-to-chip stage ($\geq 56\%$). This is driven by the shredding and decoloring stage, specifically due to the electricity and the solvent used in the process.

3.5.3.1. Higg MSI and EF 3.1 acidification results

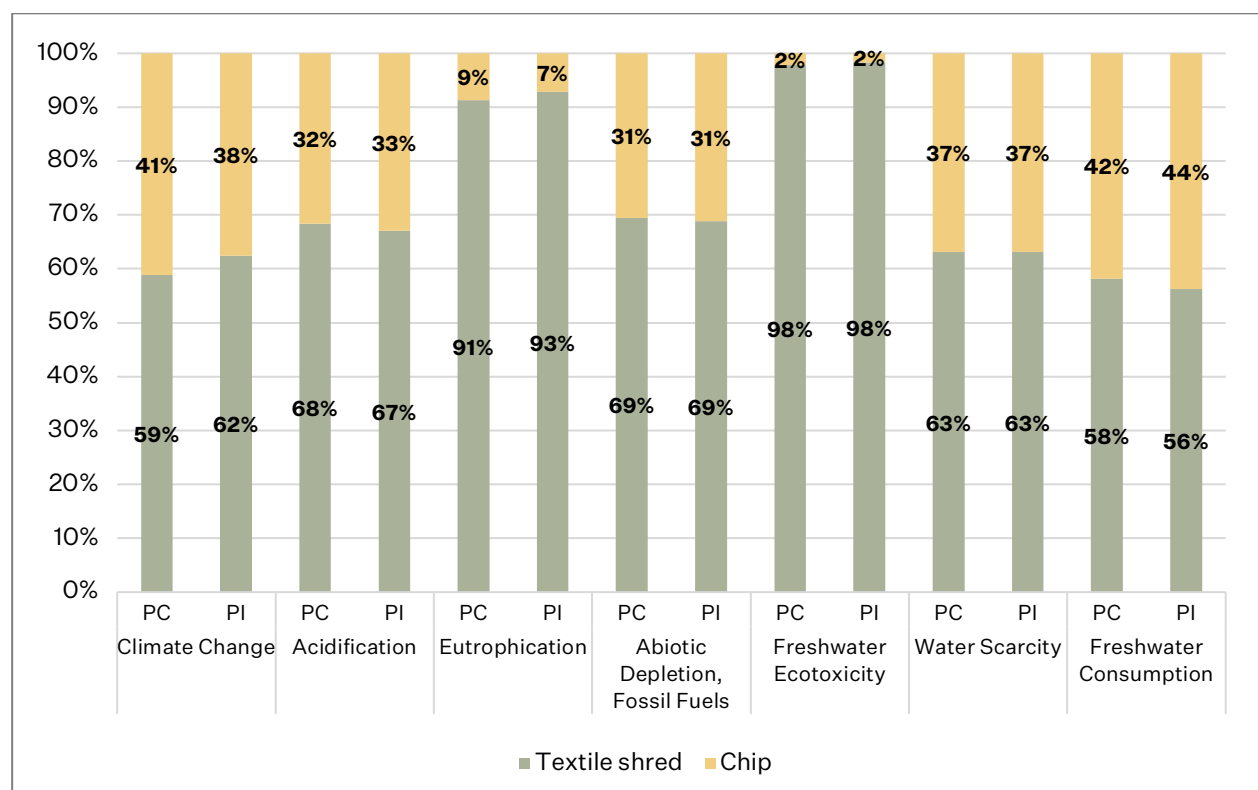
Table 30: C3—LCIA results for 1 kg chemically recycled chip—100% post-consumer textile waste

Impact category	Cradle-to-textile shreds		Textile shreds-to-chip		Total
Climate change (kg CO ₂ eq)	0.522	59%	0.364	41%	0.885
Acidification (mol H ⁺ eq)	1.45x10 ⁻³	68%	6.69x10 ⁻⁴	32%	2.12x10 ⁻³

Impact category	Cradle-to-textile shreds		Textile shreds-to-chip		Total
Eutrophication (kg PO ₄ eq)	5.60x10 ⁻³	91%	5.37x10 ⁻⁴	9%	6.14x10 ⁻³
Abiotic depletion, fossil fuels (MJ)	6.96	69%	3.06	31%	10.0
Freshwater ecotoxicity (PAF m ³ day)	6.46x10 ⁻³	98%	1.42x10 ⁻⁴	2%	6.60x10 ⁻³
Water scarcity (m ³ world eq)	0.124	63%	7.27x10 ⁻²	37%	0.197
Freshwater consumption (m ³)	0.156	58%	0.112	42%	0.268

Table 31: C3—LCIA results for 1 kg chemically recycled chip—100% post-industrial textile waste

Impact category	Cradle-to-textile shreds		Textile shreds-to-chip		Total
Climate change (kg CO ₂ eq)	0.426	62%	0.257	38%	0.683
Acidification (mol H ⁺ eq)	1.11x10 ⁻³	67%	5.48x10 ⁻⁴	33%	1.66x10 ⁻³
Eutrophication (kg PO ₄ eq)	5.37x10 ⁻³	93%	4.16x10 ⁻⁴	7%	5.78x10 ⁻³
Abiotic depletion, fossil fuels (MJ)	5.71	69%	2.59	31%	8.30
Freshwater ecotoxicity (PAF m ³ day)	6.23x10 ⁻³	98%	1.08x10 ⁻⁴	2%	6.34x10 ⁻³
Water scarcity (m ³ world eq)	0.111	63%	6.53x10 ⁻²	37%	0.176
Freshwater consumption (m ³)	0.141	56%	0.109	44%	0.250

Figure 8: C3—contribution by life cycle stage—100% post-consumer (PC) chip and 100% post-industrial (PI) chip

3.5.3.2. EF 3.1 results

Table 32 and Table 33, below, show the life cycle impact assessment (LCIA) results for the EF 3.1 impact categories for data provider C3.

Table 32: C3—EF 3.1 LCIA results for 1 kg of chemically recycled chip—100% post-consumer textile waste

Impact category	Cradle-to-textile shred		Textile shred-to-chip		Total
Acidification (mol H ⁺ eq)	1.44x10 ⁻³	68%	6.80x10 ⁻⁴	32%	2.12x10 ⁻³
Climate change (kg CO ₂ eq)	0.522	59%	0.364	41%	0.886
Climate change (biogenic) (kg CO ₂ eq)	2.82x10 ⁻⁴	44%	3.63x10 ⁻⁴	56%	6.45x10 ⁻⁴
Climate change (fossil) (kg CO ₂ eq)	0.521	59%	0.363	41%	0.885
Climate change (land use) (kg CO ₂ eq)	2.13x10 ⁻⁴	62%	1.30x10 ⁻⁴	38%	3.43x10 ⁻⁴
Ecotoxicity freshwater (CTUe)	2.20	48%	2.41	52%	4.61
Ecotoxicity freshwater (inorganics) (CTUe)	2.14	47%	2.40	53%	4.54
Ecotoxicity freshwater (organics) (CTUe)	5.87x10 ⁻²	90%	6.76x10 ⁻³	10%	6.54x10 ⁻²
Eutrophication freshwater (kg P eq)	1.50x10 ⁻⁴	54%	1.30x10 ⁻⁴	46%	2.80x10 ⁻⁴
Eutrophication marine (kg N eq)	4.10x10 ⁻⁴	69%	1.84x10 ⁻⁴	31%	5.94x10 ⁻⁴
Eutrophication terrestrial (mol N eq)	4.40x10 ⁻³	70%	1.91x10 ⁻³	30%	6.31x10 ⁻³
Human toxicity cancer (CTUh)	1.70x10 ⁻¹⁰	50%	1.69x10 ⁻¹⁰	50%	1.70x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	5.51x10 ⁻¹¹	45%	6.76x10 ⁻¹¹	55%	5.51x10 ⁻¹¹
Human toxicity cancer (organics) (CTUh)	1.15x10 ⁻¹⁰	53%	1.02x10 ⁻¹⁰	47%	1.15x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	2.54x10 ⁻⁹	65%	1.34x10 ⁻⁹	35%	2.54x10 ⁻⁹
Human toxicity non-cancer (inorganics) (CTUh)	2.31x10 ⁻⁹	65%	1.27x10 ⁻⁹	35%	2.31x10 ⁻⁹
Human toxicity non-cancer (organics) (CTUh)	2.25x10 ⁻¹⁰	76%	6.99x10 ⁻¹¹	24%	2.25x10 ⁻¹⁰
Ionizing radiation (human health) (kBq U235 eq)	3.96x10 ⁻²	54%	3.32x10 ⁻²	46%	3.96x10 ⁻²
Land use (dimensionless (pt))	3.55	62%	2.19	38%	3.55
Ozone depletion (kg CFC11 eq)	1.27x10 ⁻⁸	66%	6.49x10 ⁻⁹	34%	1.27x10 ⁻⁸
Particulate matter (disease incidence)	1.56x10 ⁻⁸	77%	4.53x10 ⁻⁹	23%	1.56x10 ⁻⁸
Photochemical ozone formation (human health) (kg NMVOC eq)	1.66x10 ⁻³	73%	6.10x10 ⁻⁴	27%	1.66x10 ⁻³
Resource use fossils (MJ (net calorific))	7.81	68%	3.74	32%	7.81
Resource use minerals and metals (kg Sb eq)	1.74x10 ⁻⁶	67%	8.48x10 ⁻⁷	33%	1.74x10 ⁻⁶
Water use (m ³ world eq)	0.124	66%	6.39x10 ⁻²	34%	0.124

Table 33: C3—EF 3.1 LCIA results for 1 kg of chemically recycled chip—100% post-industrial textile waste

Impact category	Cradle-to-textile shred		Textile shred-to-chip		Total
Acidification (mol H ⁺ eq)	1.12x10 ⁻³	67%	5.60x10 ⁻⁴	33%	1.68x10 ⁻³
Climate change (kg CO ₂ eq)	0.427	62%	0.257	38%	0.683

Impact category	Cradle-to-textile shred		Textile shred-to-chip		Total
Climate change (biogenic) (kg CO ₂ eq)	2.50x10 ⁻⁴	43%	3.37x10 ⁻⁴	57%	5.87x10 ⁻⁴
Climate change (fossil) (kg CO ₂ eq)	0.426	62%	0.256	38%	0.682
Climate change (land use) (kg CO ₂ eq)	1.80x10 ⁻⁴	62%	1.12x10 ⁻⁴	38%	2.93x10 ⁻⁴
Ecotoxicity freshwater (CTUe)	1.99	70%	0.847	30%	2.84
Ecotoxicity freshwater (inorganics) (CTUe)	1.94	70%	0.842	30%	2.78
Ecotoxicity freshwater (organics) (CTUe)	5.30x10 ⁻²	91%	4.99x10 ⁻³	9%	5.80x10 ⁻²
Eutrophication freshwater (kg P eq)	1.36x10 ⁻⁴	58%	9.85x10 ⁻⁵	42%	2.34x10 ⁻⁴
Eutrophication marine (kg N eq)	2.93x10 ⁻⁴	65%	1.55x10 ⁻⁴	35%	4.47x10 ⁻⁴
Eutrophication terrestrial (mol N eq)	3.12x10 ⁻³	66%	1.63x10 ⁻³	34%	4.75x10 ⁻³
Human toxicity cancer (CTUh)	1.52x10 ⁻¹⁰	75%	4.99x10 ⁻¹¹	25%	2.02x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	4.84x10 ⁻¹¹	73%	1.76x10 ⁻¹¹	27%	6.60x10 ⁻¹¹
Human toxicity cancer (organics) (CTUh)	1.04x10 ⁻¹⁰	76%	3.23x10 ⁻¹¹	24%	1.36x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	1.93x10 ⁻⁹	65%	1.04x10 ⁻⁹	35%	2.97x10 ⁻⁹
Human toxicity non-cancer (inorganics) (CTUh)	1.75x10 ⁻⁹	64%	9.91x10 ⁻¹⁰	36%	2.74x10 ⁻⁹
Human toxicity non-cancer (organics) (CTUh)	1.78x10 ⁻¹⁰	77%	5.26x10 ⁻¹¹	23%	2.31x10 ⁻¹⁰
Ionizing radiation (human health) (kBq U235 eq)	3.49x10 ⁻²	53%	3.05x10 ⁻²	47%	6.54x10 ⁻²
Land use (dimensionless (pt))	2.75	57%	2.10	43%	4.85
Ozone depletion (kg CFC11 eq)	1.06x10 ⁻⁸	66%	5.39x10 ⁻⁹	34%	1.60x10 ⁻⁸
Particulate matter (disease incidence)	1.08x10 ⁻⁸	77%	3.24x10 ⁻⁹	23%	1.40x10 ⁻⁸
Photochemical ozone formation (human health) (kg NMVOC eq)	1.20x10 ⁻³	71%	4.90x10 ⁻⁴	29%	1.69x10 ⁻³
Resource use fossils (MJ (net calorific))	6.46	67%	3.22	33%	9.67
Resource use minerals and metals (kg Sb eq)	1.43x10 ⁻⁶	67%	6.95x10 ⁻⁷	33%	2.13x10 ⁻⁶
Water use (m ³ world eq)	0.111	66%	5.65x10 ⁻²	34%	0.167

3.5.3.3. Contribution analysis by process

Data provider C3 operates at a pre-commercial level, and its manufacturing data is based on an engineering study for a planned commercial plant and validated using detailed mass and heat balances based on testing at a pilot plant. This makes the results uncertain, and caution should be used when drawing any conclusions from its data.

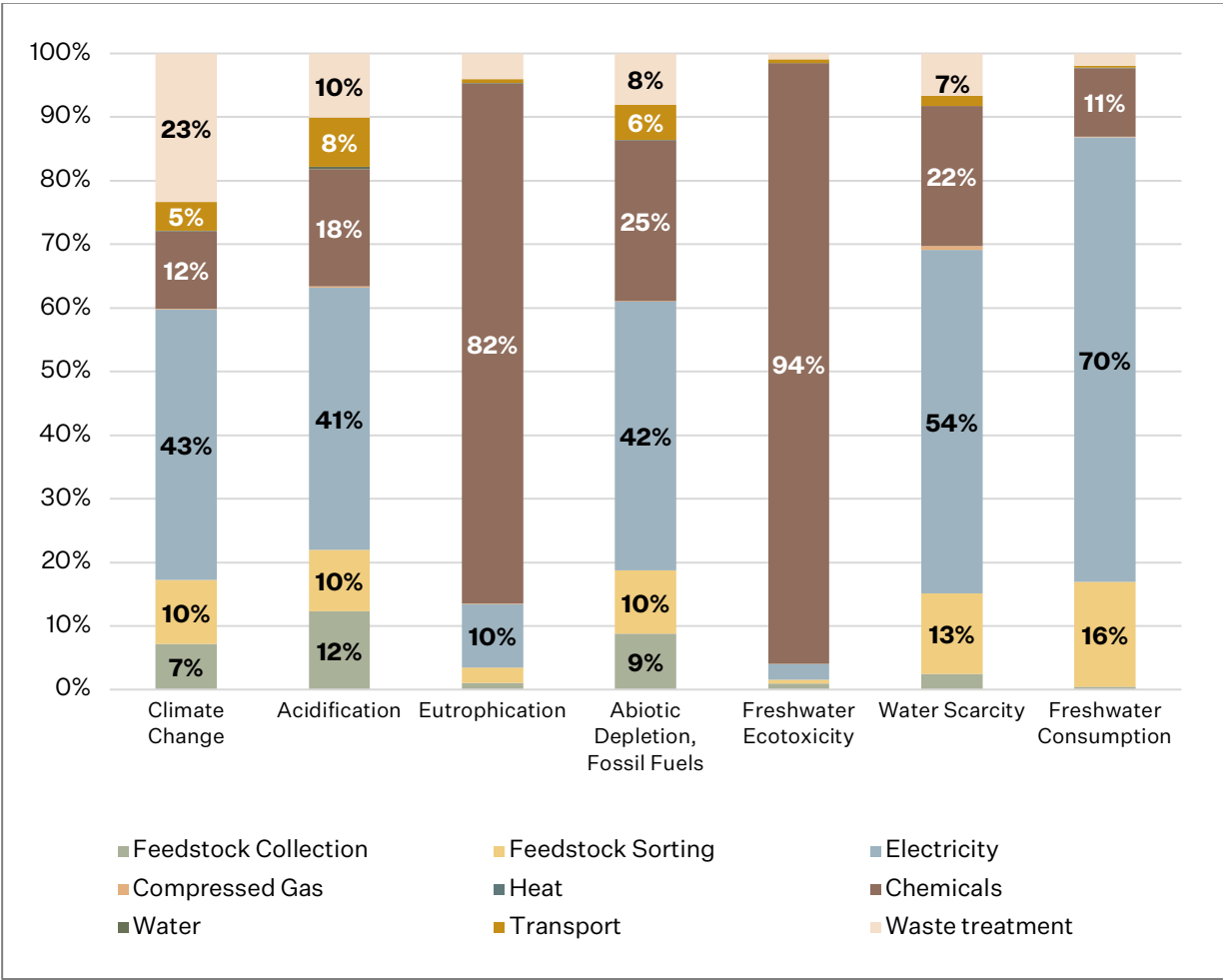
The use of electricity is the largest contributor for climate change, acidification, abiotic depletion, water scarcity, and freshwater consumption impact categories for both post-consumer (41–70%, Figure 9) and post-industrial (51–75%, Figure 10) chemically recycled chip. Electricity is not a significant contributor for the eutrophication and freshwater ecotoxicity impacts ($\leq 11\%$), which are driven almost entirely by the production of the chemicals used in the recycling process.

The feedstock collection and sorting stages contribute more to the total impacts for post-consumer chip compared to post-industrial chip. More electricity is needed to sort and process post-consumer waste compared to post-industrial waste, which leads to the higher contribution of the feedstock stage to the total impacts for post-consumer chip as opposed to post-industrial chip. The production of required chemicals, specifically the confidential solvent, is a large contributor to the eutrophication (82–85%) and freshwater ecotoxicity (94–96%) impacts. A

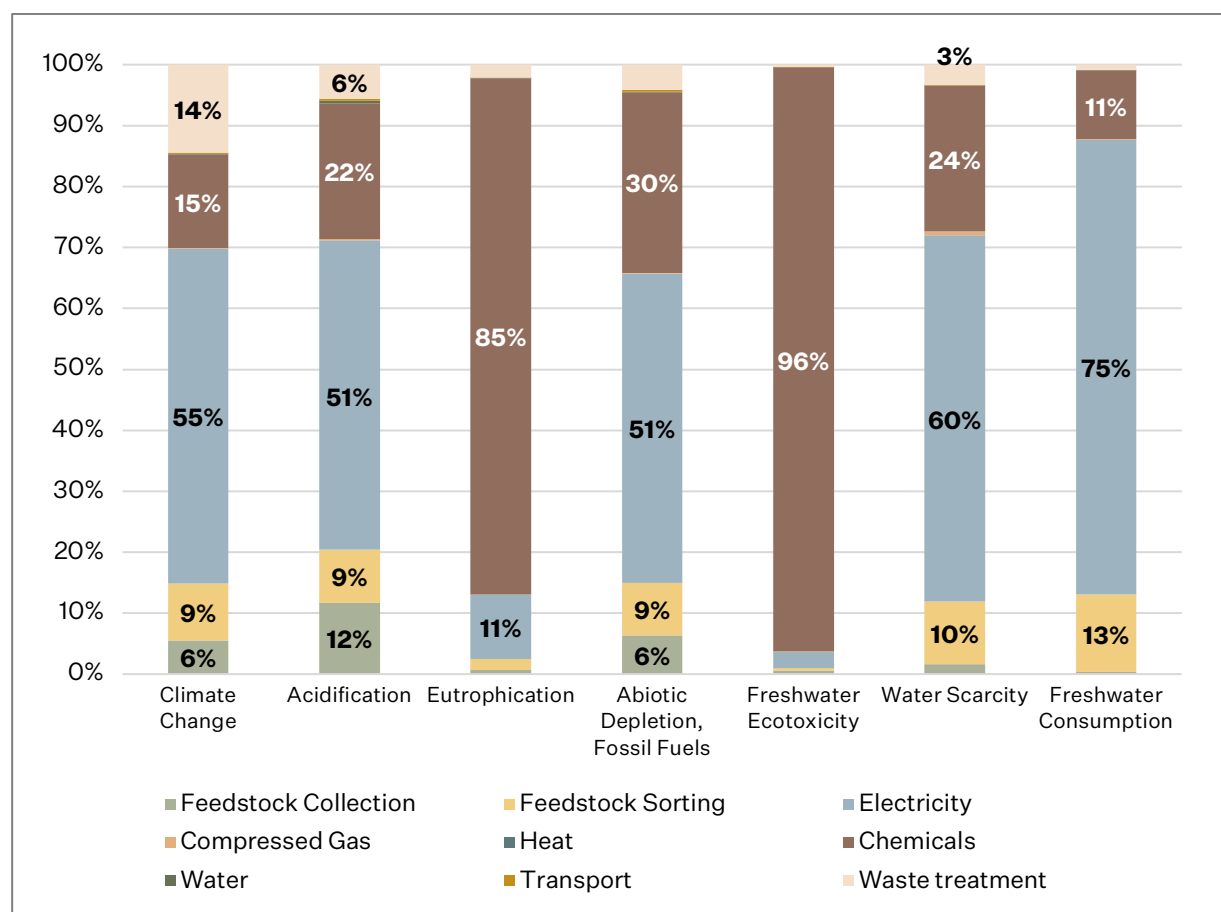
proxy dataset for organic chemicals from ecoinvent 3.11 is used to represent the confidential solvent, as C3 did not provide any data on this solvent, for the shredding and decoloring of the textile waste (Table 23, row 3). It is unclear how representative this dataset is of the impacts to produce the actual solvents used; this is noted as a limitation in this assessment.

For both types of chips, the waste treatment process is either the second or third largest contributor to climate change, acidification, and eutrophication impacts (14–23%, 6–10%, and 2–4% respectively). This is due to the incineration of the waste contaminants and the waste solvent that is used for decoloring the waste textiles. Waste treatment is not a major contributor for abiotic depletion of fossil fuels and freshwater ecotoxicity impacts.

Figure 9: C3—process-level contribution—100% post-consumer textile waste



Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

Figure 10: C3—process-level contribution—100% post-industrial textile waste

Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

3.6 Key takeaways

The most important observations relevant to the production and impact of chemically recycled PET chip are summarized below:

- Chemical recycling can be employed for both post-industrial and post-consumer textile waste feedstock and can support textile-to-textile recycling. It also helps ensure feedstock supply for polyester recycling in the face of high demand for PET bottle waste to produce packaging. However, while both commercial chemical recyclers (C1 and C2) claim their technology can be used to recycle post-consumer waste, C1 recycled <1% post-consumer waste during the data collection period and C2 recycled approximately 7%. Given the additional economic and logistical challenges with sorting and cleaning post-consumer waste, it is expected that the proportion of post-consumer waste recycled remains low.
- The three solvolytic recycling processes assessed here can decolor waste PET and so are not limited by the color of the waste. Chemical recycling can remove contaminants and additives, and, hence, expands the scope of the types of polyester waste that can be recycled. However, these recycling processes do require an input of ethylene glycol and/or methanol to ensure the recycled PET chip is equivalent in quality to virgin PET chip. The amount of this input depends on the type of chemical recycling involved.

- Energy consumption (including electricity and heat), and the use of chemicals, are the two largest environmental hotspots associated with chemical recycling of polyester. Feedstock collection is another contributor, due to the transport distances involved.

4. Thermomechanical Recycling Product Systems

In this study, three thermomechanical recyclers were evaluated (indicated as M1, M2, and M3), with their facilities located in three different regions (the United States, China, and Southeast Asia, respectively). While all three data providers produce recycled PET chip, M3 also produces recycled staple fiber directly from flake. Staple fiber, while sometimes used as fill in cushions, pillows, jackets, etc., is more often used to produce polyester spun yarn. Traditionally, thermomechanically recycled flake is first extruded to PET chip, then further processed into staple fiber as a separate batch process. However, M3 employs a large commercial production process that extrudes flake directly into staple fiber.

The thermomechanical recycling of PET chip typically involves two main stages: flake production and the processing of flake into chip. Flake production includes the collection of post-consumer PET bottles, or other types of PET waste. These materials are crushed, baled, and transported to a facility where they are sorted, cleaned, and mechanically shredded into flake. The flake is then either moved to a separate processing line within the same facility or transported to a different facility where it is extruded into recycled PET chip. During the flake-to-chip production process, a small amount (<1.5% by total mass) of titanium dioxide (TiO₂) is often added to reduce the brightness of the chip and to increase the resistance to cracking of products manufactured from the recycled chip. Color-adjusting additives can be added to reduce yellowing and improve visual consistency for the final product.

In the flake-to-staple fiber production process, ancillary chemicals—such as different types of spin finish, dispersants, and anti-foaming agents—are added to support key steps including spinning, drawing, and crimping. In spinning, molten PET is extruded through spinnerets (small holes) to form continuous filaments. Drawing stretches the filaments to align polymer chains and enhance fiber strength. Crimping adds a wavy texture to the filaments. The filaments are then cut into short lengths to create staple fiber. Titanium dioxide is also used to improve the opacity and appearance of the resulting staple fiber.

A detailed description of each data provider's product system is shown in section 4.2.

Table 34: Summary of thermomechanical recycling product systems

Thermomechanical recycler	Region of operation	Feedstock recycled	Data collection period	Functional unit
M1	United States	Post-consumer bottle waste (100%); a 50-50 blend of post-industrial textile waste and post-consumer bottle waste	January—December 2023	1 kg of post-consumer thermomechanically recycled PET chip, 1 kg thermomechanically recycled 50-50 blended PET chip
M2	China	Post-consumer bottle waste (100%)	January—December 2023	1 kg of thermomechanically recycled PET chip
M3	Southeast Asia	Post-consumer bottle waste (100%)	January—December 2022	1 kg of thermomechanically recycled PET chip; 1 kg of thermomechanically recycled staple fiber

4.1. System boundary

The system boundary for thermomechanically recycled polyester chip is cradle-to-manufacturing gate, covering all processes from the collection of waste PET bottles to the production of thermomechanically recycled PET chip. For data provider M3, data was also available for the flake to staple fiber process, which eliminates the need to produce chip. Downstream applications and packaging are excluded.

The functional unit is defined as 1 kg of thermomechanically recycled PET chip and 1 kg of thermomechanically recycled staple fiber for use in textile applications. All required inputs and generated outputs are scaled to the production of this functional unit. The function of thermomechanically recycled PET chip is as a feedstock to produce various fiber forms, such as staple fiber and filament, which can further be used to produce a wide range of textile products. Similarly, the function of thermomechanically recycled staple fiber is for use in textile products and often as a feedstock to produce spun yarn. These recycled PET chips and staple fibers can be used as drop-in replacements for virgin chips or staple fibers (i.e., they have the same functional equivalency as virgin PET chips or staple fibers). Assessing the difference in durability, ability to apply pigments, and other finishes between the chip and staple fiber produced by thermomechanical recycling technology and other technologies (i.e., virgin, chemical recycling) is outside the scope of this project. It should also be noted that PET waste can only be thermomechanically recycled a limited number of times before it becomes too degraded for further thermomechanical recycling (Patel et al., 2024). However, assessing this is also outside the scope of this LCA.

There are multiple steps that occur to turn post-industrial and post-consumer PET waste into a PET chip (Figure 11), and these steps have been divided into two life cycle stages (cradle-to-flake and flake-to-chip). Data provider M3 also produces staple fiber, which has been divided into two life cycle stages (cradle-to-flake and flake-to-staple fiber) (Figure 12). Figure 11 and Figure 12, below, show the detailed product system for thermomechanically recycled chip and staple fiber. Note that data provider M1 is the only thermomechanical recycler that uses post-industrial textile waste in its 50-50 blended PET chip. The post-industrial textile waste is directly from industrial sources, does not undergo sorting, and is added during the flake-to-chip stage. No rejected textile waste is generated in this process. All other data providers only use post-consumer bottle waste for thermomechanical recycling.

Figure 11: System boundary diagram for thermomechanically recycled chip

Note: Post-industrial textile waste is added in the flake-to-chip stage in the figure below for data provider M1.

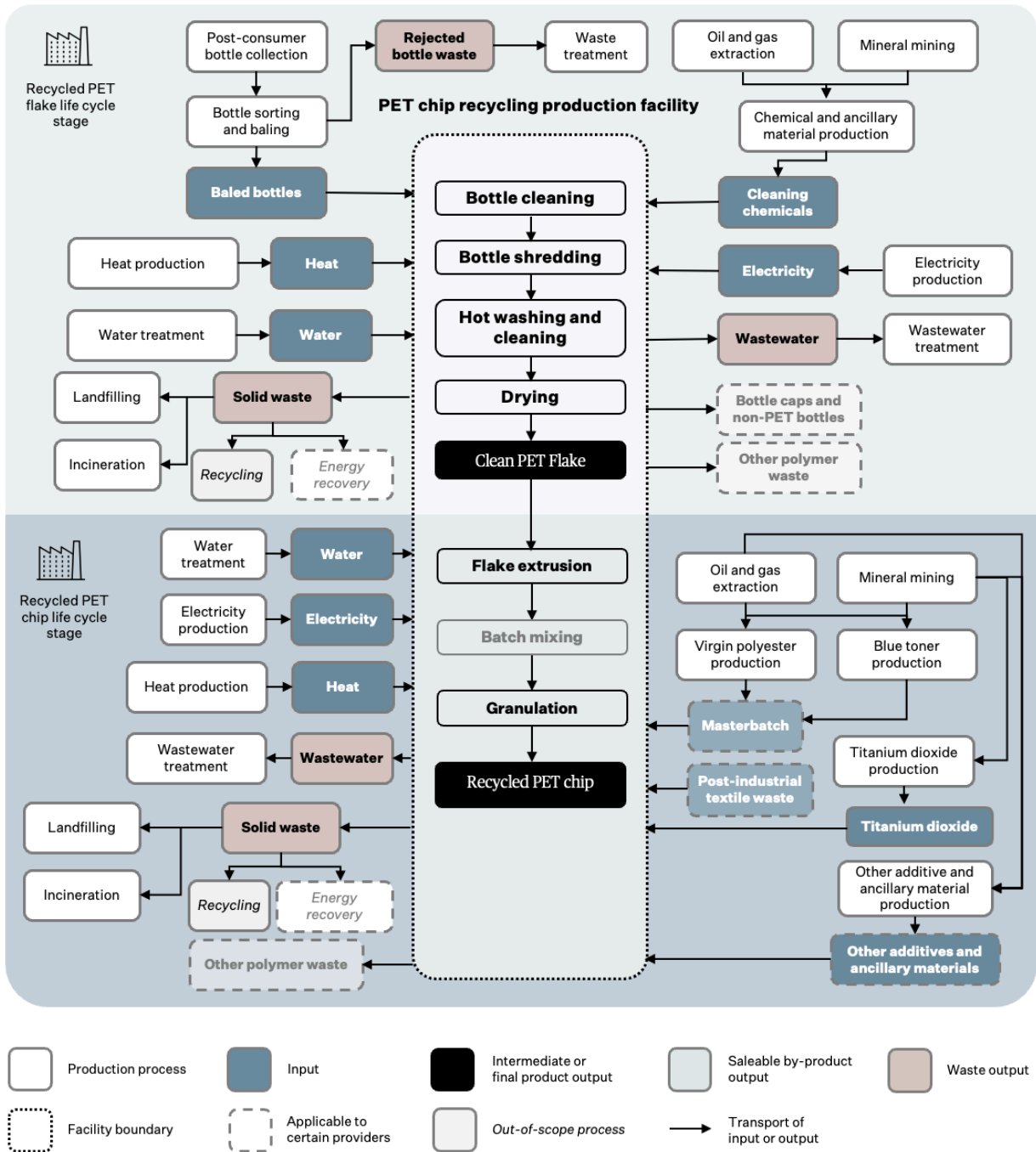
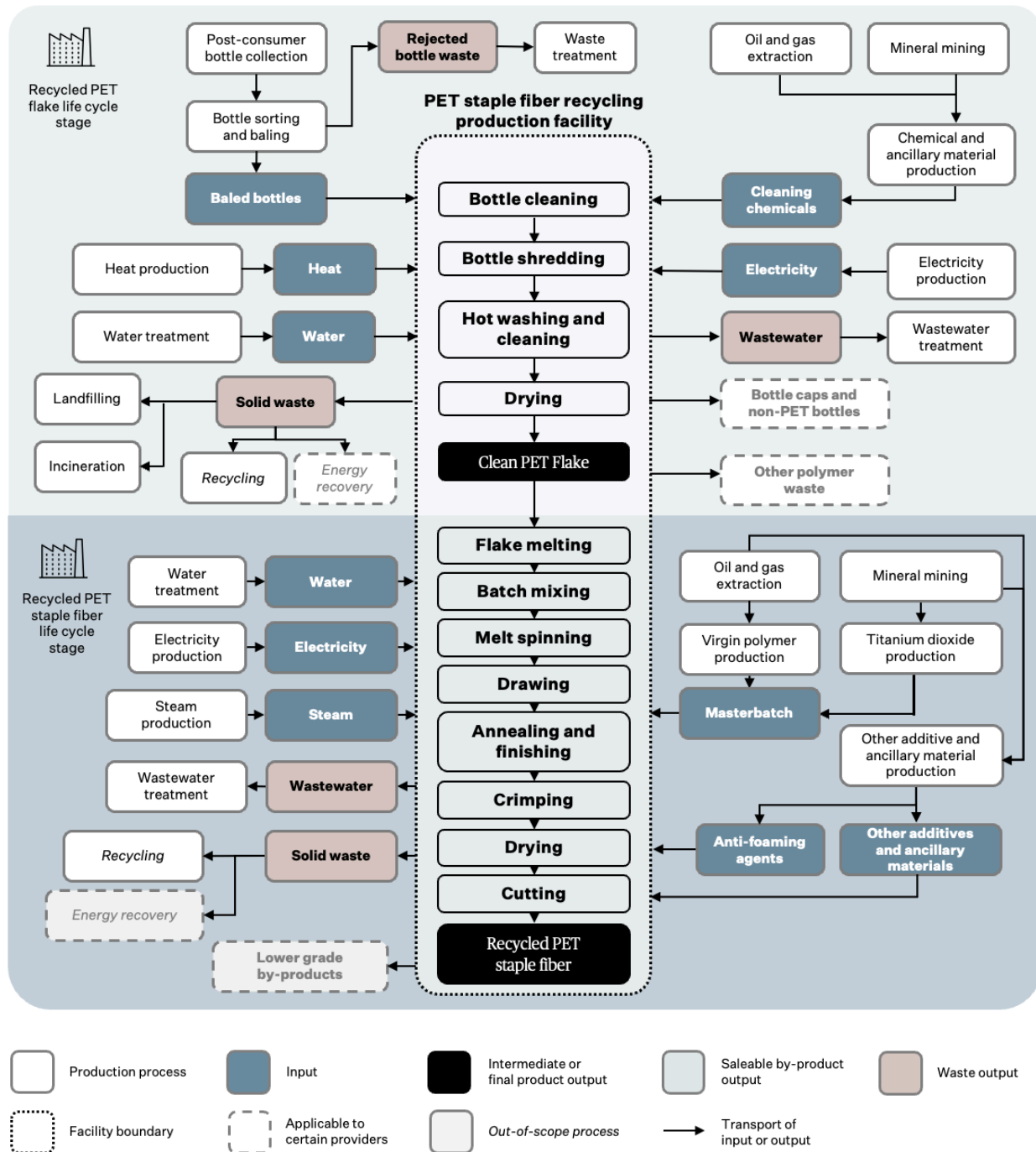


Figure 12: System boundary diagram for thermomechanically recycled staple fiber



4.2. Product system description

4.2.1. Data provider M1

4.2.1.1. Background

Data provider M1 produces two types of recycled polyester chip: chip produced from 100% post-consumer PET bottles and chip produced from a 50-50 mix of post-consumer PET bottles and post-industrial textile waste, called 50-50 blended chip. Primary data related to operations for data provider M1 was collected between January and December 2023, and the region of operation is the United States (Table 34). Data for the production of flake was also available from one supplier, which was collected between January and December 2020.

4.2.1.2. Feedstock composition and restrictions

The flake produced by data provider M1 is either clear, green, or mixed green, limiting its feedstock of post-consumer bottles to these colors. No separate decolorization process is included in its manufacturing process. Additionally, the polyester textile waste that is used in its 50-50 blended chip is procured directly from industrial sources and does not need additional sorting before being used in the chip-production process.

4.2.1.3. Manufacturing process

Waste PET bottles are washed and cleaned using surfactants and sodium hydroxide, and shredded to produce mechanically recycled flake. To manufacture the post-consumer chip, titanium dioxide is added to the flake and extruded to chip. Other chemical additives are also added at this stage. Details on their functions are withheld in this report to protect confidentiality. A similar process is used to produce the 50-50 blended chip, which, except for the inclusion of post-industrial textile waste, is nearly identical to that of the 100% post-consumer chip. Post-industrial textile waste is sorted by color to enable mechanical recycling, which cannot remove existing dyes; white textiles are prioritized as they yield a white, semi-dull final chip. The textile waste is shredded, densified, and then mixed with flake to produce the 50-50 blended chip. No co-products were generated during the production of either type of chip.

Allocation was not used to model this product system as input-output data was available for each product separately.

The process requires electricity, chemicals, heat, and water, and generates non-hazardous waste that is recycled or landfilled. The exact composition of this waste was not available. All electricity is sourced from the local grid, which is modeled based on the specific manufacturing location in the United States, adjusted using eGRID sub-region data for 2023 (Environmental Protection Agency, 2025a). The corresponding electricity mix used at the facility is presented in Table 35.

Table 35: Electricity grid mix—United States data provider M1

Type of energy	Percentage
Coal	11%
Oil	0%
Natural gas	39%
Biofuels	2%
Waste	0%
Nuclear	40%
Hydro	2%

Type of energy	Percentage
Solar PV	6%
Wind	0%
Other sources	0%

Due to rounding, values may not sum exactly to 100%.

4.2.2. Data provider M2

4.2.2.1. Background

Data provider M2 produces thermomechanically recycled chip from post-consumer waste PET bottles. M2 manufacturers bright, semi-dull, and full-dull chips. Primary data was collected for operations from January to December 2023. The region of operation is China (Table 34).

4.2.2.2. Feedstock composition and restrictions

Data provider M2 sources primarily from colorless bottle bales, though blue and green bottles are also separately collected and processed into blue and green chips and fibers. Its feedstock is limited to post-consumer PET bottles that meet its specific quality standards. Aged or degraded bottles are sorted out and excluded before the delivery and at the facility.

All feedstock is sourced domestically from within China, in accordance with the national ban on solid waste imports implemented in January 2021.

4.2.2.3. Manufacturing process

Waste bottles are first washed and cleaned using sodium hydroxide, cleaning agents, flotation agents, and defoaming agents. After cleaning, bottle caps and non-PET bottles are removed. The cleaned bottles are then shredded into flake. Titanium dioxide is added to the flake before it is extruded into chip.

Data provider M2's recycling process produces saleable wastes, such as bottle caps, non-PET bottles, and PET dust. These outputs are treated as cut-off flows under the recycled content method (section 2.5).

The process requires chemicals, electricity, heat, and water, and also generates non-hazardous sludge; the recycler was unable to provide additional information on this sludge. It is modeled using an ecoinvent dataset for the treatment of raw sewage sludge. Recycled water is used on site. A small portion of electricity (3%) is supplied by onsite solar generation, with the other 97% sourced from the local grid. Due to the lack of data on the sub-regional grid mix of China, the national China grid mix, taken from the International Energy Agency (IEA) data for 2022 electricity generation (International Energy Agency, 2024a), which was the most recent and verifiable source available at the time of this project, was used to model grid electricity. The corresponding electricity mix used at the facility is presented in Table 36.

Table 36: Electricity mix—Chinese data provider M2

Type of energy	Percentage
On-site electricity—solar	3%
Grid electricity—coal	60%
Grid electricity—oil	0%
Grid electricity—natural gas	3%
Grid electricity—biofuels	2%

Type of energy	Percentage
Grid electricity—waste	0%
Grid electricity —nuclear	5%
Grid electricity—hydro	15%
Grid electricity—solar PV	5%
Grid electricity —wind	9%
Grid electricity—other sources	0%

Due to rounding, values may not sum exactly to 100%.

4.2.3. Data provider M3

4.2.3.1. Background

Data provider M3 produces both thermomechanically recycled chip and staple fiber from post-consumer PET bottles. Primary data for data provider M3 was collected for operations between January and December 2022. The region of operation is Southeast Asia. The exact country of operation has not been included for data-provider confidentiality.

4.2.3.2. Feedstock composition and restrictions

Data provider M3 exclusively sources from colorless to light-blue, post-consumer PET bottles. Colored bottles are excluded from the recycling process to maintain consistent flake quality.

4.2.3.3. Manufacturing process

Waste PET bottles are washed and cleaned using sodium hydroxide and other cleaning agents. The cleaned bottles are shredded into flake. In the flake-to-chip stage, ancillary chemicals—including anti-yellowing agents, blue toner, a tracer chemical, and titanium dioxide—are added before the flake is extruded into chip.

In the flake-to-staple fiber production process, approximately 75% of the flake used for staple fiber production was produced internally. The remaining 25% was sourced from external suppliers located in the same metropolitan area. Due to limited supplier data, the externally sourced flake was assumed to follow the same manufacturing process as the internally produced flake. The main steps of flake-to-staple fiber production include flake melting and spinning, drawing, annealing, crimping, drying, and cutting. Spinning, drawing, and crimping are described in the introductory text of this section (section 4). Annealing is a heat treatment process that stabilizes fiber structure. Several additives are introduced to enhance material properties and support processing. These include white masterbatch (a mixture of titanium dioxide and virgin PET), a biodegradation-promoting agent, and blue toner. Ancillary chemicals are also applied throughout the process, including spin finish, dispersants, and anti-foaming agents.

Data provider M3's recycling process produces saleable polymer waste and lower-grade materials. No allocation is applied as they are treated as materials for recycling.

Both cradle-to-chip and cradle-to-staple fiber production processes require chemicals, electricity, heat, and water, and generate non-hazardous waste such as sludge, flakes, labels, crushed caps, and unrecoverable PET bottles; the recycler was unable to provide additional information on the sludge. The data provider reported that all solid waste generated during manufacturing is sent to facilities for recycling or waste-to-energy recovery (WTE). WTE is modeled as incineration with all related impacts allocated to M3. Transport of the wastes to their respective treatment facilities is included. Based on the recycled content method (section 2.5) used in this assessment, the impacts associated with recycling are allocated to the subsequent product system. Recycled water

is used onsite. A portion of electricity is supplied by onsite solar generation, approximately 2% for cradle-to-flake production, 12% for flake-to-chip production, and 30% for flake-to-staple fiber production, with the remainder sourced from the local grid. The electricity grid used in the LCA model is based on the specific manufacturing location in Southeast Asia, adjusted using International Energy Agency (IEA) data for 2022 electricity generation (International Energy Agency, 2024c) to reflect the production year. The corresponding electricity mix used at the facility is presented in Table 37 for chip production and Table 38 for staple fiber production.

The data provider granted access to its life cycle inventory data, which is presented in Table 39 and Table 40.

Table 37: Electricity mix—chip production—Southeast Asian data provider M3

Type of energy	Cradle-to-flake percentage	Flake-to-chip percentage	Cradle-to-chip percentage
On-site electricity—solar	2%	12%	8%
Grid electricity—coal	20%	18%	18%
Grid electricity—oil	6%	5%	5%
Grid electricity—natural gas	55%	49%	51%
Grid electricity —biofuels	10%	9%	9%
Grid electricity —waste	0%	0%	0%
Grid electricity—nuclear	0%	0%	0%
Grid electricity—hydro	4%	4%	4%
Grid electricity—solar PV	3%	3%	3%
Grid electricity—wind	2%	2%	2%
Grid electricity—other sources	0%	0%	0%

Due to rounding, values may not sum exactly to 100%.

Table 38: Electricity mix—staple fiber production—Southeast Asian data provider M3

Type of energy	Cradle-to-flake percentage	Flake-to-staple fiber percentage	Cradle-to-staple fiber percentage
On-site electricity—solar	2%	30%	27%
Grid electricity—coal	20%	14%	15%
Grid electricity—oil	6%	4%	4%
Grid electricity—natural gas	55%	39%	41%
Grid electricity—biofuels	10%	7%	7%
Grid electricity—waste	0%	0%	0%
Grid electricity—nuclear	0%	0%	0%
Grid electricity—hydro	4%	3%	3%
Grid electricity—solar PV	3%	2%	2%
Grid electricity —wind	2%	1%	1%
Grid electricity—other sources	0%	0%	0%

Due to rounding, values may not sum exactly to 100%.

Table 39: Life cycle inventory data for 1 kg chip produced at M3

Flow	Flake		Chip		Unit
	Input	Output	Input	Output	
Raw materials					
Baled bottles	1.35	-	-	-	kg
NaOH (50% solution)	1.62x10 ⁻²	-	-	-	kg
Industrial cleaning powder	2.03x10 ⁻³	-	-	-	kg
Titanium dioxide	-	-	1.60x10 ⁻³	-	kg
Tracer chemical	-	-	7.13x10 ⁻⁵	-	kg
Anti-yellow chemical	-	-	9.78x10 ⁻⁵	-	kg
Blue toner	-	-	9.92x10 ⁻⁵	-	kg
Recycled PET flake	-	1.01	1.01	-	
Recycled PET chip	-	-	-	1.00	kg
Facility utilities					
Grid electricity	0.294	-	0.406	-	kWh
Onsite solar	7.54x10 ⁻³	-	5.64x10 ⁻²	-	kWh
LPG	5.40x10 ⁻³	-	-	-	MJ
Coal	1.35	-	0.896	-	MJ
Recycled water	2.85	-	-	-	kg
Water	3.73	-	1.90	-	kg
Waste treatment					
Waste polymer (sold)	-	0.146	-	9.54 x10 ⁻³	kg
Waste, sorted for resale	-	1.34x10 ⁻²	-	-	kg
Waste, energy recovery (sludge)	-	6.02x10 ⁻³	-	-	kg
Waste, energy recovery (wet labels)	-	5.97x10 ⁻²	-	-	kg
Wastewater discharge	-	5.50	-	1.31	kg
Invisible loss (moisture loss)	-	5.74x10 ⁻²	-	4.00x10 ⁻³	kg
Additional waste	-	7.48x10 ⁻²	-	-	kg
Miscellaneous water loss (for example, evaporation and cleaning)	-	1.08	-	0.590	kg
Transport					
Truck transport	111	-	0.798	-	kg*km
Ship transport	8.76	-	7.29	-	kg*km
Waste transport	20.1	-	0.305	-	kg*km

Table 40: Life cycle inventory data for 1 kg staple fiber produced at M3

Flow	Flake		Staple fiber		Unit
	Input	Output	Input	Output	
Raw materials					
Baled bottles	1.52	-	-	-	kg
NaOH (50% solution)	1.81x10 ⁻²	-	-	-	kg
Industrial cleaning powder	2.28x10 ⁻³	-	-	-	kg
Titanium dioxide	-	-	7.78x10 ⁻³	-	kg
Biodegradation promoting additive	-	-	6.36x10 ⁻⁴	-	kg
Blue toner	-	-	4.38x10 ⁻⁴	-	kg
Anti-foaming agent	-	-	1.17x10 ⁻²	-	kg
Different types of spin finish & dispersants	-	-	5.96x10 ⁻³	-	kg
Silicone spray	-	-	2.92x10 ⁻⁵	-	kg
Metal sand	-	-	2.26x10 ⁻³	-	kg
Recycled PET flake	-	1.14	1.14	-	
Recycled PET staple fiber	-	-	-	1.00	kg
Facility utilities					
Grid electricity	0.330	-	1.41	-	kWh
Onsite solar	8.45x10 ⁻³	-	0.617	-	kWh
LPG	6.05x10 ⁻³	-	-	-	MJ
Coal	1.51	-	-	-	MJ
Steam	-	-	2.29	-	kg
Recycled water	3.20	-	-	-	kg
Water	4.19	-	2.20	-	kg
DM water	-	-	1.19	-	kg
Waste treatment					
Waste polymer (sold)	-	0.164	-	6.33x10 ⁻²	kg
Waste, sorted for resale	-	1.51x10 ⁻²	-	-	kg
Waste to recycle	-	-	-	7.27x10 ⁻²	kg
Waste, energy recovery (sludge)	-	6.75x10 ⁻³	-	-	kg
Waste, energy recovery (wet labels)	-	6.70x10 ⁻²	-	-	kg
Wastewater discharge	-	6.17	-	1.43	kg
Invisible loss	-	6.44x10 ⁻²	-	-	kg
Additional waste	-	8.38x10 ⁻²	-	2.87x10 ⁻²	kg
Miscellaneous water loss (for example, evaporation and cleaning)	-	1.22	-	1.96	kg
Transport					
Truck transport	125	-	46.8	-	kg*km
Ship transport	9.83	-	362	-	kg*km

Flow	Flake		Staple fiber		Unit
	Input	Output	Input	Output	
Waste transport	22.5	-	5.27	-	kg*km

4.3. Summary of assumptions

The study relies on several assumptions, which are described below:

- Ecoinvent v3.11 datasets were used to model all life cycle inventory data. While primary data was available for quantities of inputs and outputs used at each facility, ecoinvent data was used to model the production of those inputs, treatment of wastes, and all transport. Ecoinvent datasets were selected based on temporal, geographic, and technological representativeness. Except where noted, they are considered to be representative of the actual production, waste treatment, and transport processes for which primary data was not available.
- A large portion of the post-consumer bottle waste is provided by intermediary waste suppliers that are not the first to collect the waste. The post-industrial waste used by data provider M1 is sourced largely from industrial sources and primary data on transport between these suppliers and M1 is used. However, M1 also uses intermediary suppliers for some of this waste. Only some data on this collection of waste upstream of the data providers' suppliers was available. Therefore, the following assumptions are made:
 - The upstream collection distance for post-industrial waste used by data provider M1 is assumed to be 77 km, which is based on the ecoinvent transport of non-hazardous waste. For post-consumer bottle waste, where the upstream collection distance was not available, it is assumed to be 990 km, based on the ecoinvent dataset for post-consumer bottle collection and sorting. For some suppliers, this upstream collection distance was known to be 80 km. A weighted average of 216 km for upstream transport of bottles was used for the post-consumer chip.
 - For data provider M2, the upstream collection distance for post-consumer bottle waste is assumed to be 990 km, based on the ecoinvent dataset for post-consumer bottle collection and sorting.
 - Data provider M3 indicated that bottle collection occurs within the greater metropolitan area of the nearby city where the facility operates. As upstream transport data was not provided, a 100 km transport distance was assumed to represent bottle collection within the local area.
 - The sensitivity of the results to the transport distance required to collect post-consumer and post-industrial waste is tested in a scenario analysis in section 6.2.2.
- For data provider M3, approximately 25% of the flake used for staple fiber production was sourced from external suppliers located in the same metropolitan area. Due to limited supplier data, the externally sourced flake was assumed to be produced using the same manufacturing process as the internally produced flake.
- Several ancillary chemicals used in thermomechanical recycling were not available in ecoinvent, including tracer chemicals, defoaming agents, cleaning agents, flotation agents, blue toners, anti-yellowing chemicals, anti-foaming agents, dispersants, biodegradation-promoting additives, spin finishes, and silicone sprays. Instead, proxy chemical production datasets were used (see section 4.4.1 for details). These assumptions are not considered a significant limitation as these ancillary chemicals are used in very small quantities (each <1% by mass per kilogram of product), except for the freshwater ecotoxicity and eutrophication impact categories, which are discussed in section 4.4.2.

- All truck transport is modeled using the ecoinvent dataset for truck transport using the EURO 4 emission standard for vehicles in the 16–32 metric ton weight class, except for the upstream post-consumer bottle collection. The upstream bottle collection is based on the ecoinvent datasets for the collection of post-consumer bottle waste. A discussion of EURO transport standards is provided in section 6.2.
- A distance of 32 km is assumed for the transport of all manufacturing waste generated during recycling from the point of generation to a treatment facility. This assumption applies when primary data is not available and is based on the US EPA WARM model (Environmental Protection Agency, 2004).

4.4. Life cycle inventory

4.4.1. Data collection and sources

Primary data was collected from all three data providers' recycling facilities, including all inputs and outputs required to produce the functional unit. Secondary data taken from ecoinvent on textile waste recycling and waste collection distances was used to model post-industrial and post-consumer waste collection.

These inputs and outputs were modeled in openLCA v2.4 software, using datasets from the ecoinvent v3.11 database (Ecoinvent, 2024a). Ecoinvent datasets with the greatest degree of technological, geographical, and temporal representativeness were chosen; a data quality assessment is provided in section 4.4.2. Detailed descriptions of these ecoinvent datasets can be found in the accompanying ecoinvent documentation (Ecoinvent, 2024a). The LCI datasets used in the model to represent unit processes in the cradle-to-gate LCA are provided below.

Table 41: LCI datasets from ecoinvent 3.11 (2024)—LCA modeling for thermomechanical recycling

Note: To protect the confidentiality of the data providers, the acronyms that indicate the geography that the ecoinvent dataset is representative of have been removed. The word "proxy" has been added to certain datasets and is used to denote an instance when the chosen dataset is either similar to or the best match for a process flow, when specific data is unavailable or unsuitable, serving as a substitute for the actual data.

Flow	Geography	Dataset
Raw material and chemical inputs		
Waste feedstock	United States	Treatment of waste polyethylene terephthalate, for recycling, unsorted, sorting waste polyethylene terephthalate, for recycling, sorted cutoff, U (collection and sorting)
Waste feedstock	Southeast Asia	Treatment of waste polyethylene terephthalate, for recycling, unsorted, sorting waste polyethylene terephthalate, for recycling, sorted cutoff, U
Waste feedstock	China	Treatment of waste polyethylene terephthalate, for recycling, unsorted, sorting waste polyethylene terephthalate, for recycling, sorted cutoff, U (collection and sorting)
Waste feedstock	Rest-of-World	Treatment of waste polyethylene terephthalate, for recycling, unsorted, sorting waste polyethylene terephthalate, for recycling, sorted cutoff, U (collection and sorting)
Sodium hydroxide	Rest-of-World	Market for sodium hydroxide, without water, in 50% solution state sodium hydroxide, without water, in 50% solution state cutoff, U

Flow	Geography	Dataset
Sodium hydroxide	Global	Chlor-alkali electrolysis, diaphragm cell sodium hydroxide, without water, in 50% solution state cutoff, U
Surfactant	Global	Market for non-ionic surfactant non-ionic surfactant cutoff, U
Cleaning powder	Global	Market for citric acid citric acid Cutoff, U
Defoaming agent	Global/Rest-of-World	Market for fatty acid fatty acid cutoff, U Market for non-ionic surfactant non-ionic surfactant cutoff, U Market for polydimethylsiloxane polydimethylsiloxane cutoff, U (proxy)
Cleaning agent	Global	Market for fatty alcohol sulfate fatty alcohol sulfate cutoff, U Market for non-ionic surfactant non-ionic surfactant cutoff, U (proxy)
Flotation agent	Global	Market for fatty alcohol sulfate fatty alcohol sulfate cutoff, U (proxy)
Titanium dioxide	Rest-of-World	Market for titanium dioxide titanium dioxide cutoff, U
Confidential chemical additive	Global	Market for chemical, organic chemical, organic cutoff, U (proxy)
Confidential chemical additive	Global	Market for chemical, inorganic chemical, inorganic cutoff, U (proxy)
Blue toner	Global/Rest-of-World	Market for electrostatic paint electrostatic paint cutoff, U Market for polyester resin, unsaturated polyester resin, unsaturated cutoff, U Market for silica sand silica sand cutoff, U Market for titanium dioxide titanium dioxide cutoff, U (proxy)
Anti-yellow chemical	Global	Market for chemical, organic chemical, organic cutoff, U (proxy)
Tracer chemical	Global	Market for chemical, inorganic chemical, inorganic cutoff, U (proxy)
Anti-foaming agent	Rest-of-World	Market for polydimethylsiloxane polydimethylsiloxane cutoff, U (proxy)
Dispersant, Spin finish	Global	Market for fatty alcohol sulfate fatty alcohol sulfate cutoff, U Market group for tap water tap water cutoff, U (proxy)
Dispersant, Spin finish	Global	Market for non-ionic surfactant non-ionic surfactant cutoff, U (proxy)
Spin finish	Global	Market for fatty alcohol fatty alcohol cutoff, U (proxy)
Spin finish	Global	Market for fatty acid fatty acid cutoff, U Market for diethylene glycol diethylene glycol cutoff, U (proxy)
Spin finish	Global	Market for tetraethyl orthosilicate tetraethyl orthosilicate cutoff, U (proxy)
Spin finish	Global	Market for tetraethyl orthosilicate tetraethyl orthosilicate cutoff, U Market for triethyl amine triethyl amine cutoff, U Market group for tap water tap water cutoff, U (proxy)
Silicone spray	Rest-of-World	Market for liquefied petroleum gas liquefied petroleum gas cutoff, U Market for polydimethylsiloxane polydimethylsiloxane cutoff, U (proxy)
Biodegradation-promoting additive	Rest-of-World	Market for calcium carbonate, precipitated calcium carbonate, precipitated cutoff, U Polyethylene terephthalate production, granulate, amorphous polyethylene terephthalate, granulate, amorphous cutoff, U (proxy)

Flow	Geography	Dataset
Metal sand	Global	Market for steel, chromium steel 18/8 steel, chromium steel 18/8 cutoff, U
Packaging film	Rest-of-World	Packaging film production, low density polyethylene packaging film, low density polyethylene cutoff, U
Electricity and utilities		
Grid electricity	United States	Market for electricity, medium voltage electricity, medium voltage cutoff, U—custom grid mix for US sub-region (confidential)
Grid electricity	Southeast Asia	Market for electricity, medium voltage electricity, medium voltage cutoff, U—custom grid mix for Southeast Asian country (confidential)
Grid electricity	China	Market for electricity, medium voltage electricity, medium voltage cutoff, U—custom grid mix for China 2022 (IEA 2024) (Environmental Protection Agency, 2025a)
Solar electricity	Rest-of-World	Electricity production, photovoltaic, 570kWp open ground installation, multi-Si electricity, low voltage cutoff, U
Solar electricity	China	Electricity production, photovoltaic, 570kWp open ground installation, multi-Si electricity, low voltage cutoff, U—China sub-region (confidential)
Heat production—natural gas	Rest-of-World	Market for heat, district or industrial, natural gas heat, district or industrial, natural gas cutoff, U
Heat production—liquefied petroleum gas	Rest-of-World	Refinery gas, burned in furnace heat, district or industrial, other than natural gas cutoff, U
Heat production—coal	Rest-of-World	Heat production, at hard coal industrial furnace 1–10 MW heat, district or industrial, other than natural gas cutoff, U
Steam	Rest-of-World	Market for steam, in chemical industry steam, in chemical industry cutoff, U
Water	Rest-of-World	Market for tap water tap water cutoff, U
Deionized water	Rest-of-World	Market for water, deionized water, deionized cutoff, U—modified with US water flows
Ground water	Southeast Asia	Water, unspecified natural origin
Recycled water	China, Southeast Asia	Water, unspecified natural origin (proxy, no associated environmental impact)
Transport		
Truck transport	Rest-of-World	Market for transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 cutoff, U
Ship transport	Global	Market for transport, freight, sea, container ship, heavy fuel oil transport, freight, sea, container ship, heavy fuel oil cutoff, U
Waste treatment		
Sanitary landfill for inert waste	Rest-of-World	Treatment of inert waste, sanitary landfill inert waste cutoff, U
Wastewater treatment	Rest-of-World	Market for wastewater, average wastewater, average cutoff, U

Flow	Geography	Dataset
Treatment of sludge	Rest-of-World	Market for raw sewage sludge raw sewage sludge cutoff, U (sewage sludge drying and incineration)
Sludge, waste to energy	Global	Treatment of raw sewage sludge, municipal incineration raw sewage sludge cutoff, U
Plastic waste, waste to energy	Rest-of-World	Treatment of waste plastic, mixture, municipal incineration waste plastic, mixture cutoff, U—RoW

4.4.2. Data quality assessment

A data quality assessment based on the adapted PEF DQR methodology explained in section 2.7 was conducted for all thermomechanically recycled products. This data quality assessment is shown in Table 42.

The color gradient is applied to highlight relative variation within the observed range, not to represent fixed rating categories across the full 1–5 DQR range; the greenest shade is assigned to the minimum, and the reddest shade to the maximum. M1's products' data quality ratings fall within 1.5–2.0 and are rated as “very good quality.” M2's and M3's products' data quality ratings fall between 1.8–2.2; ratings between 1.5–2.0 are rated as “very good quality”, while scores that are > 2.0 and ≤ 3.0 are rated as “good quality” (section 2.7, Table 16).

Table 42: Data quality assessment for thermomechanical recycling product systems

Impact category	M1—post-consumer chip	M1—50-50 blended chip	M2—PET chip	M3—chip	M3—staple fiber
Climate change	1.80	1.81	1.90	1.95	1.93
Acidification	1.83	1.93	1.83	1.92	1.93
Eutrophication	1.93	1.92	2.03	2.14	2.02
Abiotic depletion, fossil fuels	1.79	1.76	1.92	1.95	1.92
Freshwater ecotoxicity	1.80	1.91	1.89	1.81	1.87
Water scarcity	1.69	1.65	1.89	1.98	1.91
Freshwater consumption	1.93	1.90	1.90	1.89	1.84

4.5. Life cycle impact assessment (LCIA) results

The cradle-to-gate life cycle impact results for each thermomechanical recycler are given below in sections 4.5.1–4.5.3. Each section includes the Higg MSI and EF 3.1 acidification results, along with a process-level contribution analysis; a detailed analysis of these results is explored below. In addition, the results for the EF 3.1 indicators are also included; however, no process-level contribution analysis or detailed analysis of the results was conducted for these indicators.

Contribution analysis by process explores how the different inputs and processes involved in each thermomechanical recycler's operations contribute to each impact category. The contribution to the total impact of the inputs required and treatment of waste treated from each recycling process was assessed and is shown below. A description of the input, and any additional processes involved in the production of that input, is shown in Table 43, below.

Table 43: Thermomechanical key inputs

Key inputs	Description
Feedstock collection	Collection of waste feedstock, which enters the system burden free. Includes collection-related activities upstream of the data provider's suppliers, such as transport and production of the collection container for bottle waste, as modeled in ecoinvent
Feedstock sorting	Sorting of collected waste
Electricity	Electricity used at the recycling facility
Compressed gas	Compressed air and nitrogen used at the recycling facility
Heat	Heat or steam used at the recycling facility
Chemicals	Production of chemicals used at the recycling facility
Water	Accounts for net water use (the output of treated wastewater released back to the environment subtracted from the water input) in the recycling process of each facility
Transport	Inbound truck and ship transport from the data provider's suppliers to the recycling facility, and outbound truck transport to waste treatment
Waste treatment	On-site direct emissions and off-site treatment and disposal of solid and liquid waste

4.5.1. Data provider M1

4.5.1.1. Higg MSI and EF 3.1 acidification results

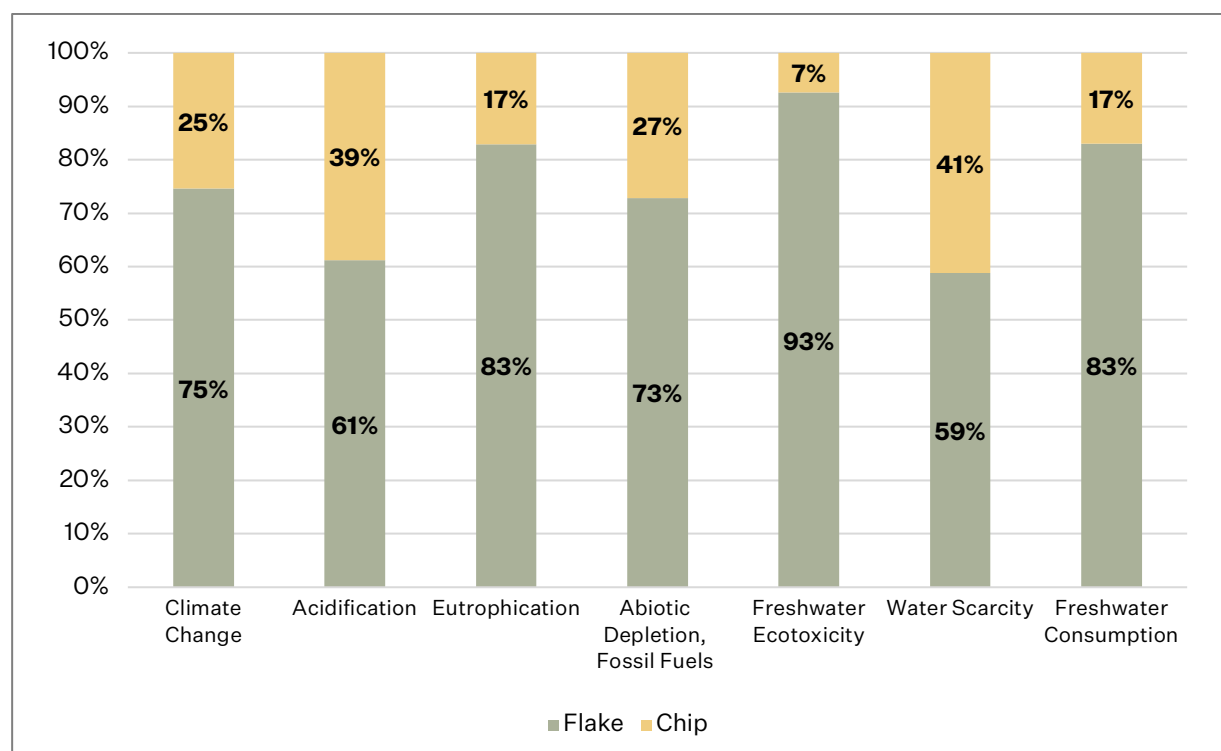
The cradle-to-flake life cycle stage is the most impactful stage ($\geq 59\%$) for the post-consumer chip produced by data provider M1 (

Figure 13). This is primarily due to the large impacts associated with post-consumer waste bottle collection. The energy required for processing these bottles into flake is another major contributor to impacts at this stage. More details are discussed in section 4.5.1.3.

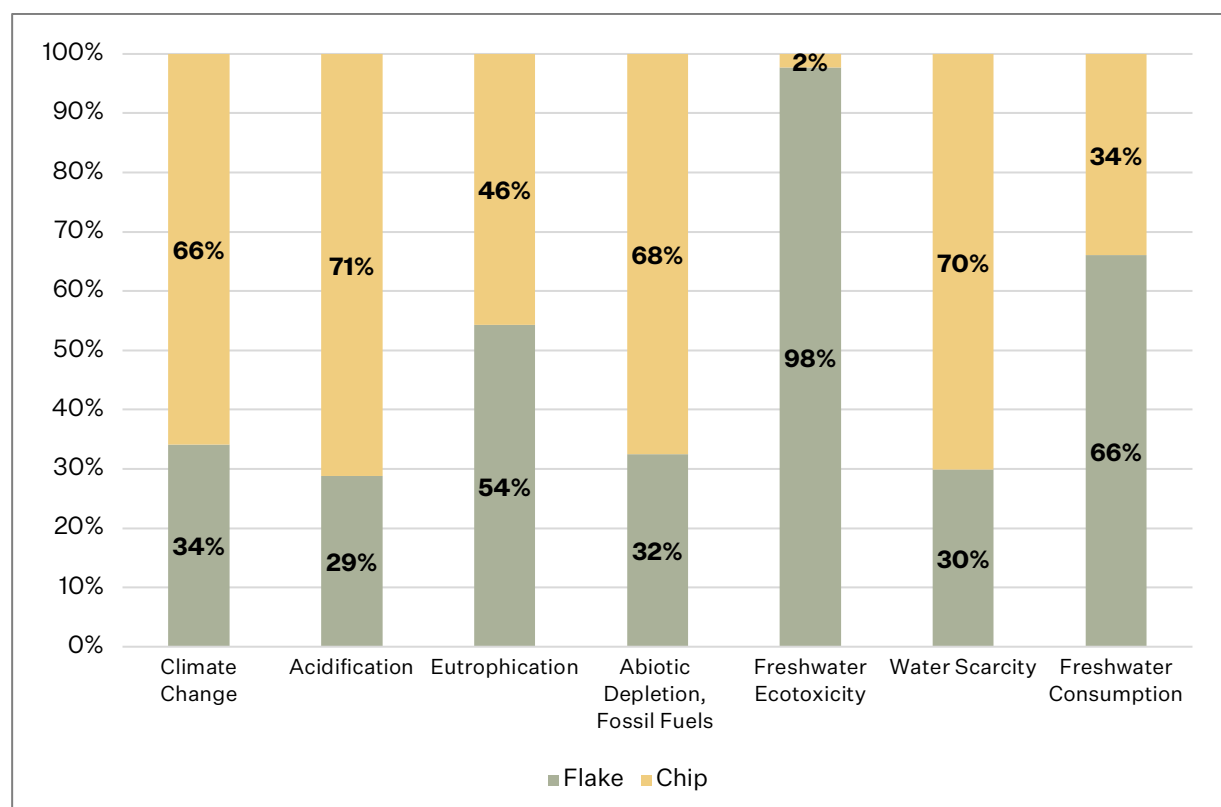
Unlike the 100% post-consumer chip, the 50-50 blended chip produced by M1 uses 50% post-industrial textile waste, which is shredded, densified, and mixed with the flake at the chip manufacturing stage. The impacts associated with the textile waste are included in the flake-to-chip stage. This results in lower cradle-to-flake stage impacts compared to post-consumer chip production, shifting the environmental impacts toward the flake-to-chip stage (Figure 14).

Table 44: M1—LCIA results for 1 kg thermomechanically recycled post-consumer chip

Impact category	Cradle-to-flake		Flake-to-chip		Total
Climate change (kg CO ₂ eq)	0.716	75%	0.243	25%	0.959
Acidification (mol H ⁺ eq)	3.00x10 ⁻³	61%	1.89x10 ⁻³	39%	4.89x10 ⁻³
Eutrophication (kg PO ₄ eq)	4.23x10 ⁻³	83%	8.72x10 ⁻⁴	17%	5.10x10 ⁻³
Abiotic depletion, fossil fuels (MJ)	8.33	73%	3.10	27%	11.4
Freshwater ecotoxicity (PAF m ³ day)	6.67x10 ⁻³	93%	5.29x10 ⁻⁴	7%	7.20x10 ⁻³
Water scarcity (m ³ world eq)	0.173	59%	0.121	41%	0.294
Freshwater consumption (m ³)	4.19x10 ⁻²	83%	8.60x10 ⁻³	17%	5.05x10 ⁻²

Figure 13: M1—contribution by life cycle stage—100% post-consumer chip**Table 45: M1—LCIA results for 1 kg thermomechanically recycled 50-50 blended chip**

Impact category	Cradle-to-flake		Flake-to-chip		Total
Climate change (kg CO ₂ eq)	0.367	34%	0.708	66%	1.07
Acidification (mol H ⁺ eq)	2.33x10 ⁻³	29%	5.77x10 ⁻³	71%	8.10x10 ⁻³
Eutrophication (kg PO ₄ eq)	1.82x10 ⁻³	54%	1.54x10 ⁻³	46%	3.36x10 ⁻³
Abiotic depletion, fossil fuels (MJ)	4.33	32%	9.03	68%	13.4
Freshwater ecotoxicity (PAF m ³ day)	1.59x10 ⁻²	98%	3.70x10 ⁻⁴	2%	1.62x10 ⁻²
Water scarcity (m ³ world eq)	9.12x10 ⁻²	30%	0.214	70%	0.305
Freshwater consumption (m ³)	2.37x10 ⁻²	66%	1.21x10 ⁻²	34%	3.58x10 ⁻²

Figure 14: M1—contribution by life cycle stage—50-50 blended chip

4.5.1.2. EF 3.1 results

Table 46 and Table 47, below, show the life cycle impact assessment (LCIA) results for the EF 3.1 impact categories for data provider M1.

Table 46: M1—EF 3.1 LCIA results for 1 kg of thermomechanically recycled post-consumer chip

Impact category	Cradle-to-flake		Flake-to-chip		Total
Acidification (mol H ⁺ eq)	3.00x10 ⁻³	61%	1.89x10 ⁻³	39%	4.89x10 ⁻³
Climate change (kg CO ₂ eq)	0.716	75%	0.243	25%	0.959
Climate change (biogenic) (kg CO ₂ eq)	0.114	100%	1.97x10 ⁻⁴	0%	0.114
Climate change (fossil) (kg CO ₂ eq)	0.601	71%	0.243	29%	0.845
Climate change (land use) (kg CO ₂ eq)	8.08x10 ⁻⁴	90%	9.07x10 ⁻⁵	10%	8.99x10 ⁻⁴
Ecotoxicity freshwater (CTUe)	4.30	83%	0.865	17%	5.17
Ecotoxicity freshwater (inorganics) (CTUe)	4.23	83%	0.852	17%	5.08
Ecotoxicity freshwater (organics) (CTUe)	7.73x10 ⁻²	85%	1.33x10 ⁻²	15%	9.07x10 ⁻²
Eutrophication freshwater (kg P eq)	1.96x10 ⁻⁴	70%	8.41x10 ⁻⁵	30%	2.80x10 ⁻⁴
Eutrophication marine (kg N eq)	1.03x10 ⁻³	70%	4.40x10 ⁻⁴	30%	1.47x10 ⁻³
Eutrophication terrestrial (mol N eq)	9.78x10 ⁻³	68%	4.69x10 ⁻³	32%	1.45x10 ⁻²
Human toxicity cancer (CTUh)	6.63x10 ⁻¹⁰	93%	5.37x10 ⁻¹¹	7%	7.17x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	1.12x10 ⁻¹⁰	80%	2.74x10 ⁻¹¹	20%	1.39x10 ⁻¹⁰

Impact category	Cradle-to-flake		Flake-to-chip		Total
Human toxicity cancer (organics) (CTUh)	5.51x10 ⁻¹⁰	95%	2.63x10 ⁻¹¹	5%	5.77x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	6.98x10 ⁻⁹	84%	1.34x10 ⁻⁹	16%	8.32x10 ⁻⁹
Human toxicity non-cancer (inorganics) (CTUh)	6.45x10 ⁻⁹	84%	1.25x10 ⁻⁹	16%	7.70x10 ⁻⁹
Human toxicity non-cancer (organics) (CTUh)	5.24x10 ⁻¹⁰	86%	8.72x10 ⁻¹¹	14%	6.12x10 ⁻¹⁰
Ionizing radiation (human health) (kBq U235 eq)	0.132	52%	0.124	48%	0.256
Land use (dimensionless (pt))	4.95	79%	1.34	21%	6.29
Ozone depletion (kg CFC11 eq)	9.54x10 ⁻⁹	78%	2.76x10 ⁻⁹	22%	1.23x10 ⁻⁸
Particulate matter (disease incidence)	8.82x10 ⁻⁸	91%	9.00x10 ⁻⁹	9%	9.72x10 ⁻⁸
Photochemical ozone formation (human health) (kg NMVOC eq)	3.39x10 ⁻³	70%	1.48x10 ⁻³	30%	4.88x10 ⁻³
Resource use fossils (MJ (net calorific))	10.5	67%	5.09	33%	15.6
Resource use minerals and metals (kg Sb eq)	2.90x10 ⁻⁶	76%	9.24x10 ⁻⁷	24%	3.82x10 ⁻⁶
Water use (m ³ world eq)	0.125	51%	0.121	49%	0.246

Table 47: M1—EF 3.1 LCIA results for 1 kg of thermomechanically recycled 50-50 blended chip

Impact category	Cradle-to-flake		Flake-to-chip		Total
Acidification (mol H ⁺ eq)	2.33x10 ⁻³	29%	5.77x10 ⁻³	71%	8.10x10 ⁻³
Climate change (kg CO ₂ eq)	0.367	34%	0.708	66%	1.07
Climate change (biogenic) (kg CO ₂ eq)	4.30x10 ⁻²	99%	3.06x10 ⁻⁴	1%	4.33x10 ⁻²
Climate change (fossil) (kg CO ₂ eq)	0.322	31%	0.707	69%	1.03
Climate change (land use) (kg CO ₂ eq)	1.38x10 ⁻³	88%	1.96x10 ⁻⁴	12%	1.58x10 ⁻³
Ecotoxicity freshwater (CTUe)	1.80	56%	1.44	44%	3.24
Ecotoxicity freshwater (inorganics) (CTUe)	1.73	55%	1.41	45%	3.15
Ecotoxicity freshwater (organics) (CTUe)	7.03x10 ⁻²	72%	2.67x10 ⁻²	28%	9.70x10 ⁻²
Eutrophication freshwater (kg P eq)	9.55x10 ⁻⁵	27%	2.55x10 ⁻⁴	73%	3.51x10 ⁻⁴
Eutrophication marine (kg N eq)	6.20x10 ⁻⁴	30%	1.43x10 ⁻³	70%	2.05x10 ⁻³
Eutrophication terrestrial (mol N eq)	6.17x10 ⁻³	29%	1.52x10 ⁻²	71%	2.14x10 ⁻²
Human toxicity cancer (CTUh)	2.35x10 ⁻¹⁰	70%	1.03x10 ⁻¹⁰	30%	3.37x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	4.97x10 ⁻¹¹	45%	6.07x10 ⁻¹¹	55%	1.10x10 ⁻¹⁰
Human toxicity cancer (organics) (CTUh)	1.85x10 ⁻¹⁰	82%	4.19x10 ⁻¹¹	18%	2.27x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	3.05x10 ⁻⁹	49%	3.13x10 ⁻⁹	51%	6.19x10 ⁻⁹
Human toxicity non-cancer (inorganics) (CTUh)	2.83x10 ⁻⁹	49%	2.94x10 ⁻⁹	51%	5.77x10 ⁻⁹
Human toxicity non-cancer (organics) (CTUh)	2.19x10 ⁻¹⁰	53%	1.96x10 ⁻¹⁰	47%	4.15x10 ⁻¹⁰
Ionizing radiation (human health) (kBq U235 eq)	6.57x10 ⁻³	1%	0.449	99%	0.455
Land use (dimensionless (pt))	2.32	39%	3.64	61%	5.97
Ozone depletion (kg CFC11 eq)	6.13x10 ⁻⁹	49%	6.38x10 ⁻⁹	51%	1.25x10 ⁻⁸
Particulate matter (disease incidence)	3.25x10 ⁻⁸	63%	1.90x10 ⁻⁸	37%	5.15x10 ⁻⁸

Impact category	Cradle-to-flake		Flake-to-chip		Total
Photochemical ozone formation (human health) (kg NMVOC eq)	2.02×10^{-3}	30%	4.64×10^{-3}	70%	6.65×10^{-3}
Resource use fossils (MJ (net calorific))	4.49	22%	16.2	78%	20.7
Resource use minerals and metals (kg Sb eq)	1.14×10^{-6}	39%	1.75×10^{-6}	61%	2.89×10^{-6}
Water use (m ³ world eq)	9.11×10^{-2}	30%	0.214	70%	0.305

4.5.1.3. Contribution analysis by process

The collection and sorting of feedstock, transport, and electricity are major hotspots for almost all impact categories for both chips produced by M1. The upstream transport of raw materials contributes 23–25% of climate change impacts, 44–69% of acidification, 7–18% of eutrophication, and 25% of abiotic depletion of fossil fuels across the two products. The collection of feedstock is another major contributor to climate change (20%), eutrophication (41%), and abiotic resource depletion impacts (29%) for the post-consumer chip produced by M1, due to the long transport distances involved in the upstream collection of bottle waste (up to 990 km) (Figure 7). Feedstock sorting is a major contributor to climate change (22%) and eutrophication (22%) impacts for the post-consumer chip, but not for the 50-50 blended chip (8% and 13%, respectively). This difference is due to sorting impacts being driven by the ecoinvent dataset for waste PET bottles used to produce PET flake. The blended chip requires less flake per functional unit because it incorporates post-industrial textile waste, which does not require sorting at the recycling facility and can be used directly.

While the upstream bottle collection distance was known for some suppliers (80 km), it was not available for most suppliers, and a secondary dataset from ecoinvent was used instead. A weighted average upstream distance of 216 km was calculated based on the amount of feedstock provided by each supplier. Given the large contribution of upstream feedstock collection to multiple impact categories, this is noted as a limitation of this study. For the 50-50 blended chip produced by M1, feedstock collection and sorting of bottle waste have a smaller contribution than they do for the post-consumer chip for all impact categories, because less bottle flake is required per kilogram of chip (Figure 16). In addition, the post-industrial textile waste (50% of the waste feedstock) is assumed to require significantly less upstream transport (77 km).

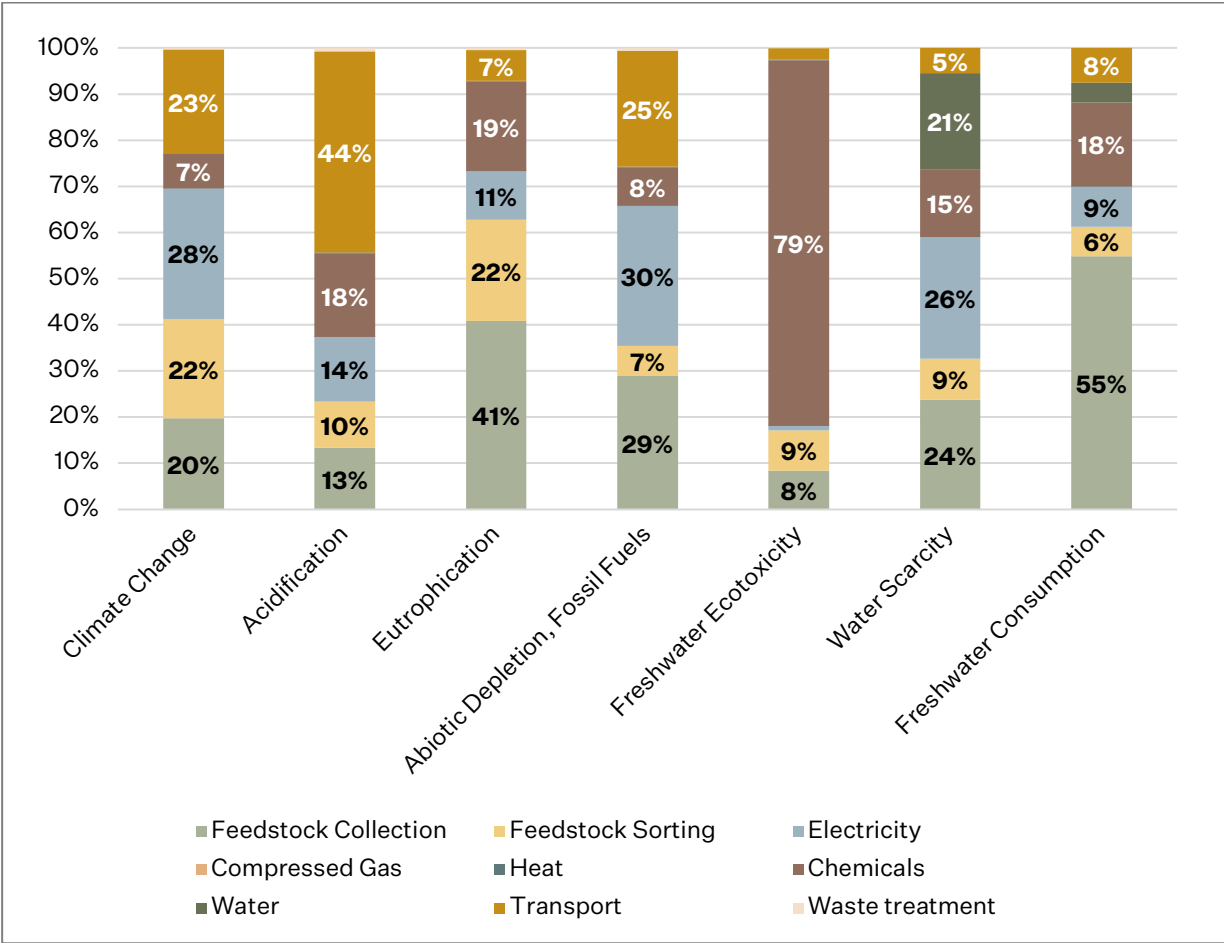
Feedstock is not a large contributor to the freshwater ecotoxicity impact category, which is dominated by the use of chemicals for the post-consumer chip (79%). The use of chemical surfactants used for cleaning are the biggest contributor to the freshwater ecotoxicity impacts for M1 (95% for 50-50 blended chip, and 79% for post-consumer chip). While M1 confirmed that these cleaning chemicals are non-ionic chemicals, specific information on their chemistry was not provided. These cleaning chemicals are modeled using ecoinvent's non-ionic surfactant dataset. While this proxy dataset is the closest match for the actual surfactants used, it is unclear how representative it is, and this is noted as a limitation of this study.

The contribution of electricity to climate change, acidification, eutrophication, and abiotic depletion is larger for 50-50 blended chip compared to post-consumer chip (18–52% vs 11–30%, respectively). This is due to the electricity required for the shredding and densification of the textile waste included in the chip stage for 50-50 blended chip, and more processing within the 50-50 blended chip flake-to-chip stage.

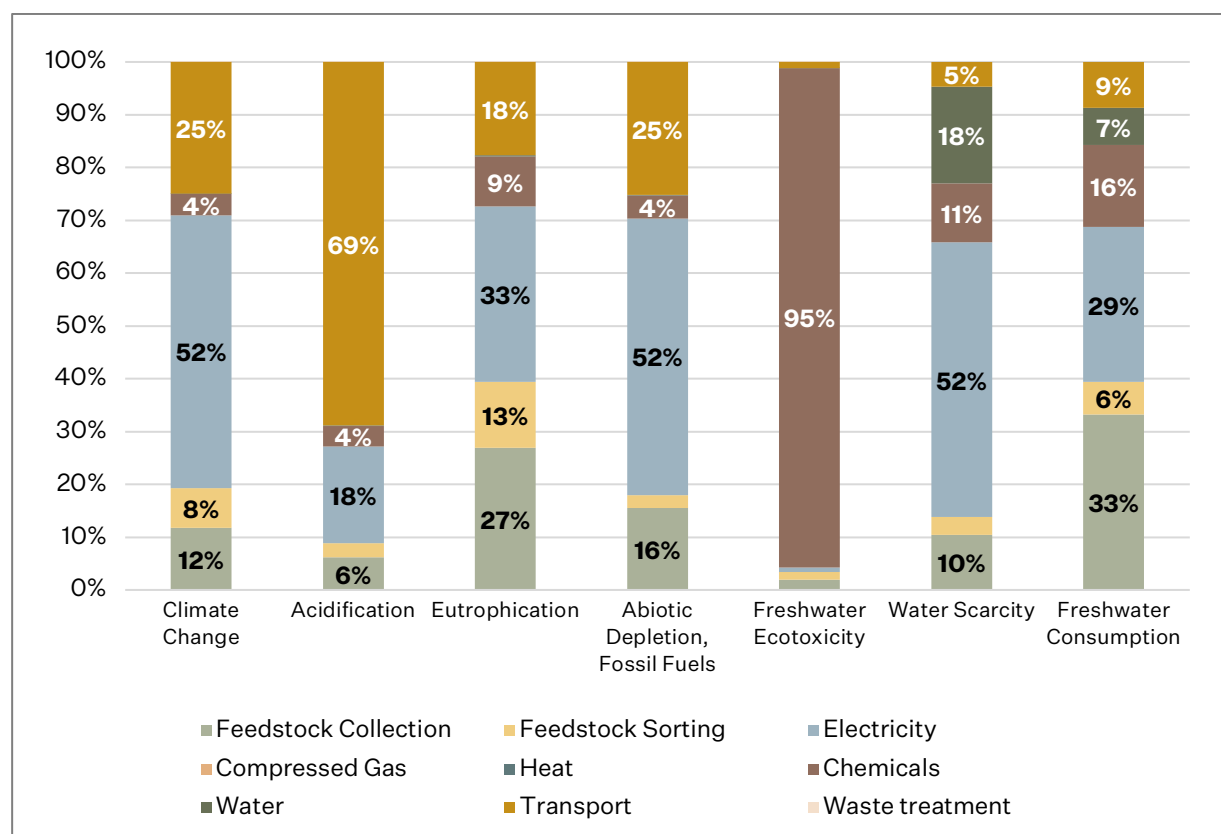
For both types of chip produced by M1, electricity used at the manufacturing facility is the largest contributor to the water-scarcity impacts (26% for post-consumer chip and 52% for the 50-50 blended chip). This is due to the large amount of nuclear energy within the electricity grid mix (40%); electricity produced by nuclear energy has a high water-scarcity impact. Collection of the

PET waste feedstock is the largest contributor to the freshwater-consumption impact category, representing 55% for the post-consumer chip and 33% for the 50-50 blended chip. Within the upstream collection of feedstock, the freshwater impact is driven heavily by the production of a low-density polyethylene (LDPE) bottle collection container used within the United States bottle sorting and collection ecoinvent dataset; this impact is from the steam-cracking process used to produce ethylene, the raw material for LDPE. Although it is surprising that container production contributes noticeably to freshwater consumption, ecoinvent has confirmed that the dataset is correctly modeled.

Figure 15: M1—process-level contribution—100% post-consumer chip



Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

Figure 16: M1—process-level contribution—50-50 blended chip

Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

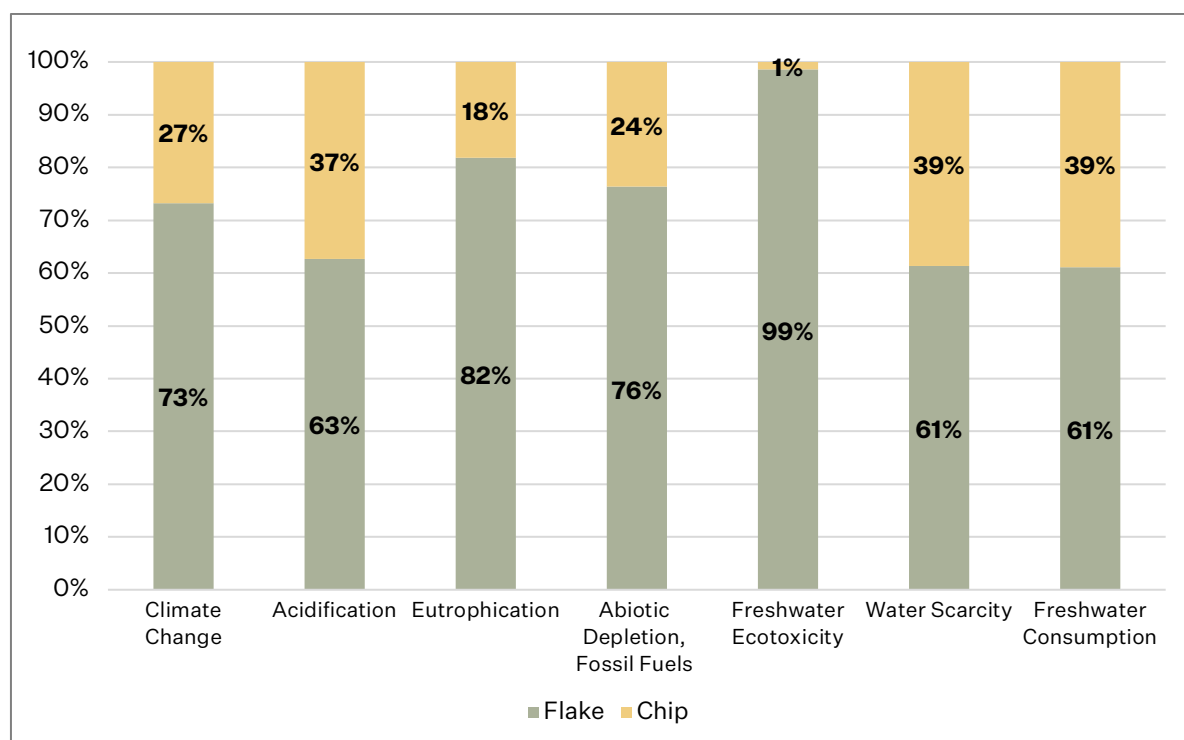
4.5.2. Data provider M2

4.5.2.1. Higg MSI and EF 3.1 acidification results

M2's cradle-to-flake life cycle stage is the most impactful ($\geq 61\%$) of all impact categories (Table 48, Figure 17). This is primarily due to post-consumer waste bottle collection. The energy required for processing these bottles into flake is another major contributor to impacts within this stage. More details are discussed in the contribution analysis by process in section 4.5.2.3.

Table 48: M2—LCIA results for 1 kg thermomechanically recycled chip

Impact category	Cradle-to-flake		Flake-to-chip		Total
Climate change (kg CO ₂ eq)	0.879	73%	0.321	27%	1.20
Acidification (mol H ⁺ eq)	3.57x10 ⁻³	63%	2.12x10 ⁻³	37%	5.69x10 ⁻³
Eutrophication (kg PO ₄ eq)	4.45x10 ⁻³	82%	9.91x10 ⁻⁴	18%	5.44x10 ⁻³
Abiotic depletion, fossil fuels (MJ)	10.3	76%	3.21	24%	13.6
Freshwater ecotoxicity (PAF m ³ day)	2.64x10 ⁻²	99%	3.68x10 ⁻⁴	1%	2.67x10 ⁻²
Water scarcity (m ³ world eq)	0.163	61%	0.103	39%	0.266
Freshwater consumption (m ³)	3.70x10 ⁻³	61%	2.36x10 ⁻³	39%	6.05x10 ⁻³

Figure 17: M2—contribution by life cycle stage**4.5.2.2. EF 3.1 results****Table 49: M2—EF 3.1 LCIA results for 1 kg of thermomechanically recycled PET chip**

Impact category	Cradle-to-flake		Flake-to-chip		Total
Acidification (mol H+ eq)	3.57x10 ⁻³	63%	2.12x10 ⁻³	37%	5.69x10 ⁻³
Climate change (kg CO ₂ eq)	0.880	73%	0.321	27%	1.20
Climate change (biogenic) (kg CO ₂ eq)	9.68x10 ⁻²	100%	3.72x10 ⁻⁴	0%	9.71x10 ⁻²
Climate change (fossil) (kg CO ₂ eq)	0.781	71%	0.320	29%	1.10
Climate change (land use) (kg CO ₂ eq)	2.22x10 ⁻³	72%	8.60x10 ⁻⁴	28%	3.08x10 ⁻³
Ecotoxicity freshwater (CTUe)	7.66	81%	1.85	19%	9.51
Ecotoxicity freshwater (inorganics) (CTUe)	7.53	80%	1.84	20%	9.37
Ecotoxicity freshwater (organics) (CTUe)	0.132	92%	1.17x10 ⁻²	8%	0.144
Eutrophication freshwater (kg P eq)	1.76x10 ⁻⁴	69%	8.02x10 ⁻⁵	31%	2.56x10 ⁻⁴
Eutrophication marine (kg N eq)	1.14x10 ⁻³	75%	3.84x10 ⁻⁴	25%	1.52x10 ⁻³
Eutrophication terrestrial (mol N eq)	1.12x10 ⁻²	73%	4.12x10 ⁻³	27%	1.53x10 ⁻²
Human toxicity cancer (CTUh)	6.03x10 ⁻¹⁰	88%	8.13x10 ⁻¹¹	12%	6.85x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	1.13x10 ⁻¹⁰	73%	4.28x10 ⁻¹¹	27%	1.56x10 ⁻¹⁰
Human toxicity cancer (organics) (CTUh)	4.90x10 ⁻¹⁰	93%	3.85x10 ⁻¹¹	7%	5.29x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	8.29x10 ⁻⁹	78%	2.34x10 ⁻⁹	22%	1.06x10 ⁻⁸
Human toxicity non-cancer (inorganics) (CTUh)	7.70x10 ⁻⁹	77%	2.24x10 ⁻⁹	23%	9.94x10 ⁻⁹
Human toxicity non-cancer (organics) (CTUh)	5.85x10 ⁻¹⁰	86%	9.73x10 ⁻¹¹	14%	6.82x10 ⁻¹⁰
Ionizing radiation (human health) (kBq U235 eq)	2.54x10 ⁻²	59%	1.78x10 ⁻²	41%	4.31x10 ⁻²

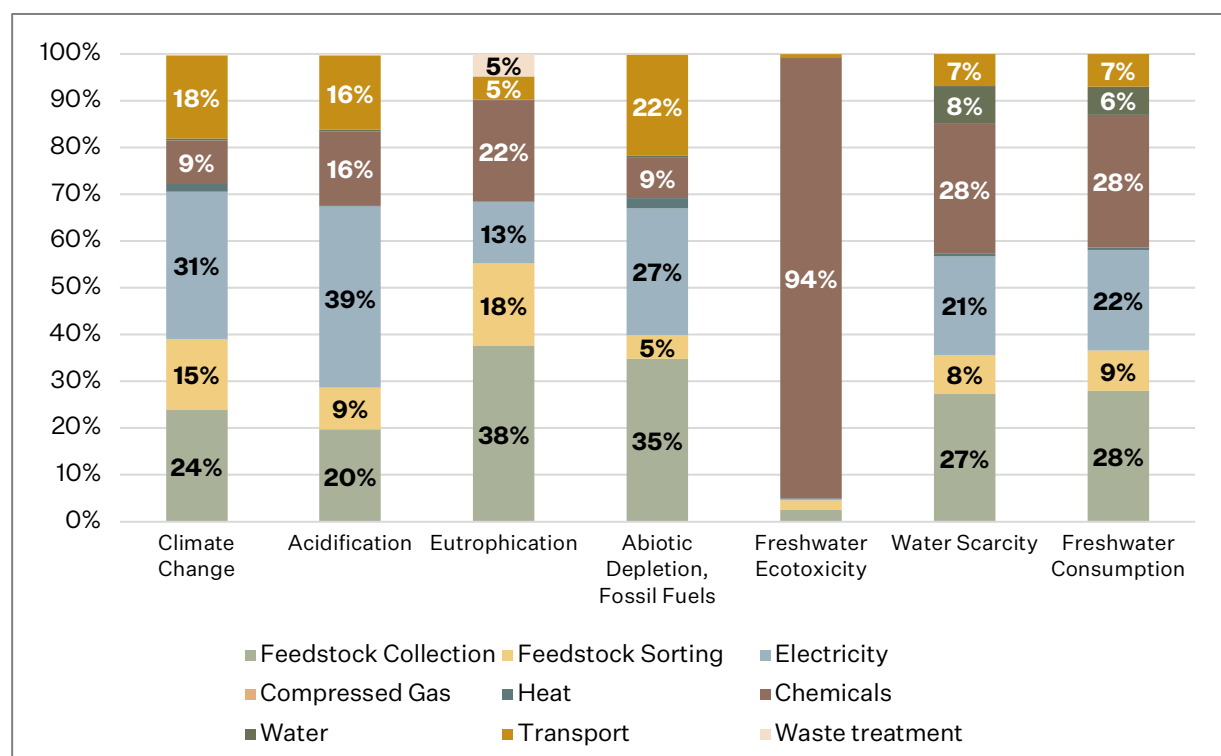
Impact category	Cradle-to-flake		Flake-to-chip		Total
Land use (dimensionless (pt))	7.10	79%	1.85	21%	8.95
Ozone depletion (kg CFC11 eq)	8.36×10^{-7}	100%	2.36×10^{-9}	0%	8.38×10^{-7}
Particulate matter (disease incidence)	9.41×10^{-8}	78%	2.63×10^{-8}	22%	1.20×10^{-7}
Photochemical ozone formation (human health) (kg NMVOC eq)	3.94×10^{-3}	76%	1.22×10^{-3}	24%	5.16×10^{-3}
Resource use fossils (MJ (net calorific))	10.9	76%	3.51	24%	14.4
Resource use minerals and metals (kg Sb eq)	3.08×10^{-6}	69%	1.36×10^{-6}	31%	4.44×10^{-6}
Water use (m ³ world eq)	0.163	61%	0.103	39%	0.266

4.5.2.3. Contribution analysis by process

Electricity use and feedstock collection are two major hotspots for PET chip produced by data provider M2 across all environmental impacts, except for freshwater ecotoxicity (Figure 18). Electricity use contributes 13–39%, while feedstock collection accounts for 20–38%, depending on the impact category. Feedstock collection is a hotspot in part due to the long transport distances assumed in the default ecoinvent bottle collection dataset (990 km), which was used in the absence of primary data on transport for post-consumer bottles. Given the large contribution of feedstock collection to multiple impact categories, and the findings of the transport sensitivity analysis (section 6.2.2), this is noted as a limitation of this study.

Freshwater ecotoxicity is primarily driven by chemicals used in the production process (94%) (Figure 18). Chemical inputs were modeled based on Material Safety Data Sheets (MSDS). Some of the modeled chemicals are surfactant-related, meaning they are either surfactants or closely related compounds such as dispersants or chemical precursors. Based on ecoinvent, many of these are derived from plant sources, which often carry high upstream freshwater ecotoxicity due to agricultural practices such as the use of pesticides and fertilizers. Several inputs include materials derived from crops like palm, coconut, and others. While all contribute to the impact, coconut-based components are associated with particularly high freshwater ecotoxicity.

For the water-scarcity and water-consumption impacts, direct water use at the facility contributes only 8% and 6%, respectively. Most of the impacts come from upstream processes, such as chemical manufacturing, electricity generation, and post-consumer bottle collection (Figure 18). While not directly shown in Figure 18, the impacts associated with the bottle-collection process are driven by the production of collection containers included in the ecoinvent dataset. These containers are made from low-density polyethylene (LDPE), a material with high upstream water consumption. Although it is surprising that container production contributes noticeably to water scarcity and freshwater consumption, ecoinvent has confirmed that the dataset is correctly modeled.

Figure 18: M2—process-level contribution

Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

4.5.3. Data provider M3

4.5.3.1. Higg MSI and EF 3.1 acidification results

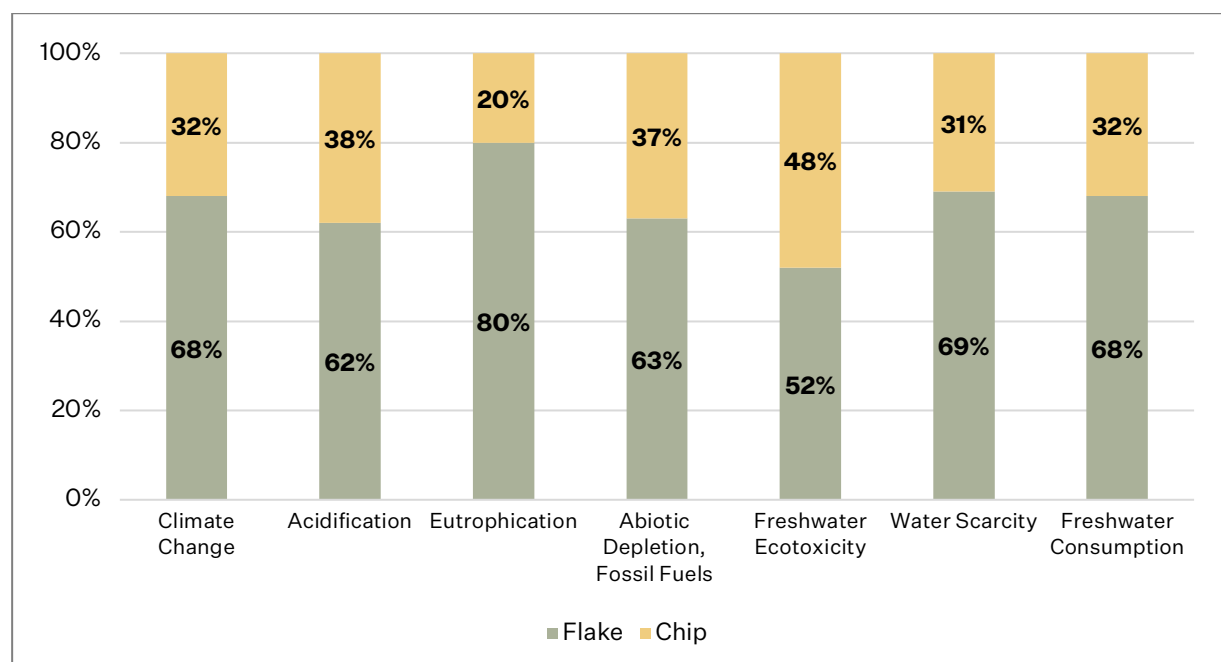
For post-consumer chip production, the cradle-to-flake life cycle stage is the most impactful (>50%) for all impact categories (Table 50, Figure 19). Staple fiber production follows a different pattern, where the flake-to-staple fiber stage contributes over 66% across all impacts (Table 51, Figure 20). The flake-to-staple fiber production stage uses more energy compared to the flake-to-chip stage, as it processes the flake directly into staple fiber, which requires additional processes (spinning, drawing, and crimping) to bypass the chip stage. The use of various chemicals—such as spin finish, dispersants, surfactants, and anti-foaming agents—further adds to some impact categories. More details on the contribution analysis are provided in section 4.5.3.3.

While the same cradle-to-flake process, which occurs at the same facility, is used to produce the flake utilized by M3's chip and staple fiber, more flake is required to produce 1 kg of staple fiber versus 1 kg of chip. Therefore, the staple fiber's cradle-to-flake stage has a higher impact than the chip's cradle-to-flake stage.

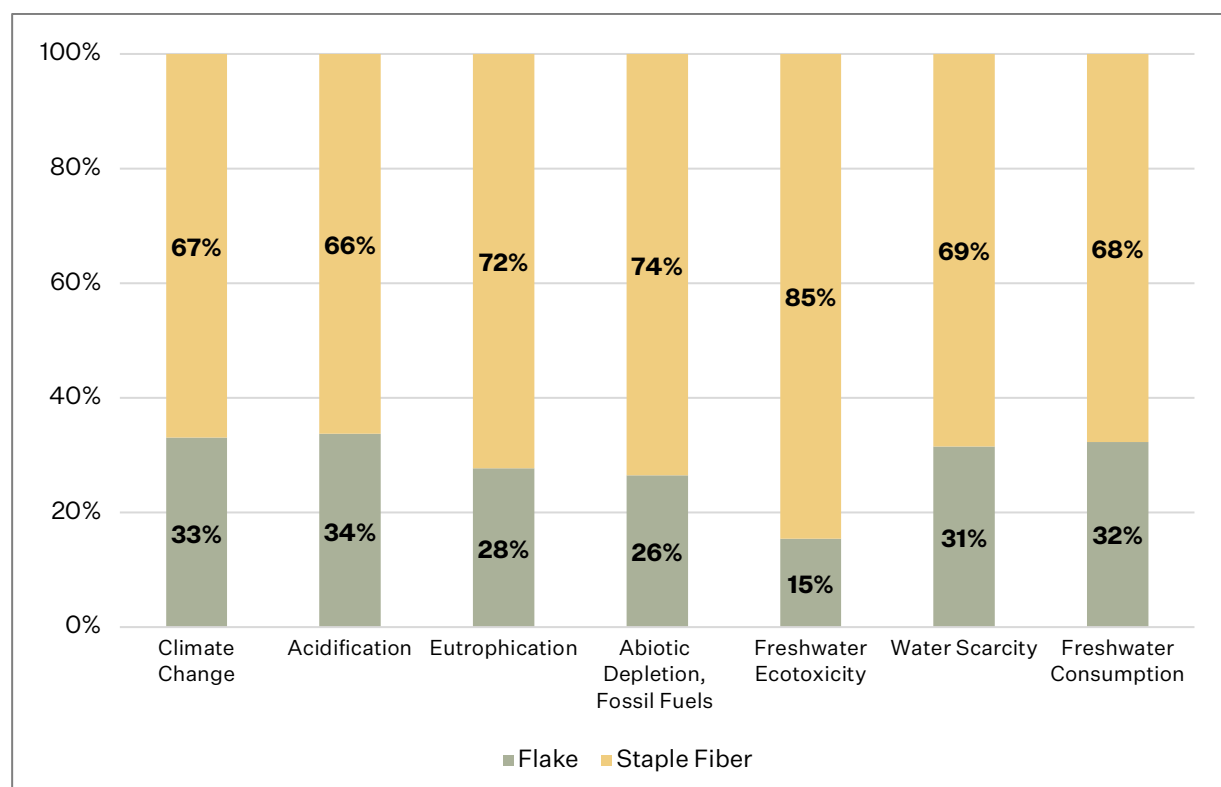
Table 50: M3—LCIA results for 1 kg thermomechanically recycled chip

Impact category	Cradle-to-flake	Flake-to-chip	Total
Climate change (kg CO ₂ eq)	0.897	68% 0.416	32% 1.31
Acidification (mol H ⁺ eq)	3.55x10 ⁻³	62% 2.18x10 ⁻³	38% 5.73x10 ⁻³
Eutrophication (kg PO ₄ eq)	3.87x10 ⁻³	80% 9.82x10 ⁻⁴	20% 4.85x10 ⁻³
Abiotic depletion, fossil fuels (MJ)	7.97	63% 4.64	37% 12.6
Freshwater ecotoxicity (PAF m ³ day)	2.40x10 ⁻²	52% 2.24x10 ⁻²	48% 4.64x10 ⁻²

Impact category	Cradle-to-flake	Flake-to-chip		Total	
Water scarcity (m ³ world eq)	0.164	69%	7.51×10^{-2}	31%	0.239
Freshwater consumption (m ³)	4.68×10^{-3}	68%	2.24×10^{-3}	32%	6.92×10^{-3}

Figure 19: M3—contribution by life cycle stage—PET chip**Table 51: M3—LCIA results for 1 kg thermomechanically recycled staple fiber**

Impact category	Cradle-to-flake	Flake-to-staple fiber		Total	
Climate change (kg CO ₂ eq)	1.01	33%	2.03	67%	3.04
Acidification (mol H ⁺ eq)	3.99×10^{-3}	34%	7.82×10^{-3}	66%	1.18×10^{-2}
Eutrophication (kg PO ₄ eq)	4.34×10^{-3}	28%	1.13×10^{-2}	72%	1.57×10^{-2}
Abiotic depletion, fossil fuels (MJ)	8.94	26%	24.9	74%	33.8
Freshwater ecotoxicity (PAF m ³ day)	2.69×10^{-2}	15%	0.147	85%	0.174
Water scarcity (m ³ world eq)	0.184	31%	0.401	69%	0.585
Freshwater consumption (m ³)	5.25×10^{-3}	32%	1.10×10^{-2}	68%	1.62×10^{-2}

Figure 20: M3— contribution by life cycle stage—PET staple fiber

4.5.3.2. EF 3.1 results

Table 52: M3—EF 3.1 LCIA results for 1 kg of thermomechanically recycled PET chip

Impact category	Cradle-to-flake		Flake-to-chip		Total
Acidification (mol H+ eq)	3.55x10 ⁻³	62%	2.18x10 ⁻³	38%	5.73x10 ⁻³
Climate change (kg CO ₂ eq)	0.897	68%	0.416	32%	1.31
Climate change (biogenic) (kg CO ₂ eq)	9.67x10 ⁻²	99%	8.66x10 ⁻⁴	1%	9.76x10 ⁻²
Climate change (fossil) (kg CO ₂ eq)	0.799	66%	0.414	34%	1.21
Climate change (land use) (kg CO ₂ eq)	1.51x10 ⁻³	59%	1.05x10 ⁻³	41%	2.56x10 ⁻³
Ecotoxicity freshwater (CTUe)	5.92	77%	1.77	23%	7.70
Ecotoxicity freshwater (inorganics) (CTUe)	5.39	81%	1.25	19%	6.63
Ecotoxicity freshwater (organics) (CTUe)	0.539	51%	0.526	49%	1.06
Eutrophication freshwater (kg P eq)	2.83x10 ⁻⁴	57%	2.11x10 ⁻⁴	43%	4.94x10 ⁻⁴
Eutrophication marine (kg N eq)	7.99x10 ⁻⁴	68%	3.73x10 ⁻⁴	32%	1.17x10 ⁻³
Eutrophication terrestrial (mol N eq)	7.15x10 ⁻³	66%	3.66x10 ⁻³	34%	1.08x10 ⁻²
Human toxicity cancer (CTUh)	6.14x10 ⁻¹⁰	88%	8.76x10 ⁻¹¹	12%	7.01x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	1.19x10 ⁻¹⁰	79%	3.17x10 ⁻¹¹	21%	1.51x10 ⁻¹⁰
Human toxicity cancer (organics) (CTUh)	4.94x10 ⁻¹⁰	90%	5.58x10 ⁻¹¹	10%	5.50x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	7.54x10 ⁻⁹	75%	2.50x10 ⁻⁹	25%	1.00x10 ⁻⁸
Human toxicity non-cancer (inorganics) (CTUh)	6.98x10 ⁻⁹	75%	2.27x10 ⁻⁹	25%	9.25x10 ⁻⁹
Human toxicity non-cancer (organics) (CTUh)	5.52x10 ⁻¹⁰	70%	2.35x10 ⁻¹⁰	30%	7.88x10 ⁻¹⁰

Impact category	Cradle-to-flake		Flake-to-chip		Total
Ionizing radiation (human health) (kBq U235 eq)	1.23x10 ⁻²	85%	2.21x10 ⁻³	15%	1.45x10 ⁻²
Land use (dimensionless (pt))	3.39	72%	1.35	28%	4.74
Ozone depletion (kg CFC11 eq)	1.18x10 ⁻⁸	60%	8.02x10 ⁻⁹	40%	1.98x10 ⁻⁸
Particulate matter (disease incidence)	9.35x10 ⁻⁸	74%	3.30x10 ⁻⁸	26%	1.26x10 ⁻⁷
Photochemical ozone formation (human health) (kg NMVOC eq)	2.50x10 ⁻³	68%	1.17x10 ⁻³	32%	3.67x10 ⁻³
Resource use fossils (MJ (net calorific))	8.31	63%	4.80	37%	13.1
Resource use minerals and metals (kg Sb eq)	2.31x10 ⁻⁶	77%	6.80x10 ⁻⁷	23%	2.99x10 ⁻⁶
Water use (m ³ world eq)	0.165	69%	7.57x10 ⁻²	31%	0.241

Table 53: M3—EF 3.1 LCIA results for 1 kg of thermomechanically recycled staple fiber

Impact category	Cradle-to-flake		Flake-to-staple fiber		Total
Acidification (mol H ⁺ eq)	3.99x10 ⁻³	34%	7.82x10 ⁻³	66%	1.18x10 ⁻²
Climate change (kg CO ₂ eq)	1.01	33%	2.03	67%	3.04
Climate change (biogenic) (kg CO ₂ eq)	0.108	96%	4.22x10 ⁻³	4%	0.113
Climate change (fossil) (kg CO ₂ eq)	0.896	31%	2.02	69%	2.92
Climate change (land use) (kg CO ₂ eq)	1.69x10 ⁻³	19%	7.17x10 ⁻³	81%	8.86x10 ⁻³
Ecotoxicity freshwater (CTUe)	6.65	21%	24.4	79%	31.0
Ecotoxicity freshwater (inorganics) (CTUe)	6.04	21%	22.3	79%	28.4
Ecotoxicity freshwater (organics) (CTUe)	0.604	23%	2.06	77%	2.66
Eutrophication freshwater (kg P eq)	3.17x10 ⁻⁴	29%	7.60x10 ⁻⁴	71%	1.08x10 ⁻³
Eutrophication marine (kg N eq)	8.97x10 ⁻⁴	37%	1.53x10 ⁻³	63%	2.43x10 ⁻³
Eutrophication terrestrial (mol N eq)	8.02x10 ⁻³	35%	1.50x10 ⁻²	65%	2.30x10 ⁻²
Human toxicity cancer (CTUh)	6.88x10 ⁻¹⁰	43%	9.27x10 ⁻¹⁰	57%	1.62x10 ⁻⁹
Human toxicity cancer (inorganics) (CTUh)	1.34x10 ⁻¹⁰	49%	1.40x10 ⁻¹⁰	51%	2.74x10 ⁻¹⁰
Human toxicity cancer (organics) (CTUh)	5.55x10 ⁻¹⁰	41%	7.87x10 ⁻¹⁰	59%	1.34x10 ⁻⁹
Human toxicity non-cancer (CTUh)	8.45x10 ⁻⁹	45%	1.05x10 ⁻⁸	55%	1.89x10 ⁻⁸
Human toxicity non-cancer (inorganics) (CTUh)	7.84x10 ⁻⁹	46%	9.34x10 ⁻⁹	54%	1.72x10 ⁻⁸
Human toxicity non-cancer (organics) (CTUh)	6.20x10 ⁻¹⁰	36%	1.12x10 ⁻⁹	64%	1.74x10 ⁻⁹
Ionizing radiation (human health) (kBq U235 eq)	1.38x10 ⁻²	38%	2.21x10 ⁻²	62%	3.59x10 ⁻²
Land use (dimensionless (pt))	3.80	26%	10.9	74%	14.7
Ozone depletion (kg CFC11 eq)	1.33x10 ⁻⁸	0%	1.09x10 ⁻⁵	100%	1.09x10 ⁻⁵
Particulate matter (disease incidence)	1.05x10 ⁻⁷	50%	1.04x10 ⁻⁷	50%	2.09x10 ⁻⁷
Photochemical ozone formation (human health) (kg NMVOC eq)	2.80x10 ⁻³	33%	5.57x10 ⁻³	67%	8.37x10 ⁻³
Resource use fossils (MJ (net calorific))	9.32	26%	25.9	74%	35.2
Resource use minerals and metals (kg Sb eq)	2.59x10 ⁻⁶	35%	4.79x10 ⁻⁶	65%	7.38x10 ⁻⁶
Water use (m ³ world eq)	0.185	31%	0.403	69%	0.588

4.5.3.3. Contribution analysis by process

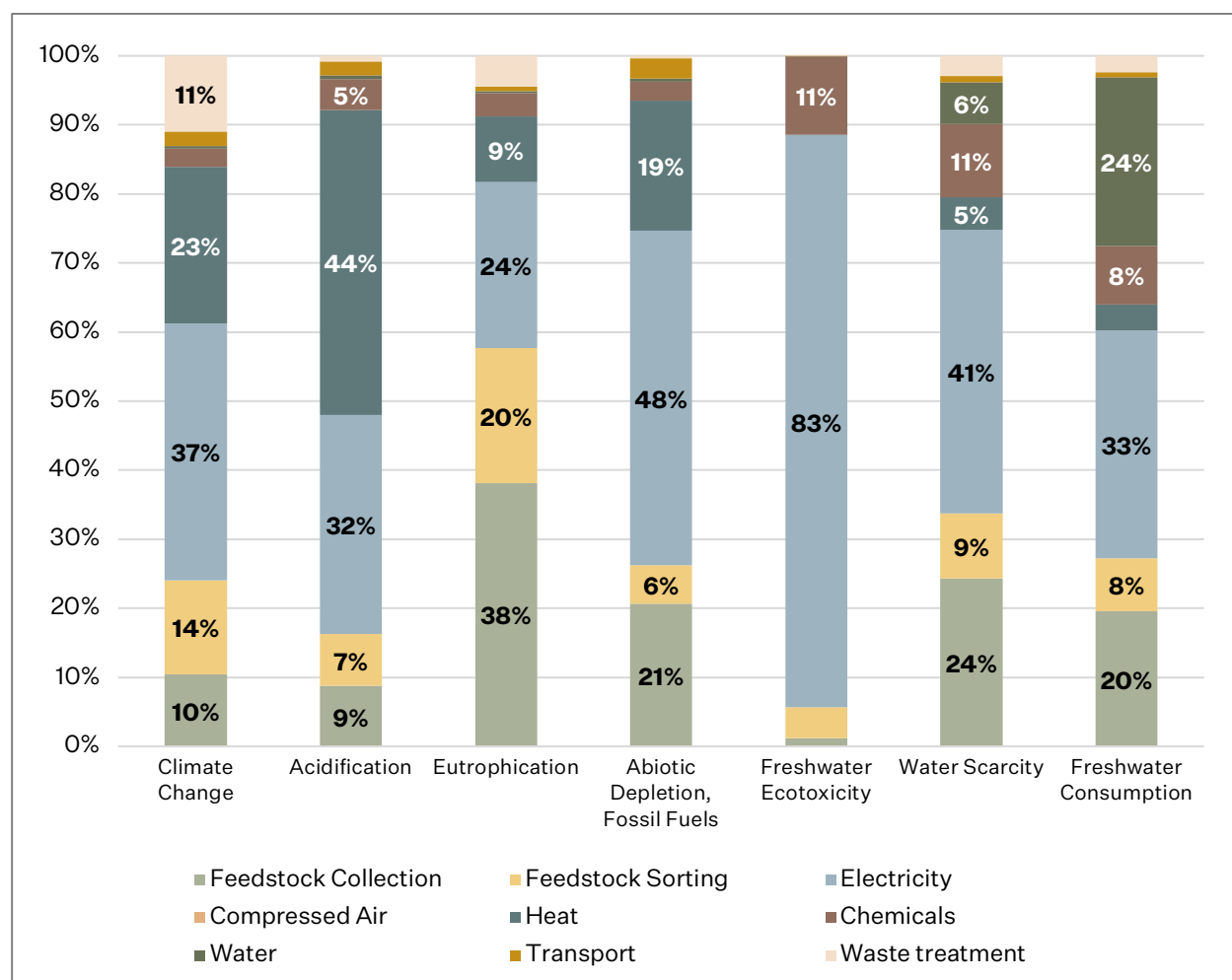
For cradle-to-chip production, electricity is a major contributor across all impacts, accounting for 24–83% (Figure 21). Heat is another notable contributor to climate change (23%), acidification (44%), eutrophication (9%), and abiotic resource depletion (19%), as it is mostly generated using coal.

Besides electricity being the dominant driver of water scarcity (41%) and freshwater consumption (33%), feedstock collection, chemicals, and onsite water use also contribute to these impact categories. Feedstock collection accounts for 24% of water scarcity and 20% of freshwater consumption; this is discussed in a later paragraph, below. Chemicals add 11% to water scarcity and 8% to freshwater consumption. Water used at the facility contributes 24% to freshwater consumption, but only 6% to water scarcity over the cradle-to-gate life cycle. The water scarcity impact category considers regional water scarcity or abundance. As M3 is located in an area with low water stress, water taken from the region has a lower impact within this impact category.

Freshwater ecotoxicity is mainly driven by electricity (83%), with chemical inputs contributing an additional 11%. The impact of electricity is determined by the grid mix used by M3, which includes bagasse-based bioenergy. Bagasse is a by-product of sugarcane processing and is modeled using a global ecoinvent dataset as part of a heat and power cogeneration process. This specific ecoinvent electricity dataset is globally representative of bagasse-based bioenergy, meaning it includes a mix of different countries' technologies. A deeper examination of the upstream data included within this dataset reveals it may not fully reflect the specific feedstock sources or agricultural practices specific to the Southeast Asian country in which M3 is located. As part of the bagasse-based bioenergy, this dataset includes the upstream production of sugarcane cultivation. The sugarcane production dataset is representative of sugarcane produced globally, but most of the freshwater ecotoxicity impact is linked to sugarcane cultivation in India. Key contributors to freshwater ecotoxicity from sugarcane cultivation include direct agricultural emissions from fertilizer and pesticide use, as well as the use of creosote-treated wood trellises employed on the farms. The lack of better data to model bagasse-based bioenergy is noted as a limitation specific to the freshwater ecotoxicity impact category of M3's recycling process.

Chemical inputs are a smaller but still relevant contributor to freshwater ecotoxicity (11%). They were modeled based on Material Safety Data Sheets (MSDS) or other information provided by the data provider. The cleaning powder used for washing in the cradle-to-flake stage is a proprietary anionic surfactant, which includes some upstream agricultural feedstocks (Ma et al., 2022). As noted in earlier sections, agricultural sources can carry high upstream ecotoxicity impacts from pesticide and fertilizer use.

Feedstock collection, which includes both upstream bottle collection transport and the production of a low-density polyethylene (LDPE) collection container, is another notable contributor to several impact categories, including eutrophication (38%), abiotic resource depletion (21%), water scarcity (24%), and freshwater consumption (20%). Unlike the other thermomechanical recyclers in this section, upstream bottle-collection transport plays a smaller role, as M3 sources bottles locally (within approximately 100 km). Most of the feedstock collection impacts are driven by the production of the LDPE collection container. Although this contribution is unexpectedly high, as discussed in earlier sections, ecoinvent confirmed that the dataset is correctly modeled.

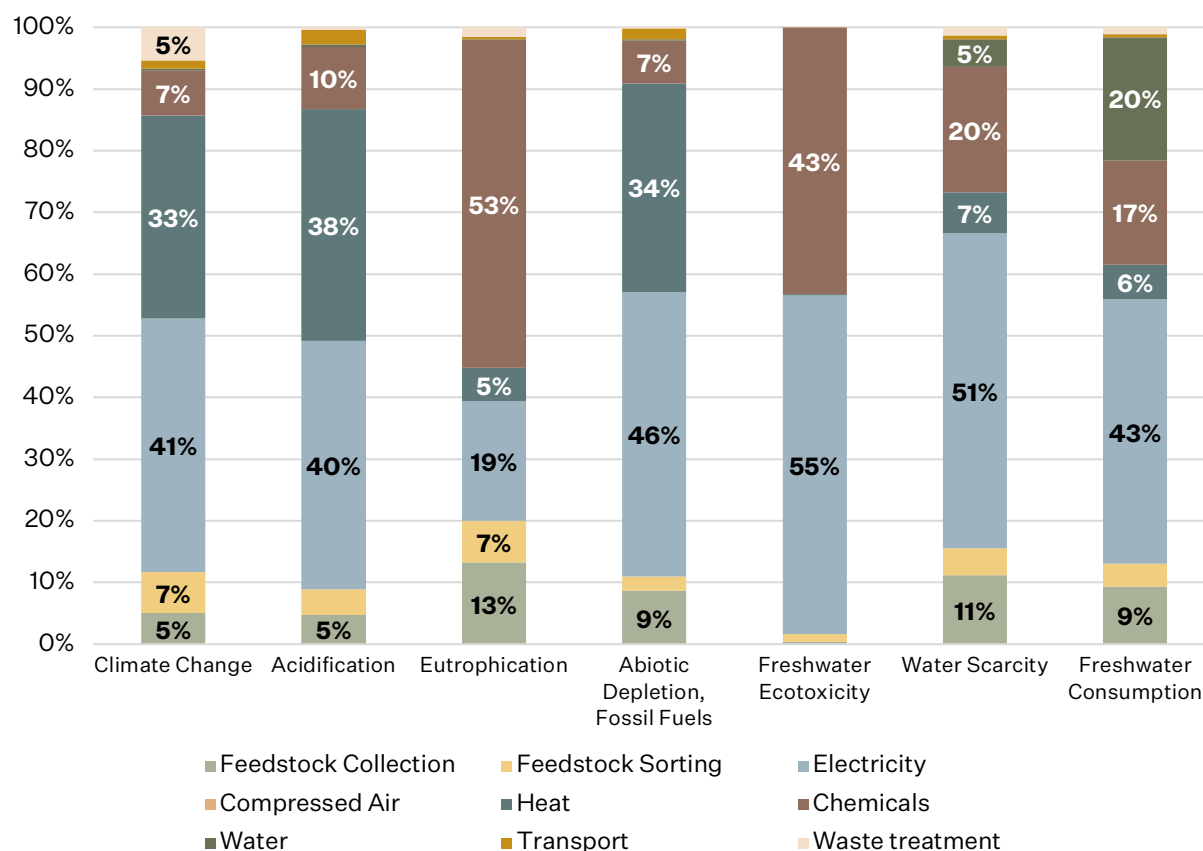
Figure 21: M3—process-level contribution—PET chip

Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

For cradle-to-staple fiber production, electricity and heat dominate the impacts for climate change, acidification, and abiotic resource depletion (40–46% for electricity, and 33–38% for heat) (Figure 22). Electricity also drives water scarcity (51%) and freshwater consumption (43%). As discussed above in section 4.5.3.1, the flake-to-staple fiber production stage uses more energy compared to M3's flake-to-chip stage, as it processes the flake directly into staple fiber and bypasses the chip stage.

For freshwater ecotoxicity, electricity is the largest contributor (55%), followed by chemicals (43%). The high electricity share is primarily due to the grid mix used by M3, which includes bagasse-based bioenergy. Contributions to impacts from chemical production are mainly linked to surfactant-related substances used as dispersants and spin finish. As discussed in previous sections, based on the ecoinvent datasets used, some of these chemicals are derived from agricultural sources, which carry high upstream ecotoxicity impacts due to pesticide and fertilizer use.

Chemical production is the largest contributor to eutrophication (53%), mainly driven by polydimethylsiloxane (PDMS), an anti-foaming agent used in the staple fiber production.

Figure 22: M3—process-level contribution—PET staple fiber

Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

4.6. Key takeaways

The most important observations relevant to the production and impact of thermomechanically recycled chip are summarized below:

- Thermomechanical recycling is used mainly to recycle post-consumer PET bottle waste, but it can also be used to recycle post-industrial textile waste. It requires homogeneous, high-quality waste inputs as it is unable to remove contaminants or additives within the PET. It is not able to decolor waste PET, and so the recycled chip or staple fiber matches the color of the waste used.
- Electricity is a consistent contributor to climate change, acidification, eutrophication, and abiotic depletion of fossil fuels across all products and data providers ($\geq 11\%$). Feedstock collection also contributes notably to these impact categories, particularly for M2, where an ecoinvent default bottle collection distance of 990 km is used. In addition to transport, the production of LDPE collection containers—modeled using default data from ecoinvent—further contributes to the collection-related impacts.
- Freshwater ecotoxicity is driven almost entirely ($\geq 79\%$) by surfactant-related chemicals, which are used to clean incoming waste in M1 and M2's recycling process. For M3, chemicals and electricity together are responsible for $\geq 94\%$ of its impact. The contribution from electricity is largely driven by upstream processes in the regional grid mix, particularly sugarcane cultivation associated with bagasse-based bioenergy.

- Water scarcity and freshwater-consumption impacts for thermomechanically recycled chip and staple fiber production are primarily influenced by electricity (9–52%), feedstock collection (9–55%)—mostly driven by the upstream production of the LDPE collection container—and chemicals (8–28%). Facility water use is also a main contributor, particularly for M3’s freshwater consumption and for M1’s water scarcity.

5. Virgin Production Product Systems

In this study, one virgin PET producer, referred to as V1, was evaluated across two production sites in the same Southeast Asian country, referred to as Facility 1 and Facility 2, covering five products: three continuously polymerized staple fibers (including black and white), batch polymerized black partially oriented yarn (POY), and continuously polymerized white drawn textured yarn (DTY) (Table 54).

V1 produces virgin PET through two methods: continuous polymerization and batch polymerization. Continuous polymerization is the primary method used by V1. In this method, two petrochemical-derived raw materials—monoethylene glycol (MEG) and purified terephthalic acid (PTA)—are continuously fed into a reactor system. The reaction involves two key chemical reactions: esterification, which produces an intermediate compound and water, followed by polycondensation, which links the intermediate compounds, forms long PET chains, and releases additional water. The reaction produces PET melt, a molten form of plastic, which is then used directly in downstream processing. One processing route produces staple fiber, where the PET melt is extruded into thin strands and then cut into short, uniform fibers. Another route spins the PET melt into partially oriented yarn (POY), which consists of long, continuous filaments that have been partially stretched to improve strength but remain unfinished. Stretching aligns the polymer molecules, creating a more ordered structure that resists breaking. POY can be further processed into drawn textured yarn (DTY) through a mechanical drawing and texturing process. This process stretches and crimps the fibers, introducing small, controlled bends or waves that enhance elasticity, softness, and fullness.

Monoethylene glycol (MEG), also referred to in industry and by chemical recyclers as ethylene glycol (EG), used by the virgin producer in this study, was modeled using the ethylene oxide production route available in the ecoinvent database. MEG is commonly produced through the direct hydration of ethylene oxide (Zhang et al., 2024), which is typically derived from oil or natural gas. This pathway is the standard practice globally and is reflected in the ecoinvent ethylene glycol datasets (Ecoinvent, 2024b). However, MEG can also be produced using a different and more energy-intensive process that utilizes coal syngas. This coal-to-ethylene glycol (CtEG) process is conducted in China along with the traditional MEG production route (Qian et al., 2022). V1 does not source MEG from China, but the CtEG pathway is included in the sensitivity analysis to test its potential impact (section 6.3).

Batch polymerization follows the same chemical process but operates in separate batches instead of a continuous flow. V1 uses this method for small-scale or specialty-grade PET production. Batch polymerization produces PET chips, which are later melted and processed into staple fiber, POY, or DTY.

A detailed description of each product’s systems is shown in section 5.2.

Table 54: Summary of virgin PET product systems

Product	Facility	Region of operation	Data collection period	Production pathway	Functional unit
SF1	Facility 1	Southeast Asia	January—December 2022	Continuous polymerization of melt → melt to staple fiber	1 kg of black virgin staple fiber
SF2	Facility 1	Southeast Asia	January—December 2022	Continuous polymerization of melt → melt to staple fiber	1 kg of white virgin staple fiber
SF3	Facility 2	Southeast Asia	January—December 2022	Continuous polymerization of melt → melt to staple fiber	1 kg of white virgin staple fiber

Product	Facility	Region of operation	Data collection period	Production pathway	Functional unit
POY	Facility 2	Southeast Asia	January—December 2022	Batch polymerization of chip → chip to POY	1 kg of virgin partially oriented yarn (POY)
DTY	Facility 2	Southeast Asia	January—December 2022	Continuous polymerization of melt → melt to POY → POY to DTY	1 kg of virgin drawn textured yarn (DTY)

5.1. System boundary

The system boundary for each virgin PET product is its cradle-to-manufacturing gate (for example, cradle-to-staple fiber, cradle-to-POY, cradle-to-DTY), covering all processes required to produce each of these virgin PET products (Table 54), including the upstream extraction and processing of petrochemical feedstocks. Each product system also includes transportation of materials, energy inputs, and waste management. Downstream applications and packaging are excluded.

The functional unit for each product is shown in Table 54, above. All required inputs and generated outputs are scaled to the production of this functional unit. These virgin PET products serve different functions. Staple fiber can be used to produce a variety of textile products, including spun yarn, fabrics, and fillings. POY typically serves as an intermediate input to make DTY or fully drawn yarn (FDY). DTY is a fully processed, textured yarn product used directly in weaving and knitting.

There are multiple steps that occur to convert petrochemical feedstocks into virgin PET products (Figure 23–Figure 25), and these steps have been divided into discrete life cycle stages. For staple fiber, the system is divided into two stages: cradle-to-melt and melt-to-staple fiber. For POY, the system is divided into cradle-to-chip and chip-to-POY. For DTY, the system is divided into cradle-to-melt, melt-to-POY, and POY-to-DTY stages.

Figure 23–25 show the detailed product systems for virgin PET staple fiber, POY, and DTY, respectively.

Figure 23: System boundary diagram for continuously polymerized virgin PET staple fiber

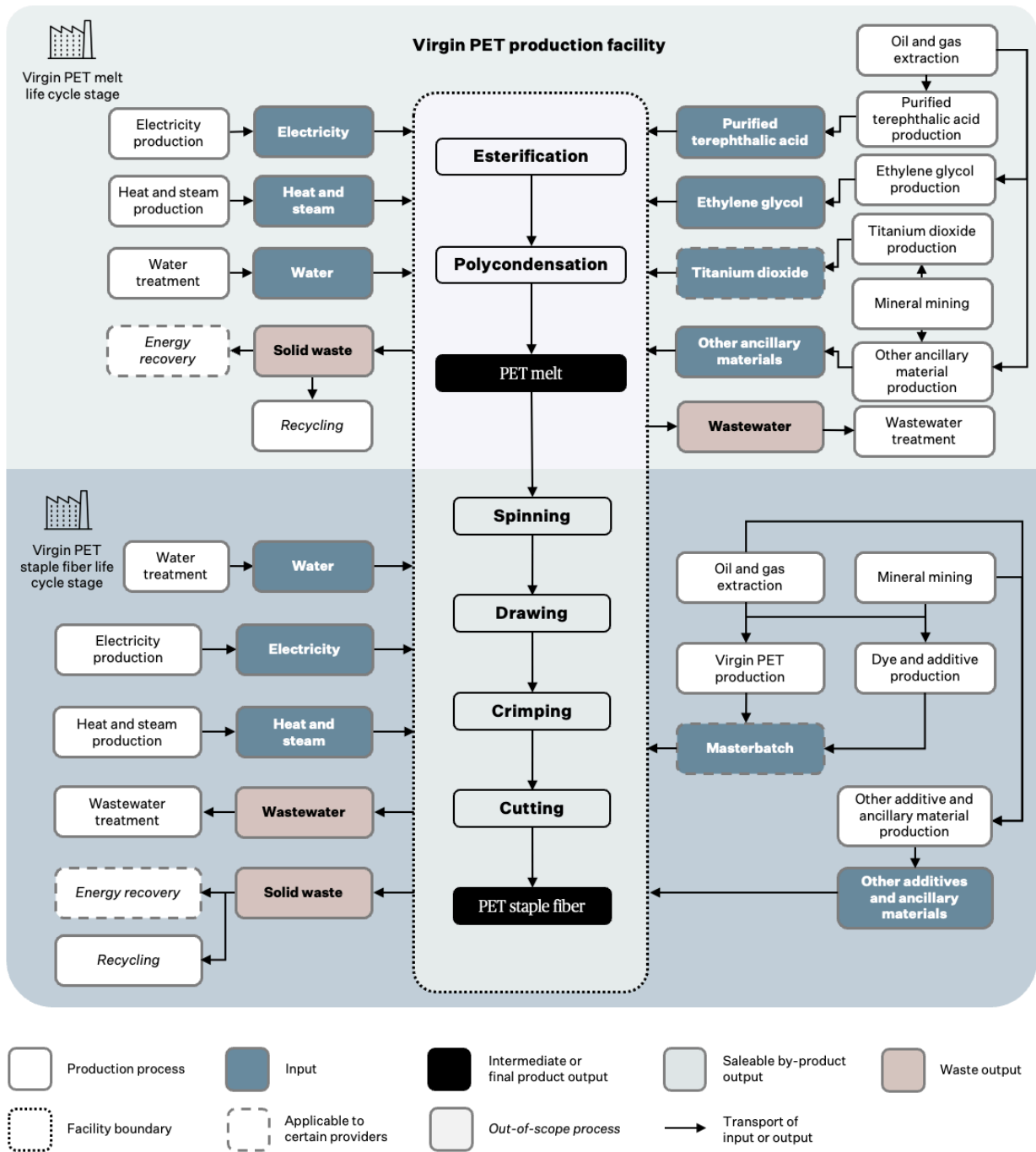


Figure 24: System boundary diagram for batch polymerized virgin PET POY

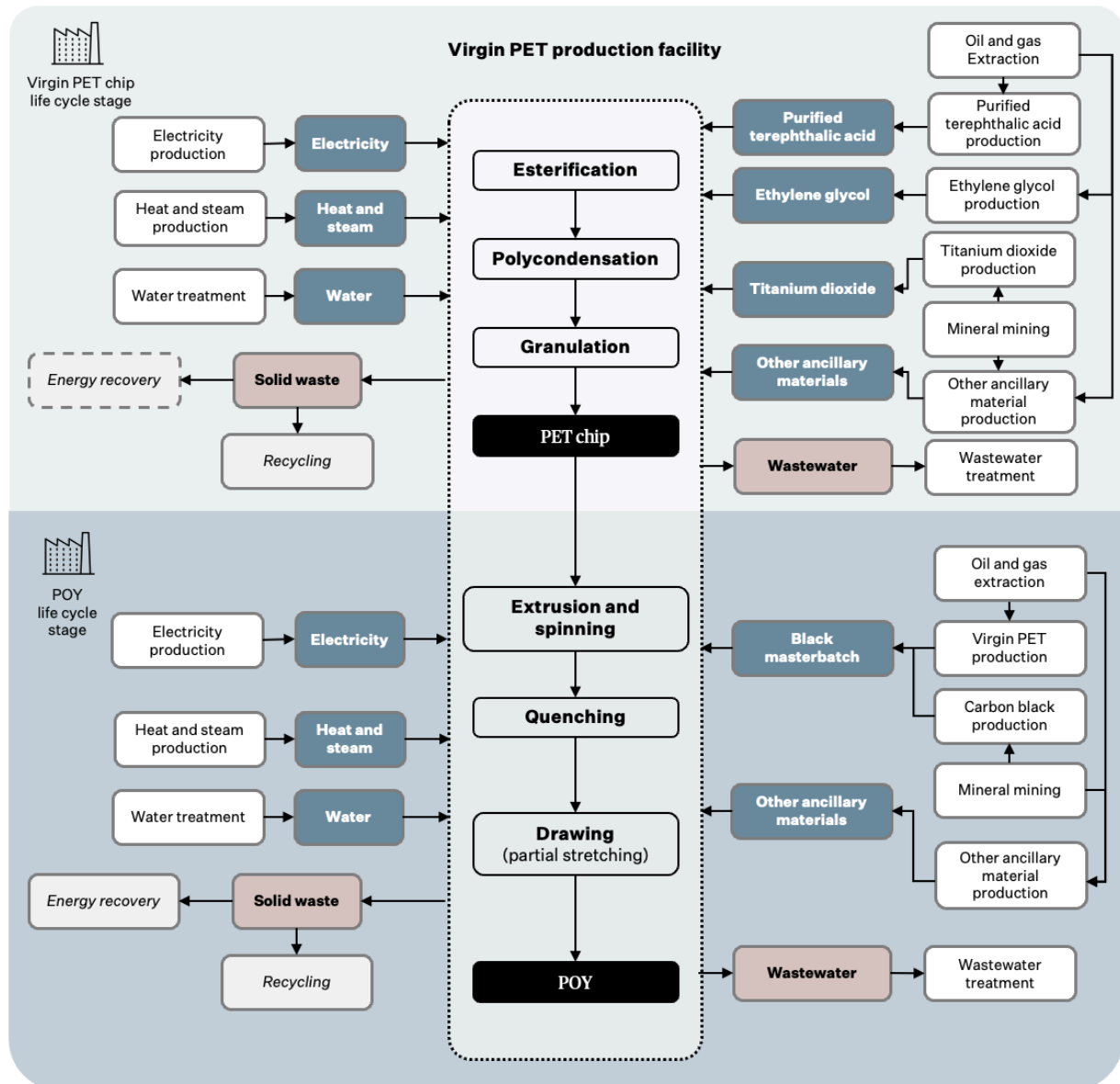
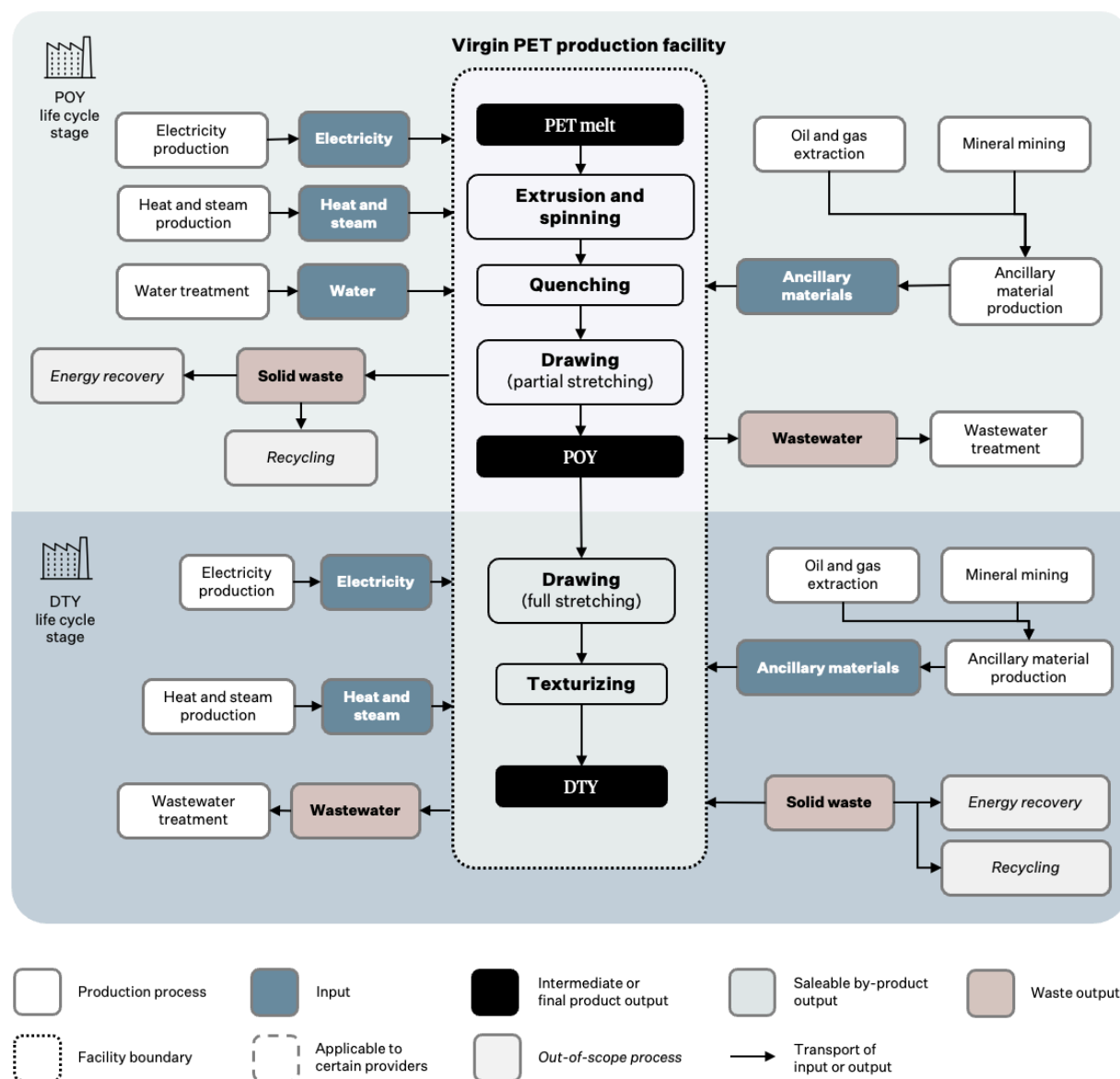


Figure 25: System boundary diagram for continuously polymerized virgin PET DTY

5.2. Product system description

5.2.1. Staple fiber products (SF1, SF2, SF3)

5.2.1.1 Background

The data provider manufactures three virgin PET staple fiber products: SF1 (black), SF2 (white), at Facility 1, and SF3 (white) at Facility 2. All three product systems follow a similar cradle-to-staple fiber system boundary (Figure 23), with differences in the incorporation of pigment additives. Primary data collected from the manufacturing facilities represents production between January and December 2022.

5.2.1.2 Manufacturing process

Virgin melt is first produced through continuous polymerization using monoethylene glycol (MEG), purified terephthalic acid (PTA), and a small amount of diethylene glycol (DEG). These raw

materials undergo esterification and polycondensation to form PET melt, which is directly processed into staple fiber.

SF1 and SF2 are produced from the same PET melt. In the melt-to-staple fiber stage, black masterbatch is added to SF1, and titanium dioxide (white color) is added for SF2. The melt is then extruded, spun, drawn, crimped, and cut into staple fiber.

SF3 is produced at Facility 2, where titanium dioxide is added during the cradle-to-melt stage. This produces a white PET melt, eliminating the need for pigment addition in the melt-to-fiber stage. The white melt is then processed into staple fiber using the same operations as SF1 and SF2.

At Facility 1, electricity used in production is sourced from both onsite solar generation (12% for cradle-to-melt, and 9% for melt-to-staple fiber) and the local electricity grid (88% for cradle-to-melt, and 91% for melt-to-staple fiber). At Facility 2, electricity is supplied from a combination of onsite coal (73%) and onsite solar generation (1%), as well as the local grid (25%). Due to rounding, the percentages do not sum exactly to 100%. The electricity grid mix used in the LCA model is region-specific and based on the confidential manufacturing locations in Southeast Asia, adjusted using the 2022 electricity generation data (International Energy Agency, 2024c) to reflect the production year. The corresponding electricity mix is presented in Table 55 for Facility 1, and in Table 56 for Facility 2. Facility 2 is newer and operates more efficiently, requiring less energy in production. Additionally, Facility 1 relies mainly on coal for heat, while Facility 2 uses more natural gas, which has higher combustion efficiency.

The data provider reported that all solid waste generated during manufacturing is sent to facilities for recycling or waste-to-energy recovery (WTE). For waste streams reported as "recycled and sent to waste-to-energy recovery," a 20:80 incineration-to-recycling ratio was applied in the LCA models. This ratio was informed by confidential literature data (Confidential literature source, 2022) on industrial plastic production waste from the Southeast Asian country where V1 is located, with a conservative adjustment made for modeling. The source is not disclosed to maintain the anonymity of the data provider and the location in which they operate. WTE is modeled as incineration, and all of the impacts are allocated to V1. Transport of the wastes to their respective treatment facilities is included. Based on the recycled content method (section 2.5) used in this assessment, the impacts associated with recycling are excluded from the system boundary and are allocated to the subsequent product system.

Input-output data was available for PET melt and PET staple fiber separately; allocation was not used.

The data provider has provided its life cycle inventory (LCI) data for all of its products, which is presented in Table 57–Table 59.

Table 55: Electricity mix used for SF1 and SF2—Facility 1— Southeast Asia

Type of energy	Cradle-to-melt percentage	Melt-to-staple fiber percentage	Cradle-to-staple fiber percentage
On-site electricity—solar	12%	9%	9%
Grid electricity—coal	18%	18%	18%
Grid electricity—oil	5%	5%	5%
Grid electricity—natural gas	49%	51%	51%
Grid electricity—biofuels	9%	9%	9%
Grid electricity—waste	0%	0%	0%

Type of energy	Cradle-to-melt percentage	Melt-to-staple fiber percentage	Cradle-to-staple fiber percentage
Grid electricity—nuclear	0%	0%	0%
Grid electricity—hydro	4%	4%	4%
Grid electricity—solar PV	3%	3%	3%
Grid electricity—wind	2%	2%	2%
Grid electricity—other sources	0%	0%	0%

Due to rounding, values may not sum exactly to 100%.

Table 56: Electricity mix used for SF3—Facility 2—Southeast Asia

Type of energy	Percentage
On-site electricity—coal	73%
On-site electricity—solar	1%
Grid electricity—coal	5%
Grid electricity—oil	2%
Grid electricity—natural gas	14%
Grid electricity—biofuels	3%
Grid electricity—waste	0%
Grid electricity—nuclear	0%
Grid electricity—hydro	1%
Grid electricity—solar PV	1%
Grid electricity—wind	1%
Grid electricity—other sources	0%

Due to rounding, values may not sum exactly to 100%.

Table 57: Life cycle inventory data for 1 kg SF1 produced at Facility 1

Flow	Melt		Staple fiber		Unit
	Input	Output	Input	Output	
Raw materials					
Purified terephthalic acid	0.775	-	-	-	kg
Monoethylene glycol	0.303	-	-	-	kg
Diethylene glycol	6.55x10 ⁻⁴	-	-	-	kg
Antimony	1.71x10 ⁻³	-	-	-	kg
Titanium dioxide	3.45x10 ⁻⁵	-	3.83x10 ⁻⁴	-	kg
Black masterbatch	-	-	8.94x10 ⁻²	-	kg
Biodegradation promoting additive	-	-	5.31x10 ⁻⁴	-	kg
Different types of spin finish	-	-	5.90x10 ⁻³	-	kg
Refrigerant	-	-	9.03x10 ⁻⁷	-	kg
Silicone spray	-	-	8.44x10 ⁻⁶	-	kg

Flow	Melt		Staple fiber		Unit
	Input	Output	Input	Output	
Sand	-	-	2.44x10 ⁻⁴	-	kg
Moisture from atmosphere	2.97x10 ⁻²	-	-	-	kg
Uncolored PET melt	-	0.936	0.936	-	kg
Black staple fiber SF1	-	-	-	1.00	kg
Facility utilities					
Grid electricity	4.25x10 ⁻³	-	0.603	-	kWh
Onsite solar	5.98x10 ⁻⁴	-	5.90x10 ⁻²	-	kWh
LPG (heat)	4.25x10 ⁻³	-	7.59x10 ⁻³	-	MJ
Coal (heat)	3.68	-	4.51	-	MJ
Heavy fuel oil (heat)	0.348	-	2.53x10 ⁻²	-	MJ
Nitrogen	1.14x10 ⁻²	-	-	-	kg
DM water	-	-	2.45	-	kg
Waste treatment					
Waste to recycle or for sale	-	9.06x10 ⁻⁴	-	2.62x10 ⁻²	kg
Waste, energy recovery	-	3.81x10 ⁻⁴	-	-	kg
Wastewater discharge	-	-	-	2.45	kg
Emissions to air					
Water from stoichiometry	-	0.172	-	-	kg
Transport					
Truck transport	229	-	1.69x10 ⁻²	-	kg*km
Ship transport	7.44	-	340	-	kg*km
Waste transport	4.13x10 ⁻²	-	0.827	-	kg*km

Table 58: Life cycle inventory data for 1 kg SF2 produced at Facility 1

Flow	Melt		Staple fiber		Unit
	Input	Output	Input	Output	
Raw materials					
Purified terephthalic acid	0.852	-	-	-	kg
Monoethylene glycol	0.332	-	-	-	kg
Diethylene glycol	7.19x10 ⁻⁴	-	-	-	kg
Antimony	1.85x10 ⁻³	-	-	-	kg
Titanium dioxide	3.79x10 ⁻⁵	-	4.31x10 ⁻⁴	-	kg
Different types of spin finish	-	-	7.71x10 ⁻³	-	kg
Refrigerant	-	-	9.91x10 ⁻⁷	-	kg
Silicone spray	-	-	9.26x10 ⁻⁶	-	kg
Sand	-	-	2.65x10 ⁻⁴	-	kg

Flow	Melt		Staple fiber		Unit
	Input	Output	Input	Output	
Moisture from atmosphere	3.19×10^{-2}	-	-	-	kg
Uncolored PET melt	-	1.03	1.03	-	kg
White staple fiber SF2	-	-	-	1.00	kg
Facility utilities					
Grid electricity	4.63×10^{-3}	-	0.662	-	kWh
Onsite solar	6.56×10^{-4}	-	6.57×10^{-2}	-	kWh
LPG (heat)	4.63×10^{-3}	-	7.98×10^{-3}	-	MJ
Coal (heat)	4.04	-	4.96	-	MJ
Heavy fuel oil (heat)	0.382	-	2.84×10^{-2}	-	MJ
Nitrogen	1.25×10^{-2}	-	-	-	kg
DM water	-	-	7.32	-	kg
Waste treatment					
Waste to recycle or for sale	-	9.94×10^{-4}	-	2.83×10^{-2}	kg
Waste, energy recovery	-	4.19×10^{-4}	-	-	kg
Wastewater discharge	-	-	-	7.32	kg
Emissions to air					
Water from stoichiometry	-	0.189	-	-	kg
Transport					
Truck transport	252	-	3.31×10^{-2}	-	kg*km
Ship transport	8.17	-	36.7	-	kg*km
Waste transport	4.52×10^{-2}	-	0.906	-	kg*km

Table 59: Life cycle inventory data for 1 kg SF3 produced at Facility 2

Flow	Melt		Staple fiber		Unit
	Input	Output	Input	Output	
Raw materials					
Purified terephthalic acid	0.862	-	-	-	kg
Monoethylene glycol	0.334	-	-	-	kg
Diethylene glycol	2.07x10 ⁻³	-	-	-	kg
Titanium	1.88x10 ⁻⁴	-	-	-	kg
Titanium dioxide	2.58x10 ⁻³	-	-	-	kg
Lubricating oil	7.19x10 ⁻⁶	-	5.60x10 ⁻⁵	-	kg
Different types of spin finish and ancillary chemicals	-	-	4.09x10 ⁻³	-	kg
Dowtherm RP	-	-	4.42x10 ⁻⁴	-	kg
Refrigerant	-	-	2.41x10 ⁻⁶	-	kg

Flow	Melt		Staple fiber		Unit
	Input	Output	Input	Output	
White PET melt	-	1.00	1.00	-	kg
White staple fiber SF3	-	-	-	1.00	kg
Facility utilities					
Grid electricity	3.15×10^{-2}	-	6.36×10^{-2}	-	kWh
Onsite solar	1.71×10^{-3}	-	3.47×10^{-3}	-	kWh
Onsite coal electricity	9.05×10^{-2}	-	0.183	-	kWh
Natural gas (heat)	2.56	-	-	-	MJ
LPG (heat)	-	-	2.47×10^{-2}	-	MJ
Steam	1.61×10^{-2}	-	0.772	-	kg
Nitrogen	3.43×10^{-3}	-	-	-	kg
DM water	-	-	0.651	-	kg
Emissions to air					
Water from stoichiometry	-	0.191	-	-	kg
Waste treatment					
Waste to recycle	-	1.41×10^{-3}	-	6.81×10^{-4}	kg
Waste, energy recovery	-	-	-	5.96×10^{-4}	kg
Waste, recycle & energy recovery*	-	-	-	5.79×10^{-3}	kg
Wastewater discharge	-	-	-	0.651	kg
Transport					
Truck transport	12.7	-	28.9	-	kg*km
Ship transport	1,141	-	41.4	-	kg*km
Waste transport	0.135	-	0.677	-	kg*km

*Both waste treatment methods were included for the waste. In the LCA models, a 20:80 incineration-to-recycling ratio was applied, informed by literature data (Confidential literature source, 2022).

5.2.2. Partially oriented yarn (black POY)

5.2.2.1 Background

The data provider produces one type of partially oriented yarn (POY), referred to in this report as black POY, manufactured at Facility 2. This black POY has a linear density of 85 denier and consists of 34 individual filaments. The product system is cradle-to-POY, as shown in the top half of Figure 24. Primary data (i.e., data collected from manufacturing facilities) represents production between January and December 2022.

An intermediate white POY is also produced for use in drawn textured yarn (DTY), which is described in section 5.2.3.

5.2.2.2 Manufacturing process

Virgin PET chip is first produced through batch polymerization. MEG, PTA, and a small amount of DEG are chemically reacted to form PET polymer, which is then cooled and granulated into PET chips for POY production.

In the chip-to-POY stage, PET chips are melted, mixed with black masterbatch, and extruded through spinnerets to form continuous filaments. These filaments are cooled and partially drawn to align the polymer chains, producing the final product, black POY.

As with staple fiber production, the process requires electricity, heat, and water. At Facility 2, electricity is sourced from a combination of onsite coal combustion (73%), onsite solar generation (1%), and the local electricity grid (25%). Due to rounding, the percentages do not sum exactly to 100%. The electricity grid mix modeled in the LCA is based on the confidential Southeast Asian manufacturing location and adjusted using 2022 electricity generation data (International Energy Agency, 2024c). The corresponding electricity mix used at Facility 2 is presented in Table 60.

The data provider reported that all solid waste generated during manufacturing is sent to facilities for recycling or waste-to-energy recovery (WTE). For waste streams reported as "recycled and sent to waste-to-energy recovery," a 20:80 incineration-to-recycling ratio was applied in the LCA models. This ratio was informed by confidential literature data (Confidential literature source, 2022) on industrial plastic production waste from the Southeast Asian country where V1 is located, with a conservative adjustment made for modeling. The source is not disclosed to maintain the anonymity of the data provider and the location in which it operates. WTE is modeled as incineration and all of the impacts are allocated to V1. Transport of the wastes to their respective treatment facilities is included. Based on the recycled content method (section 2.5) used in this assessment, the impacts associated with recycling are excluded from the system boundary and are allocated to the subsequent product system.

Input-output data was available for PET chip and POY separately; allocation was not used.

The data provider granted access to its manufacturing data, presented in Table 61.

Table 60: Electricity mix used for black POY production—Facility 2— Southeast Asia

Type of energy	Percentage
On-site electricity—coal	73%
On-site electricity—solar	1%
Grid electricity—coal	5%
Grid electricity—oil	2%
Grid electricity—natural gas	14%
Grid electricity—biofuels	3%
Grid electricity—waste	0%
Grid electricity—nuclear	0%
Grid electricity—hydro	1%
Grid electricity—solar PV	1%
Grid electricity—wind	1%
Grid electricity—other sources	0%

Due to rounding, values may not sum exactly to 100%.

Table 61: Life cycle inventory data for 1 kg POY produced at Facility 2

Flow	Chip		POY		Unit
	Input	Output	Input	Output	
Raw materials					
Purified terephthalic acid	0.907	-	-	-	kg
Monoethylene glycol	0.352	-	-	-	kg
Diethylene glycol	2.20x10 ⁻³	-	-	-	kg
Titanium	1.97x10 ⁻⁴	-	-	-	kg
Titanium dioxide	2.71x10 ⁻³	-	-	-	kg
Lubricating oil	7.95x10 ⁻⁶	-	1.22x10 ⁻⁵	-	kg
Red & blue toners	1.22x10 ⁻⁵	-	-	-	kg
Black masterbatch	-	-	5.99x10 ⁻⁵	-	kg
Spin finish oil	-	-	6.26x10 ⁻³	-	kg
Dowtherm A	-	-	1.80x10 ⁻⁴	-	kg
PET chip (specialty chip)	-	1.06	1.06	-	kg
Black POY	-	-	-	1.00	kg
Facility utilities					
Grid electricity	3.32x10 ⁻²	-	0.368	-	kWh
Onsite solar	1.81x10 ⁻³	-	2.00x10 ⁻²	-	kWh
Onsite coal electricity	9.53x10 ⁻²	-	1.06	-	kWh
Natural gas (heat)	2.69	-	-	-	MJ
LPG (heat)	-	-	1.18x10 ⁻²	-	MJ
Steam	1.69x10 ⁻²	-	0.517	-	kg
Nitrogen	3.61x10 ⁻³	-	3.12x10 ⁻²	-	kg
DM water	2.17x10 ⁻²	-	2.52x10 ⁻²	-	kg
Emissions to air					
Water from stoichiometry	-	0.201	-	-	kg
Nitrogen oxides	-	1.71x10 ⁻⁴	-	-	kg
Sulfur oxides	-	8.32x10 ⁻⁷	-	-	kg
Waste treatment					
Waste to recycle	-	1.49x10 ⁻³	-	-	kg
Waste, recycle & energy recovery*	-	-	-	6.70x10 ⁻²	kg
Wastewater discharge	-	2.17x10 ⁻²	-	2.52x10 ⁻²	kg
Transport					
Truck transport	13.3	-	0.422	-	kg*km
Ship transport	1,201	-	35.4	-	kg*km
Waste transport	0.142	-	6.38	-	kg*km

*Both waste treatment methods were included for the waste. In the LCA models, a 20:80 incineration-to-recycling ratio was applied, informed by literature data (Confidential literature source, 2022).

5.2.3. Drawn textured yarn (white DTY)

5.2.3.1 Background

The data provider produces one type of drawn textured yarn (DTY), referred to in this report as white DTY, manufactured at Facility 2. This white DTY has a linear density of 150 denier and consists of 34 individual filaments. The product system is cradle-to-DTY, as shown in Figure 25. Primary data (i.e., data collected from manufacturing facilities) represents production between January and December 2022.

5.2.3.2 Manufacturing process

First, white PET melt is produced, as described in section 5.2.1. Titanium dioxide is added during the cradle-to-melt stage. The melt is then processed into white POY through extrusion, cooling, and partial drawing, as outlined in section 5.2.2. In the POY-to-DTY stage, the white POY undergoes mechanical drawing and texturing to produce white DTY, which is suitable for direct use in weaving and knitting applications.

As with staple fiber and POY production, the process requires electricity, heat, and water. At Facility 2, electricity is sourced from a combination of onsite coal combustion (73%), onsite solar generation (1%), and the local electricity grid (25%). Due to rounding, the percentages do not sum exactly to 100%. The electricity grid mix modeled in the LCA is based on the (confidential) Southeast Asian manufacturing location and adjusted using 2022 electricity generation data (International Energy Agency, 2024c). The corresponding electricity mix used at the facility is presented in Table 62.

The data provider reported that all solid waste generated during manufacturing is sent to facilities for recycling or waste-to-energy recovery (WTE). For waste streams reported as "recycled and sent to waste-to-energy recovery," a 20:80 incineration-to-recycling ratio was applied in the LCA models. This ratio was informed by (confidential) literature data (Confidential literature source, 2022) on industrial plastic production waste from the Southeast Asian country where V1 is located, with a conservative adjustment made for modeling. The source is not disclosed to maintain the anonymity of the data provider and the location in which they operate. WTE is modeled as incineration, and all of the impacts are allocated to V1. Transport of the wastes to their respective treatment facilities is included. Based on the recycled content method (section 2.5) used in this assessment, the impacts associated with recycling are excluded from the system boundary and are allocated to the subsequent product system.

Input-output data was available for PET melt, POY, and DTY separately; allocation was not used.

The data provider granted access to its manufacturing data, presented in Table 63.

Table 62: Electricity mix used for white DTY production—Facility 2—Southeast Asia

Type of energy	Percentage
On-site electricity—coal	73%
On-site electricity—solar	1%
Grid electricity—coal	5%
Grid electricity—oil	2%
Grid electricity—natural gas	14%
Grid electricity—biofuels	3%
Grid electricity—waste	0%
Grid electricity—nuclear	0%

Type of energy	Percentage
Grid electricity—hydro	1%
Grid electricity—solar PV	1%
Grid electricity—wind	1%
Grid electricity—other sources	0%

Due to rounding, values may not sum exactly to 100%.

Table 63: Life cycle inventory data for 1 kg DTY produced at Facility 2

Flow	Melt		POY		DTY		Unit
	Input	Output	Input	Output	Input	Output	
Raw materials							
Purified terephthalic acid	0.872	-	-	-	-	-	kg
Monoethylene glycol	0.338	-	-	-	-	-	kg
Diethylene glycol	2.13x10 ⁻³	-	-	-	-	-	kg
Titanium	1.92x10 ⁻⁴	-	-	-	-	-	kg
Titanium dioxide	2.66x10 ⁻³	-	-	-	-	-	kg
Red and blue toners	1.31x10 ⁻⁵	-	-	-	-	-	kg
Lubricating oil	7.98x10 ⁻⁶	-	1.25x10 ⁻⁵	-	3.32x10 ⁻⁵	-	kg
Spin finish	-	-	3.67x10 ⁻³	-	1.21x10 ⁻²	-	kg
White PET melt	-	1.02	1.02	-	-	-	
White POY	-	-	-	1.02	1.02	-	
White DTY	-	-	-	-	-	1.00	kg
Facility utilities							
Grid electricity	3.19x10 ⁻²	-	0.155	-	0.368	-	kWh
Onsite solar	1.60x10 ⁻³	-	8.46x10 ⁻³	-	2.00x10 ⁻²	-	kWh
Onsite coal electricity	9.15x10 ⁻²	-	0.446	-	1.06	-	kWh
Natural gas (heat)	2.59	-	-	-	-	-	MJ
LPG (heat)	-	-	9.45x10 ⁻³	-	1.10x10 ⁻²	-	MJ
Steam	1.65x10 ⁻²	-	4.34x10 ⁻²	-	9.02x10 ⁻⁴	-	kg
Nitrogen	3.48x10 ⁻³	-	-	-	-	-	kg
DM water	-	-	2.29x10 ⁻²	-	-	-	kg
Emissions to air							
Water from stoichiometry	-	0.194	-	-	-	-	kg
Nitrogen oxides	-	1.60x10 ⁻⁴	-	-	-	-	kg
Sulfur oxides	-	1.06x10 ⁻⁶	-	-	-	-	kg
Waste treatment							
Waste to recycle	-	1.44x10 ⁻³	-	-	-	-	kg
Waste, recycle & energy recovery*	-	-	-	6.62x10 ⁻³	-	2.68x10 ⁻³	kg
Additional waste & scrap loss*	-	-	-	-	-	2.70x10 ⁻²	kg

Flow	Melt		POY		DTY		Unit
	Input	Output	Input	Output	Input	Output	
Wastewater discharge	-	-	-	2.29x10 ⁻²	-	-	kg
Transport							
Truck transport	12.8	-	0.241	-	6.64x10 ⁻³	-	kg*km
Ship transport	1,155	-	18.1	-	22.3	-	kg*km
Waste transport	0.137	-	0.630	-	2.65	-	kg*km

**Both waste treatment methods were included for the waste. In the LCA models, a 20:80 incineration-to-recycling ratio was applied, informed by literature data (Confidential literature source, 2022).*

5.3. Summary of assumptions

The study relies on several assumptions, which are described below:

- Ecoinvent v3.11 datasets were used to model all life cycle inventory data. While primary data was available for the quantities of inputs and outputs used at each facility, ecoinvent data was used to model the production of those inputs, treatment of wastes, and all transport. Ecoinvent datasets were selected based on temporal, geographic, and technological representativeness. Except where noted, they are considered to be representative of the actual production, waste treatment, and transport processes for which primary data was not available.
- Several chemicals used in virgin PET production were not available in the ecoinvent database and were modeled using proxy datasets, including the spin finish, a surfactant, cleaning agents, a biodegradation-promoting additive, a blue toner, a red toner, and a heat transfer fluid. Instead, proxy chemical datasets were used (see section 5.4.1 for details). These assumptions are not considered a significant limitation as these chemicals are used in very small quantities (each <1% by mass required per kilogram of product), except for the freshwater ecotoxicity impact category, which is discussed in section 5.4.2.
- As noted in the results below, the production of purified terephthalic acid (PTA) and monoethylene glycol (MEG) are major contributors to all impact categories except freshwater ecotoxicity. However, no primary data on their production was available. In addition, it is unknown where these chemicals were ultimately produced. An ecoinvent dataset representing the global average production of PTA and MEG was used, and is assumed to be sufficiently representative of the actual production of these chemicals as no better data was available.
- All truck transport is modeled using the ecoinvent dataset for truck transport using the EURO 4 emission standard for vehicles in the 16–32 metric ton weight class. A discussion of EURO transport standards is provided in section 6.2.
- A distance of 32 km is assumed for the transport of manufacturing waste generated during recycling from the point of generation to a treatment facility. This assumption applies when primary data is not available, and it is based on the US EPA WARM model (Environmental Protection Agency, 2004).
- For waste streams listed as recycled and sent to waste-to-energy recovery, a 20:80 incineration-to-recycling ratio was applied in the LCA models. This ratio was informed by confidential literature data (Confidential literature source, 2022) on industrial plastic production waste from the Southeast Asian country where V1 is located, with a conservative adjustment made for modeling. The source is not disclosed to maintain the anonymity of the data provider and the location in which it operates.

5.4. Life cycle inventory

5.4.1. Data collection and sources

Primary data was collected from one virgin PET producer at two facilities, including all inputs and outputs required to produce the functional unit.

These inputs and outputs were modeled in openLCA v2.4 software, using datasets from the ecoinvent v3.11 database (Ecoinvent, 2024a). Ecoinvent datasets with the greatest degree of technological, geographical, and temporal representativeness were chosen; a data quality assessment is provided in section 5.4.2. Detailed descriptions of these ecoinvent datasets can be found in the accompanying ecoinvent documentation (Ecoinvent, 2024a). The LCI datasets used in the model to represent unit processes in the cradle-to-gate LCA are provided in Table 64 below.

Table 64: LCI datasets from ecoinvent 3.11 (2024)—LCA modeling for virgin production

Note: To protect the confidentiality of the data providers, the geography of the ecoinvent datasets (chosen for the specific area in which the manufacturer operates) has been removed. The word "proxy" has been added to certain datasets and is used to denote an instance when the chosen dataset is similar to or the best match for a process flow when specific data is unavailable or unsuitable, serving as a substitute for the actual data.

Flow	Geography	Dataset
Raw material and chemical inputs		
Monoethylene glycol	Rest-of-World	Market for ethylene glycol ethylene glycol cutoff, U
Purified terephthalic acid	Global	Market for purified terephthalic acid purified terephthalic acid cutoff, U
Diethylene glycol	Rest-of-World	Market for diethylene glycol diethylene glycol cutoff, U
Titanium dioxide	Rest-of-World	Market for titanium dioxide titanium dioxide cutoff, U
Black masterbatch	Global, Rest-of-World	Market for carbon black carbon black cutoff, U Polyethylene terephthalate production, granulate, amorphous polyethylene terephthalate, granulate, amorphous cutoff, U
Antimony	Global	Market for antimony antimony cutoff, U
Titanium	Global	Market for titanium titanium cutoff, U
Spin finish	Global	Market for chemical, organic chemical, organic cutoff, U Market for paraffin paraffin cutoff, U (proxy)
Spin finish	Global	Market for fatty acid fatty acid Cutoff, U (proxy)
Spin finish	Global	Market for fatty alcohol fatty alcohol cutoff, U (proxy)
Spin finish	Global, Rest-of-World	Market for fatty acid methyl ester fatty acid methyl ester cutoff, U Market for lubricating oil lubricating oil cutoff, U Market for non-ionic surfactant non-ionic surfactant Cutoff, U Market for fatty alcohol sulfate fatty alcohol sulfate cutoff, U Market for water, deionized water, deionized cutoff, U Market for methanol methanol cutoff, U Market for diethylene glycol diethylene glycol cutoff, U (proxy)
Spin finish (anti-foaming agent)	Rest-of-World	Market for polydimethylsiloxane polydimethylsiloxane Cutoff, U (proxy)

Flow	Geography	Dataset
Spin finish	Rest-of-World	Market for ethoxylated alcohol (AE7) ethoxylated alcohol (AE7) cutoff, U (proxy)
Silicone spray	Rest-of-World	market for liquefied petroleum gas liquefied petroleum gas cutoff, U Market for polydimethylsiloxane polydimethylsiloxane cutoff, U (proxy)
Surfactant	Global	Market for non-ionic surfactant non-ionic surfactant cutoff, U (proxy)
Dispersing agent (fatty alcohol)	Global	Market for fatty alcohol fatty alcohol cutoff, U (proxy)
Lubricating oil, grease	Rest-of-World	Market for lubricating oil lubricating oil cutoff, U
Cleaning agents	Global	Market for cleaning consumables, without water, in 13.6% solution state cleaning consumables, without water, in 13.6% solution state cutoff, U (proxy)
Biodegradation-promoting additive	Rest-of-World	market for calcium carbonate, precipitated calcium carbonate, precipitated cutoff, U polyethylene terephthalate production, granulate, amorphous polyethylene terephthalate, granulate, amorphous cutoff, U (proxy)
Blue toner	Global, Rest-of-World	Market for chemical, organic chemical, organic cutoff, U Market for titanium dioxide titanium dioxide cutoff, U (proxy)
Red toner	Global, Rest-of-World	Market for chemical, organic chemical, organic cutoff, U Market for titanium dioxide titanium dioxide cutoff, U (proxy)
Heat transfer fluid	Rest-of-World	Market for wood preservative, creosote wood preservative, creosote cutoff, U (proxy)
Heat transfer fluid	Global	Market for diphenylether-compound diphenylether-compound cutoff, U (proxy)
Refrigerant	Global	Market for tetrafluoroethane, R134a tetrafluoroethane, R134a cutoff, U
Sand	Rest-of-World	Market for sand sand cutoff, U
Electricity and utilities		
Grid electricity	Southeast Asia	Market for electricity, medium voltage electricity, medium voltage cutoff, U—custom grid mix for Southeast Asian country (confidential)
Coal electricity	Southeast Asia	Electricity production, hard coal electricity, high voltage cutoff, U—Southeast Asian country (confidential)
Solar electricity	Rest-of-World	Electricity production, photovoltaic, 570kWp open ground installation, multi-Si electricity, low voltage cutoff, U
Natural gas	Rest-of-World	Market for heat, district or industrial, natural gas heat, district or industrial, natural gas cutoff, U
Heavy fuel oil	Rest-of-World	Heat production, heavy fuel oil, at industrial furnace 1 MW heat, district or industrial, other than natural gas cutoff, U
Liquefied petroleum gas	Rest-of-World	Refinery gas, burned in furnace heat, district or industrial, other than natural gas cutoff, U

Flow	Geography	Dataset
Coal	Rest-of-World	Heat production, at hard coal industrial furnace 1-10 MW heat, district or industrial, other than natural gas cutoff, U
Steam	Rest-of-World	Market for steam, in chemical industry steam, in chemical industry cutoff, U
Nitrogen	Rest-of-World	Market for nitrogen, liquid nitrogen, liquid cutoff, U
Water	Rest-of-World	Market for water, deionized water, deionized cutoff, U
Transport		
Truck transport	Rest-of-World	Market for transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 transport, freight, lorry, 16–32 metric ton, diesel, EURO 4 cutoff, U
Ship transport	Global	Market for transport, freight, sea, container ship, heavy fuel oil transport, freight, sea, container ship, heavy fuel oil cutoff, U
Waste treatment		
Wastewater treatment	Rest-of-World	Treatment of wastewater, average, wastewater treatment wastewater, average cutoff, U
Waste-to-energy recovery	Rest-of-World	Treatment of hazardous waste, hazardous waste incineration, with energy recovery hazardous waste, for incineration cutoff, U

5.4.2. Data quality assessment

A data quality assessment, based on the adapted PEF DQR methodology explained in section 2.7, was conducted for all virgin polyester products. This data quality assessment is shown in Table 65, below.

The color gradient is applied to highlight relative variation within the observed range, not to represent fixed rating categories across the full 1–5 DQR range. All data quality ratings fall within 1.8–2.0, and are rated as “very good quality” (section 2.7, Table 16), with the greenest shade assigned to the minimum, and the reddest shade to the maximum.

Table 65: Data quality assessment for virgin product systems

Impact category	SF1	SF2	SF3	POY	DTY
Climate change	1.87	1.87	1.86	1.84	1.82
Acidification	1.88	1.87	1.87	1.84	1.83
Eutrophication	1.88	1.88	1.87	1.86	1.85
Abiotic depletion, fossil fuels	1.88	1.87	1.87	1.85	1.84
Freshwater ecotoxicity	1.94	1.91	1.93	1.92	1.97
Water scarcity	1.88	1.87	1.87	1.86	1.86
Freshwater consumption	1.88	1.87	1.87	1.86	1.86

5.5. Life cycle impact assessment (LCIA) results

The cradle-to-gate life cycle impact results for each product are given below in sections 5.5.1–5.5.3. Each section includes the Higg MSI and EF 3.1 acidification results, along with a process-level contribution analysis; a detailed analysis of these results is explored below. In addition, the results for the EF 3.1 indicators are also included; however, no process-level contribution analysis or detailed analysis of the results was conducted for these indicators. Results are broken out by life cycle stage.

Contribution analysis by process explores how the different inputs and processes involved in each product contribute to each impact category in sections 5.5.1.3, 5.5.2.3, and 5.5.3.3. The contribution to the total impact of the inputs required and treatment of waste generated from each recycling process was assessed and is shown below. A description of the input and any additional processes involved in the production of that input are shown in Table 66, below.

Table 66: Virgin PET production key inputs

Key inputs	Description
PTA & MEG	Production of purified terephthalic acid and monoethylene glycol
Electricity	Electricity used at the facility
Compressed gas	Compressed air and nitrogen used at the facility
Heat	Heat or steam used at the facility
Other chemicals	Production of chemicals and materials (other than PTA and MEG) used at the facility.
Water	Accounts for net water use (the output of treated wastewater released back to the environment subtracted from the water input) in the recycling process of each facility
Transport	Inbound truck and ship transport to the recycling facility and outbound truck transport to waste treatment
Waste treatment	On-site direct emissions and off-site treatment of solid and liquid waste

5.5.1. Staple fiber (SF1, SF2, SF3)

5.5.1.1. Higg MSI and EF 3.1 acidification results

The LCIA results for the three virgin staple fiber products show differences greater than 10% from the average across several impact categories, indicating that the products are sufficiently distinct to be evaluated individually. An unweighted average is also shown in Table 67. For each product, LCIA results are broken down by life cycle stage, and are presented in Table 68–Table 70.

Table 67: Cradle-to-gate LCIA results for 1 kg virgin PET staple fiber products (average, SF1, SF2, SF3)

Impact category	Average	SF1		SF2		SF3	
	Total	Total	% Diff	Total	% Diff	Total	% Diff
Climate change (kg CO ₂ eq)	4.55	4.74	4%	4.93	8%	3.96	-13%
Acidification (mol H ⁺ eq)	2.24x10 ⁻²	2.49x10 ⁻²	11%	2.61x10 ⁻²	17%	1.61x10 ⁻²	-28%
Eutrophication (kg PO ₄ eq)	3.26x10 ⁻²	3.11x10 ⁻²	-4%	3.54x10 ⁻²	9%	3.12x10 ⁻²	-4%
Abiotic depletion, fossil fuels (MJ)	80.7	82.4	2%	83.2	3%	76.3	-5%
Freshwater ecotoxicity (PAF m ³ day)	9.56x10 ⁻²	0.144	50%	0.112	17%	3.08x10 ⁻²	-68%

Impact category	Average	SF1		SF2		SF3	
	Total	Total	% Diff	Total	% Diff	Total	% Diff
Water scarcity (m ³ world eq)	0.841	0.865	3%	0.892	6%	0.765	-9%
Freshwater consumption (m ³)	1.97x10 ⁻²	2.02x10 ⁻²	3%	2.10x10 ⁻²	7%	1.78x10 ⁻²	-9%

Note: "% Diff" indicates the percentage difference of each product's result relative to the average.

Table 68: LCIA results for 1 kg black virgin staple fiber SF1

Impact category	Cradle-to-melt		Melt-to-staple fiber		Total
Climate change (kg CO ₂ eq)	3.41	72%	1.34	28%	4.74
Acidification (mol H ⁺ eq)	1.69x10 ⁻²	68%	8.06x10 ⁻³	32%	2.49x10 ⁻²
Eutrophication (kg PO ₄ eq)	2.74x10 ⁻²	88%	3.75x10 ⁻³	12%	3.11x10 ⁻²
Abiotic depletion, fossil fuels (MJ)	65.1	79%	17.3	21%	82.4
Freshwater ecotoxicity (PAF m ³ day)	6.23x10 ⁻³	4%	0.138	96%	0.144
Water scarcity (m ³ world eq)	0.665	77%	0.200	23%	0.865
Freshwater consumption (m ³)	1.55x10 ⁻²	77%	4.71x10 ⁻³	23%	2.02x10 ⁻²

Table 69: LCIA results for 1 kg white virgin staple fiber SF2

Impact category	Cradle-to-melt		Melt-to-staple fiber		Total
Climate change (kg CO ₂ eq)	3.74	76%	1.19	24%	4.93
Acidification (mol H ⁺ eq)	1.85x10 ⁻²	71%	7.63x10 ⁻³	29%	2.61x10 ⁻²
Eutrophication (kg PO ₄ eq)	3.01x10 ⁻²	85%	5.35x10 ⁻³	15%	3.54x10 ⁻²
Abiotic depletion, fossil fuels (MJ)	71.4	86%	11.8	14%	83.2
Freshwater ecotoxicity (PAF m ³ day)	6.84x10 ⁻³	6%	0.105	94%	0.112
Water scarcity (m ³ world eq)	0.730	82%	0.162	18%	0.892
Freshwater consumption (m ³)	1.70x10 ⁻²	81%	3.96x10 ⁻³	19%	2.10x10 ⁻²

Table 70: LCIA results for white virgin staple fiber SF3

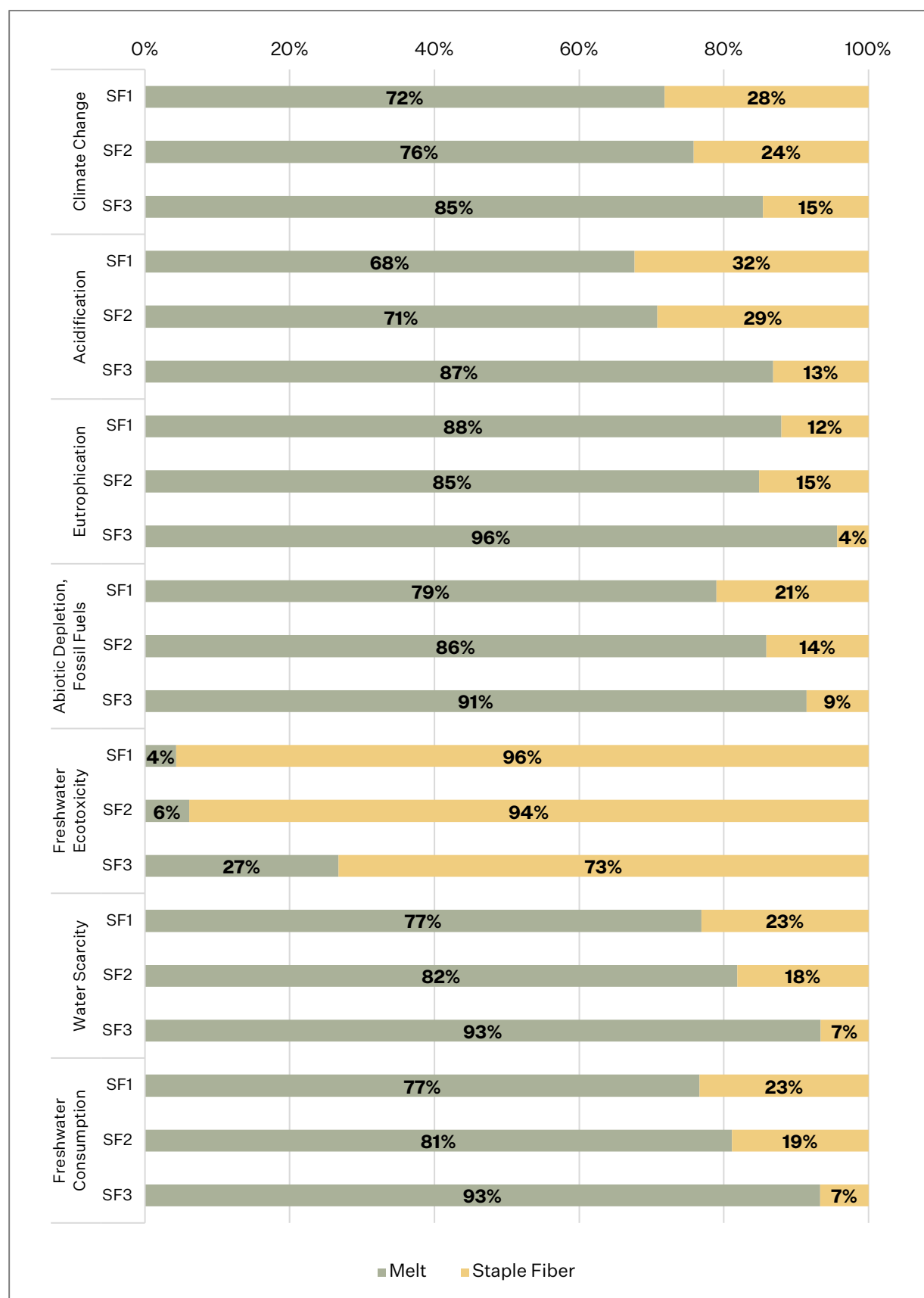
Impact category	Cradle-to-melt		Melt-to-staple fiber		Total
Climate change (kg CO ₂ eq)	3.39	85%	0.577	15%	3.96
Acidification (mol H ⁺ eq)	1.40x10 ⁻²	87%	2.13x10 ⁻³	13%	1.61x10 ⁻²
Eutrophication (kg PO ₄ eq)	2.98x10 ⁻²	96%	1.35x10 ⁻³	4%	3.12x10 ⁻²
Abiotic depletion, fossil fuels (MJ)	69.8	91%	6.56	9%	76.3
Freshwater ecotoxicity (PAF m ³ day)	8.24x10 ⁻³	27%	2.26x10 ⁻²	73%	3.08x10 ⁻²
Water scarcity (m ³ world eq)	0.714	93%	5.07x10 ⁻²	7%	0.765
Freshwater consumption (m ³)	1.66x10 ⁻²	93%	1.20x10 ⁻³	7%	1.78x10 ⁻²

For all three products, the cradle-to-melt stage is the most impactful stage (>68%), except for freshwater ecotoxicity (Figure 26). For climate change, the cradle-to-melt stage accounts for more

than 72% of the total impact for each product (Figure 26). The primary driver is the upstream production of purified terephthalic acid (PTA) and monoethylene glycol (MEG). An exception is freshwater ecotoxicity, which is dominated by the melt-to-staple fiber stage (>73%); this is discussed in more detail in section 5.5.1.3.

Across most impact categories, staple fiber (SF) 3 exhibits the lowest cradle-to-staple fiber impacts compared to SF1 and SF2, except for eutrophication, where the result is about the same as SF1 (total results in Table 68–Table 70). SF3's lower total impacts are driven by much lower melt-to-staple fiber stage impacts. SF3 is produced at a different facility (referred to as Facility 2) than SF1 and SF2 (which are produced at Facility 1). Facility 2 has newer and more efficient operations than Facility 1. Because of this, the total electricity demand for SF3 is lower than for SF1 and SF2. In addition, Facility 2 relies primarily on high-efficiency natural gas combustion to generate heat, while Facility 1 uses less efficient coal combustion. These operational differences are the main reason for the lower impact of SF3.

SF1 and SF2's impacts are generally comparable as they are both produced at Facility 1. SF2 shows slightly higher cradle-to-staple fiber impacts than SF1 across most impact categories, except for freshwater ecotoxicity. The difference arises from the PET melt requirements; PET melt is produced at the end of the first life cycle stage. SF1, a black SF, uses a small amount (84 grams) of black masterbatch as a dye in the melt-to-staple fiber stage. SF1's black masterbatch contains polybutylene terephthalate (PBT), PET, and a black pigment blend. Because data was not available on PBT production, the composition of the pigment blend, or the relative mass shares of PBT, PET, and pigment within the masterbatch, it was modeled as a simplified 50/50 mixture of virgin PET and carbon black. In this approximation, the virgin PET serves as the carrier for the carbon black colorant. So overall, SF1's use of black masterbatch reduces the amount of PET melt required compared to SF2, which drives SF2's slightly higher impacts in climate change, acidification, eutrophication, abiotic depletion of fossil fuels, water scarcity, and freshwater consumption. Freshwater ecotoxicity is higher for SF1, as it uses more surfactant-related spin finish and additives during fiber processing than SF2.

Figure 26: Contribution by life cycle stage—virgin staple fiber SF1–SF3

5.5.1.2. EF 3.1 results**Table 71: EF 3.1 LCIA results for black virgin staple fiber SF1**

Impact category	Cradle-to-melt		Melt-to-staple fiber		Total
Acidification (mol H ⁺ eq)	1.69x10 ⁻²	68%	8.06x10 ⁻³	32%	2.49x10 ⁻²
Climate change (kg CO ₂ eq)	3.41	72%	1.34	28%	4.74
Climate change (biogenic) (kg CO ₂ eq)	2.25x10 ⁻³	58%	1.62x10 ⁻³	42%	3.87x10 ⁻³
Climate change (fossil) (kg CO ₂ eq)	3.40	72%	1.33	28%	4.73
Climate change (land use) (kg CO ₂ eq)	2.24x10 ⁻³	25%	6.69x10 ⁻³	75%	8.93x10 ⁻³
Ecotoxicity freshwater (CTUe)	12.9	72%	4.98	28%	17.9
Ecotoxicity freshwater (inorganics) (CTUe)	12.6	77%	3.86	23%	16.4
Ecotoxicity freshwater (organics) (CTUe)	0.309	22%	1.12	78%	1.43
Eutrophication freshwater (kg P eq)	7.70x10 ⁻⁴	62%	4.76x10 ⁻⁴	38%	1.25x10 ⁻³
Eutrophication marine (kg N eq)	2.77x10 ⁻³	69%	1.22x10 ⁻³	31%	3.99x10 ⁻³
Eutrophication terrestrial (mol N eq)	3.02x10 ⁻²	71%	1.21x10 ⁻²	29%	4.22x10 ⁻²
Human toxicity cancer (CTUh)	6.95x10 ⁻¹⁰	74%	2.46x10 ⁻¹⁰	26%	9.41x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	3.13x10 ⁻¹⁰	77%	9.15x10 ⁻¹¹	23%	4.04x10 ⁻¹⁰
Human toxicity cancer (organics) (CTUh)	3.82x10 ⁻¹⁰	71%	1.54x10 ⁻¹⁰	29%	5.36x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	3.16x10 ⁻⁸	80%	8.02x10 ⁻⁹	20%	3.96x10 ⁻⁸
Human toxicity non-cancer (inorganics) (CTUh)	2.32x10 ⁻⁸	76%	7.32x10 ⁻⁹	24%	3.06x10 ⁻⁸
Human toxicity non-cancer (organics) (CTUh)	8.38x10 ⁻⁹	92%	6.95x10 ⁻¹⁰	8%	9.07x10 ⁻⁹
Ionizing radiation (human health) (kBq U235 eq)	0.120	90%	1.34x10 ⁻²	10%	0.133
Land use (dimensionless (pt))	8.52	70%	3.59	30%	12.1
Ozone depletion (kg CFC11 eq)	1.34x10 ⁻⁵	94%	8.30x10 ⁻⁷	6%	1.42x10 ⁻⁵
Particulate matter (disease incidence)	1.95x10 ⁻⁷	60%	1.29x10 ⁻⁷	40%	3.24x10 ⁻⁷
Photochemical ozone formation (human health) (kg NMVOC eq)	1.44x10 ⁻²	77%	4.35x10 ⁻³	23%	1.87x10 ⁻²
Resource use fossils (MJ (net calorific))	67.8	79%	17.8	21%	85.6
Resource use minerals and metals (kg Sb eq)	2.20x10 ⁻³	100%	2.87x10 ⁻⁶	0%	2.20x10 ⁻³
Water use (m ³ world eq)	0.665	77%	0.200	23%	0.865

Table 72: EF 3.1 LCIA results for white virgin staple fiber SF2

Impact category	Cradle-to-melt		Melt-to-staple fiber		Total
Acidification (mol H ⁺ eq)	1.85x10 ⁻²	71%	7.63x10 ⁻³	29%	2.61x10 ⁻²
Climate change (kg CO ₂ eq)	3.74	76%	1.19	24%	4.93
Climate change (biogenic) (kg CO ₂ eq)	2.47x10 ⁻³	53%	2.21x10 ⁻³	47%	4.67x10 ⁻³
Climate change (fossil) (kg CO ₂ eq)	3.74	76%	1.18	24%	4.92
Climate change (land use) (kg CO ₂ eq)	2.46x10 ⁻³	34%	4.69x10 ⁻³	66%	7.15x10 ⁻³
Ecotoxicity freshwater (CTUe)	14.1	54%	12.1	46%	26.3

Impact category	Cradle-to-melt		Melt-to-staple fiber		Total
Ecotoxicity freshwater (inorganics) (CTUe)	13.8	56%	11.1	44%	24.9
Ecotoxicity freshwater (organics) (CTUe)	0.339	24%	1.05	76%	1.39
Eutrophication freshwater (kg P eq)	8.45×10^{-4}	63%	4.96×10^{-4}	37%	1.34×10^{-3}
Eutrophication marine (kg N eq)	3.04×10^{-3}	73%	1.11×10^{-3}	27%	4.15×10^{-3}
Eutrophication terrestrial (mol N eq)	3.31×10^{-2}	75%	1.10×10^{-2}	25%	4.41×10^{-2}
Human toxicity cancer (CTUh)	7.64×10^{-10}	67%	3.81×10^{-10}	33%	1.15×10^{-9}
Human toxicity cancer (inorganics) (CTUh)	3.44×10^{-10}	81%	8.06×10^{-11}	19%	4.25×10^{-10}
Human toxicity cancer (organics) (CTUh)	4.20×10^{-10}	58%	3.01×10^{-10}	42%	7.21×10^{-10}
Human toxicity non-cancer (CTUh)	3.47×10^{-8}	83%	7.15×10^{-9}	17%	4.18×10^{-8}
Human toxicity non-cancer (inorganics) (CTUh)	2.55×10^{-8}	79%	6.66×10^{-9}	21%	3.22×10^{-8}
Human toxicity non-cancer (organics) (CTUh)	9.19×10^{-9}	95%	4.92×10^{-10}	5%	9.69×10^{-9}
Ionizing radiation (human health) (kBq U235 eq)	0.131	95%	7.61×10^{-3}	5%	0.139
Land use (dimensionless (pt))	9.35	75%	3.11	25%	12.5
Ozone depletion (kg CFC11 eq)	1.47×10^{-5}	78%	4.03×10^{-6}	22%	1.87×10^{-5}
Particulate matter (disease incidence)	2.14×10^{-7}	64%	1.20×10^{-7}	36%	3.34×10^{-7}
Photochemical ozone formation (human health) (kg NMVOC eq)	1.58×10^{-2}	82%	3.40×10^{-3}	18%	1.92×10^{-2}
Resource use fossils (MJ (net calorific))	74.4	86%	12.1	14%	86.5
Resource use minerals and metals (kg Sb eq)	2.41×10^{-3}	100%	1.21×10^{-6}	0%	2.41×10^{-3}
Water use (m ³ world eq)	0.730	82%	0.162	18%	0.893

Table 73: EF 3.1 LCIA results for white virgin staple fiber SF3

Impact category	Cradle-to-melt		Melt-to-staple fiber		Total
Acidification (mol H ⁺ eq)	1.40×10^{-2}	87%	2.13×10^{-3}	13%	1.61×10^{-2}
Climate change (kg CO ₂ eq)	3.39	85%	0.577	15%	3.96
Climate change (biogenic) (kg CO ₂ eq)	2.61×10^{-3}	84%	5.06×10^{-4}	16%	3.11×10^{-3}
Climate change (fossil) (kg CO ₂ eq)	3.38	85%	0.574	15%	3.96
Climate change (land use) (kg CO ₂ eq)	2.47×10^{-3}	52%	2.28×10^{-3}	48%	4.75×10^{-3}
Ecotoxicity freshwater (CTUe)	12.9	89%	1.61	11%	14.5
Ecotoxicity freshwater (inorganics) (CTUe)	12.5	90%	1.45	10%	14.0
Ecotoxicity freshwater (organics) (CTUe)	0.371	69%	0.165	31%	0.536
Eutrophication freshwater (kg P eq)	7.68×10^{-4}	79%	2.05×10^{-4}	21%	9.73×10^{-4}
Eutrophication marine (kg N eq)	2.49×10^{-3}	88%	3.54×10^{-4}	12%	2.84×10^{-3}
Eutrophication terrestrial (mol N eq)	2.62×10^{-2}	89%	3.38×10^{-3}	11%	2.96×10^{-2}
Human toxicity cancer (CTUh)	7.02×10^{-10}	89%	9.03×10^{-11}	11%	7.92×10^{-10}
Human toxicity cancer (inorganics) (CTUh)	2.92×10^{-10}	91%	2.93×10^{-11}	9%	3.21×10^{-10}
Human toxicity cancer (organics) (CTUh)	4.10×10^{-10}	87%	6.10×10^{-11}	13%	4.71×10^{-10}

Impact category	Cradle-to-melt		Melt-to-staple fiber		Total
Human toxicity non-cancer (CTUh)	2.45x10 ⁻⁸	91%	2.39x10 ⁻⁹	9%	2.69x10 ⁻⁸
Human toxicity non-cancer (inorganics) (CTUh)	1.99x10 ⁻⁸	90%	2.26x10 ⁻⁹	10%	2.22x10 ⁻⁸
Human toxicity non-cancer (organics) (CTUh)	4.58x10 ⁻⁹	97%	1.30x10 ⁻¹⁰	3%	4.70x10 ⁻⁹
Ionizing radiation (human health) (kBq U235 eq)	0.129	97%	3.74x10 ⁻³	3%	0.132
Land use (dimensionless (pt))	8.37	90%	0.980	10%	9.35
Ozone depletion (kg CFC11 eq)	1.49x10 ⁻⁵	100%	7.04x10 ⁻⁹	0%	1.49x10 ⁻⁵
Particulate matter (disease incidence)	1.33x10 ⁻⁷	88%	1.83x10 ⁻⁸	12%	1.52x10 ⁻⁷
Photochemical ozone formation (human health) (kg NMVOC eq)	1.42x10 ⁻²	92%	1.27x10 ⁻³	8%	1.55x10 ⁻²
Resource use fossils (MJ (net calorific))	72.8	92%	6.70	8%	79.5
Resource use minerals and metals (kg Sb eq)	2.45x10 ⁻⁵	99%	3.61x10 ⁻⁷	1%	2.49x10 ⁻⁵
Water use (m ³ world eq)	0.714	93%	5.07x10 ⁻²	7%	0.765

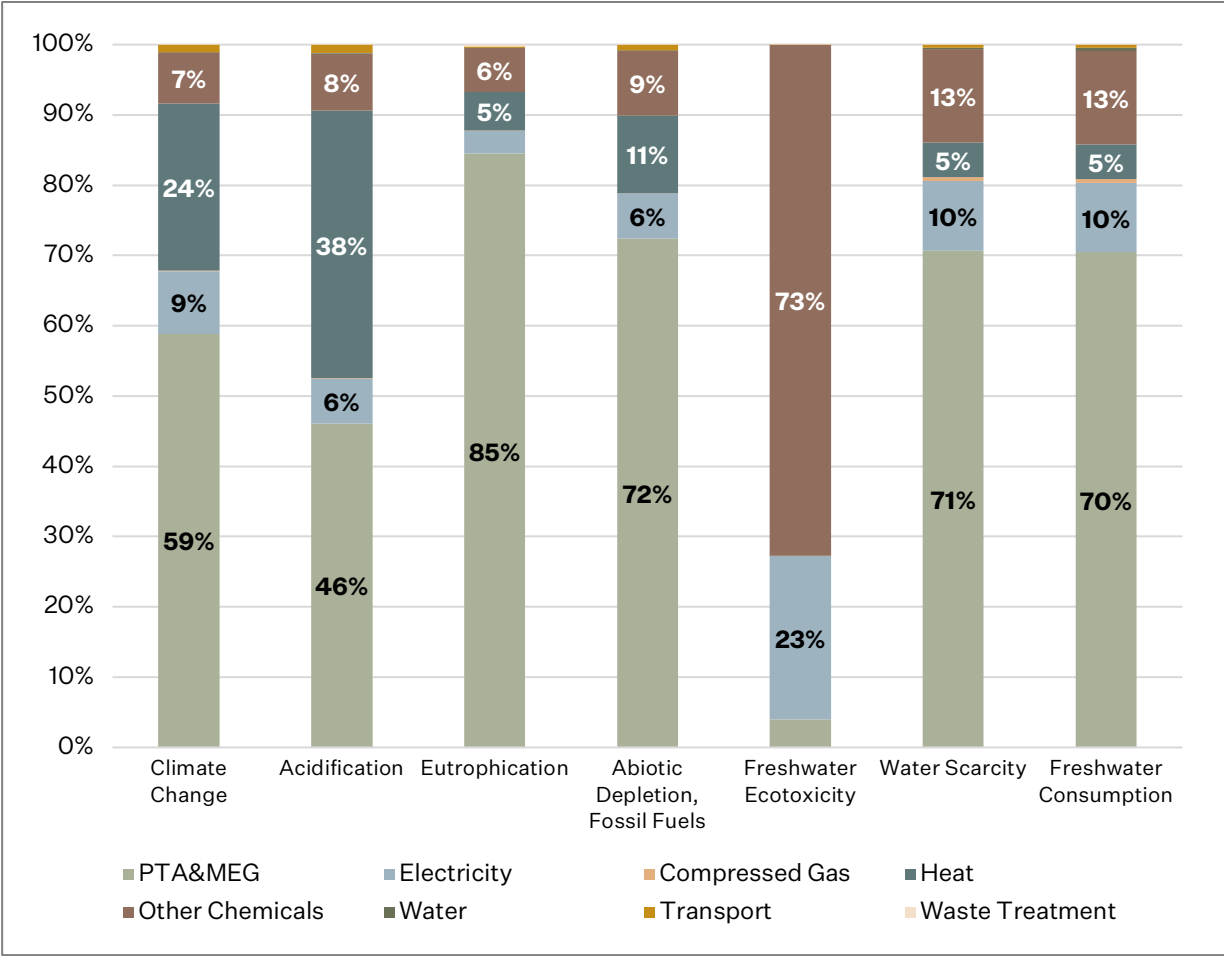
5.5.1.3. Contribution analysis by process

Across all three staple fiber products (SF1, SF2, and SF3), the production and use of PTA and MEG are the dominant contributors across all impact categories (46–94%), except for freshwater ecotoxicity (Figure 27–Figure 29). For climate change, PTA and MEG account for 59% for SF1 (Figure 27), 62% for SF2 (Figure 28), and 78% for SF3 (Figure 29).

For freshwater ecotoxicity, the dominant contributors are surfactant-related chemicals (for example, surfactants, dispersants, chemical precursors) used in the melt-to-staple fiber stage, contributing 73% for SF1 (Figure 27), 61% for SF2 (Figure 28), and 62% for SF3 (Figure 29). As noted in earlier sections, some of these chemicals are modeled through ecoinvent datasets that include inputs derived from agricultural sources, such as coconut and palm, which carry high upstream ecotoxicity impacts due to pesticide and fertilizer use. Electricity use is another major contributor (17–33%, Figure 27–Figure 29), primarily from bagasse-based bioenergy included in the national grid mix where V1 is located. Bagasse, a by-product of sugarcane processing, is modeled using an ecoinvent heat and power cogeneration dataset, which includes upstream sugarcane cultivation. While the ecoinvent electricity dataset is listed as regionally representative of V1's grid mix, most of the freshwater ecotoxicity impact is linked to the sugarcane cultivation practices in India, particularly fertilizer and pesticide emissions, and the use of creosote-treated wood trellises. The lack of region-specific data to model bagasse-based bioenergy is noted as a limitation specific to the freshwater ecotoxicity impact category.

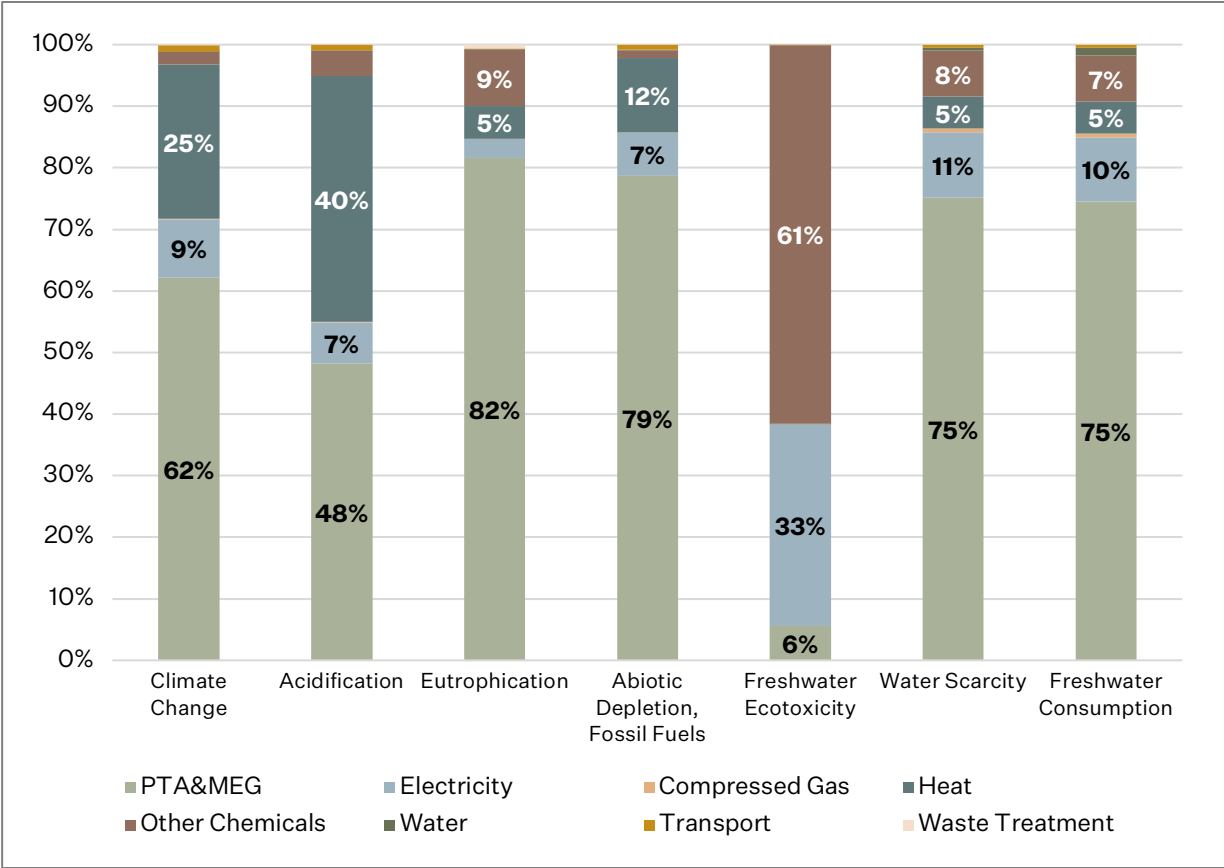
At Facility 1 (Figure 27 for SF1, and Figure 28 for SF2), heat is the second-largest contributor to multiple impact categories, including climate change (24–25%), acidification (38–0%), and abiotic depletion of fossil fuels (11–12%). This is due to the facility's reliance on coal combustion for the majority of its heat supply, supplemented by heavy fuel oil and liquefied petroleum gas.

Figure 27: Process-level contribution—virgin staple fiber SF1



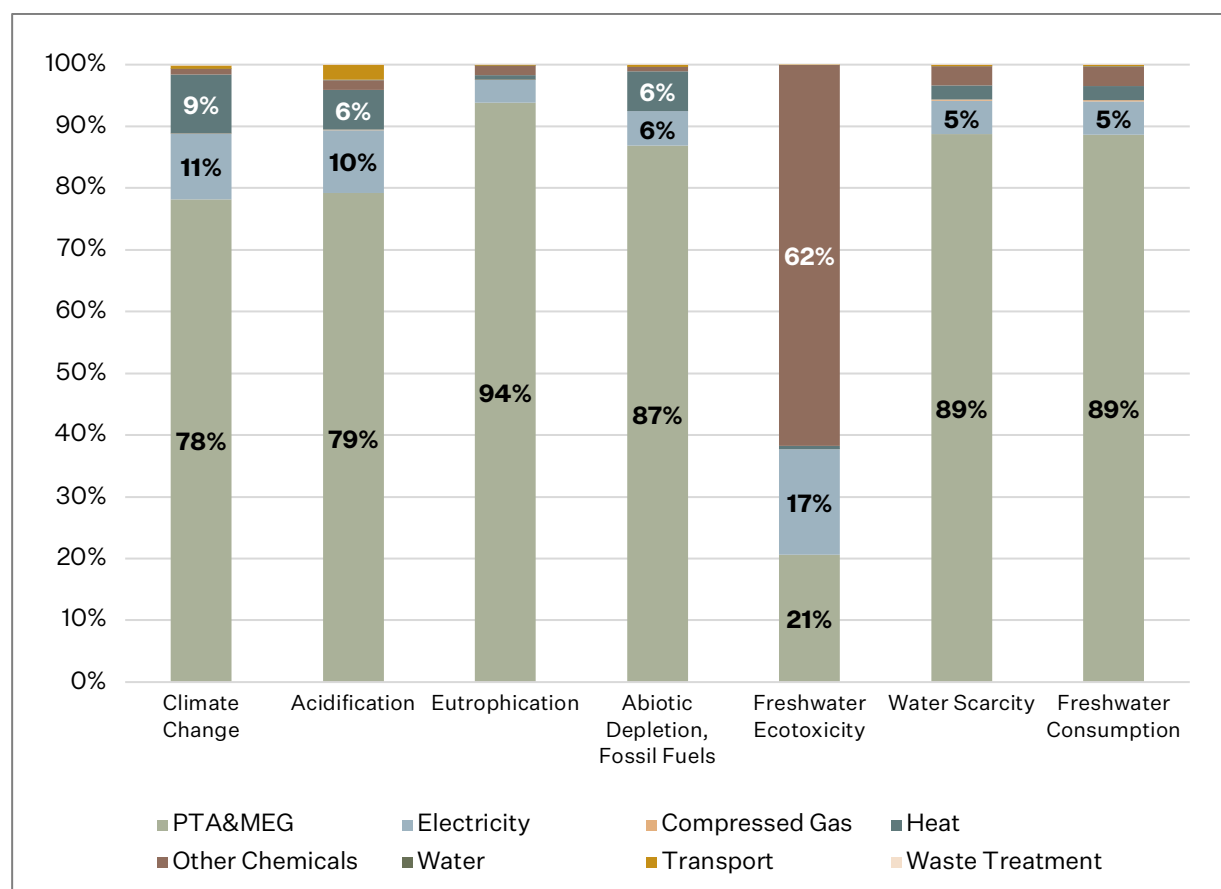
Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

Figure 28: Process-level contribution—virgin staple fiber SF2



Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

At Facility 2 (Figure 29 for SF3), the second-largest contributor to climate change, acidification, and abiotic depletion of fossil fuels is electricity (6–11%). This facility operates with a mixed electricity supply, including onsite coal-fired generation (73%), solar energy (1%), and the local electricity grid (25%) (Table 56). Heat ranks third in these categories (6–9%).

Figure 29: Process-level contribution—virgin staple fiber SF3

Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

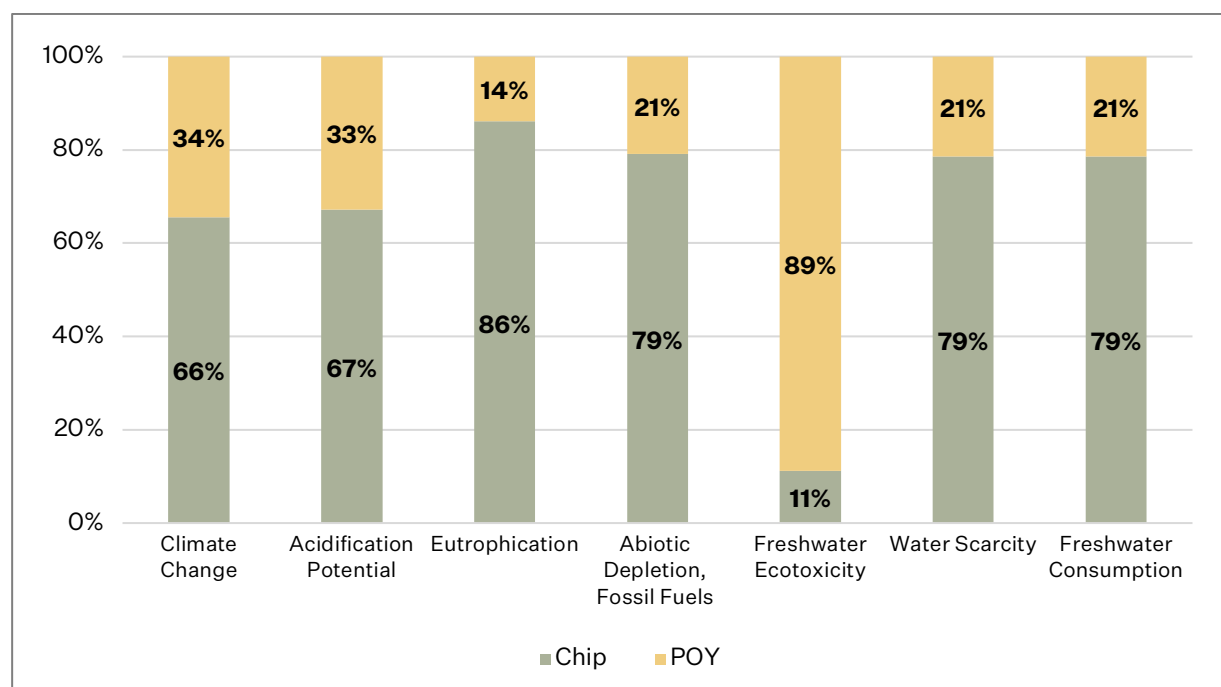
5.5.2. Partially oriented yarn (black POY)

5.5.2.1. Higg MSI and EF 3.1 acidification results

Similar to virgin staple fiber, the LCIA results for black POY are largely driven by the cradle-to-chip stage, which contributes >66% of the impact for all impact categories, except freshwater ecotoxicity, which is dominated by the chip-to-POY stage (89%) (Table 74, Figure 30). The processes driving these results are discussed in more detail in section 5.5.2.2.

Table 74: LCIA results for black virgin POY

Impact category	Cradle-to-chip		Chip-to-POY		Total
Climate change (kg CO ₂ eq)	3.56	66%	1.87	34%	5.44
Acidification (mol H ⁺ eq)	1.49x10 ⁻²	67%	7.27x10 ⁻³	33%	2.21x10 ⁻²
Eutrophication (kg PO ₄ eq)	3.14x10 ⁻²	86%	5.08x10 ⁻³	14%	3.65x10 ⁻²
Abiotic depletion, fossil fuels (MJ)	73.4	79%	19.4	21%	92.8
Freshwater ecotoxicity (PAF m ³ day)	8.67x10 ⁻³	11%	6.93x10 ⁻²	89%	7.79x10 ⁻²
Water scarcity (m ³ world eq)	0.752	79%	0.204	21%	0.956
Freshwater consumption (m ³)	1.75x10 ⁻²	79%	4.76x10 ⁻³	21%	2.23x10 ⁻²

Figure 30: Contribution by life cycle stage—black virgin POY**5.5.2.2. EF 3.1 results****Table 75: EF 3.1 LCIA results for black virgin POY**

Impact category	Cradle-to-chip		Chip-to-POY		Total
Acidification (mol H+ eq)	1.49x10 ⁻²	67%	7.27x10 ⁻³	33%	2.21x10 ⁻²
Climate change (kg CO ₂ eq)	3.56	66%	1.87	34%	5.44
Climate change (biogenic) (kg CO ₂ eq)	2.75x10 ⁻³	55%	2.27x10 ⁻³	45%	5.01x10 ⁻³
Climate change (fossil) (kg CO ₂ eq)	3.56	66%	1.87	34%	5.42
Climate change (land use) (kg CO ₂ eq)	2.60x10 ⁻³	34%	5.12x10 ⁻³	66%	7.72x10 ⁻³
Ecotoxicity freshwater (CTUe)	13.6	66%	7.12	34%	20.7
Ecotoxicity freshwater (inorganics) (CTUe)	13.2	67%	6.37	33%	19.6
Ecotoxicity freshwater (organics) (CTUe)	0.390	34%	0.749	66%	1.14
Eutrophication freshwater (kg P eq)	8.08x10 ⁻⁴	44%	1.02x10 ⁻³	56%	1.83x10 ⁻³
Eutrophication marine (kg N eq)	2.68x10 ⁻³	68%	1.24x10 ⁻³	32%	3.92x10 ⁻³
Eutrophication terrestrial (mol N eq)	2.83x10 ⁻²	72%	1.12x10 ⁻²	28%	3.96x10 ⁻²
Human toxicity cancer (CTUh)	7.38x10 ⁻¹⁰	75%	2.50x10 ⁻¹⁰	25%	9.89x10 ⁻¹⁰
Human toxicity cancer (inorganics) (CTUh)	3.07x10 ⁻¹⁰	72%	1.22x10 ⁻¹⁰	28%	4.29x10 ⁻¹⁰
Human toxicity cancer (organics) (CTUh)	4.31x10 ⁻¹⁰	77%	1.29x10 ⁻¹⁰	23%	5.60x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	2.57x10 ⁻⁸	74%	9.01x10 ⁻⁹	26%	3.48x10 ⁻⁸
Human toxicity non-cancer (inorganics) (CTUh)	2.09x10 ⁻⁸	71%	8.56x10 ⁻⁹	29%	2.95x10 ⁻⁸
Human toxicity non-cancer (organics) (CTUh)	4.81x10 ⁻⁹	91%	4.50x10 ⁻¹⁰	9%	5.26x10 ⁻⁹
Ionizing radiation (human health) (kBq U235 eq)	0.135	94%	9.30x10 ⁻³	6%	0.145
Land use (dimensionless (pt))	8.81	70%	3.71	30%	12.5

Impact category	Cradle-to-chip		Chip-to-POY		Total
Ozone depletion (kg CFC11 eq)	1.57x10 ⁻⁵	100%	1.23x10 ⁻⁸	0%	1.57x10 ⁻⁵
Particulate matter (disease incidence)	1.41x10 ⁻⁷	79%	3.81x10 ⁻⁸	21%	1.79x10 ⁻⁷
Photochemical ozone formation (human health) (kg NMVOC eq)	1.51x10 ⁻²	81%	3.47x10 ⁻³	19%	1.86x10 ⁻²
Resource use fossils (MJ (net calorific))	76.6	80%	19.6	20%	96.2
Resource use minerals and metals (kg Sb eq)	2.58x10 ⁻⁵	96%	1.21x10 ⁻⁶	4%	2.70x10 ⁻⁵
Water use (m ³ world eq)	0.752	79%	0.204	21%	0.956

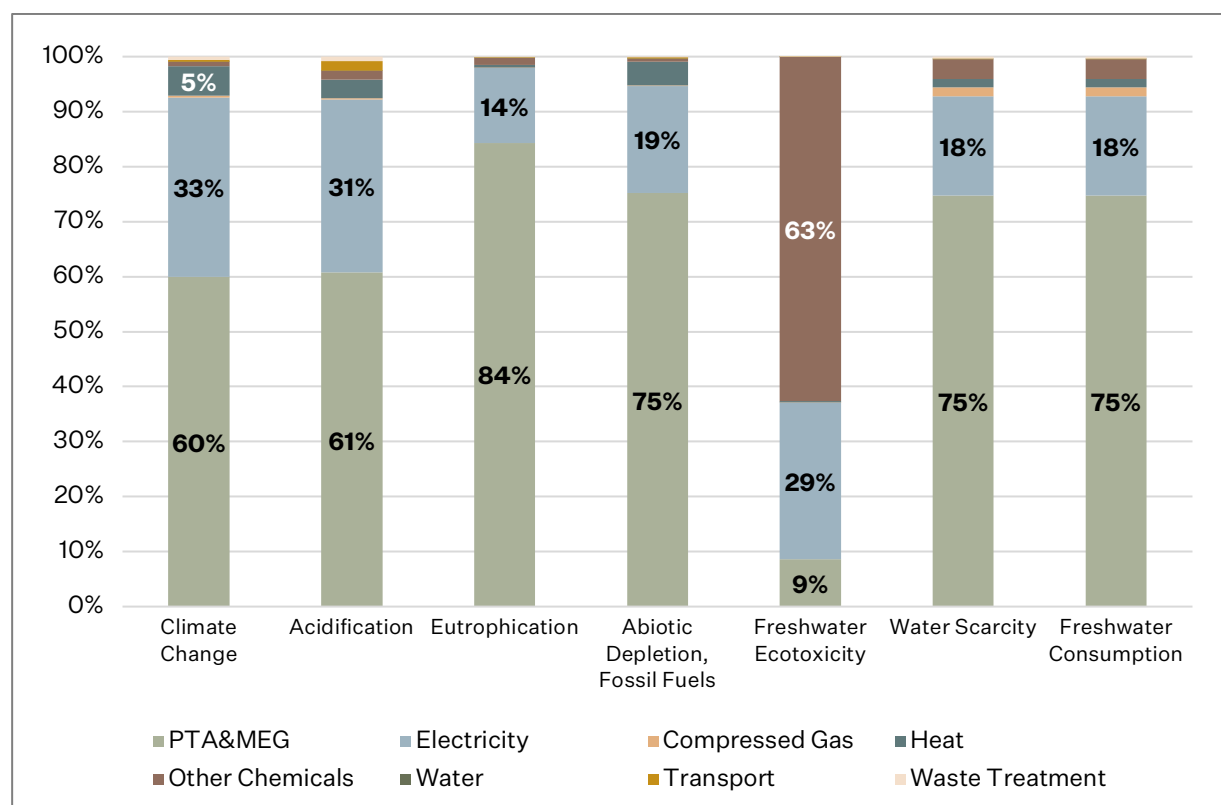
5.5.2.3. Contribution analysis by process

The black POY is produced at the same site as SF3, Facility 2. The LCIA results are primarily driven by PTA and MEG (60–84%) across most impact categories—except freshwater ecotoxicity (Figure 31). These two inputs account for 60% in climate change, 61% in acidification, 84% in eutrophication, 75% in abiotic depletion of fossil fuels, 75% in water scarcity, and 75% in freshwater consumption impacts.

Electricity is the second-largest contributor across these impact categories (14–33%, Figure 31). Facility 2 uses a substantial amount of onsite coal-fired power (73% of electricity used), supplemented by the local electricity grid (25%) and a small portion from onsite solar generation (1%) (Table 60); due to rounding, percentages do not total 100%.

Freshwater ecotoxicity shows a different pattern. The dominant contributor is the spin finish chemical (63%, Figure 31) which contains surfactant-related components. As noted earlier, some of these surfactant-related chemicals are modeled throughecoinvent datasets that include plant-based sources, such as coconut and palm, which carry high upstream ecotoxicity impacts due to pesticide and fertilizer use. Electricity is the next-largest contributor (29%, Figure 31) largely due to the bagasse-based bioenergy included in the regional grid mix. As detailed in sections 4.5.3.3 and 5.5.1.3, there is uncertainty in the upstream agricultural processes related to the bagasse bioenergy, and this is noted as a limitation.

Overall, PTA and MEG production, along with electricity use, are the main hotspots. For freshwater ecotoxicity, the surfactant-related spin finish is the key driver.

Figure 31: Process-level contribution—black virgin POY

Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

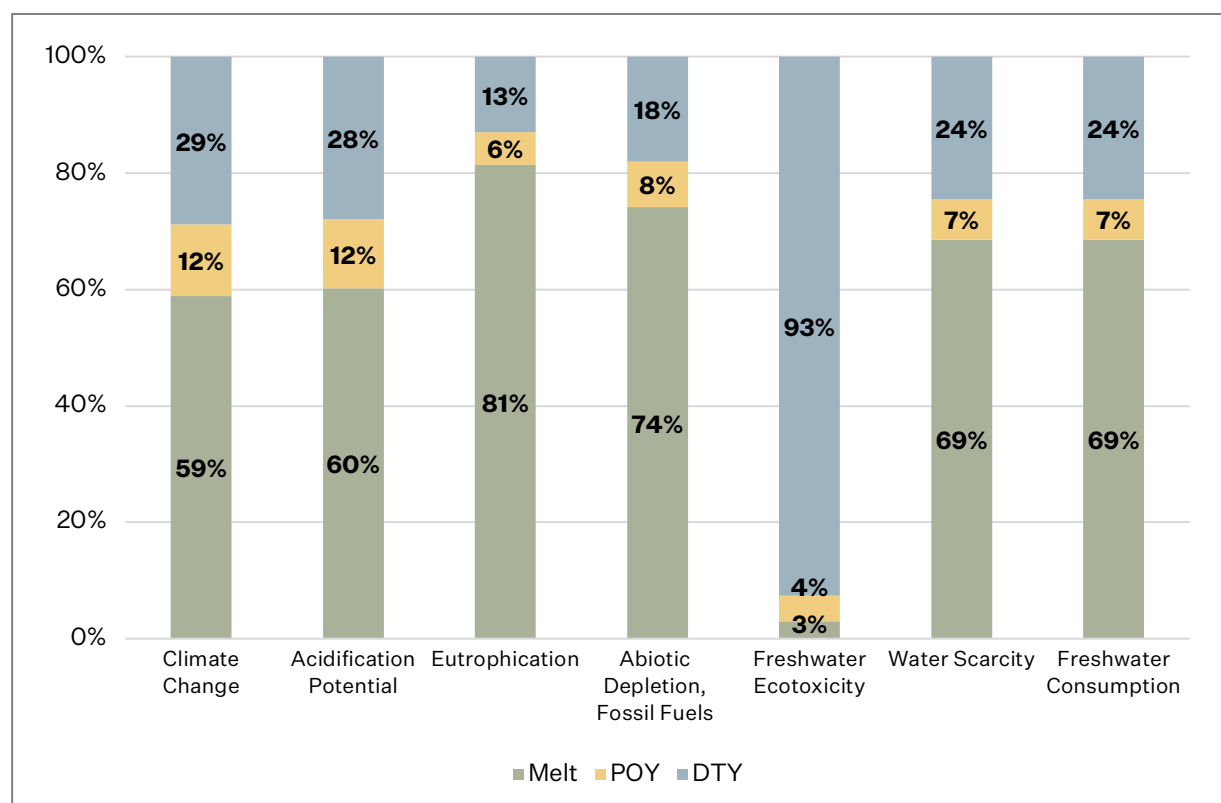
5.5.3. Drawn textured yarn (white DTY)

5.5.3.1. Higg MSI and EF 3.1 acidification results

The LCIA results for white DTY are divided into three life cycle stages: cradle-to-melt, melt-to-POY, and POY-to-DTY. The results are largely driven by the cradle-to-melt stage, responsible for over 59% to all impact categories except freshwater ecotoxicity (Table 76, Figure 32). For freshwater ecotoxicity, the POY-to-DTY stage contributes the majority of impact (93%). This is discussed in more detail in section 5.5.3.3.

Table 76: LCIA results for white virgin DTY

Impact category	Cradle-to-melt		Melt-to-POY		POY-to-DTY		Total
Climate change (kg CO ₂ eq)	3.43	59%	0.719	12%	1.68	29%	5.83
Acidification (mol H ⁺ eq)	1.43x10 ⁻²	60%	2.81x10 ⁻³	12%	6.63x10 ⁻³	28%	2.37x10 ⁻²
Eutrophication (kg PO ₄ eq)	3.02x10 ⁻²	81%	2.07x10 ⁻³	6%	4.83x10 ⁻³	13%	3.71x10 ⁻²
Abiotic depletion, fossil fuels (MJ)	70.6	74%	7.47	8%	17.2	18%	95.3
Freshwater ecotoxicity (PAF m ³ day)	8.35x10 ⁻³	3%	1.22x10 ⁻²	4%	0.256	93%	0.277
Water scarcity (m ³ world eq)	0.723	69%	7.37x10 ⁻²	7%	0.259	24%	1.06
Freshwater consumption (m ³)	1.68x10 ⁻²	69%	1.72x10 ⁻³	7%	6.02x10 ⁻³	24%	2.46x10 ⁻²

Figure 32: Contribution by life cycle stage for white virgin DTY

5.5.3.2. EF 3.1 results

Table 77: EF 3.1 LCIA results for white virgin DTY

Impact category	Cradle-to-melt		Melt-to-POY		POY-to-DTY		Total
Acidification (mol H ⁺ eq)	1.43x10 ⁻²	60%	2.81x10 ⁻³	12%	6.63x10 ⁻³	28%	2.37x10 ⁻²
Climate change (kg CO ₂ eq)	3.43	59%	0.719	12%	1.68	29%	5.83
Climate change (biogenic) (kg CO ₂ eq)	2.64x10 ⁻³	44%	9.44x10 ⁻⁴	16%	2.35x10 ⁻³	40%	5.93x10 ⁻³
Climate change (fossil) (kg CO ₂ eq)	3.42	59%	0.717	12%	1.67	29%	5.81
Climate change (land use) (kg CO ₂ eq)	2.50x10 ⁻³	17%	6.86x10 ⁻⁴	5%	1.14x10 ⁻²	78%	1.46x10 ⁻²
Ecotoxicity freshwater (CTUe)	13.1	58%	2.68	12%	6.92	31%	22.7
Ecotoxicity freshwater (inorganics) (CTUe)	12.7	60%	2.47	12%	5.89	28%	21.0
Ecotoxicity freshwater (organics) (CTUe)	0.376	23%	0.216	13%	1.03	63%	1.62
Eutrophication freshwater (kg P eq)	7.77x10 ⁻⁴	35%	4.22x10 ⁻⁴	19%	9.96x10 ⁻⁴	45%	2.20x10 ⁻³
Eutrophication marine (kg N eq)	2.58x10 ⁻³	61%	4.56x10 ⁻⁴	11%	1.19x10 ⁻³	28%	4.23x10 ⁻³
Eutrophication terrestrial (mol N eq)	2.73x10 ⁻²	65%	4.23x10 ⁻³	10%	1.03x10 ⁻²	25%	4.18x10 ⁻²
Human toxicity cancer (CTUh)	7.11x10 ⁻¹⁰	70%	7.86x10 ⁻¹¹	8%	2.22x10 ⁻¹⁰	22%	1.01x10 ⁻⁹
Human toxicity cancer (inorganics) (CTUh)	2.95x10 ⁻¹⁰	66%	4.45x10 ⁻¹¹	10%	1.08x10 ⁻¹⁰	24%	4.48x10 ⁻¹⁰
Human toxicity cancer (organics) (CTUh)	4.15x10 ⁻¹⁰	74%	3.41x10 ⁻¹¹	6%	1.14x10 ⁻¹⁰	20%	5.63x10 ⁻¹⁰
Human toxicity non-cancer (CTUh)	2.48x10 ⁻⁸	67%	3.57x10 ⁻⁹	10%	8.46x10 ⁻⁹	23%	3.68x10 ⁻⁸
Human toxicity non-cancer (inorganics) (CTUh)	2.01x10 ⁻⁸	64%	3.40x10 ⁻⁹	11%	8.05x10 ⁻⁹	25%	3.16x10 ⁻⁸

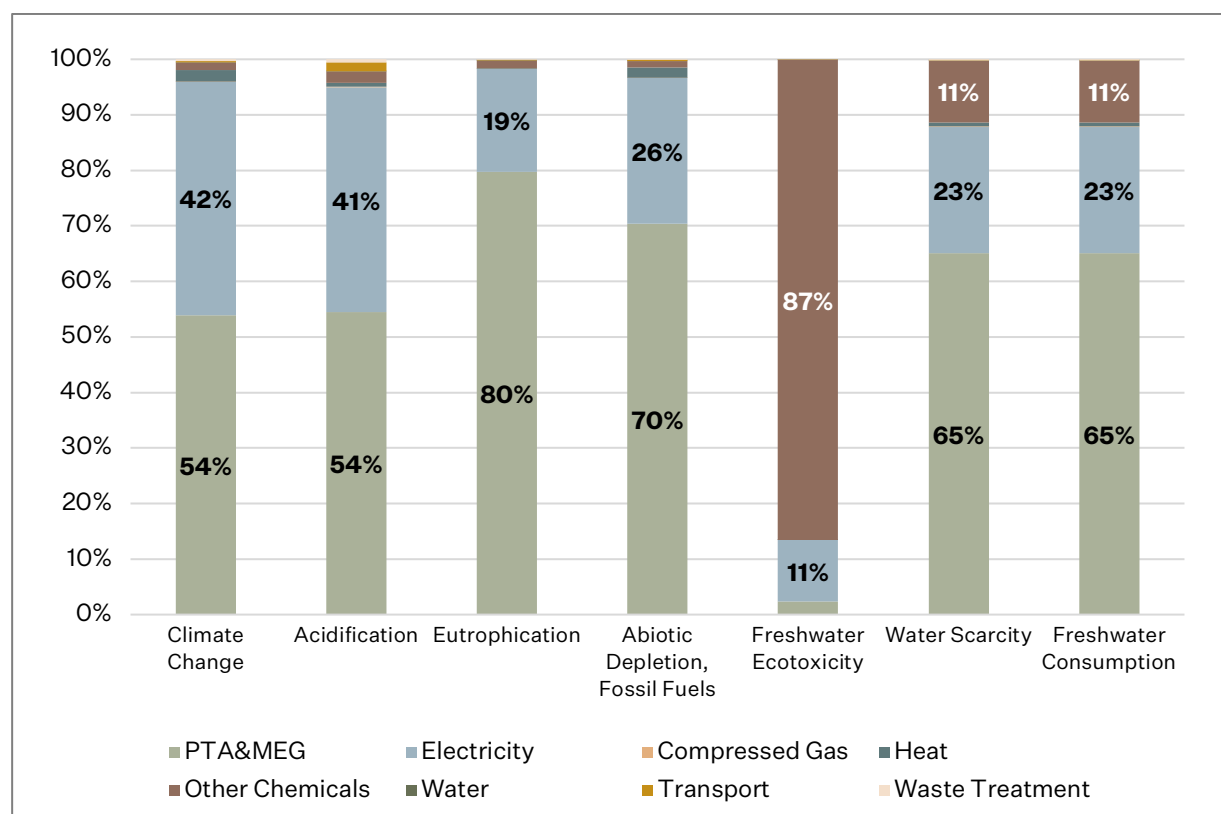
Impact category	Cradle-to-melt		Melt-to-POY		POY-to-DTY		Total
Human toxicity non-cancer (organics) (CTUh)	4.63x10 ⁻⁹	89%	1.69x10 ⁻¹⁰	3%	4.08x10 ⁻¹⁰	8%	5.21x10 ⁻⁹
Ionizing radiation (human health) (kBq U235 eq)	0.130	93%	2.92x10 ⁻³	2%	6.54x10 ⁻³	5%	0.140
Land use (dimensionless (pt))	8.48	60%	1.29	9%	4.27	30%	14.0
Ozone depletion (kg CFC11 eq)	1.51x10 ⁻⁵	100%	4.09x10 ⁻⁹	0%	9.38x10 ⁻⁹	0%	1.51x10 ⁻⁵
Particulate matter (disease incidence)	1.35x10 ⁻⁷	75%	1.30x10 ⁻⁸	7%	3.09x10 ⁻⁸	17%	1.79x10 ⁻⁷
Photochemical ozone formation (human health) (kg NMVOC eq)	1.45x10 ⁻²	77%	1.29x10 ⁻³	7%	3.00x10 ⁻³	16%	1.88x10 ⁻²
Resource use fossils (MJ (net calorific))	73.7	75%	7.53	8%	17.3	18%	98.6
Resource use minerals and metals (kg Sb eq)	2.48x10 ⁻⁵	93%	5.13x10 ⁻⁷	2%	1.24x10 ⁻⁶	5%	2.66x10 ⁻⁵
Water use (m ³ world eq)	0.723	69%	7.37x10 ⁻²	7%	0.259	24%	1.06

5.5.3.3. Contribution analysis by process

Similar to the other virgin PET products manufactured at Facility 2, the impacts from white DTY are largely driven by the production of PTA and MEG for all impact categories, except for freshwater ecotoxicity (Figure 33). PTA and MEG account for 54% of climate change, 54% of acidification, 80% of eutrophication, 70% of abiotic resource depletion, 65% of water scarcity, and 65% freshwater consumption. Electricity is the second-largest contributor across these categories, ranging from 19–42% (Figure 33). It is particularly high for climate change (42%), acidification (41%), abiotic depletion (26%), and water consumption-related impacts (23%). These impacts are related to Facility 2's large use of onsite coal-fired power (73% of total electricity use), with smaller inputs from the local grid (25%) and onsite solar (1%); due to rounding, percentages do not total 100%.

For freshwater ecotoxicity, the dominant contributor is surfactant-related spin finish agents, which accounts for 87% of the total impact. As noted earlier, some of these surfactant-related chemicals are modeled throughecoinvent datasets that include inputs derived from agricultural sources, such as coconut and palm, which carry high upstream ecotoxicity impacts due to pesticide and fertilizer use. Electricity is the next-largest contributor (11%, Figure 33), largely due to the bagasse-based bioenergy included in the regional grid mix. As detailed in previous sections (sections 4.5.3.3, 5.5.1.3, 5.5.2.3), there is uncertainty in the upstream agricultural processes related to the bagasse bioenergy, and this is noted as a limitation.

Overall, PTA and MEG production, along with electricity use, are the main hotspots in DTY production. For freshwater ecotoxicity, the surfactant-related spin finish is the key driver.

Figure 33: Process-level contribution—white virgin DTY

Note: For processes contributing less than 5% to the total impact, individual percentages are not displayed in the graph.

5.6. Key takeaways

The most important observations relevant to the production and impact of virgin PET products are summarized below:

- As far as the authors are aware, this dataset represents the first publicly available virgin PET chip, melt, and SF production from Southeast Asia. Given that Asia produces over half of the world's virgin PET, this dataset helps to fill an important data gap (Coherent Market Insights, 2025; Research and Markets, 2023; Intel Market Research, 2025).
- The production of chemicals used in the polymerization process, primarily purified terephthalic acid (PTA) and monoethylene glycol (MEG), is the dominant contributor (46–94%) to all impact categories, except freshwater ecotoxicity, for all five virgin PET products (SF1, SF2, SF3, black POY, white DTY).
- Energy use (electricity and heat) is another major contributor across most impact categories.
- Freshwater ecotoxicity is driven by the use of non-polymerization-related chemicals, such as surfactant-related spin finish.

6. Sensitivity Analyses

Sensitivity analyses explore how responsive LCA results are to changes to the parameters within an LCA model. Given that recycling technologies can be deployed in any part of the world, three sensitivity analyses were conducted to better understand variations in the electricity grid mix, transport logistics to collect PET waste, and how the technology and location of the production of key chemicals affect the results. Due to limited space, abbreviations are used for impact categories in the sensitivity analysis results tables: climate change (CC), acidification (AP), eutrophication (EP), abiotic depletion of fossil fuels (AD), freshwater ecotoxicity (FE), water scarcity (WS), and freshwater consumption (FC). Full impact category names and units are provided in Table 78, below.

Table 78: Abbreviations used for impact categories

Impact category	Abbreviation
Climate change (kg CO ₂ eq)	CC
Acidification (mol H ⁺ eq)	AP
Eutrophication (kg PO ₄ eq)	EP
Abiotic depletion, fossil fuels (MJ)	AD
Freshwater ecotoxicity (PAF m ³ day)	FE
Water scarcity (m ³ world eq)	WS
Freshwater consumption (m ³)	FC

6.1. Electricity scenarios

While primary data was available for the sources of electricity used by each data provider, the different production technologies included in this study can be used in any location around the world. Different regions of the world utilize different sources of electricity, some with much higher and lower environmental impacts than others. Therefore, a sensitivity analysis was conducted to explore how the overall results change with differing sources of electricity.

Two electricity scenarios were modeled: 100% coal electricity and 100% renewable electricity (with a 50-50 split of wind and solar energy), in addition to the baseline electricity mixes that are currently used by each data provider in this study (Table 79–Table 83). The baseline scenarios refer to the electricity mixes currently used by data providers at their manufacturing facilities. The two additional scenarios were chosen to represent the minimum and maximum range of environmental impacts possible due to the use of electricity. While optimistic, a 100% renewable electricity scenario was chosen as it showcases the growing ambition in several industries and groups like RE100 (RE100, 2025) towards using 100% renewable electricity.

Electricity generated by burning coal is widely considered one of the most environmentally harmful sources of energy, and certainly the most impactful from a climate change perspective (United Nations Economic Commission for Europe, 2021). Coal power is still used by 108 countries (Global Energy Monitor, 2025), including all the countries in which these data providers are located. Conversely, electricity generated using renewable wind and solar is considered among the cleanest sources of electricity (United Nations Economic Commission for Europe, 2021) and is increasing in use across the world, especially in Asia (International Renewable Energy Agency, 2025). The outcomes from this analysis can help determine to what level changing the electricity mix will affect the results. The results for each technology type are shown in sections 6.1.1–6.1.3.

These scenarios were applied to the foreground inventory, specifically the electricity used by the recycling and virgin production facilities, for which primary data was collected. These scenarios do not include any changes in background datasets.

Table 79: Baseline electricity mixes for the Chinese data providers (C1, C2, M2)

Type of energy	C1	C2	M2
On-site electricity—solar	3%	3%	3%
Grid electricity—coal	60%	60%	60%
Grid electricity—oil	0%	0%	0%
Grid electricity—natural gas	3%	3%	3%
Grid electricity—biofuels	2%	2%	2%
Grid electricity—waste	0%	0%	0%
Grid electricity—nuclear	5%	5%	5%
Grid electricity—hydro	15%	15%	15%
Grid electricity—solar PV	5%	5%	5%
Grid electricity—wind	9%	9%	9%
Grid electricity—other sources	0%	0%	0%

The baseline grid mix was adjusted based on IEA (International Energy Agency, 2024a). Due to rounding, values may not sum exactly to 100%.

Table 80: Baseline grid mix for the European data provider (C3)

Type of energy	C3
Grid electricity—coal	11%
Grid electricity—oil	1%
Grid electricity—natural gas	31%
Grid electricity—biofuels	5%
Grid electricity—waste	2%
Grid electricity—nuclear	2%
Grid electricity—hydro	0%
Grid electricity—solar PV	11%
Grid electricity—wind	14%
Grid electricity—other sources	1%
Grid electricity—imported	20%

The baseline grid mix was adjusted based on IEA (International Energy Agency, 2024b). Due to rounding, values may not sum exactly to 100%.

Table 81: Baseline grid mix for the United States data provider (M1)

Type of energy	M1
Grid electricity—coal	11%
Grid electricity—oil	0%
Grid electricity—natural gas	39%

Type of energy	M1
Grid electricity — biofuels	2%
Grid electricity — waste	0%
Grid electricity — nuclear	40%
Grid electricity — hydro	2%
Grid electricity — solar PV	6%
Grid electricity — wind	0%
Grid electricity — other sources	0%

The baseline grid mix was adjusted based on US EPA (Environmental Protection Agency, 2025a). Due to rounding, values may not sum exactly to 100%.

Table 82: Baseline electricity mixes for the Southeast Asian data provider (M3)

Type of energy	M3—chip	M3—staple fiber
On-site electricity—solar	8%	27%
Grid electricity—coal	18%	15%
Grid electricity—oil	5%	4%
Grid electricity—natural gas	51%	41%
Grid electricity—biofuels	9%	7%
Grid electricity—waste	0%	0%
Grid electricity—nuclear	0%	0%
Grid electricity—hydro	4%	3%
Grid electricity—solar PV	3%	2%
Grid electricity—wind	2%	1%
Grid electricity - Other sources	0%	0%

The baseline grid mix was adjusted based on IEA data (International Energy Agency, 2024c). Due to rounding, values may not sum exactly to 100%.

Table 83: Baseline electricity mixes for the Southeast Asian data provider (V1)

Type of energy	V1—Facility 1 (SF1, SF2)	V1—Facility 2 (SF3, POY, DTY)
On-site electricity—coal	0%	73%
On-site electricity—solar	9%	1%
Grid electricity—coal	18%	5%
Grid electricity—oil	5%	2%
Grid electricity—natural gas	51%	14%
Grid electricity—biofuels	9%	3%
Grid electricity—waste	0%	0%
Grid electricity—nuclear	0%	0%
Grid electricity—hydro	4%	1%
Grid electricity—solar PV	3%	1%
Grid electricity — wind	2%	1%

Type of energy	V1—Facility 1 (SF1, SF2)	V1—Facility 2 (SF3, POY, DTY)
Grid electricity—other sources	0%	0%

The baseline grid mix was adjusted based on IEA data (International Energy Agency, 2024c). Due to rounding, values may not sum exactly to 100%.

6.1.1. Chemical recycling electricity analysis

Using renewable electricity reduces impacts across all data providers for climate change, acidification, eutrophication, and abiotic depletion of fossil fuels (Figure 34–Figure 37). In contrast, coal electricity increases these impacts across the board. The extent of change depends on two key factors: the relative contribution of electricity to each specific impact category, and the electricity mix used in the baseline scenario.

The electricity contribution to each impact category determines how sensitive the results are to changes in the electricity scenario. For example, electricity accounts for 55% of climate change for data provider C3's post-industrial chip (Figure 10), much higher than the 24% contribution for C1's recycled chip (Figure 6). C3's post-industrial chip also shows the largest decrease under the renewable electricity scenario (-54%, Table 90) and the largest increase in the coal-based electricity scenario (+93%, Table 91). In comparison, C1's recycled chip shows the smallest change across scenarios: a 21% decrease under the renewable scenario (Table 84) and a 10% increase under the coal scenario (Table 85).

Impact categories with lower electricity contributions show much smaller changes across scenarios. For example, eutrophication is largely driven by chemicals; electricity contributes <5% to eutrophication for C1 (Figure 6) and C2 (Figure 7), and 10–11% for C3's post-consumer and post-industrial chips (Figure 9–Figure 10). As a result, eutrophication shows relatively small changes. Under the renewable scenario, C1 and C2 show only a 3% decrease, while the coal scenario results in a 2% increase. For C3 post-consumer and post-industrial chips, eutrophication decreases by 8% under the renewable scenario and increases by 36% under the coal scenario. Despite being high among the eutrophication changes, this 36% increase remains the smallest coal-scenario increase compared to the other impact categories—climate change, acidification, and abiotic depletion of fossil fuels.

The amount of coal and renewable electricity used in the baseline scenario electricity mix is the other key factor that influences the magnitude of change when switching between electricity scenarios. For instance, data providers C1 and C2, both located in China, use a large percentage of coal-based electricity (60%, Table 79), while the European grid mix uses only 14% (Table 80). As a result, C1 and C2 experience smaller increases in the climate change results under the coal scenario (+10% for C1, Table 85; +9% for C2,

Table 87) compared to larger decreases under the renewable scenario (-21% for C1, Table 84; -20% for C2, Table 86). In contrast, C3, located in Europe, shows a greater increase in climate change under the coal scenario (+76% for post-consumer chip, Table 89; +93% for post-industrial chip, Table 91), compared to the reductions under the renewable scenario (-44% for post-consumer chip, Table 88; -54% for post-industrial chip, Table 90).

For water scarcity and freshwater consumption, data providers C1 and C2 show a similar trend (Figure 34–Figure 35): impacts decrease under the renewable electricity scenario and increase under the coal scenario. However, data provider C3 exhibits a different pattern: impacts decrease under both scenarios. This difference is due to variations in the baseline electricity mix. The European country whose grid mix C3 is based on (kept anonymous to protect their identity), imports hydroelectricity from alpine reservoirs, which have high water-scarcity and freshwater-consumption impacts. In contrast, China's hydropower, which makes up 15% of the electricity mix for C1 and C2, is represented in ecoinvent as non-reservoir types (i.e., pumped storage and run-of-

river), which have lower impacts. As a result, C3 shows a larger reduction because its baseline model includes reservoir-based hydropower, while the C1 and C2 baselines do not; in both the renewable (wind and solar) and coal scenarios, reservoir-based hydropower is excluded. It should be noted that this may not reflect the actual composition of hydropower in China's electricity grid, as China also operates reservoir-based hydropower, but no detailed data is available on the share of each type.

Freshwater ecotoxicity shows a different trend compared to the other impact categories: it increases under the renewable scenario and decreases under the coal scenario, with limited sensitivity—less than 5% change under both scenarios for all data providers. This pattern is linked to the higher freshwater ecotoxicity associated with wind and solar electricity, due to the upstream production of wind turbines and solar panels.

The results of this sensitivity analysis show that changing the electricity mix used by solvolytic chemical recycling will affect the overall environmental impact of all impact categories, sometimes substantially. Climate change, acidification, and abiotic depletion of fossil fuels are particularly sensitive, while eutrophication and freshwater ecotoxicity are not. Freshwater-consumption and water-scarcity impacts tend to decrease under both renewable and coal scenarios when the baseline electricity mix includes high-impact sources, such as reservoir-based hydropower, due to their removal. The sensitivity analysis highlights that increasing the use of renewable electricity can reduce the environmental impacts associated with electricity production. The benefit seen from increasing the percentage of renewable electricity used is dependent upon the amount used in the baseline mix and the electricity intensity of the recycling process. Companies looking to set up new recycling facilities should look for regions with large amounts of renewable energy in the grid mix, or consider entering into contracts with renewable producers. Organizations sourcing PET chips (whether recycled or virgin) should give consideration to the energy sources used to produce these materials, and we would encourage organizations to work with the supply chain to increase the demand for, and availability of, chip produced using renewable energy sources to lower overall impact.

Sections 6.1.1.1–6.1.1.3 below present the results of the electricity scenario analysis for each chemical recycler (Table 84–Table 91, Figure 34–Figure 37).

6.1.1.1. Data provider C1 results

Table 84: C1—chemically recycled chip—Scenario "Electricity—Renewable"

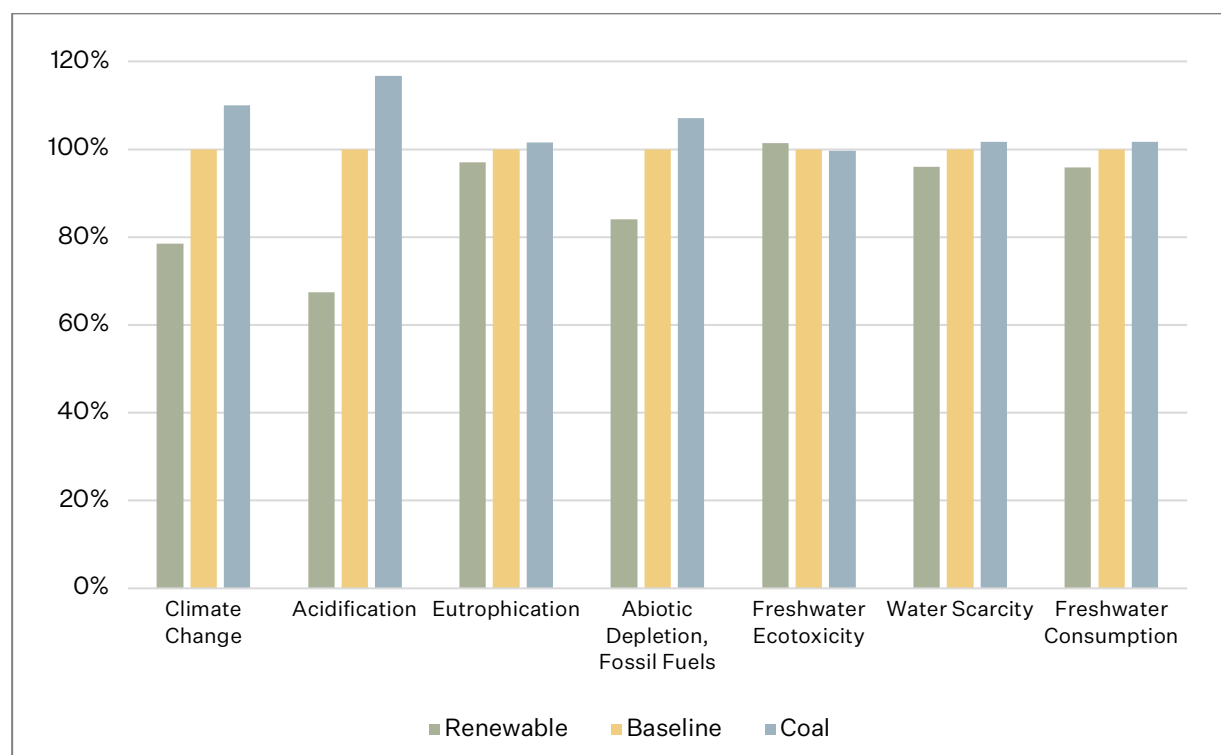
Impact category	Textile shreds production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	0.304	0.260	-14%	1.46	1.13	-23%	1.77	1.39	-21%
AP	1.36x10 ⁻³	1.11x10 ⁻³	-19%	5.37x10 ⁻³	3.42x10 ⁻³	-36%	6.73x10 ⁻³	4.53x10 ⁻³	-33%
EP	4.12x10 ⁻⁴	3.35x10 ⁻⁴	-19%	2.25x10 ⁻²	2.19x10 ⁻²	-3%	2.29x10 ⁻²	2.22x10 ⁻²	-3%
AD	3.96	3.54	-11%	19.1	15.8	-17%	23.0	19.4	-16%
FE	2.51x10 ⁻⁴	2.60x10 ⁻⁴	3%	5.10x10 ⁻³	5.16x10 ⁻³	1%	5.35x10 ⁻³	5.42x10 ⁻³	1%
WS	2.86x10 ⁻²	2.63x10 ⁻²	-8%	0.458	0.441	-4%	0.487	0.467	-4%
FC	6.66x10 ⁻⁴	6.13x10 ⁻⁴	-8%	1.05x10 ⁻²	1.01x10 ⁻²	-4%	1.12x10 ⁻²	1.07x10 ⁻²	-4%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 85: C1—chemically recycled chip—Scenario "Electricity—Coal"

Impact Category	Textile shreds production			Chip production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	0.304	0.324	7%	1.46	1.62	11%	1.77	1.94	10%
AP	1.36×10^{-3}	1.49×10^{-3}	9%	5.37×10^{-3}	6.36×10^{-3}	19%	6.73×10^{-3}	7.85×10^{-3}	17%
EP	4.12×10^{-4}	4.54×10^{-4}	10%	2.25×10^{-2}	2.28×10^{-2}	1%	2.29×10^{-2}	2.33×10^{-2}	2%
AD	3.96	4.15	5%	19.1	20.5	8%	23.0	24.7	7%
FE	2.51×10^{-4}	2.49×10^{-4}	-1%	5.10×10^{-3}	5.08×10^{-3}	0%	5.35×10^{-3}	5.33×10^{-3}	0%
WS	2.86×10^{-2}	2.95×10^{-2}	3%	0.458	0.465	2%	0.487	0.495	2%
FC	6.66×10^{-4}	6.87×10^{-4}	3%	1.05×10^{-2}	1.07×10^{-2}	2%	1.12×10^{-2}	1.13×10^{-2}	2%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 34: Comparison of electricity scenarios for chemically recycled chip produced by data provider C1

6.1.1.2. Data provider C2 results

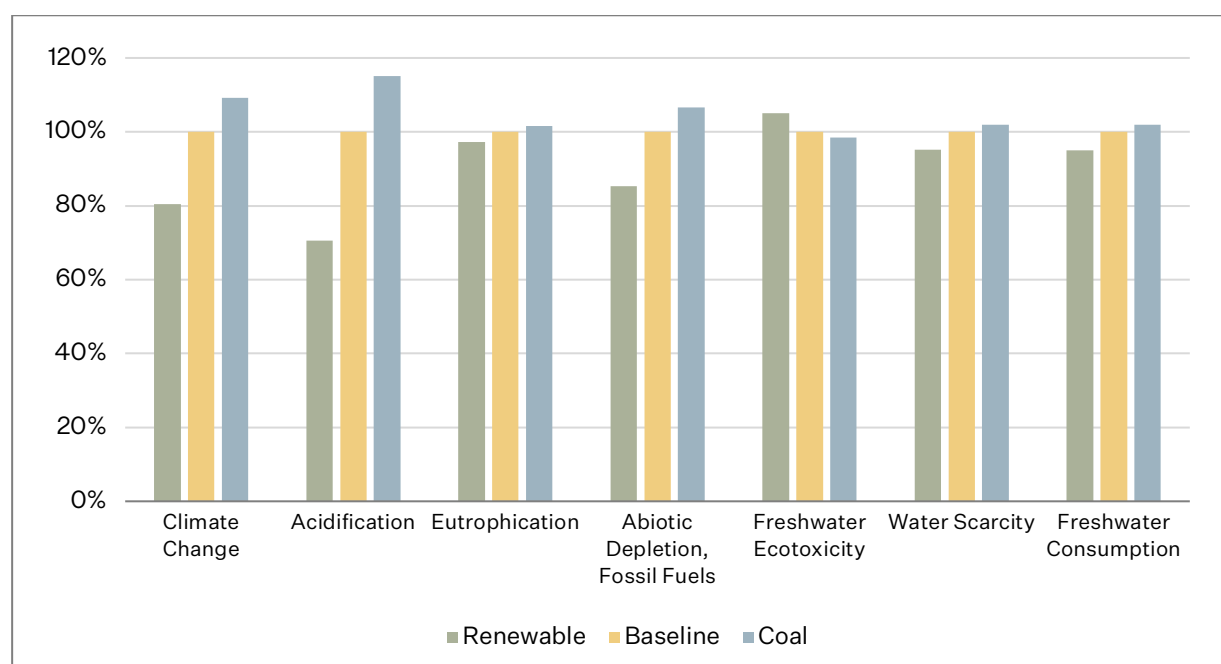
Table 86: C2—chemically recycled chip—Scenario "Electricity—Renewable"

Impact category	Baseline	Renewable electricity	% Difference
Climate change (kg CO ₂ eq)	2.24	1.80	-20%
Acidification (mol H ⁺ eq)	8.63×10^{-3}	6.09×10^{-3}	-30%
Eutrophication (kg PO ₄ eq)	2.81×10^{-2}	2.73×10^{-2}	-3%
Abiotic depletion, fossil fuels (MJ)	28.9	24.6	-15%

Impact category	Baseline	Renewable electricity	% Difference
Freshwater ecotoxicity (PAF m ³ day)	1.67x10 ⁻³	1.75x10 ⁻³	5%
Water scarcity (m ³ world eq)	0.468	0.445	-5%
Freshwater consumption (m ³)	1.07x10 ⁻²	1.01x10 ⁻²	-5%

Table 87: C2—chemically recycled chip—Scenario "Electricity—Coal"

Impact category	Baseline	Coal Electricity	% Difference
Climate change (kg CO ₂ eq)	2.24	2.44	9%
Acidification (mol H ⁺ eq)	8.63x10 ⁻³	9.94x10 ⁻³	15%
Eutrophication (kg PO ₄ eq)	2.81x10 ⁻²	2.85x10 ⁻²	2%
Abiotic depletion, fossil fuels (MJ)	28.9	30.8	7%
Freshwater ecotoxicity (PAF m ³ day)	1.67x10 ⁻³	1.64x10 ⁻³	-2%
Water scarcity (m ³ world eq)	0.468	0.477	2%
Freshwater consumption (m ³)	1.07x10 ⁻²	1.09x10 ⁻²	2%

Figure 35: Comparison of electricity scenarios for chemically recycled chip produced by data provider C2**6.1.1.3. Data provider C3 results****Table 88: C3—chemically recycled post-consumer chip—Scenario "Electricity—Renewable"**

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	0.522	0.311	-40%	0.364	0.181	-50%	0.885	0.492	-44%

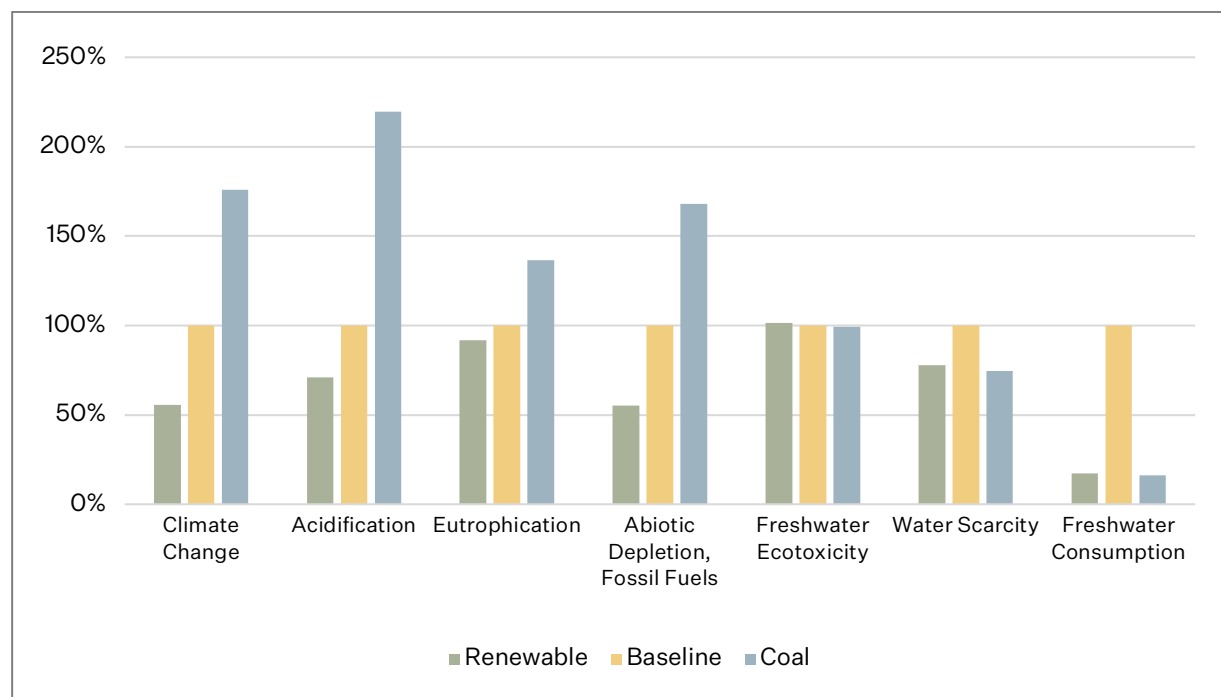
Impact category	Textile shreds production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
AP	1.45x10 ⁻³	1.12x10 ⁻³	-23%	6.69x10 ⁻⁴	3.82x10 ⁻⁴	-43%	2.12x10 ⁻³	1.50x10 ⁻³	-29%
EP	5.60x10 ⁻³	5.33x10 ⁻³	-5%	5.37x10 ⁻⁴	3.00x10 ⁻⁴	-44%	6.14x10 ⁻³	5.63x10 ⁻³	-8%
AD	6.96	4.56	-34%	3.06	0.978	-68%	10.0	5.54	-45%
FE	6.46x10 ⁻³	6.50x10 ⁻³	1%	1.42x10 ⁻⁴	1.82x10 ⁻⁴	28%	6.60x10 ⁻³	6.68x10 ⁻³	1%
WS	0.124	0.101	-19%	7.27x10 ⁻²	5.25x10 ⁻²	-28%	0.197	0.154	-22%
FC	0.156	3.70x10 ⁻²	-76%	0.112	9.12x10 ⁻³	-92%	0.268	4.61x10 ⁻²	-83%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 89: C3—chemically recycled post-consumer chip—Scenario "Electricity—Coal"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	0.522	0.882	69%	0.364	0.676	86%	0.885	1.56	76%
AP	1.45x10 ⁻³	2.80x10 ⁻³	94%	6.69x10 ⁻⁴	1.84x10 ⁻³	176%	2.12x10 ⁻³	4.64x10 ⁻³	119%
EP	5.60x10 ⁻³	6.80x10 ⁻³	21%	5.37x10 ⁻⁴	1.57x10 ⁻³	193%	6.14x10 ⁻³	8.37x10 ⁻³	36%
AD	6.96	10.6	52%	3.06	6.23	103%	10.0	16.8	68%
FE	6.46x10 ⁻³	6.43x10 ⁻³	0%	1.42x10 ⁻⁴	1.17x10 ⁻⁴	-17%	6.60x10 ⁻³	6.55x10 ⁻³	-1%
WS	0.124	9.74x10 ⁻²	-22%	7.27x10 ⁻²	4.92x10 ⁻²	-32%	0.197	0.147	-26%
FC	0.156	3.53x10 ⁻²	-77%	0.112	7.68x10 ⁻³	-93%	0.268	4.30x10 ⁻²	-84%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 36: Comparison of electricity scenarios for chemically recycled post-consumer chip produced by data provider C3**Table 90: C3—chemically recycled post-industrial chip—Scenario "Electricity—Renewable"**

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	0.426	0.238	-44%	0.257	7.43×10^{-2}	-71%	0.683	0.313	-54%
AP	1.11×10^{-3}	8.18×10^{-4}	-27%	5.48×10^{-4}	2.62×10^{-4}	-52%	1.66×10^{-3}	1.08×10^{-3}	-35%
EP	5.37×10^{-3}	5.12×10^{-3}	-5%	4.16×10^{-4}	1.79×10^{-4}	-57%	5.78×10^{-3}	5.30×10^{-3}	-8%
AD	5.71	3.56	-38%	2.59	0.514	-80%	8.30	4.08	-51%
FE	6.23×10^{-3}	6.27×10^{-3}	1%	1.08×10^{-4}	1.48×10^{-4}	36%	6.34×10^{-3}	6.42×10^{-3}	1%
WS	0.111	9.00×10^{-2}	-19%	6.53×10^{-2}	4.51×10^{-2}	-31%	0.176	0.135	-23%
FC	0.141	3.44×10^{-2}	-76%	0.109	6.26×10^{-3}	-94%	0.250	4.07×10^{-2}	-84%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

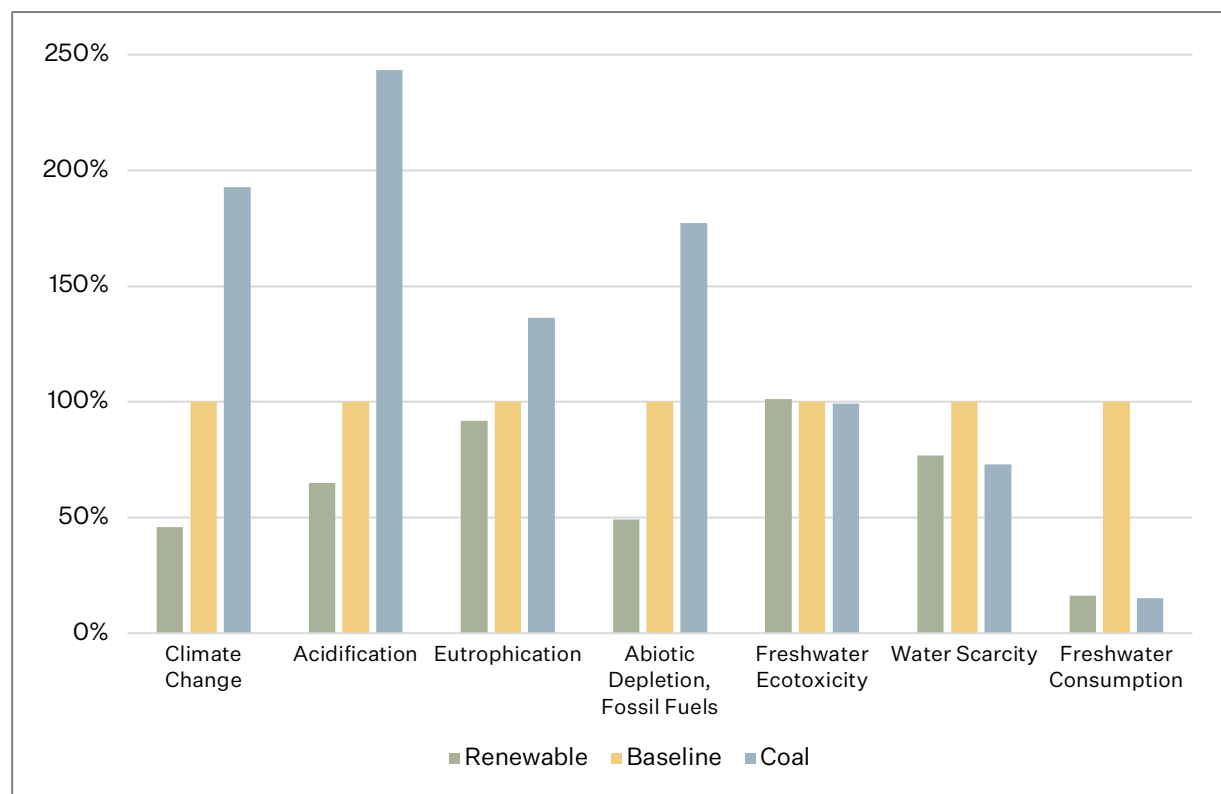
Table 91: C3—chemically recycled post-industrial chip—Scenario "Electricity—Coal"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	0.426	0.748	75%	0.257	0.569	122%	0.683	1.32	93%
AP	1.11×10^{-3}	2.32×10^{-3}	109%	5.48×10^{-4}	1.72×10^{-3}	214%	1.66×10^{-3}	4.04×10^{-3}	143%
EP	5.37×10^{-3}	6.43×10^{-3}	20%	4.16×10^{-4}	1.45×10^{-3}	249%	5.78×10^{-3}	7.88×10^{-3}	36%
AD	5.71	8.96	57%	2.59	5.75	122%	8.30	14.7	77%
FE	6.23×10^{-3}	6.20×10^{-3}	0%	1.08×10^{-4}	8.35×10^{-5}	-23%	6.34×10^{-3}	6.29×10^{-3}	-1%

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
WS	0.111	8.67×10^{-2}	-22%	6.53×10^{-2}	4.19×10^{-2}	-36%	0.176	0.129	-27%
FC	0.141	3.29×10^{-2}	-77%	0.109	4.81×10^{-3}	-96%	0.250	3.77×10^{-2}	-85%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 37: Comparison of electricity scenarios for chemically recycled post-industrial chip produced by data provider C3



6.1.2. Thermomechanical recycling electricity analysis

Similar to chemical recycling, the use of renewable electricity lowers the impacts for all thermomechanically recycled products in the climate change, acidification, eutrophication, and abiotic depletion of fossil fuels impact categories (Figure 38–Figure 42). In contrast, the use of coal electricity increases the impacts across these impact categories. Freshwater ecotoxicity, water scarcity, and freshwater consumption follow a different trend, with direction and magnitude of change varying by data provider. As with chemical recycling, the extent of change depends on two key factors: the relative contribution of electricity to each specific impact category, and the electricity mix used in the baseline scenario. More detail on the electricity contribution analysis is provided in sections 4.5.1.3, 4.5.2.3, and 4.5.3.3.

The magnitude of change under the alternative electricity scenarios is strongly influenced by the share of coal and renewable power in the baseline electricity mix for each data provider. M2, located in China, relies heavily on coal-based electricity (60%, Table 36), whereas M3, in Southeast Asia, uses 18% coal for chip production and 15% for staple fiber production (Table 37 and Table 38, respectively). M1, located in the US, has the lowest coal share at 11% (Table 35). Onsite solar generation is included in the baseline scenarios for both M2 (3%, Table 36) and M3 (8% for chip and 27% for staple fiber; Table 37 and Table 38, respectively).

These different baseline electricity mixes explain why the coal scenario produces a larger increase in impacts for M1 (Figure 38–Figure 39) and M3 (Figure 41–Figure 42), and a comparatively smaller increase for M2 (Figure 40). For example, under the coal scenario, climate change impacts for M1 and M3 increase by more than 43% (Tables 93, 95, 99, and 101), whereas M2's chip production increases by only 13% (Table 97).

The pattern reverses for acidification. M2 shows the largest decrease under the renewable scenario, while reductions for M1 and M3 are more modest. This is because hard coal electricity has a high acidification potential, largely due to sulfur dioxide (SO₂) and nitrogen oxide (NO_x) emissions. Consequently, removing coal from the electricity mix leads to substantial reductions in acidification impacts, particularly for M2, whose baseline coal share is highest.

For water scarcity and freshwater consumption, data provider M2 shows a similar trend (Figure 40): impacts decrease under the renewable scenario, and increase under the coal scenario. However, M1 and M3 exhibit a different trend, with impacts decreasing under both scenarios (Figure 38–Figure 39, Figure 41–Figure 42). This is due to differences in the baseline electricity mix.

For M1, the US sub-regional grid includes 40% nuclear energy (Table 81), which has higher water-scarcity and freshwater-consumption impacts than coal electricity. M3's baseline mix (Table 82) includes reservoir-based hydropower and bagasse-based electricity (biofuels). Both sources have higher water-scarcity and freshwater-consumption impacts than coal. For bagasse-based electricity, these impacts originate from sugarcane production. Because the renewable (wind and solar) and coal scenarios exclude these water-intensive sources, M1 and M3 show reductions in water scarcity and freshwater consumption compared to the baseline under both scenarios.

Freshwater ecotoxicity shows a different trend compared to the other impact categories. For M1 and M2, freshwater ecotoxicity is not sensitive to changes in the electricity mix, with $\leq 1\%$ change across both scenarios; their freshwater ecotoxicity impact is driven almost entirely by the use of surfactants, which contributes more than 79% across all three products (Figure 15–Figure 17). The slight increase under the renewable scenario is linked to the higher freshwater ecotoxicity associated with wind and solar electricity, due to the upstream production of wind turbines and solar panels. For M3, freshwater ecotoxicity is sensitive to changes in the electricity mix, with electricity responsible for 83% of this impact for chip and 55% for staple fiber under the baseline scenario. A decrease in freshwater ecotoxicity is seen for both products under the renewable (54–82%) and coal (55–82%) scenarios. This surprising reduction is due to the removal of bagasse-based electricity generation, which is included in the baseline electricity mix of the country in which M3 is located. As discussed in section 4.5.3.3, the dataset used to represent this bagasse-based bioenergy carries a high freshwater ecotoxicity impact due to sugarcane production.

As seen for chemical recycling, the results of this sensitivity analysis show that changing the grid mix used by thermomechanical recyclers can affect the overall environmental impact of all impact categories, sometimes substantially. Climate change, acidification, eutrophication, and abiotic depletion of fossil fuels are particularly sensitive. Freshwater ecotoxicity, water scarcity, and freshwater consumption are generally less sensitive, with the exception of M3's freshwater ecotoxicity, which shows notable changes due to differences in the baseline electricity mix used in the Southeast Asian country where M3 is located. Once again, this assessment shows the advantages of utilizing renewable energy. It emphasizes the need for companies to consider the type of electricity available when establishing new recycling facilities and for organizations to consider the source of electricity used to produce PET chip, and to work with their supply chains to increase the use of renewable energy.

Sections 6.1.2.1–6.1.2.3 below present the results of the electricity scenario analysis for each thermomechanical recycler (Table 92–Table 101, Figure 38–Figure 42).

6.1.2.1. Data provider M1 results**Table 92: M1—thermomechanically recycled post-consumer chip—Scenario "Electricity—Renewable"**

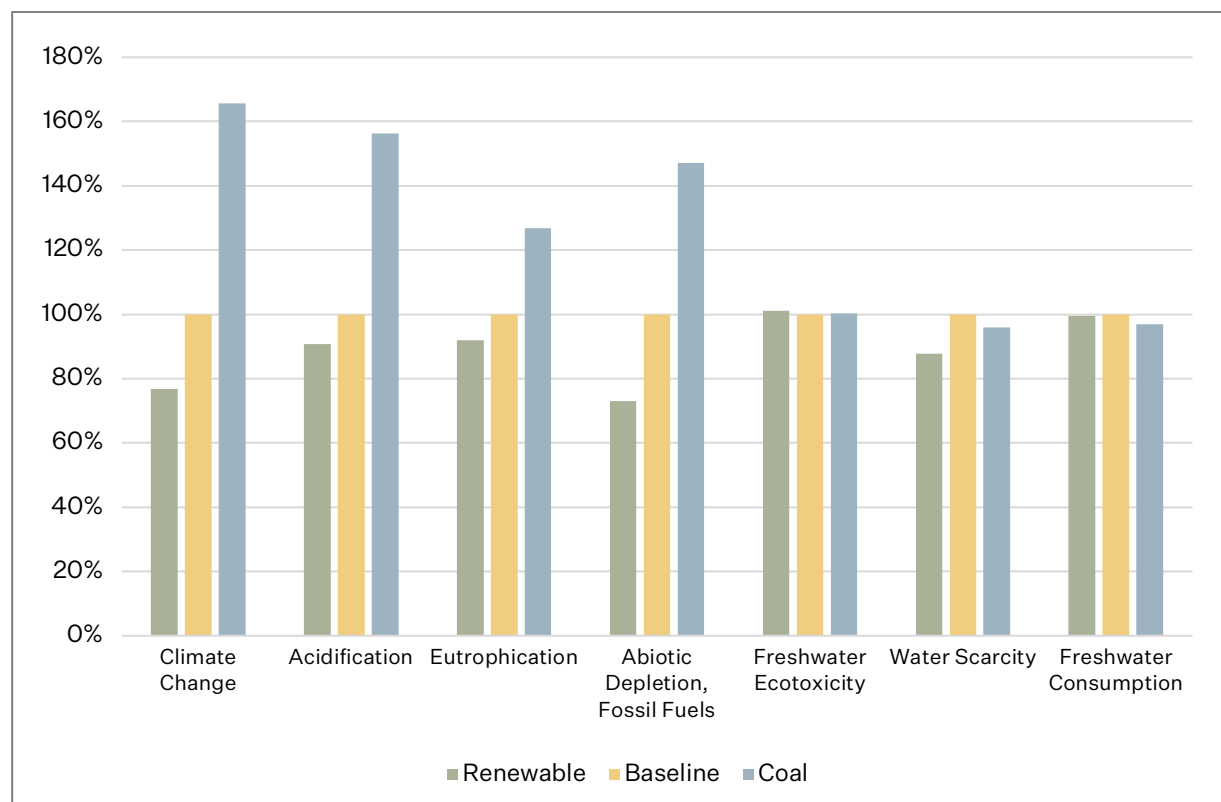
Impact category	Flake production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	0.716	0.599	-16%	0.243	0.137	-44%	0.959	0.736	-23%
AP	3.00x10 ⁻³	2.71x10 ⁻³	-10%	1.89x10 ⁻³	1.73x10 ⁻³	-9%	4.89x10 ⁻³	4.44x10 ⁻³	-9%
EP	4.23x10 ⁻³	3.99x10 ⁻³	-6%	8.72x10 ⁻⁴	6.91x10 ⁻⁴	-21%	5.10x10 ⁻³	4.69x10 ⁻³	-8%
AD	8.33	6.67	-20%	3.10	1.66	-46%	11.4	8.33	-27%
FE	6.67x10 ⁻³	6.71x10 ⁻³	1%	5.29x10 ⁻⁴	5.69x10 ⁻⁴	7%	7.20x10 ⁻³	7.28x10 ⁻³	1%
WS	0.173	0.152	-12%	0.121	0.106	-12%	0.294	0.258	-12%
FC	4.19x10 ⁻²	4.11x10 ⁻²	-2%	8.60x10 ⁻³	9.20x10 ⁻³	7%	5.05x10 ⁻²	5.03x10 ⁻²	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 93: M1—thermomechanically recycled post-consumer chip—Scenario "Electricity—Coal"

Impact category	Flake production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	0.716	1.03	44%	0.243	0.557	129%	0.959	1.59	66%
AP	3.00x10 ⁻³	4.39x10 ⁻³	47%	1.89x10 ⁻³	3.25x10 ⁻³	72%	4.89x10 ⁻³	7.64x10 ⁻³	56%
EP	4.23x10 ⁻³	4.92x10 ⁻³	16%	8.72x10 ⁻⁴	1.54x10 ⁻³	77%	5.10x10 ⁻³	6.46x10 ⁻³	27%
AD	8.33	11.0	32%	3.10	5.84	89%	11.4	16.8	47%
FE	6.67x10 ⁻³	6.68x10 ⁻³	0%	5.29x10 ⁻⁴	5.40x10 ⁻⁴	2%	7.20x10 ⁻³	7.22x10 ⁻³	0%
WS	0.173	0.164	-5%	0.121	0.118	-3%	0.294	0.282	-4%
FC	4.19x10 ⁻²	4.04x10 ⁻²	-4%	8.60x10 ⁻³	8.60x10 ⁻³	0%	5.05x10 ⁻²	4.90x10 ⁻²	-3%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 38: Comparison of electricity scenarios for thermomechanically recycled post-consumer chip produced by data provider M1**Table 94: M1—thermomechanically recycled 50-50 blended chip—Scenario "Electricity—Renewable"**

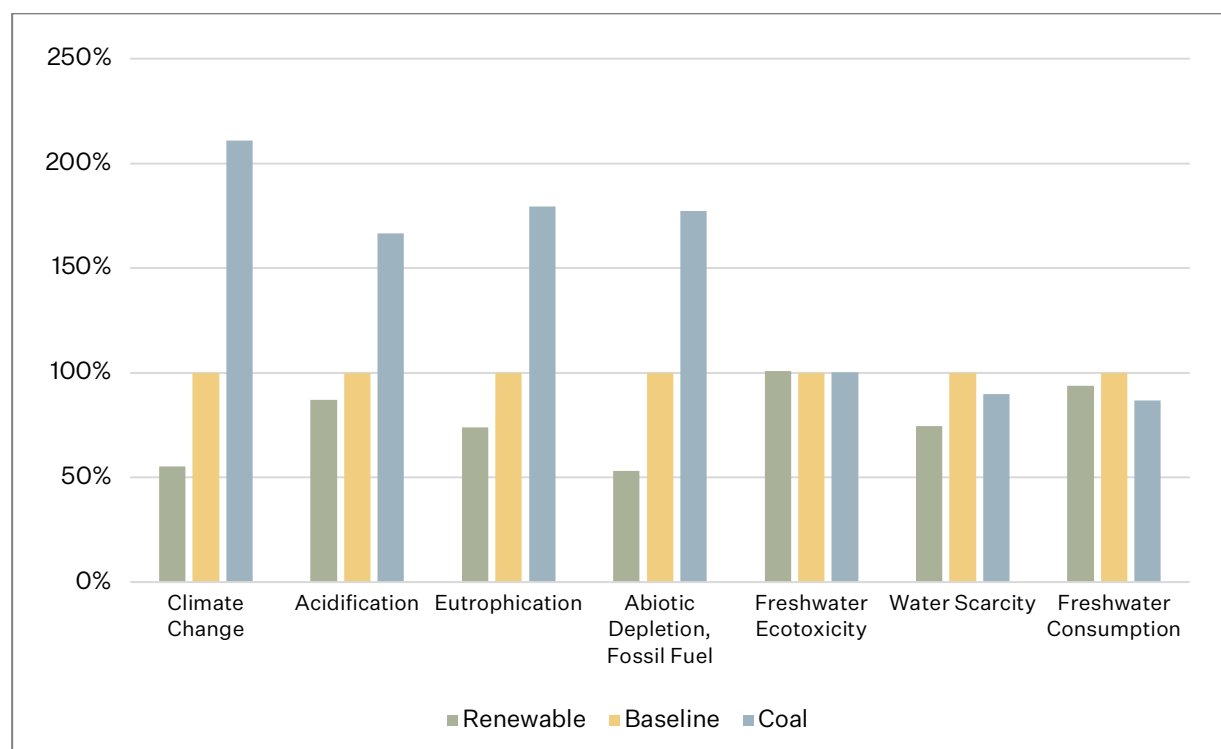
Impact category	Flake production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	0.367	0.276	-25%	0.708	0.316	-55%	1.07	0.592	-45%
AP	2.33x10 ⁻³	1.90x10 ⁻³	-19%	5.77x10 ⁻³	5.17x10 ⁻³	-10%	8.10x10 ⁻³	7.06x10 ⁻³	-13%
EP	1.82x10 ⁻³	1.61x10 ⁻³	-12%	1.54x10 ⁻³	8.75x10 ⁻⁴	-43%	3.36x10 ⁻³	2.49x10 ⁻³	-26%
AD	4.33	3.32	-23%	9.03	3.76	-58%	13.4	7.08	-47%
FE	1.59x10 ⁻²	1.59x10 ⁻²	0%	3.70x10 ⁻⁴	5.13x10 ⁻⁴	39%	1.62x10 ⁻²	1.64x10 ⁻²	1%
WS	9.12x10 ⁻²	6.82x10 ⁻²	-25%	0.214	0.159	-26%	0.305	0.227	-26%
FC	2.37x10 ⁻²	1.92x10 ⁻²	-19%	1.21x10 ⁻²	1.44x10 ⁻²	18%	3.58x10 ⁻²	3.36x10 ⁻²	-6%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 95: M1—thermomechanically recycled 50-50 blended chip—Scenario "Electricity—Coal"

Impact category	Flake production			Chip production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	0.367	0.411	12%	0.708	1.86	162%	1.07	2.27	111%
AP	2.33x10 ⁻³	2.73x10 ⁻³	17%	5.77x10 ⁻³	1.08x10 ⁻²	86%	8.10x10 ⁻³	1.35x10 ⁻²	67%
EP	1.82x10 ⁻³	2.03x10 ⁻³	11%	1.54x10 ⁻³	4.00x10 ⁻³	160%	3.36x10 ⁻³	6.03x10 ⁻³	79%
AD	4.33	4.61	6%	9.03	19.1	111%	13.4	23.7	77%
FE	1.59x10 ⁻²	1.59x10 ⁻²	0%	3.70x10 ⁻⁴	4.09x10 ⁻⁴	11%	1.62x10 ⁻²	1.63x10 ⁻²	0%
WS	9.12x10 ⁻²	7.13x10 ⁻²	-22%	0.214	0.203	-5%	0.305	0.274	-10%
FC	2.37x10 ⁻²	1.89x10 ⁻²	-20%	1.21x10 ⁻²	1.21x10 ⁻²	0%	3.58x10 ⁻²	3.10x10 ⁻²	-13%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 39: Comparison of electricity scenarios for thermomechanically recycled 50-50 blended chip produced by data provider M1

6.1.2.2. Data Provider M2 results

Table 96: M2—thermomechanically recycled chip—Scenario "Electricity—Renewable"

Impact category	Flake production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	0.879	0.736	-16%	0.321	0.120	-63%	1.20	0.856	-29%
AP	3.57x10 ⁻³	2.74x10 ⁻³	-23%	2.12x10 ⁻³	9.60x10 ⁻⁴	-55%	5.69x10 ⁻³	3.70x10 ⁻³	-35%
EP	4.45x10 ⁻³	4.20x10 ⁻³	-6%	9.91x10 ⁻⁴	6.36x10 ⁻⁴	-36%	5.44x10 ⁻³	4.83x10 ⁻³	-11%

Impact category	Flake production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
AD	10.3	8.95	-13%	3.21	1.26	-61%	13.6	10.2	-25%
FE	2.64x10 ⁻²	2.64x10 ⁻²	0%	3.68x10 ⁻⁴	4.07x10 ⁻⁴	11%	2.67x10 ⁻²	2.68x10 ⁻²	0%
WS	0.163	0.156	-5%	0.103	9.23x10 ⁻²	-10%	0.266	0.248	-7%
FC	3.70x10 ⁻³	3.52x10 ⁻³	-5%	2.36x10 ⁻³	2.11x10 ⁻³	-10%	6.05x10 ⁻³	5.63x10 ⁻³	-7%

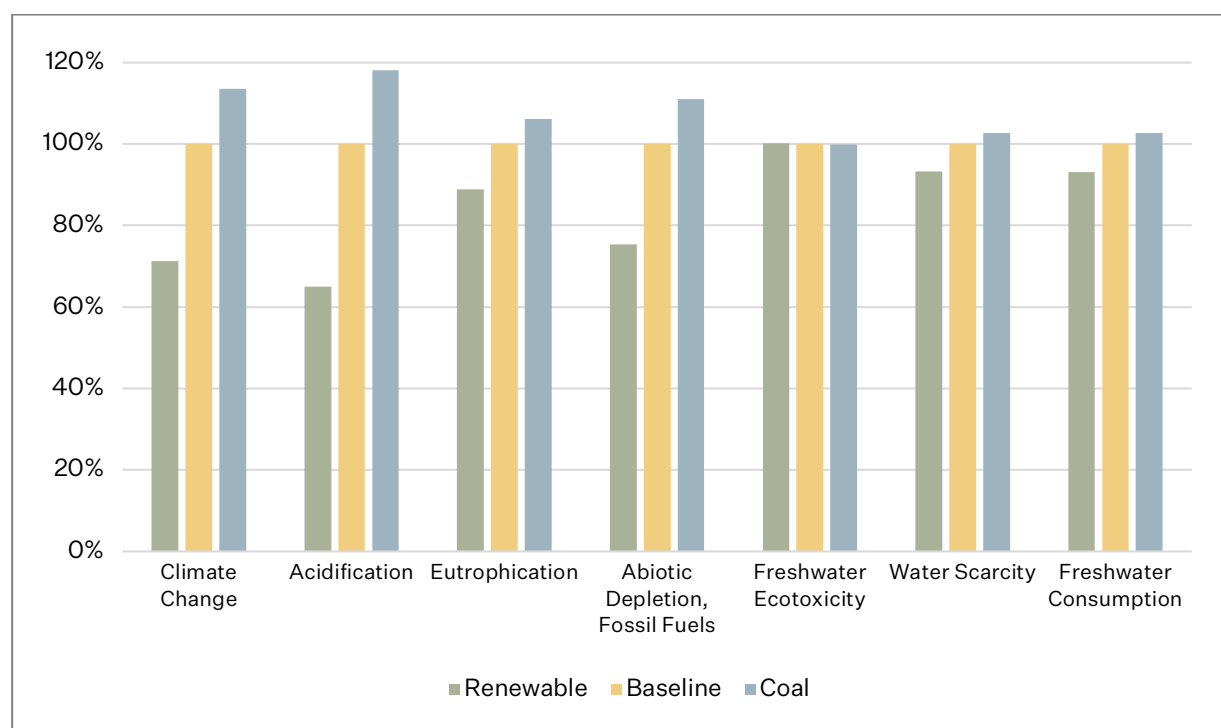
Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 97: M2—thermomechanically recycled chip—Scenario "Electricity—Coal"

Impact category	Flake production			Chip production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	0.879	0.947	8%	0.321	0.416	30%	1.20	1.36	13%
AP	3.57x10 ⁻³	4.00x10 ⁻³	12%	2.12x10 ⁻³	2.73x10 ⁻³	28%	5.69x10 ⁻³	6.73x10 ⁻³	18%
EP	4.45x10 ⁻³	4.59x10 ⁻³	3%	9.91x10 ⁻⁴	1.19x10 ⁻³	20%	5.44x10 ⁻³	5.78x10 ⁻³	6%
AD	10.3	11.0	6%	3.21	4.08	27%	13.6	15.0	11%
FE	2.64x10 ⁻²	2.64x10 ⁻²	0%	3.68x10 ⁻⁴	3.56x10 ⁻⁴	-3%	2.67x10 ⁻²	2.67x10 ⁻²	0%
WS	0.163	0.166	2%	0.103	0.107	4%	0.266	0.273	3%
FC	3.70x10 ⁻³	3.76x10 ⁻³	2%	2.36x10 ⁻³	2.45x10 ⁻³	4%	6.05x10 ⁻³	6.22x10 ⁻³	3%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 40: Comparison of electricity scenarios for thermomechanically recycled chip produced by data provider M2



6.1.2.3. Data provider M3 results**Table 98: M3—thermomechanically recycled chip—Scenario "Electricity—Renewable"**

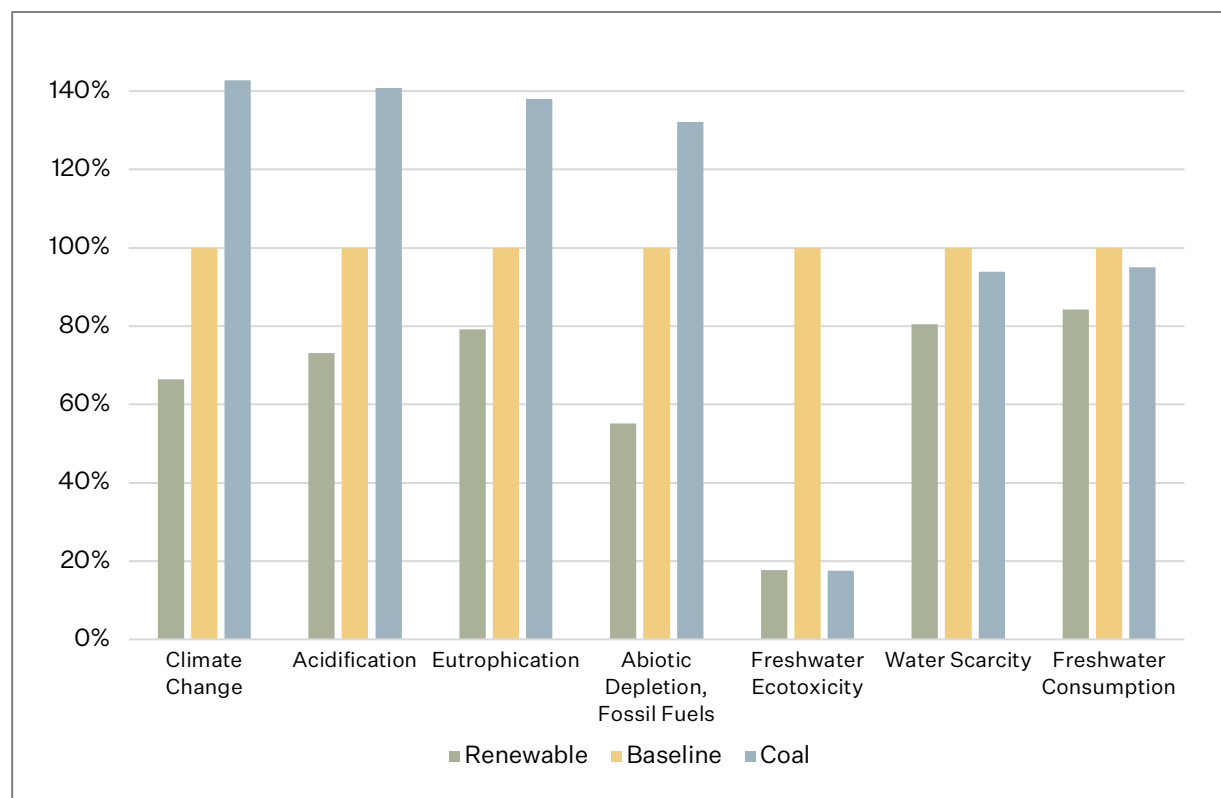
Impact category	Flake production			Chip production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	0.897	0.712	-21%	0.416	0.160	-61%	1.31	0.873	-34%
AP	3.55x10 ⁻³	2.91x10 ⁻³	-18%	2.18x10 ⁻³	1.28x10 ⁻³	-41%	5.73x10 ⁻³	4.19x10 ⁻³	-27%
EP	3.87x10 ⁻³	3.45x10 ⁻³	-11%	9.82x10 ⁻⁴	3.92x10 ⁻⁴	-60%	4.85x10 ⁻³	3.84x10 ⁻³	-21%
AD	7.97	5.60	-30%	4.64	1.36	-71%	12.6	6.95	-45%
FE	2.40x10 ⁻²	7.92x10 ⁻³	-67%	2.24x10 ⁻²	2.87x10 ⁻⁴	-99%	4.64x10 ⁻²	8.21x10 ⁻³	-82%
WS	0.164	0.145	-11%	7.51x10 ⁻²	4.70x10 ⁻²	-37%	0.239	0.192	-20%
FC	4.68x10 ⁻³	4.24x10 ⁻³	-9%	2.24x10 ⁻³	1.58x10 ⁻³	-29%	6.92x10 ⁻³	5.82x10 ⁻³	-16%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 99: M3—thermomechanically recycled chip—Scenario "Electricity—Coal"

Impact category	Flake production			Chip production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	0.897	1.11	24%	0.416	0.766	84%	1.31	1.87	43%
AP	3.55x10 ⁻³	4.44x10 ⁻³	25%	2.18x10 ⁻³	3.63x10 ⁻³	67%	5.73x10 ⁻³	8.07x10 ⁻³	41%
EP	3.87x10 ⁻³	4.58x10 ⁻³	18%	9.82x10 ⁻⁴	2.12x10 ⁻³	116%	4.85x10 ⁻³	6.70x10 ⁻³	38%
AD	7.97	9.44	18%	4.64	7.23	56%	12.6	16.7	32%
FE	2.40x10 ⁻²	7.89x10 ⁻³	-67%	2.24x10 ⁻²	2.41x10 ⁻⁴	-99%	4.64x10 ⁻²	8.13x10 ⁻³	-82%
WS	0.164	0.158	-4%	7.51x10 ⁻²	6.64x10 ⁻²	-12%	0.239	0.224	-6%
FC	4.68x10 ⁻³	4.54x10 ⁻³	-3%	2.24x10 ⁻³	2.03x10 ⁻³	-9%	6.92x10 ⁻³	6.57x10 ⁻³	-5%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 41: Comparison of electricity scenarios for thermomechanically recycled chip produced by data provider M3**Table 100: M3—thermomechanically recycled staple fiber—Scenario "Electricity—Renewable"**

Impact category	Flake production			Staple fiber production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	1.01	0.799	-21%	2.03	1.14	-44%	3.04	1.94	-36%
AP	3.99x10 ⁻³	3.26x10 ⁻³	-18%	7.82x10 ⁻³	4.65x10 ⁻³	-41%	1.18x10 ⁻²	7.91x10 ⁻³	-33%
EP	4.34x10 ⁻³	3.87x10 ⁻³	-11%	1.13x10 ⁻²	9.24x10 ⁻³	-18%	1.57x10 ⁻²	1.31x10 ⁻²	-16%
AD	8.94	6.28	-30%	24.9	13.3	-46%	33.8	19.6	-42%
FE	2.69x10 ⁻²	8.89x10 ⁻³	-67%	0.147	7.05x10 ⁻²	-52%	0.174	7.94x10 ⁻²	-54%
WS	0.184	0.163	-11%	0.401	0.282	-30%	0.585	0.445	-24%
FC	5.25x10 ⁻³	4.76x10 ⁻³	-9%	1.10x10 ⁻²	8.20x10 ⁻³	-25%	1.62x10 ⁻²	1.30x10 ⁻²	-20%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

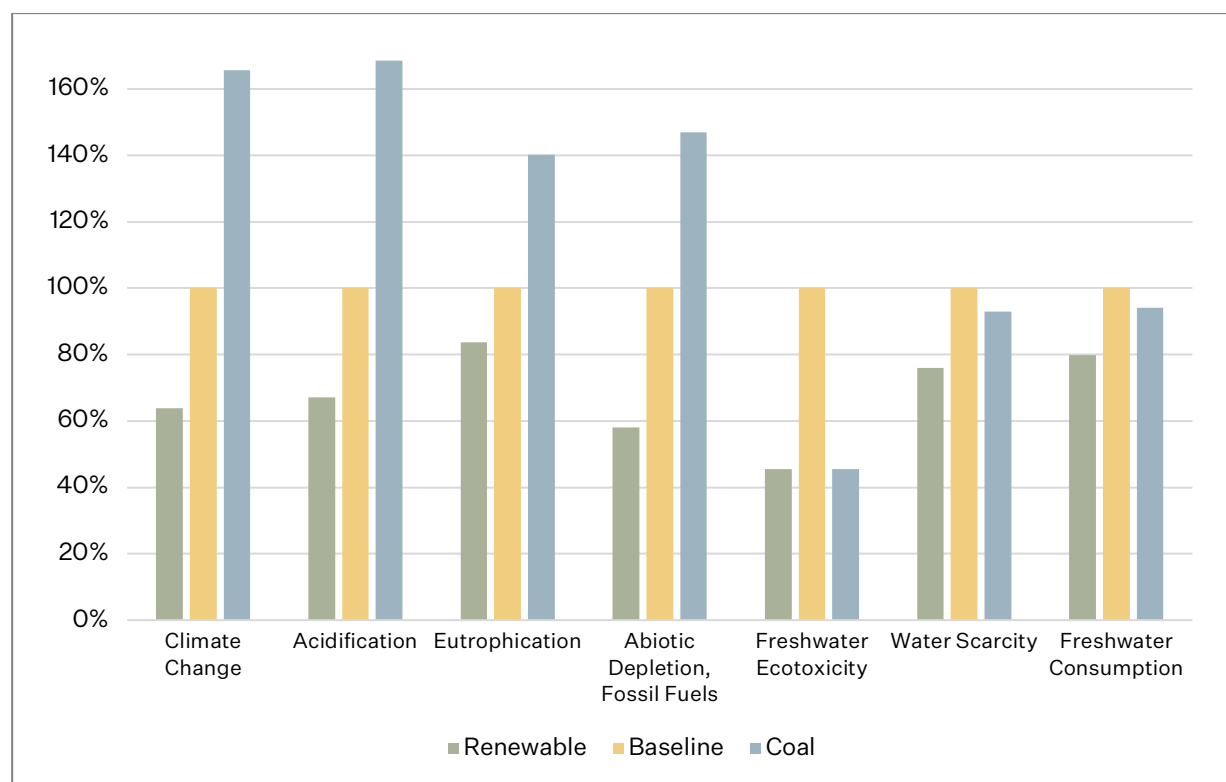
Table 101: M3—thermomechanically recycled staple fiber—Scenario "Electricity—Coal"

Impact category	Flake production			Staple fiber production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	1.01	1.24	24%	2.03	3.79	87%	3.04	5.04	66%
AP	3.99x10 ⁻³	4.98x10 ⁻³	25%	7.82x10 ⁻³	1.49x10 ⁻²	91%	1.18x10 ⁻²	1.99x10 ⁻²	69%
EP	4.34x10 ⁻³	5.14x10 ⁻³	18%	1.13x10 ⁻²	1.68x10 ⁻²	49%	1.57x10 ⁻²	2.20x10 ⁻²	40%

Impact category	Flake production			Staple fiber production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
AD	8.94	10.6	18%	24.9	39.1	57%	33.8	49.7	47%
FE	2.69×10^{-2}	8.85×10^{-3}	-67%	0.147	7.03×10^{-2}	-52%	0.174	7.92×10^{-2}	-55%
WS	0.184	0.177	-4%	0.401	0.367	-9%	0.585	0.544	-7%
FC	5.25×10^{-3}	5.09×10^{-3}	-3%	1.10×10^{-2}	1.02×10^{-2}	-7%	1.62×10^{-2}	1.53×10^{-2}	-6%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 42: Comparison of electricity scenarios for thermomechanically recycled staple fiber produced by data provider M3



6.1.3. Virgin production of polyester electricity analysis

Following a similar trend as chemical and thermomechanical recycling, the use of renewable electricity lowers all impacts across all virgin PET products (Figure 43–Figure 47). The use of coal electricity increases the impacts for climate change, acidification, eutrophication, and abiotic depletion of fossil fuels, but lowers the impact from freshwater ecotoxicity, water scarcity, and freshwater consumption impact categories (Figure 43–Figure 47). The extent of these changes depends on the composition of the baseline electricity mix used at each facility and the contribution of electricity to each data provider's impact. As discussed in sections 6.1.1 and 6.1.2, the contribution of electricity to the total impact is dependent upon electricity intensity (for example, kWh per kilogram of product produced) and the impact intensity of the electricity for any impact category (for example, impact per kWh) compared to the impact intensity of the other inputs (chemicals, heat, etc.).

Renewable electricity reduces climate change impacts by 8–10% for staple fiber (Table 102, 104, 106), 31% for POY (Table 108), and 40% for DTY (Table 110). Coal electricity increases them by 2–

11% for staple fiber (Tables 103, 105, and Table 107), 7% for POY (Table 109), and 9% for DTY (Table 111). One key factor influencing the extent of change is the baseline electricity mix. SF3, POY, and DTY are produced at Facility 2, where 78% of electricity comes from coal—73% from an onsite coal power plant and 5% from the grid mix (Table 83). Because the baseline already includes a high share of coal, switching entirely to coal results in only a small increase in total climate change impact—2% for SF3 (Table 107), 7% for POY (Table 109), and 9% for DTY (Table 111). In contrast, SF1 and SF2 are produced at Facility 1, which uses 18% coal electricity (Table 83). As a result, switching to 100% coal at Facility 1 results in slightly larger increases in climate impacts (10–11%, Table 103 and Table 105).

The second factor is electricity intensity. POY and DTY require much more electricity—approximately double or more than that of staple fiber (SF1 and SF2). Electricity contributes a larger share to their total climate change impact at baseline: 33% for POY (Figure 31) and 42% for DTY (Figure 33), compared to 9–11% for staple fiber (Figure 27–Figure 29). As a result, POY and DTY are more responsive to changes in the electricity source. Switching to renewable electricity led to the largest reductions in climate change impacts compared to the virgin staple fibers: 31% for POY (Table 108) and 40% for DTY (Table 110). These large decreases reflect both the higher electricity intensity and coal-intensive baseline electricity mix. Among the staple fibers, SF1 and SF2—produced at the same facility—use similar amounts of electricity per kilogram of product, while SF3—produced at a different facility—uses about half as much electricity compared to SF1 and SF2. Due to the combined effects of baseline electricity mix and energy intensity, the reductions under the renewable scenario are similar across SF1–SF3 (8–10%, Table 102, 104, and 106). Under the coal scenario, however, SF3 shows only a 2% increase (Table 107) while SF1 and SF2 increase 10 and 11%, respectively (Table 103 and Table 105).

Other impact categories—acidification, eutrophication, and abiotic depletion of fossil fuels—follow similar trends to climate change (Figure 43–Figure 47). Under the renewable electricity scenario, reductions are more noticeable for POY and DTY: 29–37% for acidification, 13–17% for eutrophication, and 18–25% for abiotic depletion of fossil fuels (Table 108 and Table 110). In contrast, reductions for SF1–SF3 are more modest: 5–9% for acidification, 3–4% for eutrophication, and 5–6% for abiotic depletion (Table 104, 106). Under the coal scenario, SF1, SF2, POY, and DTY all show small increases: 7–9% for acidification, 3–5% for eutrophication, and 3–5% for abiotic depletion (Table 103, 105, 109, and 111). SF3 shows only limited increases (1–2%) across these impact categories (Table 107) due to its low electricity intensity and already coal-intensive baseline.

In addition to the decrease under the renewable scenario (2–9%), water scarcity and freshwater consumption also show slight decreases under the coal scenario ($\leq 2\%$) (Figure 43–Figure 47, Table 102–Table 111). This trend is primarily due to the removal of reservoir-based hydropower and bagasse-based electricity (biofuels) from the baseline electricity mix (Table 83), with the latter's impacts originating from sugarcane production. Both sources carry higher water scarcity and freshwater consumption impacts than coal. Because the coal scenario excludes these sources, the results decrease slightly compared to the baseline.

Freshwater ecotoxicity shows a different pattern compared to the other impact categories. Across all products and facilities, impacts decrease under both the renewable and coal electricity scenarios (Figure 43–Figure 47). This trend is driven by the removal of bagasse-based electricity generation, which is included in the baseline local electricity mix used by the virgin PET producer. Bagasse is a by-product of sugarcane processing and is combusted for power and heat generation. The upstream agricultural production of sugarcane is associated with high freshwater ecotoxicity impacts. As a result, the decrease for both renewable and coal scenarios is nearly identical for each product (11–33%, Table 102–Table 111). More details are discussed in sections 5.5.1.3, 5.5.2.3, and 5.5.3.3.

The results of this sensitivity analysis confirm that changes to the electricity mix can affect the environmental impacts of virgin PET production across all impact categories, with varying levels of sensitivity across impact categories and products. Climate change, acidification, abiotic depletion of fossil fuels, and eutrophication all show sensitivity to changes in the electricity mix, particularly for POY and DTY, which use more electricity. Staple fiber shows lower sensitivity due to lower electricity intensity. Freshwater consumption and water scarcity are less sensitive, with small reductions observed under both scenarios due to the exclusion of high water-impact electricity sources in the baseline. Freshwater ecotoxicity is highly sensitive in this analysis, driven by the removal of bagasse-based electricity from the baseline mix, resulting in consistent and substantial reductions across all products. These findings, again, highlight the importance of considering the source of electricity used and the importance of working with PET-producing supply chains to help them increase the amount of renewable electricity used.

Sections 6.1.3.1–6.1.3.3 below present the results of the electricity scenario analysis for each virgin PET product (Table 102–Table 111, Figure 43–Figure 47).

6.1.3.1. Staple fiber results (SF1, SF2, SF3)

Table 102: Virgin staple fiber SF1—Scenario "Electricity—Renewable"

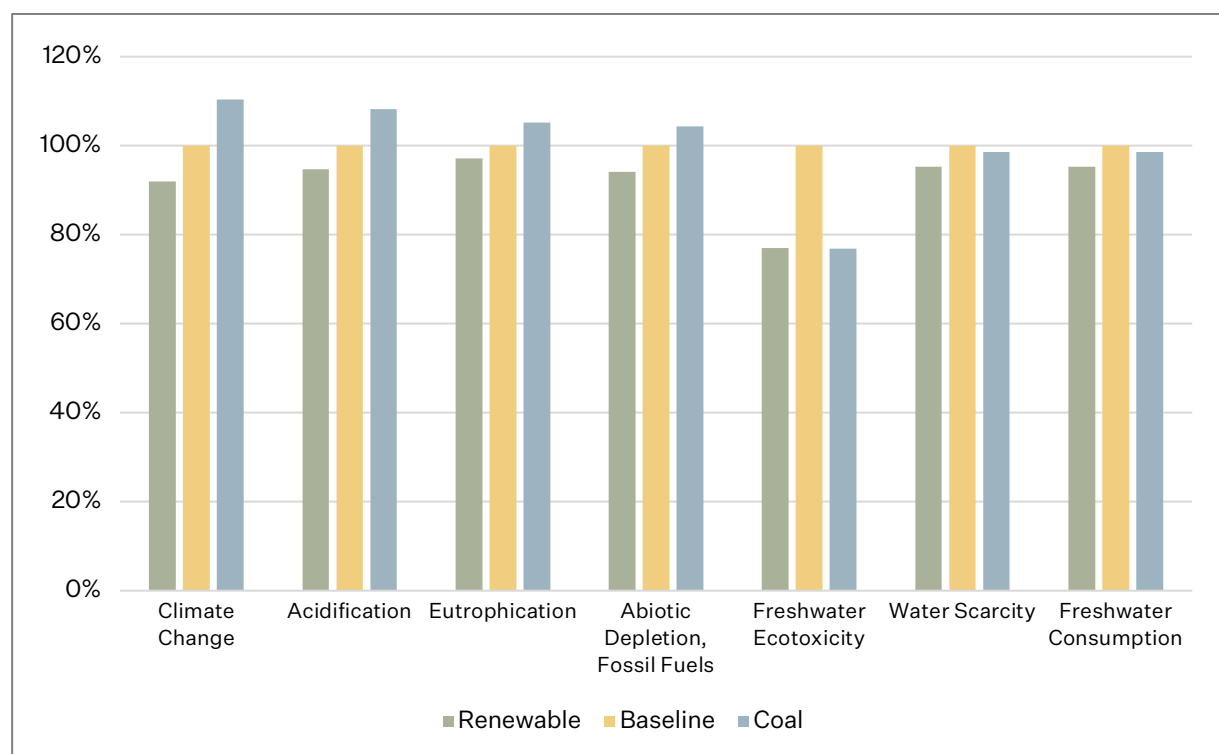
Impact category	Melt production			Staple fiber production			Total		
	Baseline	Renewable Electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	3.41	3.40	0%	1.34	0.956	-28%	4.74	4.36	-8%
AP	1.69x10 ⁻²	1.69x10 ⁻²	0%	8.06x10 ⁻³	6.73x10 ⁻³	-16%	2.49x10 ⁻²	2.36x10 ⁻²	-5%
EP	2.74x10 ⁻²	2.74x10 ⁻²	0%	3.75x10 ⁻³	2.88x10 ⁻³	-23%	3.11x10 ⁻²	3.03x10 ⁻²	-3%
AD	65.1	65.1	0%	17.3	12.5	-28%	82.4	77.5	-6%
FE	6.23x10 ⁻³	6.00x10 ⁻³	-4%	0.138	0.105	-24%	0.144	0.111	-23%
WS	0.665	0.665	0%	0.200	0.159	-20%	0.865	0.824	-5%
FC	1.55x10 ⁻²	1.55x10 ⁻²	0%	4.71x10 ⁻³	3.77x10 ⁻³	-20%	2.02x10 ⁻²	1.93x10 ⁻²	-5%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 103: Virgin staple fiber SF1—Scenario "Electricity—Coal"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	3.41	3.41	0%	1.34	1.82	37%	4.74	5.24	10%
AP	1.69x10 ⁻²	1.69x10 ⁻²	0%	8.06x10 ⁻³	1.01x10 ⁻²	25%	2.49x10 ⁻²	2.70x10 ⁻²	8%
EP	2.74x10 ⁻²	2.74x10 ⁻²	0%	3.75x10 ⁻³	5.36x10 ⁻³	43%	3.11x10 ⁻²	3.28x10 ⁻²	5%
AD	65.1	65.1	0%	17.3	20.9	20%	82.4	86.0	4%
FE	6.23x10 ⁻³	6.00x10 ⁻³	-4%	0.138	0.105	-24%	0.144	0.111	-23%
WS	0.665	0.665	0%	0.200	0.187	-6%	0.865	0.852	-1%
FC	1.55x10 ⁻²	1.55x10 ⁻²	0%	4.71x10 ⁻³	4.42x10 ⁻³	-6%	2.02x10 ⁻²	1.99x10 ⁻²	-1%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 43: Comparison of electricity scenarios for virgin staple fiber SF1**Table 104: Virgin staple fiber SF2—Scenario "Electricity—Renewable"**

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	3.74	3.74	0%	1.19	0.773	-35%	4.93	4.51	-9%
AP	1.85x10 ⁻²	1.85x10 ⁻²	0%	7.63x10 ⁻³	6.17x10 ⁻³	-19%	2.61x10 ⁻²	2.47x10 ⁻²	-6%
EP	3.01x10 ⁻²	3.01x10 ⁻²	0%	5.35x10 ⁻³	4.39x10 ⁻³	-18%	3.54x10 ⁻²	3.44x10 ⁻²	-3%
AD	71.4	71.4	0%	11.8	6.41	-45%	83.2	77.8	-6%
FE	6.84x10 ⁻³	6.58x10 ⁻³	-4%	0.105	6.91x10 ⁻²	-34%	0.112	7.57x10 ⁻²	-32%
WS	0.730	0.730	0%	0.162	0.118	-28%	0.892	0.848	-5%
FC	1.70x10 ⁻²	1.70x10 ⁻²	0%	3.96x10 ⁻³	2.92x10 ⁻³	-26%	2.10x10 ⁻²	1.99x10 ⁻²	-5%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 105: Virgin staple fiber SF2—Scenario "Electricity—Coal"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	3.74	3.74	0%	1.19	1.73	45%	4.93	5.47	11%
AP	1.85x10 ⁻²	1.85x10 ⁻²	0%	7.63x10 ⁻³	9.87x10 ⁻³	29%	2.61x10 ⁻²	2.84x10 ⁻²	9%
EP	3.01x10 ⁻²	3.01x10 ⁻²	0%	5.35x10 ⁻³	7.11x10 ⁻³	33%	3.54x10 ⁻²	3.72x10 ⁻²	5%
AD	71.4	71.5	0%	11.8	15.7	33%	83.2	87.1	5%

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
FE	6.84×10^{-3}	6.58×10^{-3}	-4%	0.105	6.90×10^{-2}	-34%	0.112	7.56×10^{-2}	-33%
WS	0.730	0.730	0%	0.162	0.148	-9%	0.892	0.878	-2%
FC	1.70×10^{-2}	1.70×10^{-2}	0%	3.96×10^{-3}	3.64×10^{-3}	-8%	2.10×10^{-2}	2.06×10^{-2}	-2%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 44: Comparison of electricity scenarios for virgin staple fiber SF2

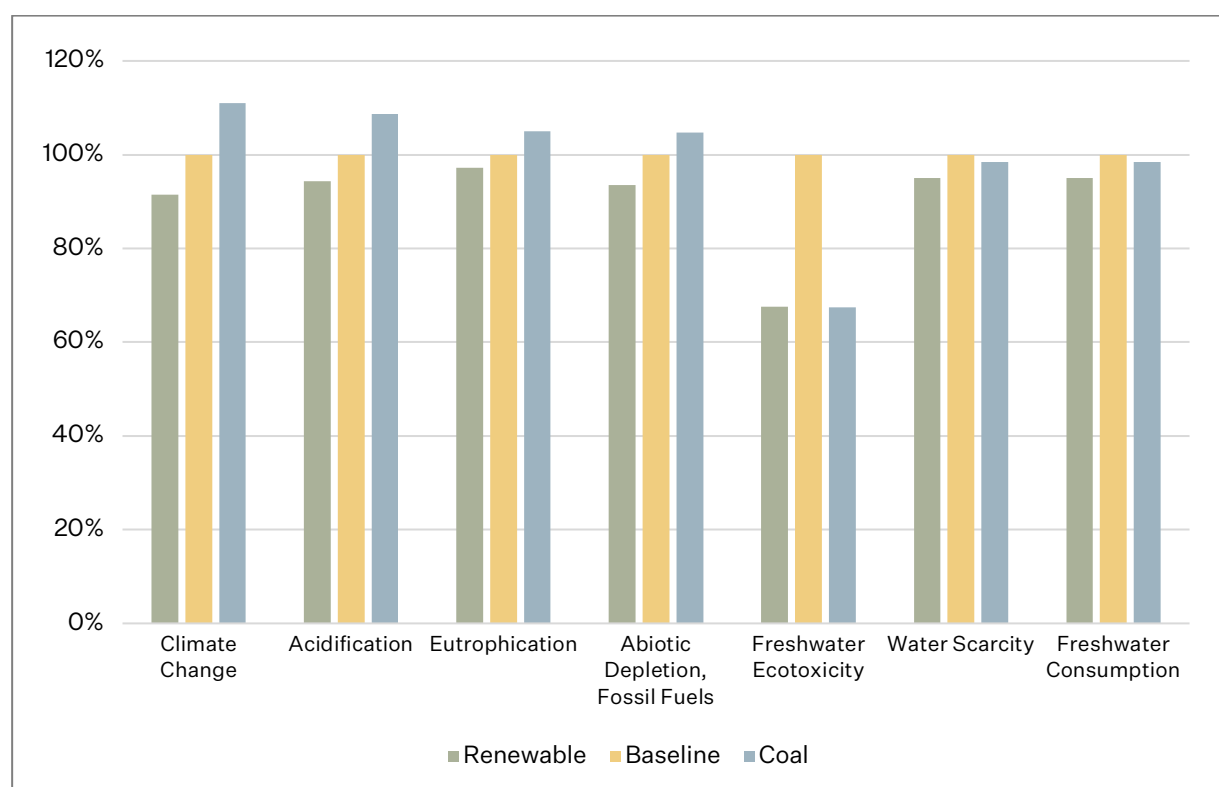


Table 106: Virgin staple fiber SF3—Scenario "Electricity—Renewable"

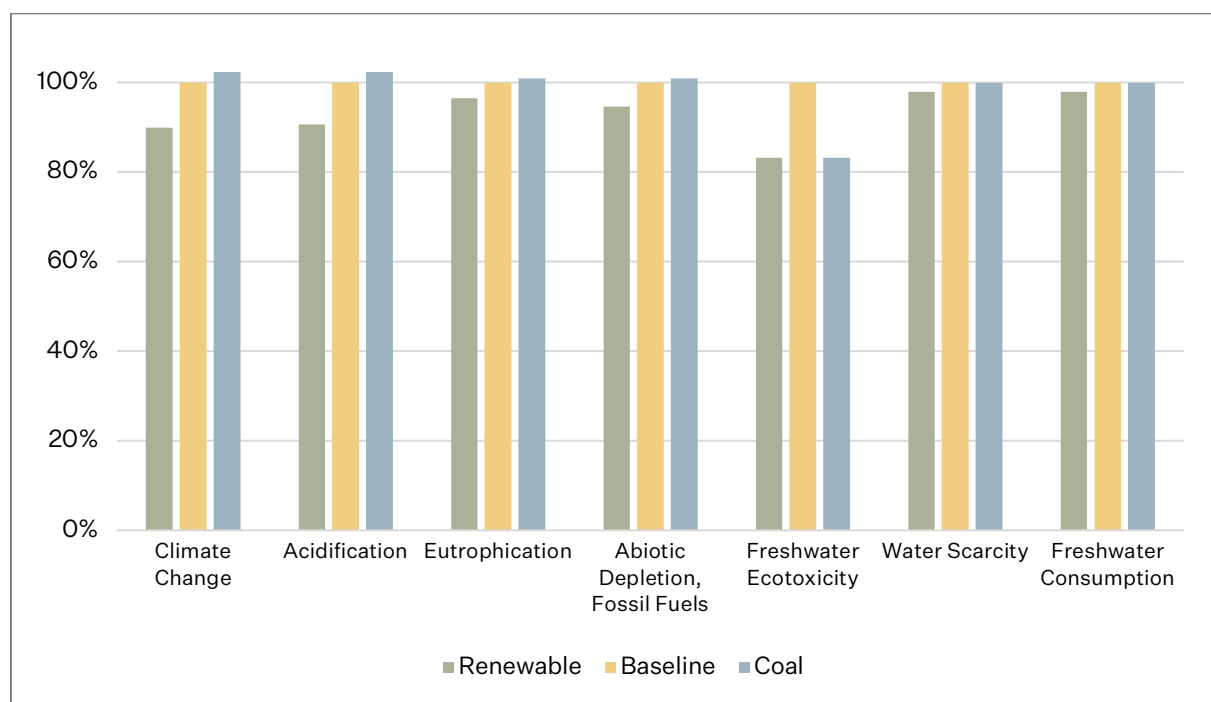
Impact category	Melt production			Staple fiber production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	3.39	3.25	-4%	0.577	0.312	-46%	3.96	3.57	-10%
AP	1.40×10^{-2}	1.35×10^{-2}	-4%	2.13×10^{-3}	1.12×10^{-3}	-47%	1.61×10^{-2}	1.46×10^{-2}	-9%
EP	2.98×10^{-2}	2.94×10^{-2}	-1%	1.35×10^{-3}	6.10×10^{-4}	-55%	3.12×10^{-2}	3.01×10^{-2}	-4%
AD	69.8	68.4	-2%	6.56	3.84	-41%	76.3	72.3	-5%
FE	8.24×10^{-3}	6.53×10^{-3}	-21%	2.26×10^{-2}	1.91×10^{-2}	-15%	3.08×10^{-2}	2.57×10^{-2}	-17%
WS	0.714	0.709	-1%	5.07×10^{-2}	4.00×10^{-2}	-21%	0.765	0.749	-2%
FC	1.66×10^{-2}	1.65×10^{-2}	-1%	1.20×10^{-3}	9.49×10^{-4}	-21%	1.78×10^{-2}	1.75×10^{-2}	-2%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 107: Virgin staple fiber SF3—Scenario "Electricity—Coal"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	3.39	3.42	1%	0.577	0.639	11%	3.96	4.06	2%
AP	1.40×10^{-2}	1.41×10^{-2}	1%	2.13×10^{-3}	2.39×10^{-3}	12%	1.61×10^{-2}	1.65×10^{-2}	2%
EP	2.98×10^{-2}	2.99×10^{-2}	0%	1.35×10^{-3}	1.55×10^{-3}	15%	3.12×10^{-2}	3.15×10^{-2}	1%
AD	69.8	70.0	0%	6.56	7.02	7%	76.3	77.0	1%
FE	8.24×10^{-3}	6.52×10^{-3}	-21%	2.26×10^{-2}	1.91×10^{-2}	-15%	3.08×10^{-2}	2.56×10^{-2}	-17%
WS	0.714	0.714	0%	5.07×10^{-2}	5.05×10^{-2}	0%	0.765	0.765	0%
FC	1.66×10^{-2}	1.66×10^{-2}	0%	1.20×10^{-3}	1.19×10^{-3}	0%	1.78×10^{-2}	1.78×10^{-2}	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 45: Comparison of electricity scenarios for virgin staple fiber SF3

6.1.3.2. Partially oriented yarn results (black POY)

Table 108: Black virgin POY—Scenario "Electricity—Renewable"

Impact category	Chip production			POY production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
CC	3.56	3.42	-4%	1.87	0.338	-82%	5.44	3.76	-31%
AP	1.49×10^{-2}	1.43×10^{-2}	-4%	7.27×10^{-3}	1.42×10^{-3}	-80%	2.21×10^{-2}	1.57×10^{-2}	-29%
EP	3.14×10^{-2}	3.10×10^{-2}	-1%	5.08×10^{-3}	7.98×10^{-4}	-84%	3.65×10^{-2}	3.18×10^{-2}	-13%
AD	73.4	72.0	-2%	19.4	3.68	-81%	92.8	75.7	-18%

Impact category	Chip production			POY production			Total		
	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff	Baseline	Renewable electricity	% Diff
FE	8.67×10^{-3}	6.87×10^{-3}	-21%	6.93×10^{-2}	4.93×10^{-2}	-29%	7.79×10^{-2}	5.62×10^{-2}	-28%
WS	0.752	0.746	-1%	0.204	0.143	-30%	0.956	0.889	-7%
FC	1.75×10^{-2}	1.74×10^{-2}	-1%	4.76×10^{-3}	3.32×10^{-3}	-30%	2.23×10^{-2}	2.07×10^{-2}	-7%

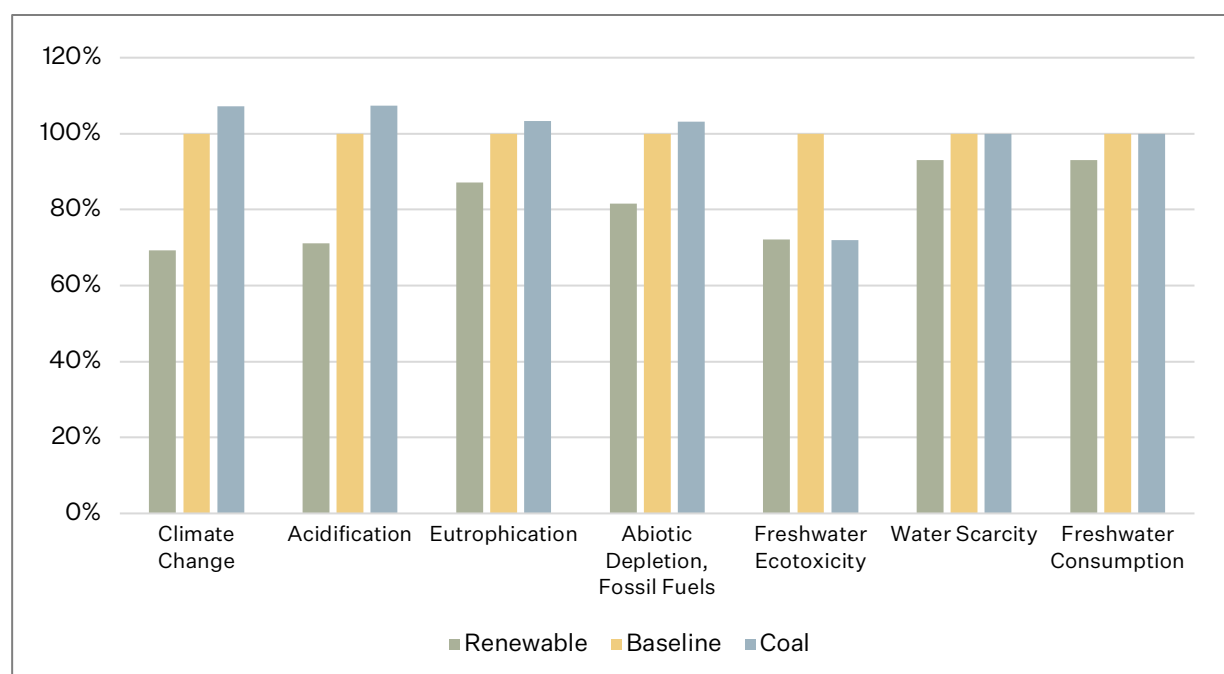
Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 109: Black virgin POY—Scenario "Electricity—Coal"

Impact category	Chip production			POY production			Total		
	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff	Baseline	Coal Electricity	% Diff
CC	3.56	3.60	1%	1.87	2.23	19%	5.44	5.83	7%
AP	1.49×10^{-2}	1.50×10^{-2}	1%	7.27×10^{-3}	8.75×10^{-3}	20%	2.21×10^{-2}	2.37×10^{-2}	7%
EP	3.14×10^{-2}	3.15×10^{-2}	0%	5.08×10^{-3}	6.21×10^{-3}	22%	3.65×10^{-2}	3.77×10^{-2}	3%
AD	73.4	73.6	0%	19.4	22.0	14%	92.8	95.7	3%
FE	8.67×10^{-3}	6.86×10^{-3}	-21%	6.93×10^{-2}	4.92×10^{-2}	-29%	7.79×10^{-2}	5.60×10^{-2}	-28%
WS	0.752	0.751	0%	0.204	0.203	-1%	0.956	0.955	0%
FC	1.75×10^{-2}	1.75×10^{-2}	0%	4.76×10^{-3}	4.73×10^{-3}	-1%	2.23×10^{-2}	2.22×10^{-2}	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 46: Comparison of electricity scenarios for black virgin POY



6.1.3.3. Drawn textured yarn results (white DTY)**Table 110: White virgin DTY—Scenario "Electricity—Renewable"**

Impact	Melt production			POY production			DTY production			Total		
	Base	RE	%	Base	RE	%	Base	RE	%	Base	RE	%
CC	3.43	3.30	-4%	0.719	6.99x10 ⁻²	-90%	1.68	0.146	-91%	5.83	3.51	-40%
AP	1.43x10 ⁻²	1.38x10 ⁻²	-4%	2.81x10 ⁻³	3.37x10 ⁻⁴	-88%	6.63x10 ⁻³	7.92x10 ⁻⁴	-88%	2.37x10 ⁻²	1.49x10 ⁻²	-37%
EP	3.02x10 ⁻²	2.98x10 ⁻²	-1%	2.07x10 ⁻³	2.66x10 ⁻⁴	-87%	4.83x10 ⁻³	5.61x10 ⁻⁴	-88%	3.71x10 ⁻²	3.07x10 ⁻²	-17%
AD	70.6	69.3	-2%	7.47	0.830	-89%	17.2	1.52	-91%	95.3	71.6	-25%
FE	8.35x10 ⁻³	6.61x10 ⁻³	-21%	1.22x10 ⁻²	3.77x10 ⁻³	-69%	0.256	0.236	-8%	0.277	0.247	-11%
WS	0.723	0.718	-1%	7.37x10 ⁻²	4.77x10 ⁻²	-35%	0.259	0.197	-24%	1.06	0.962	-9%
FC	1.68x10 ⁻²	1.67x10 ⁻²	-1%	1.72x10 ⁻³	1.11x10 ⁻³	-35%	6.02x10 ⁻³	4.58x10 ⁻³	-24%	2.46x10 ⁻²	2.24x10 ⁻²	-9%

Abbreviations: Base = Baseline; RE = Renewable Electricity.

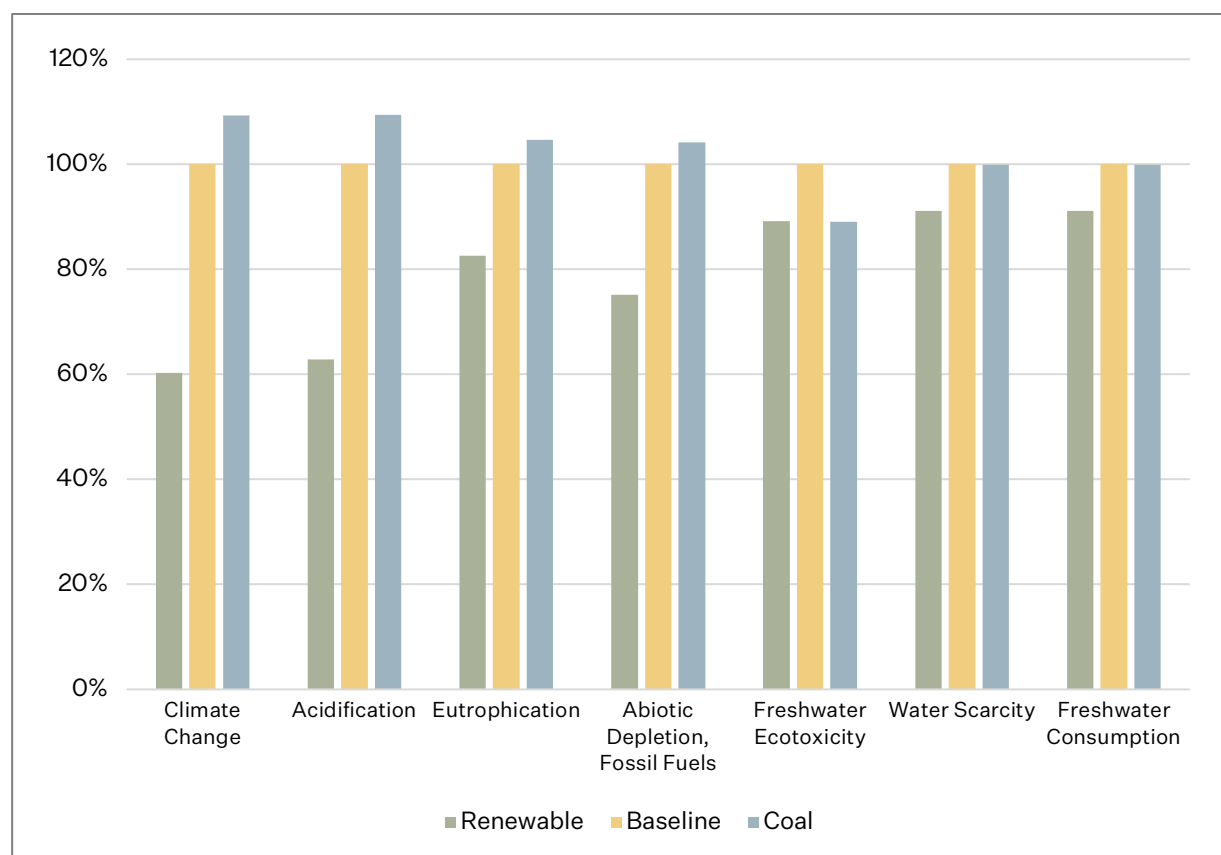
"%" indicates the percentage difference between baseline and scenario results.

Table 111: White virgin DTY—Scenario "Electricity—Coal"

Impact	Melt production			POY production			DTY production			Total		
	Base	Coal	%	Base	Coal	%	Base	Coal	%	Base	Coal	%
CC	3.43	3.46	1%	0.719	0.870	21%	1.68	2.04	21%	5.83	6.37	9%
AP	1.43x10 ⁻²	1.44x10 ⁻²	1%	2.81x10 ⁻³	3.43x10 ⁻³	22%	6.63x10 ⁻³	8.11x10 ⁻³	22%	2.37x10 ⁻²	2.60x10 ⁻²	9%
EP	3.02x10 ⁻²	3.03x10 ⁻²	0%	2.07x10 ⁻³	2.55x10 ⁻³	23%	4.83x10 ⁻³	5.97x10 ⁻³	23%	3.71x10 ⁻²	3.88x10 ⁻²	5%
AD	70.6	70.8	0%	7.47	8.59	15%	17.2	19.9	15%	95.3	99.3	4%
FE	8.35x10 ⁻³	6.60x10 ⁻³	-21%	1.22x10 ⁻²	3.71x10 ⁻³	-70%	0.256	0.236	-8%	0.277	0.247	-11%
WS	0.723	0.723	0%	7.37x10 ⁻²	7.33x10 ⁻²	-1%	0.259	0.257	0%	1.06	1.05	0%
FC	1.68x10 ⁻²	1.68x10 ⁻²	0%	1.72x10 ⁻³	1.71x10 ⁻³	-1%	6.02x10 ⁻³	5.99x10 ⁻³	0%	2.46x10 ⁻²	2.45x10 ⁻²	0%

Abbreviations: Impact = Impact Category; Base = Baseline; Coal = Coal Electricity.

"%" indicates the percentage difference between baseline and scenario results.

Figure 47: Comparison of electricity scenarios for white virgin DTY

6.2. Truck transport scenarios

For each recycler included in the study, there are two legs of transport: feedstock collection and raw material transport. Feedstock collection covers the gathering of waste feedstock, while raw material transport refers to moving the raw materials to the recycling facility (for example, chemicals and waste feedstock). Primary data was available for nearly all raw material transport; however, there was a lack of data on the upstream collection of waste feedstock for data providers C3 and M2. In addition, the relatively large mass of waste feedstock required for recycling and the, at times, long upstream collection distances, mean that upstream collection of feedstock can be a significant contributor to overall environmental impact. This, coupled with the large variation in collection distances among the data providers, indicated a need to better understand how the total environmental impact is affected when feedstock collection distances change, as could be the case with improved data or if the recycling technology is operated in different geographic locations. Therefore, this analysis focuses exclusively on the transport associated with feedstock collection.

Within feedstock collection, truck transport was the sole focus of this scenario. While ship transport can be part of the upstream supply chain, it is not relevant for the data providers in this project, as truck transport contributes substantially more to environmental impact per ton-kilometer. Ships have a lower impact per ton-kilometer because they can transport significantly more mass using less fuel than trucks. In addition, the transport scenario only focuses on recycling technologies. Virgin production of PET is excluded from this sensitivity analysis, as transport of raw materials was a negligible contribution to total impact.

For each chemical and thermomechanical recycler, a high and low truck transport scenario was modeled. Similar to the electricity scenarios, these transport scenarios were created to

understand how the likely minimum and maximum environmental impact from upstream PET waste transport could affect the results, with the high intensity scenario representing the worst environmental impact and the low intensity scenario representing the opposite.

Emissions from fuel combustion

In addition to varying the waste collection distance, the high and low intensity scenarios also varied with the cleanliness of truck engines and the resulting emissions from fuel combustion using the EURO emission standards present in the ecoinvent database; all transport was modeled using secondary datasets from the ecoinvent database.

The ecoinvent database, while international in scope, was founded in Europe and is European focused, and uses the EURO emission standards to represent the quantity and type of vehicle emissions from fuel combustion. The EURO emission standards are a set of emission standards that regulate pollutants (like carbon dioxide and particulate matter) released by vehicles into the atmosphere (European Automobile Manufacturers' Association, 2022). The EURO 1 standard was introduced in 1992 and represents the oldest and least stringent standard. The latest standard, EURO 6, was introduced in 2014 and is the most stringent standard for vehicles, representing the least pollution. Since the ecoinvent database only uses the EURO standards for transport datasets, emission standards for transport processes in all regions included in this study are assumed to fall between EURO 1 and EURO 6.

While the EURO emission standards are the only ones used within the transport datasets, non-European datasets exist that change other parameters (fuel specs, routing/loads, market transport distances, production of the vehicles) based on the region selected. In this study, a European truck transport dataset is used to represent all truck transport for recycler C3 (Table 23), while a Rest-of-World (RoW) truck transport dataset is used for all other PET producers (Table 23, Table 41, and Table 64).

For the collection of post-consumer bottle waste in the baseline scenario, the EURO emission standard contained in the ecoinvent dataset for the collection of post-consumer bottle waste was used (shown in Table 112). For the collection of post-consumer and post-industrial textile waste in the baseline scenario, a EURO 4 emission standard was assumed for all truck transport as a conservative average.

The high-intensity scenario uses EURO 3 as the vehicle emission standard for all data providers, which is the most emission-intensive option available within ecoinvent's market transport datasets; a market transport dataset represents the average transport conditions within a given region. While EURO 1 and EURO 2 emission standards are used within some ecoinvent datasets, they are limited to Brazil and South Africa, which are not representative of transport conditions in the data providers' regions. Therefore, the EURO 3 standard is a plausible, lower-bound assumption that reflects older vehicle fleets still in use.

For the low-intensity scenario, the emission standards follow the most stringent emissions currently applicable to each data provider's country at the time this report was prepared. The EURO emission standards used for each data provider are shown in Table 112.

Waste feedstock collection distances

The baseline distances required to collect post-industrial and post-consumer PET textile waste, used in chemical and thermomechanical recycling, were based on a mix of primary data and secondary sources from the literature reviewed, where available. In cases where no data was available, proxy data from ecoinvent was used. For post-consumer bottle waste, used only in thermomechanical recycling, an ecoinvent market dataset was used to represent the transport activity. Distances were based on primary data where available. Otherwise, the default distances in the ecoinvent datasets were used. The ecoinvent market datasets for truck transport represent

average regional transport services, incorporating a weighted mix of transport modes, distances, vehicle types, and emission standards.

The low-intensity scenario transport distances are based solely on the country/region in which each data provider is located, irrespective of the type of waste being collected. For China, this distance was assumed to be 50 km, based on China Association of Urban Environmental Sanitation's publication, which indicates that most cities and counties have areas of 1,000–3,000 square kilometers with average municipal solid waste transport distances between 30 and 50 kilometers (Liu, 2019). Additionally, a study by Chen et al. (2019) on the life cycle assessment of end-of-life treatments of waste plastics in China, also used an estimated transport distance of 50 km for waste plastic mixtures transported to waste treatment (Chen et al., 2019). For Europe and the United States, this distance was assumed to be 32 km, based on the US EPA WARM model (Environmental Protection Agency, 2004). This distance was selected as a default value by the EPA as a reasonable average for local waste collection operations. For Southeast Asia, the low-intensity distance is assumed to be 60 km, based on the Circulate Initiative's report, which uses this value as a default assumption for modeling the collection of plastic waste to waste treatment in Southeast Asian countries (The Circulate Initiative, 2023b).

For the high-intensity scenario, transport distances are generally defined by doubling the values used in the baseline scenario. An exception is made for post-industrial textile waste associated with data provider M1, since doubling the generic baseline value of 77 km, which has a high amount of uncertainty associated with it, is not considered representative of the high-intensity conditions. As demonstrated by data providers C1 and C2, which have an average post-industrial waste collection distance of 967 km and 818 km, respectively (Table 112), post-industrial textile waste may be collected from a much broader geographic range. Thus, for data provider M1, the high-intensity transport distance for post-industrial textile waste is double the baseline transport distance used to collect its respective post-consumer feedstocks. This approach minimizes the chances of underestimating the worst-case transport distance for post-industrial textile waste.

For information on the baseline transport distances, see the Summary of Assumptions sections within the chemical recycling (section 3.3) and thermomechanical recycling (section 4.3).

Table 112 shows all transport distances used in each scenario by each data provider.

Table 112: Parameters for transport scenarios

Data provider	Region	Scenario name	Feedstock type	Transport distance (km)	Emission standard for truck transport
C1	China	Baseline	Post-industrial textiles (100%)	967*	EURO 4
		Low intensity	Post-industrial textiles	50	EURO 6
		High intensity	Post-industrial textiles	1934	EURO 3
C2	China	Baseline	Post-industrial textiles (93%)	818*	EURO 4
		Baseline	Post-consumer textiles (7%)	1200	EURO 4
		Low intensity	Post-consumer and post-industrial textiles	50	EURO 6
		High intensity	Post-industrial textiles	1636	EURO 3
		High intensity	Post-consumer textiles	2400	EURO 3
C3	Europe	Baseline	Post-consumer textiles (100% for post-consumer chip)	310	EURO 4

Data provider	Region	Scenario name	Feedstock type	Transport distance (km)	Emission standard for truck transport
		Baseline	Post-industrial textiles (100% for post-industrial chip)	200	EURO 4
		Low intensity	Post-consumer and post-industrial textiles	32	EURO 6
		High intensity	Post-consumer textiles	620	EURO 3
		High intensity	Post-industrial textiles	400	EURO 3
M1	United States	Baseline	Post-consumer bottles (for post-consumer chip)	216**	EURO 4
		Baseline	Post-consumer bottles (for 50-50 blended chip)	990	EURO 4
		Baseline	Post-industrial textiles (for 50-50 blended chip)	77	EURO 4
		Low intensity	Post-consumer bottles and post-industrial textiles	32	EURO 6
		High intensity	Post-consumer bottles (for post-consumer chip)	432	EURO 3
		High intensity	Post-consumer bottles and post-industrial textiles (for 50-50 blended chip)	1980	EURO 3
M2	China	Baseline	Post-consumer bottles	990	EURO 3 - EURO 6 (ecoinvent default mix)
		Low intensity	Post-consumer bottles	50	EURO 6
		High intensity	Post-consumer bottles	1980	EURO 3
M3	Southeast Asia	Baseline	Post-consumer bottles	100*	EURO 3 - EURO 6 (ecoinvent default mix)
		Low intensity	Post-consumer bottles	60	EURO 5
		High intensity	Post-consumer bottles	200	EURO 3

* Indicates primary data collected from data providers

**Indicates a weighted average of primary and secondary data on collection distances

6.2.1. Chemical recycling transport analysis

As expected, the overall results show that impacts increase across all categories and data providers under the high-intensity scenario, and decrease under the low-intensity scenario (Figure 48–Figure 51). The magnitude of change depends on two key factors: the contribution of textile waste collection transport to each impact category, and the differences in transport distances and emission standards between the baseline and scenario conditions.

Among the impact categories, climate change, acidification, and abiotic depletion of fossil fuels are the impact categories most sensitive to changes in transport parameters across all three data providers. Freshwater ecotoxicity is also sensitive for C2, and shows some sensitivity for C1, but not for C3. In the baseline model, feedstock collection contributes <1% to C3's freshwater ecotoxicity (Figure 9–Figure 10), while it contributes 4% and 13% for C1 (Figure 6) and C2 (Figure 7), respectively. Eutrophication, water scarcity, and freshwater consumption are fairly insensitive. This is explained by the low contribution of upstream textile waste collection in these categories. For example, eutrophication is almost entirely driven by chemical use, which contributes 82–93%

of the impact across all data providers, while feedstock collection contributes $\leq 1\%$. Water scarcity and freshwater consumption are driven by chemical production and electricity use across all data providers, with facility water use being another contributor for C1 and C2. For these two impact categories, textile waste collection accounts for less than 5%. More detail on contribution analysis is provided in Sections 3.5.1.3, 3.5.2.3, and 3.5.3.3.

The magnitude of change also depends on differences between the baseline transport distances and emission standards, and those used under the high- and low-intensity scenarios, with larger differences resulting in greater changes in the results. For instance, C1 and C2 show larger changes in climate change under both high-intensity (+14% and +10%, respectively) and low-intensity (-13 and -10%, respectively) scenarios (Table 115–Table 118). This corresponds to the wide range in transport distances. C1 has a baseline of 967 km, a low-intensity distance of 50 km, and a high-intensity distance of 1,934 km. C2 has a baseline distance of 818 km for post-industrial textile waste and 1,200 km for post-consumer textile waste, a low-intensity distance of 50 km, and a high-intensity distance of 1,636 km for post-industrial and 2,400 km for post-consumer waste. In contrast, C3 shows smaller changes in climate change: from -7% to -5% under low-intensity scenarios and +6% under high-intensity scenarios. The smaller variation in results is due to narrower differences in modeled transport distances. C3's baseline includes 310 km for post-consumer and 200 km for post-industrial textile waste, with scenario distances of 32 km (low intensity), 620 km (high intensity for post-consumer), and 400 km (high intensity for post-industrial).

The emission standard of the truck influences certain environmental impact categories, but its effect plays a relatively small role compared to the effect of transport distance. Table 113 shows the effect of changing from EURO 4 to EURO 3 or EURO 6, per kg-km of truck transport. For most categories—climate change, abiotic depletion of fossil fuels, water scarcity, and freshwater consumption—the percentage differences are small ($\pm 1\text{--}2\%$), indicating low sensitivity to emission standard changes. In contrast, transport distances scale impact linearly, and can vary by orders of magnitude across scenarios, making it a much stronger driver of total transport-related impact.

Emission standards have a more noticeable effect on impact categories related to regulated pollutants. For acidification and eutrophication, more stringent emission standards (for example, EURO 6) reduce outputs of pollutants (for example, NO_x and NH₃), which are major contributors to these impact categories. The change from EURO 4 to EURO 6 lowers acidification by 44–48%, while changing to EURO 3 increases it by 36–38%. Similarly, for eutrophication, stricter limits on nitrogen-based emissions lead to decreases of 26–33% when changing from EURO 4 to EURO 6, and increases of 22–26% when changing to EURO 3.

Freshwater ecotoxicity shows the largest modeled difference, with an increase of 60–62% when changing from EURO 4 to EURO 3. This increase is driven by the elevated emissions of a few toxic substances, most notably acrolein and formaldehyde. As shown in Table 114, acrolein and formaldehyde together account for 43% of the freshwater ecotoxicity under EURO 3 for both the European and Rest-of-World (RoW) datasets, but drop to 7–9% under EURO 4 and 6. The other top contributing substances (pyrene, cumene, fipronil, and phenol) all show relatively consistent absolute contributions across emission standards. However, their percentage contributions increase in EURO 4 and 6, reflecting the reduced total impact, primarily due to the reduced emissions of acrolein and formaldehyde per kg-km truck transport. The results show that improved combustion and emission controls in newer vehicle classes greatly decrease overall freshwater ecotoxicity impacts, even though not all harmful chemicals (such as acrolein and formaldehyde) are reduced by this improved technology.

Overall, this analysis shows that changes in truck transport intensity can greatly affect the impact results, particularly for climate change, acidification, abiotic depletion of fossil fuels, and freshwater ecotoxicity. Upstream transport distances need to be considered when determining the location of a recycling facility or in deciding where to source recycled PET chip. The results also

show that, among changes in distances and emission standards, transport distance has a stronger influence across multiple impact categories. More stringent emission standards help reduce specific pollutant-related impacts (acidification, eutrophication, and freshwater ecotoxicity), but reductions in transport distances—such as through local sourcing—yield broader and more significant reductions across impact categories. Therefore, both emission standards and transport distance should be considered, but the latter remains the dominant factor when assessing the environmental performance of upstream transport for recycled PET chip.

Sections 6.2.1.1–6.2.1.3, below, show the results for the transport scenario analysis for each chemical recycler (Figure 48–Figure 51, Table 115–Table 122).

Table 113: Change (%) in environmental impacts per kg-km of truck transport compared to EURO 4 emission standard (European and Rest-of-World datasets)

Impact category	European dataset			Rest-of-World dataset		
	EURO 3	EURO 4	EURO 6	EURO 3	EURO 4	EURO 6
Climate change (kg CO ₂ eq)	1%	0%	-1%	1%	0%	-1%
Acidification (mol H ⁺ eq)	38%	0%	-48%	36%	0%	-44%
Eutrophication (kg PO ₄ eq)	26%	0%	-33%	22%	0%	-26%
Abiotic depletion, fossil fuels (MJ)	1%	0%	-2%	1%	0%	-2%
Freshwater ecotoxicity (PAF m ³ day)	62%	0%	-2%	60%	0%	-2%
Water scarcity (m ³)	0%	0%	0%	-1%	0%	-1%
Freshwater consumption (m ³)	0%	0%	0%	-1%	0%	-1%

Note: Values represent the relative change (%) in impact when using EURO 3 or EURO 6 datasets compared to EURO 4.

Table 114: Top contributing elementary flows to freshwater ecotoxicity (as % of total impact per kg-km truck transport)

Elementary flow	European dataset			Rest-of-World dataset		
	EURO 3	EURO 4	EURO 6	EURO 3	EURO 4	EURO 6
Acrolein	25%	5%	4%	25%	4%	4%
Formaldehyde	18%	4%	3%	17%	4%	3%
Pyrene	8%	14%	14%	9%	15%	15%
Cumene	7%	11%	12%	7%	11%	12%
Fipronil	5%	7%	8%	6%	9%	9%
Phenol	5%	8%	8%	5%	8%	8%

Note: Values represent percentage contributions to total freshwater ecotoxicity impact (PAF m³ day) per kg-km of truck transport.

6.2.1.1. Data provider C1 results

Table 115: C1—chemically recycled chip—Scenario "Transport—Low Intensity"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.304	6.70x10 ⁻²	-78%	1.46	1.46	0%	1.77	1.53	-13%

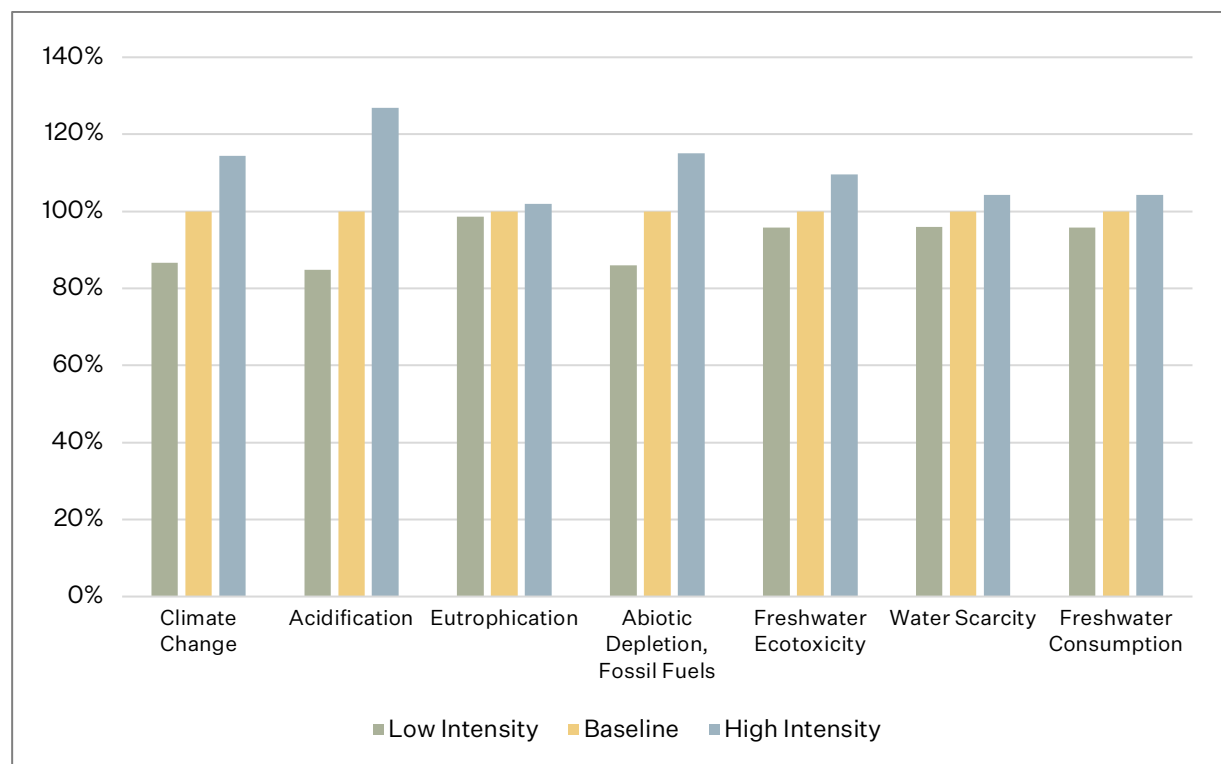
Impact category	Textile shreds production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
AP	1.36×10^{-3}	3.37×10^{-4}	-75%	5.37×10^{-3}	5.37×10^{-3}	0%	6.73×10^{-3}	5.71×10^{-3}	-15%
EP	4.12×10^{-4}	1.11×10^{-4}	-73%	2.25×10^{-2}	2.25×10^{-2}	0%	2.29×10^{-2}	2.26×10^{-2}	-1%
AD	3.96	0.726	-82%	19.1	19.1	0%	23.0	19.8	-14%
FE	2.51×10^{-4}	2.99×10^{-5}	-88%	5.10×10^{-3}	5.10×10^{-3}	0%	5.35×10^{-3}	5.13×10^{-3}	-4%
WS	2.86×10^{-2}	8.69×10^{-3}	-70%	0.458	0.458	0%	0.487	0.467	-4%
FC	6.66×10^{-4}	2.02×10^{-4}	-70%	1.05×10^{-2}	1.05×10^{-2}	0%	1.12×10^{-2}	1.07×10^{-2}	-4%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 116: C1—chemically recycled chip—Scenario "Transport—High Intensity"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	0.304	0.559	84%	1.46	1.46	0%	1.77	2.02	14%
AP	1.36×10^{-3}	3.17×10^{-3}	133%	5.37×10^{-3}	5.37×10^{-3}	0%	6.73×10^{-3}	8.54×10^{-3}	27%
EP	4.12×10^{-4}	8.60×10^{-4}	109%	2.25×10^{-2}	2.25×10^{-2}	0%	2.29×10^{-2}	2.34×10^{-2}	2%
AD	3.96	7.44	88%	19.1	19.1	0%	23.0	26.5	15%
FE	2.51×10^{-4}	7.64×10^{-4}	204%	5.10×10^{-3}	5.10×10^{-3}	0%	5.35×10^{-3}	5.86×10^{-3}	10%
WS	2.86×10^{-2}	4.91×10^{-2}	72%	0.458	0.458	0%	0.487	0.507	4%
FC	6.66×10^{-4}	1.14×10^{-3}	72%	1.05×10^{-2}	1.05×10^{-2}	0%	1.12×10^{-2}	1.16×10^{-2}	4%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 48: Comparison of transport scenarios for chemically recycled chip produced by data provider C1**6.2.1.2. Data provider C2 results****Table 117: C2—chemically recycled chip—Scenario "Transport—Low Intensity"**

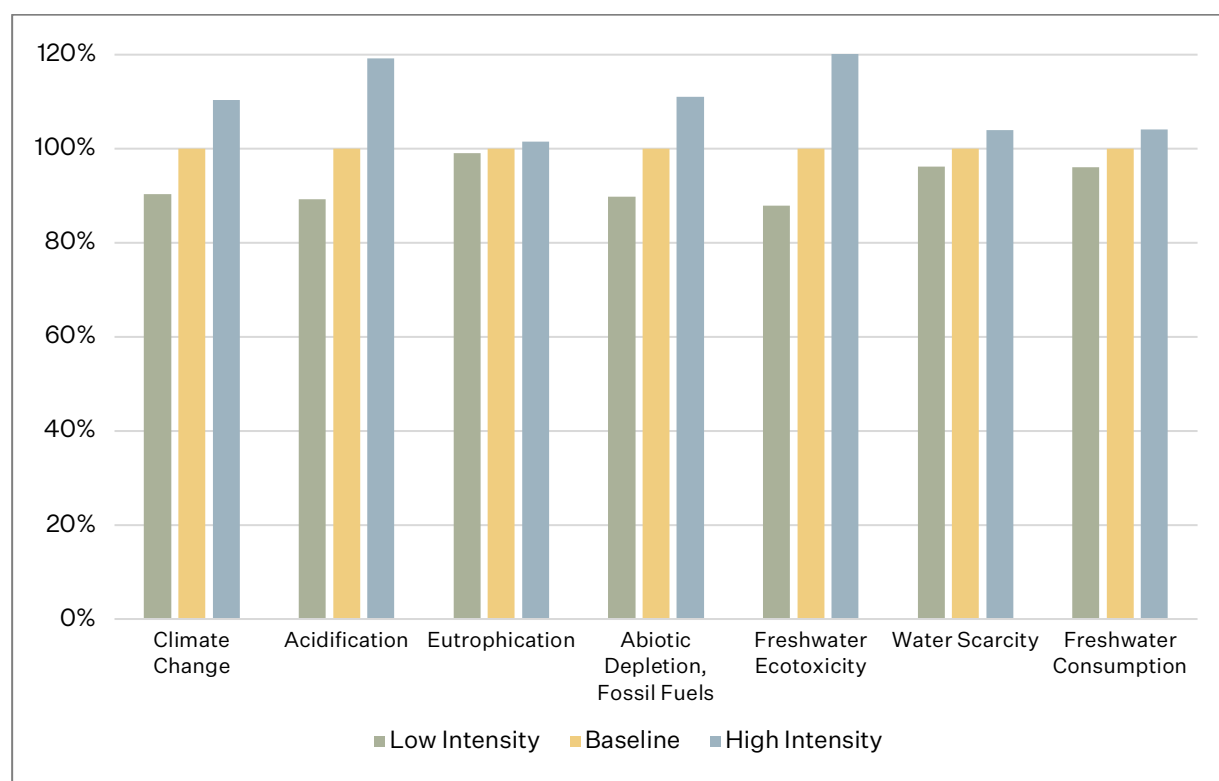
Impact category	Baseline	Low intensity	% Difference
Climate change (kg CO ₂ eq)	2.24	2.02	-10%
Acidification (mol H ⁺ eq)	8.63x10 ⁻³	7.70x10 ⁻³	-11%
Eutrophication (kg PO ₄ eq)	2.81x10 ⁻²	2.78x10 ⁻²	-1%
Abiotic depletion, fossil fuels (MJ)	28.9	26.0	-10%
Freshwater ecotoxicity (PAF m ³ day)	1.67x10 ⁻³	1.46x10 ⁻³	-12%
Water scarcity (m ³ world eq)	0.468	0.450	-4%
Freshwater consumption (m ³)	1.07x10 ⁻²	1.03x10 ⁻²	-4%

Table 118: C2—chemically recycled chip—Scenario "Transport—High Intensity"

Impact category	Baseline	High intensity	% Difference
Climate change (kg CO ₂ eq)	2.24	2.47	10%
Acidification (mol H ⁺ eq)	8.63x10 ⁻³	1.03x10 ⁻²	19%
Eutrophication (kg PO ₄ eq)	2.81x10 ⁻²	2.85x10 ⁻²	1%
Abiotic depletion, fossil fuels (MJ)	28.9	32.1	11%
Freshwater ecotoxicity (PAF m ³ day)	1.67x10 ⁻³	2.13x10 ⁻³	28%
Water scarcity (m ³ world eq)	0.468	0.486	4%

Impact category	Baseline	High intensity	% Difference
Freshwater consumption (m ³)	1.07x10 ⁻²	1.11x10 ⁻²	4%

Figure 49: Comparison of transport scenarios for chemically recycled chip produced by data provider C2



6.2.1.3. Data provider C3 results

Table 119: C3—chemically recycled post-consumer chip—Scenario "Transport—Low Intensity"

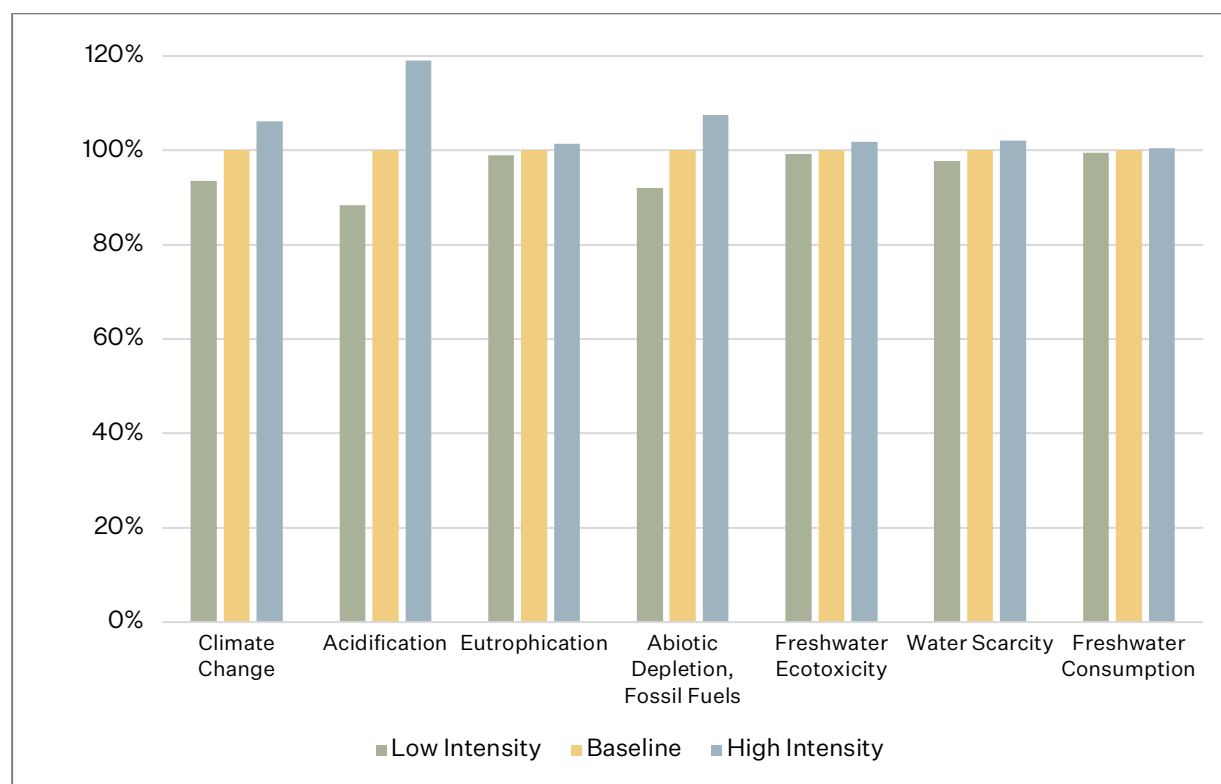
Impact category	Textile shreds production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.522	0.464	-11%	0.364	0.364	0%	0.885	0.828	-7%
AP	1.45x10 ⁻³	1.20x10 ⁻³	-17%	6.69x10 ⁻⁴	6.69x10 ⁻⁴	0%	2.12x10 ⁻³	1.87x10 ⁻³	-12%
EP	5.60x10 ⁻³	5.54x10 ⁻³	-1%	5.37x10 ⁻⁴	5.37x10 ⁻⁴	0%	6.14x10 ⁻³	6.08x10 ⁻³	-1%
AD	6.96	6.16	-12%	3.06	3.06	0%	10.0	9.22	-8%
FE	6.46x10 ⁻³	6.40x10 ⁻³	-1%	1.42x10 ⁻⁴	1.42x10 ⁻⁴	0%	6.60x10 ⁻³	6.54x10 ⁻³	-1%
WS	0.124	0.120	-4%	7.27x10 ⁻²	7.27x10 ⁻²	0%	0.197	0.193	-2%
FC	0.156	0.155	-1%	0.112	0.112	0%	0.268	0.267	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 120: C3—chemically recycled post-consumer chip—Scenario "Transport—High Intensity"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	0.522	0.576	10%	0.364	0.364	0%	0.885	0.940	6%
AP	1.45x10 ⁻³	1.85x10 ⁻³	28%	6.69x10 ⁻⁴	6.69x10 ⁻⁴	0%	2.12x10 ⁻³	2.52x10 ⁻³	19%
EP	5.60x10 ⁻³	5.69x10 ⁻³	2%	5.37x10 ⁻⁴	5.37x10 ⁻⁴	0%	6.14x10 ⁻³	6.23x10 ⁻³	1%
AD	6.96	7.72	11%	3.06	3.06	0%	10.0	10.8	8%
FE	6.46x10 ⁻³	6.58x10 ⁻³	2%	1.42x10 ⁻⁴	1.42x10 ⁻⁴	0%	6.60x10 ⁻³	6.72x10 ⁻³	2%
WS	0.124	0.128	3%	7.27x10 ⁻²	7.27x10 ⁻²	0%	0.197	0.201	2%
FC	0.156	0.157	1%	0.112	0.112	0%	0.268	0.270	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 50: Comparison of transport scenarios for chemically recycled post-consumer chip produced by data provider C3**Table 121: C3—chemically recycled post-industrial chip—Scenario "Transport—Low Intensity"**

Impact category	Flake production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.426	0.395	-7%	0.257	0.257	0%	0.683	0.651	-5%
AP	1.11x10 ⁻³	9.72x10 ⁻⁴	-13%	5.48x10 ⁻⁴	5.48x10 ⁻⁴	0%	1.66x10 ⁻³	1.52x10 ⁻³	-9%
EP	5.37x10 ⁻³	5.33x10 ⁻³	-1%	4.16x10 ⁻⁴	4.16x10 ⁻⁴	0%	5.78x10 ⁻³	5.75x10 ⁻³	-1%

Impact category	Flake production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
AD	5.71	5.27	-8%	2.59	2.59	0%	8.30	7.86	-5%
FE	6.23x10 ⁻³	6.20x10 ⁻³	0%	1.08x10 ⁻⁴	1.08x10 ⁻⁴	0%	6.34x10 ⁻³	6.30x10 ⁻³	0%
WS	0.111	0.108	-2%	6.53x10 ⁻²	6.53x10 ⁻²	0%	0.176	0.174	-1%
FC	0.141	0.140	0%	0.109	0.109	0%	0.250	0.250	0%

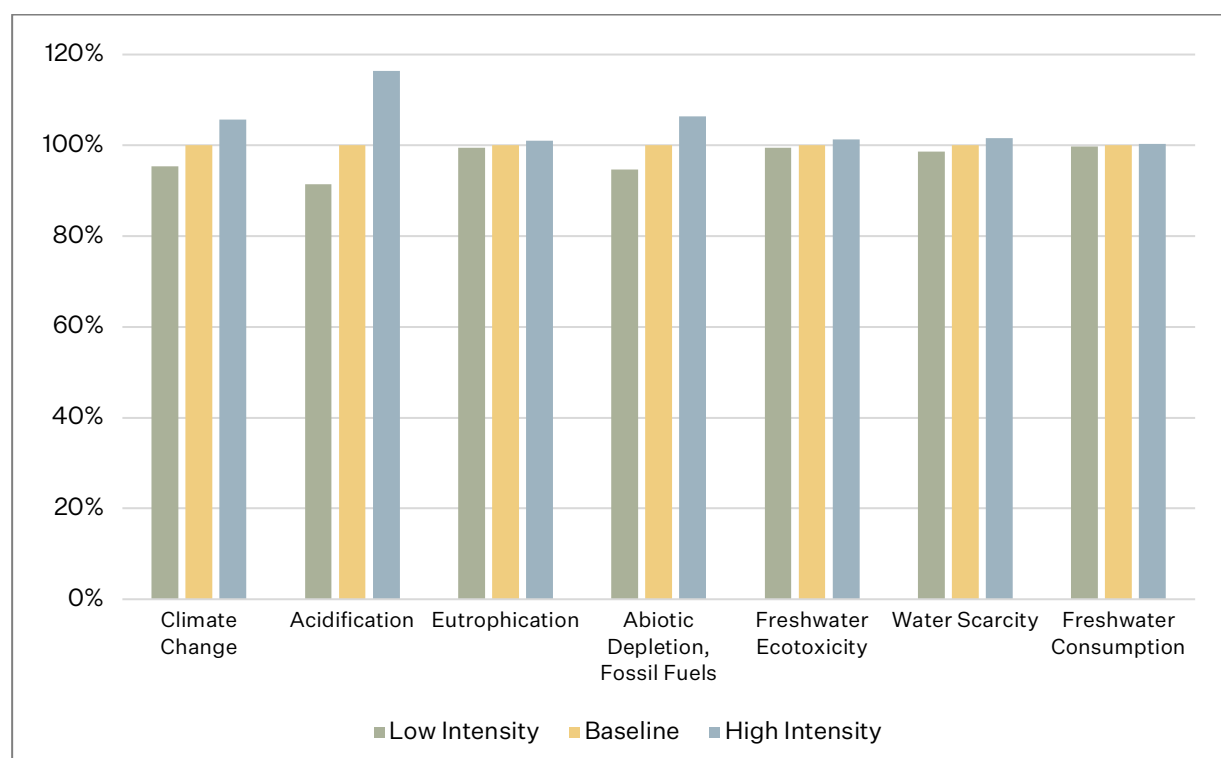
Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 122: C3—chemically recycled post-industrial chip—Scenario " Transport—High Intensity "

Impact category	Flake production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	0.426	0.465	9%	0.257	0.257	0%	0.683	0.722	6%
AP	1.11x10 ⁻³	1.39x10 ⁻³	25%	5.48x10 ⁻⁴	5.48x10 ⁻⁴	0%	1.66x10 ⁻³	1.93x10 ⁻³	16%
EP	5.37x10 ⁻³	5.43x10 ⁻³	1%	4.16x10 ⁻⁴	4.16x10 ⁻⁴	0%	5.78x10 ⁻³	5.84x10 ⁻³	1%
AD	5.71	6.24	9%	2.59	2.59	0%	8.30	8.84	6%
FE	6.23x10 ⁻³	6.31x10 ⁻³	1%	1.08x10 ⁻⁴	1.08x10 ⁻⁴	0%	6.34x10 ⁻³	6.42x10 ⁻³	1%
WS	0.111	0.114	3%	6.53x10 ⁻²	6.53x10 ⁻²	0%	0.176	0.179	2%
FC	0.141	0.142	1%	0.109	0.109	0%	0.250	0.251	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 51: Comparison of transport scenarios for chemically recycled post-industrial chip produced by data provider C3



6.2.2. Thermomechanical recycling transport analysis

Similar to chemical recycling, the results for thermomechanical recycling follow a consistent pattern: impacts for all impact categories increase under the high-intensity transport scenarios and decrease under the low-intensity scenarios (Figure 52–Figure 56). However, the magnitude of change varies.

M1's post-consumer chip and M3's products (chip and staple fiber) show limited sensitivity ($\leq 6\%$ and $\leq 2\%$, respectively; Table 125–Table 128, Table 131–Table 134). This is due to their relatively short baseline transport distances—216 km for M1's post-consumer chip and 100 km for M3's. This causes the changes to collection distances within the low-intensity scenario (32 km for M1 and 60 km for M3) and high-intensity scenario (432 km for M1 and 200 km for M3) to be modest. In addition, M3's staple fiber feedstock collection is not a large contributor to impact ($\leq 13\%$). As a result, total impact changes across scenarios remain small for these three products.

In contrast, M1's 50-50 blended chip and M2's post-consumer chip exhibit higher sensitivity due to greater changes in modeled distances. For M1's 50-50 blended chip, the baseline transport includes 990 km for post-consumer bottle waste and 77 km for post-industrial textile waste. The low-intensity scenario assumes 32 km for both feedstock streams, while the high-intensity scenario increases the distance to 1,980 km. For M2, transport distance changes from a 990 km baseline to 50 km under low intensity and 1,980 km under high intensity. These substantial changes in transport distance, especially under the high-intensity scenario, result in greater variation in total impacts. The most sensitive impact categories are climate change, acidification, and abiotic depletion of fossil fuels (Figure 53–Figure 54). For M1's 50-50 blended chip, these impacts change by -4% to -7% under low intensity (Table 127), and +22% to +30% under high intensity (Table 128). For M2, the same impact categories change by -12% to -16% under low intensity (Table 129), and +14% to +22% under high intensity (Table 130).

Freshwater ecotoxicity, eutrophication, water scarcity, and freshwater consumption are less sensitive to upstream feedstock transport scenarios. It is important to note that feedstock collection includes two components in the ecoinvent dataset: transport, and the production of a low-density polyethylene (LDPE) collection container used for post-consumer PET bottles. The production of the collection container drives impacts in these four categories, outweighing the influence of transport distance or vehicle emission standards. Therefore, these four impact categories show less sensitivity to changes in transport scenarios. Additional details on the collection container can be found in sections 4.5.1.3, 4.5.2.3, and 4.5.3.3.

Additionally, for freshwater ecotoxicity, feedstock collection contributes less than 5% for all product (Figure 16, 18, 21, and Figure 22) except M1 post-consumer chip, where the contribution is 8% (Figure 15). Most of the freshwater ecotoxicity impact is driven by chemical production or by a combination of electricity and chemicals (79–98%). Therefore, the overall change across scenarios is small for freshwater ecotoxicity impacts (-1% to +3%).

The emission results are similar to chemical recycling (section 6.2.1). More stringent emission standards lead to reductions in impact categories associated with regulated pollutants, such as acidification, eutrophication, and freshwater ecotoxicity (Table 123). However, these reductions are relatively small in magnitude compared to the changes across transport distances. Climate change, abiotic depletion of fossil fuels, water scarcity, and freshwater consumption show limited sensitivity to emission standard changes (± 1 –2%). The most notable difference is seen in freshwater ecotoxicity, which decreases by 50% when moving from EURO 3 to EURO 4. This large change is driven by greatly reduced emissions of a few high toxicity chemicals such as acrolein and formaldehyde (Table 124). As with chemical recycling, these findings show that transport distance is generally the dominant driver of upstream transport-related impacts in thermomechanical recycling, while emission standards have more targeted effects on pollutant-sensitive impact categories. Both transport distance and the emission standard should be considered in supplier

evaluations, but reducing transport distance will typically result in a greater reduction across most environmental impact categories.

Sections 6.2.2.1–6.2.2.3, below, show the results for the transport scenario analysis for each thermomechanical recycler (Figure 52–Figure 56, Table 125–Table 134).

Table 123: Change (%) in environmental impacts per kg-km of truck transport compared to EURO 4 emission standard

Impact category	EURO 3	EURO 4	EURO 5	EURO 6
Climate change (kg CO ₂ eq)	2%	0%	1%	-3%
Acidification (mol H ⁺ eq)	39%	0%	-17%	-39%
Eutrophication (kg PO ₄ eq)	24%	0%	-9%	-23%
Abiotic depletion, fossil fuels (MJ)	2%	0%	0%	0%
Freshwater ecotoxicity (PAF m ³ day)	50%	0%	0%	-1%
Water scarcity (m ³)	-1%	0%	-1%	0%
Freshwater consumption (m ³)	-1%	0%	-1%	0%

Note: Values represent the relative change (%) in impact when using EURO 3, EURO 5, or EURO 6 datasets compared to EURO 4.

Table 124: Top contributing elementary flows to freshwater ecotoxicity (as % of total impact per kg-km truck transport)

Elementary flow	EURO 3	EURO 4	EURO 5	EURO 6
Acrolein	22%	4%	4%	4%
Formaldehyde	16%	4%	4%	3%
Pyrene	8%	13%	13%	13%
Cumene	8%	12%	12%	12%
Phenol	6%	8%	8%	8%
Fipronil	5%	8%	8%	8%

Note: Values represent percentage contributions to total freshwater ecotoxicity impact (PAF m³ day) per kg-km of truck transport.

6.2.2.1. Data provider M1 results

Table 125: M1—thermomechanically recycled post-consumer chip—Scenario "Transport—Low Intensity"

Impact category	Flake production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.716	0.698	-3%	0.243	0.243	0%	0.959	0.941	-2%
AP	3.00x10 ⁻³	2.86x10 ⁻³	-4%	1.89x10 ⁻³	1.89x10 ⁻³	0%	4.89x10 ⁻³	4.76x10 ⁻³	-3%
EP	4.23x10 ⁻³	4.19x10 ⁻³	-1%	8.72x10 ⁻⁴	8.72x10 ⁻⁴	0%	5.10x10 ⁻³	5.06x10 ⁻³	-1%
AD	8.33	7.91	-5%	3.10	3.10	0%	11.4	11.0	-4%
FE	6.67x10 ⁻³	6.65x10 ⁻³	0%	5.29x10 ⁻⁴	5.30x10 ⁻⁴	0%	7.20x10 ⁻³	7.18x10 ⁻³	0%
WS	0.173	0.171	-1%	0.121	0.121	0%	0.294	0.292	-1%

Impact category	Flake production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
FC	4.19×10^{-2}	4.13×10^{-2}	-2%	8.60×10^{-3}	8.60×10^{-3}	0%	5.05×10^{-2}	4.99×10^{-2}	-1%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 126: M1—thermomechanically recycled post-consumer chip—Scenario "Transport—High Intensity"

Impact category	Flake production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	0.716	0.764	7%	0.243	0.243	0%	0.959	1.01	5%
AP	3.00×10^{-3}	3.26×10^{-3}	9%	1.89×10^{-3}	1.89×10^{-3}	0%	4.89×10^{-3}	5.16×10^{-3}	6%
EP	4.23×10^{-3}	4.30×10^{-3}	2%	8.72×10^{-4}	8.72×10^{-4}	0%	5.10×10^{-3}	5.17×10^{-3}	1%
AD	8.33	8.85	6%	3.10	3.10	0%	11.4	12.0	5%
FE	6.67×10^{-3}	6.74×10^{-3}	1%	5.29×10^{-4}	5.30×10^{-4}	0%	7.20×10^{-3}	7.27×10^{-3}	1%
WS	0.173	0.177	2%	0.121	0.121	0%	0.294	0.298	1%
FC	4.19×10^{-2}	4.27×10^{-2}	2%	8.60×10^{-3}	8.60×10^{-3}	0%	5.05×10^{-2}	5.13×10^{-2}	2%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 52: Comparison of transport scenarios for thermomechanically recycled post-consumer chip produced by data provider M1

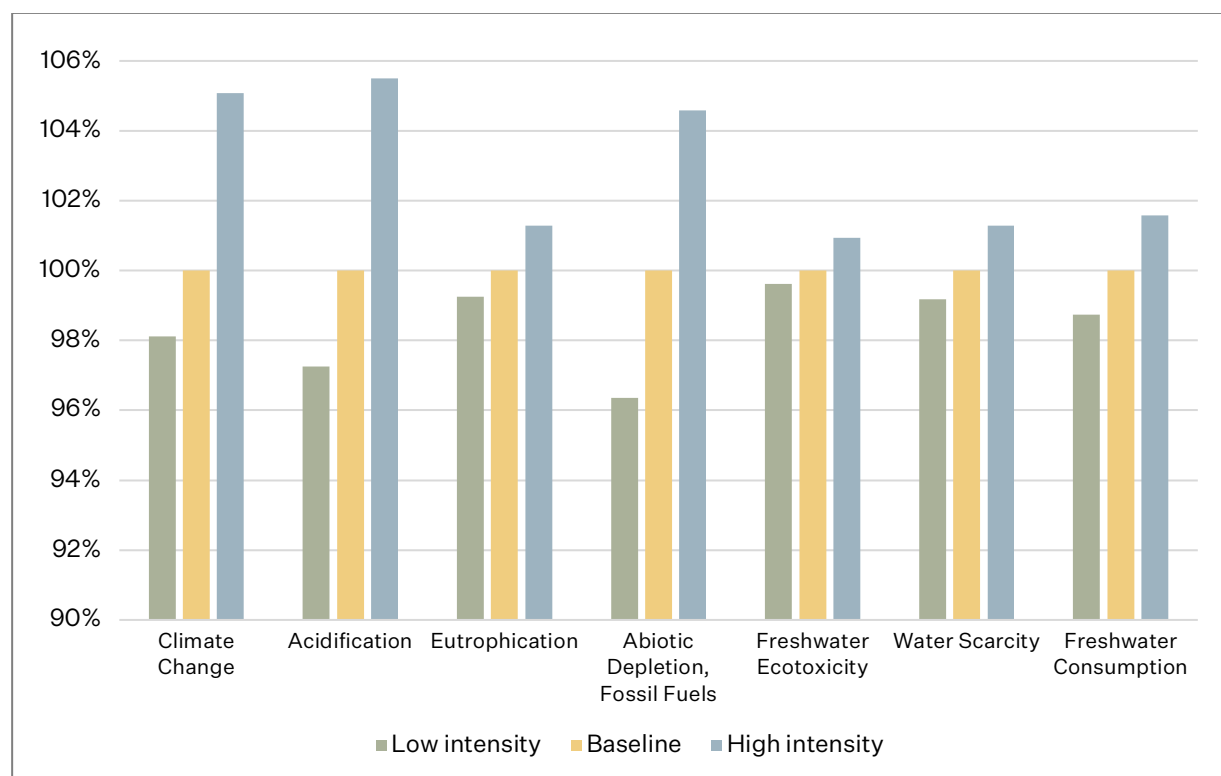


Table 127: M1—thermomechanically recycled 50-50 blended chip—Scenario "Transport—Low Intensity"

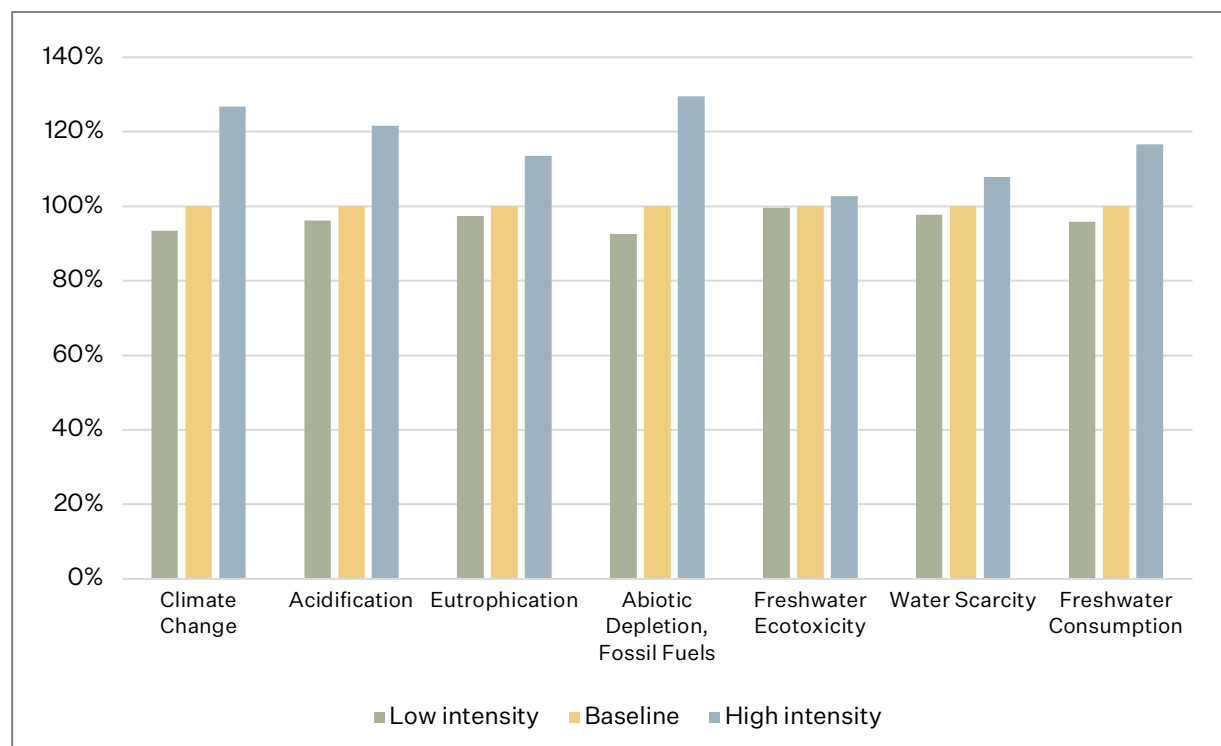
Impact category	Flake production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.367	0.298	-19%	0.708	0.706	0%	1.07	1.00	-7%
AP	2.33×10^{-3}	2.04×10^{-3}	-12%	5.77×10^{-3}	5.75×10^{-3}	0%	8.10×10^{-3}	7.80×10^{-3}	-4%
EP	1.82×10^{-3}	1.74×10^{-3}	-5%	1.54×10^{-3}	1.53×10^{-3}	0%	3.36×10^{-3}	3.27×10^{-3}	-3%
AD	4.33	3.37	-22%	9.03	9.00	0%	13.4	12.4	-7%
FE	1.59×10^{-2}	1.58×10^{-2}	0%	3.70×10^{-4}	3.68×10^{-4}	0%	1.62×10^{-2}	1.62×10^{-2}	0%
WS	9.11×10^{-2}	8.46×10^{-2}	-7%	0.230	0.230	0%	0.321	0.315	-2%
FC	2.37×10^{-2}	2.22×10^{-2}	-6%	1.21×10^{-2}	1.21×10^{-2}	0%	3.58×10^{-2}	3.43×10^{-2}	-4%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 128: M1—thermomechanically recycled 50-50 blended chip—Scenario "Transport—High Intensity"

Impact category	Flake production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	0.367	0.440	20%	0.708	0.921	30%	1.07	1.36	27%
AP	2.33×10^{-3}	2.87×10^{-3}	23%	5.77×10^{-3}	6.99×10^{-3}	21%	8.10×10^{-3}	9.85×10^{-3}	22%
EP	1.82×10^{-3}	1.95×10^{-3}	7%	1.54×10^{-3}	1.86×10^{-3}	21%	3.36×10^{-3}	3.82×10^{-3}	14%
AD	4.33	5.37	24%	9.03	11.9	32%	13.4	17.3	30%
FE	1.59×10^{-2}	1.60×10^{-2}	1%	3.70×10^{-4}	6.90×10^{-4}	87%	1.62×10^{-2}	1.67×10^{-2}	3%
WS	9.12×10^{-2}	9.79×10^{-2}	7%	0.214	0.232	8%	0.305	0.330	8%
FC	2.37×10^{-2}	2.52×10^{-2}	7%	1.21×10^{-2}	1.65×10^{-2}	36%	3.58×10^{-2}	4.18×10^{-2}	17%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 53: Comparison of transport scenarios for thermomechanically recycled 50-50 blended chip produced by data provider M1**6.2.2.2. Data provider M2 results****Table 129: M2—thermomechanically recycled chip—Scenario "Transport—Low Intensity"**

Impact category	Flake production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.879	0.723	-18%	0.321	0.321	0%	1.20	1.04	-13%
AP	3.57×10^{-3}	2.90×10^{-3}	-19%	2.12×10^{-3}	2.12×10^{-3}	0%	5.69×10^{-3}	5.02×10^{-3}	-12%
EP	4.45×10^{-3}	4.25×10^{-3}	-4%	9.91×10^{-4}	9.91×10^{-4}	0%	5.44×10^{-3}	5.25×10^{-3}	-4%
AD	10.3	8.14	-21%	3.21	3.21	0%	13.6	11.3	-16%
FE	2.64×10^{-2}	2.62×10^{-2}	-1%	3.68×10^{-4}	3.68×10^{-4}	0%	2.67×10^{-2}	2.66×10^{-2}	-1%
WS	0.163	0.149	-9%	0.103	0.103	0%	0.266	0.251	-6%
FC	3.70×10^{-3}	3.35×10^{-3}	-9%	2.36×10^{-3}	2.36×10^{-3}	0%	6.05×10^{-3}	5.70×10^{-3}	-6%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

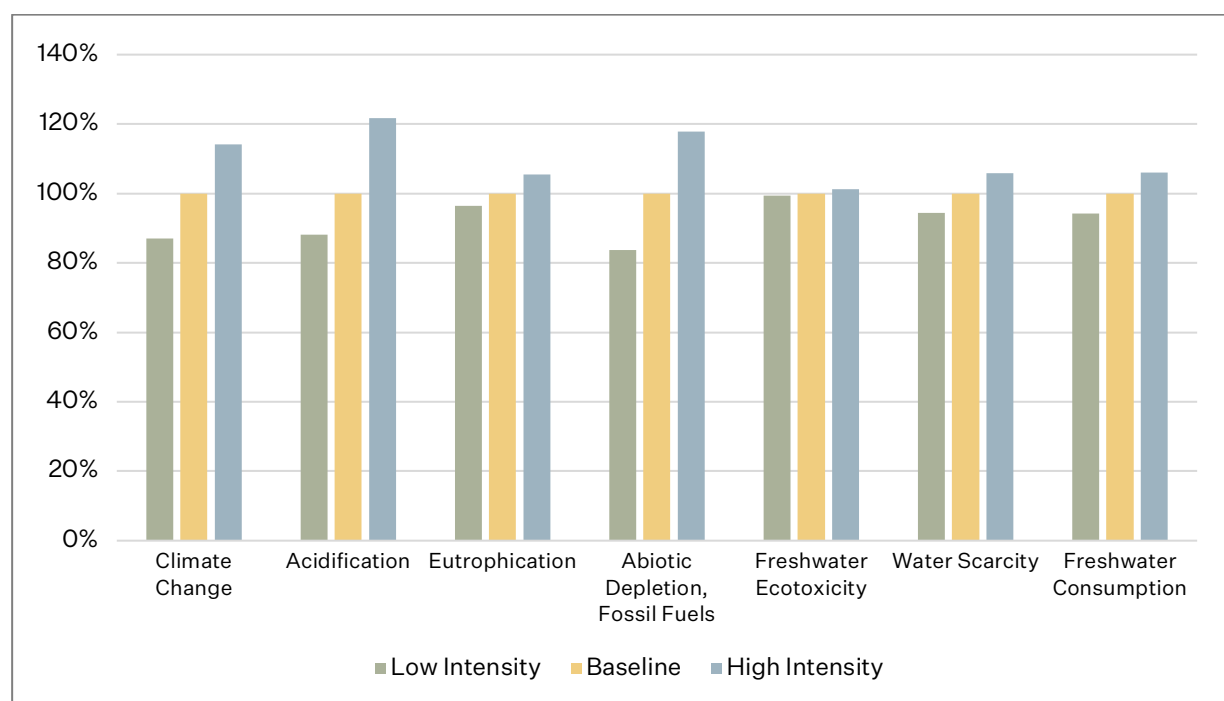
Table 130: M2—thermomechanically recycled chip—Scenario "Transport—High Intensity"

Impact category	Flake production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	0.879	1.05	19%	0.321	0.321	0%	1.20	1.37	14%
AP	3.57×10^{-3}	4.80×10^{-3}	35%	2.12×10^{-3}	2.12×10^{-3}	0%	5.69×10^{-3}	6.93×10^{-3}	22%

Impact category	Flake production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
EP	4.45×10^{-3}	4.75×10^{-3}	7%	9.91×10^{-4}	9.91×10^{-4}	0%	5.44×10^{-3}	5.74×10^{-3}	6%
AD	10.3	12.8	23%	3.21	3.21	0%	13.6	16.0	18%
FE	2.64×10^{-2}	2.67×10^{-2}	1%	3.68×10^{-4}	3.68×10^{-4}	0%	2.67×10^{-2}	2.70×10^{-2}	1%
WS	0.163	0.179	9%	0.103	0.103	0%	0.266	0.282	6%
FC	3.70×10^{-3}	4.06×10^{-3}	10%	2.36×10^{-3}	2.36×10^{-3}	0%	6.05×10^{-3}	6.41×10^{-3}	6%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 54: Comparison of transport scenarios for thermomechanically recycled chip produced by data provider M2



6.2.2.3. Data provider M3 results**Table 131: M3—thermomechanically recycled chip—Scenario "Transport—Low Intensity"**

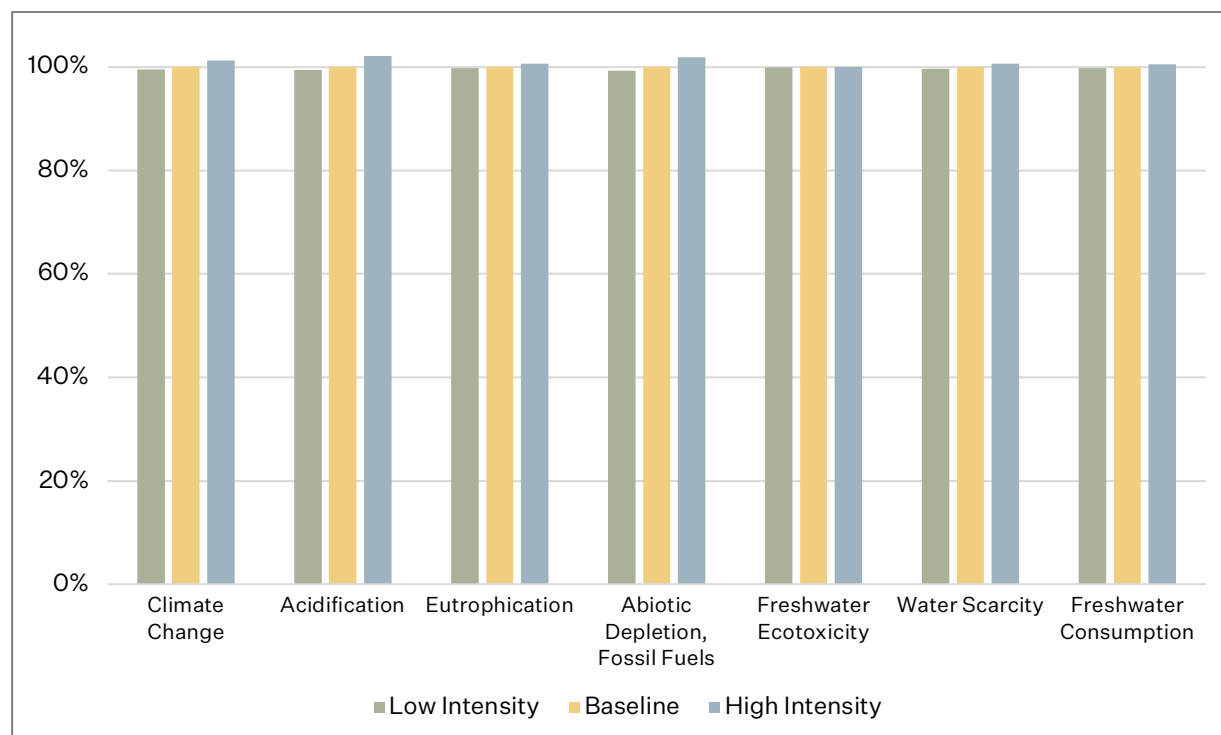
Impact category	Flake production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.897	0.890	-1%	0.416	0.416	0%	1.31	1.31	0%
AP	3.55x10 ⁻³	3.52x10 ⁻³	-1%	2.18x10 ⁻³	2.18x10 ⁻³	0%	5.73x10 ⁻³	5.70x10 ⁻³	-1%
EP	3.87x10 ⁻³	3.86x10 ⁻³	0%	9.82x10 ⁻⁴	9.82x10 ⁻⁴	0%	4.85x10 ⁻³	4.85x10 ⁻³	0%
AD	7.97	7.88	-1%	4.64	4.64	0%	12.6	12.5	-1%
FE	2.40x10 ⁻²	2.40x10 ⁻²	0%	2.24x10 ⁻²	2.24x10 ⁻²	0%	4.64x10 ⁻²	4.64x10 ⁻²	0%
WS	0.164	0.164	0%	7.51x10 ⁻²	7.51x10 ⁻²	0%	0.239	0.239	0%
FC	4.68x10 ⁻³	4.66x10 ⁻³	0%	2.24x10 ⁻³	2.24x10 ⁻³	0%	6.92x10 ⁻³	6.90x10 ⁻³	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 132: M3—thermomechanically recycled chip—Scenario "Transport—High Intensity"

Impact category	Flake production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High Intensity	% Diff
CC	0.897	0.914	2%	0.416	0.416	0%	1.31	1.33	1%
AP	3.55x10 ⁻³	3.68x10 ⁻³	3%	2.18x10 ⁻³	2.18x10 ⁻³	0%	5.73x10 ⁻³	5.86x10 ⁻³	2%
EP	3.87x10 ⁻³	3.90x10 ⁻³	1%	9.82x10 ⁻⁴	9.82x10 ⁻⁴	0%	4.85x10 ⁻³	4.88x10 ⁻³	1%
AD	7.97	8.21	3%	4.64	4.64	0%	12.6	12.9	2%
FE	2.40x10 ⁻²	2.40x10 ⁻²	0%	2.24x10 ⁻²	2.24x10 ⁻²	0%	4.64x10 ⁻²	4.65x10 ⁻²	0%
WS	0.164	0.166	1%	7.51x10 ⁻²	7.51x10 ⁻²	0%	0.239	0.241	1%
FC	4.68x10 ⁻³	4.71x10 ⁻³	1%	2.24x10 ⁻³	2.24x10 ⁻³	0%	6.92x10 ⁻³	6.95x10 ⁻³	1%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 55: Comparison of transport scenarios for thermomechanically recycled chip produced by data provider M3**Table 133: M3—thermomechanically recycled staple fiber—Scenario "Transport—Low Intensity"**

Impact category	Flake production			Staple fiber production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	1.01	0.999	-1%	2.03	2.03	0%	3.04	3.03	0%
AP	3.99×10^{-3}	3.95×10^{-3}	-1%	7.82×10^{-3}	7.82×10^{-3}	0%	1.18×10^{-2}	1.18×10^{-2}	0%
EP	4.34×10^{-3}	4.33×10^{-3}	0%	1.13×10^{-2}	1.13×10^{-2}	0%	1.57×10^{-2}	1.57×10^{-2}	0%
AD	8.94	8.84	-1%	24.9	24.9	0%	33.8	33.7	0%
FE	2.69×10^{-2}	2.69×10^{-2}	0%	0.147	0.147	0%	0.174	0.174	0%
WS	0.184	0.183	0%	0.401	0.401	0%	0.585	0.585	0%
FC	5.25×10^{-3}	5.23×10^{-3}	0%	1.10×10^{-2}	1.10×10^{-2}	0%	1.62×10^{-2}	1.62×10^{-2}	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

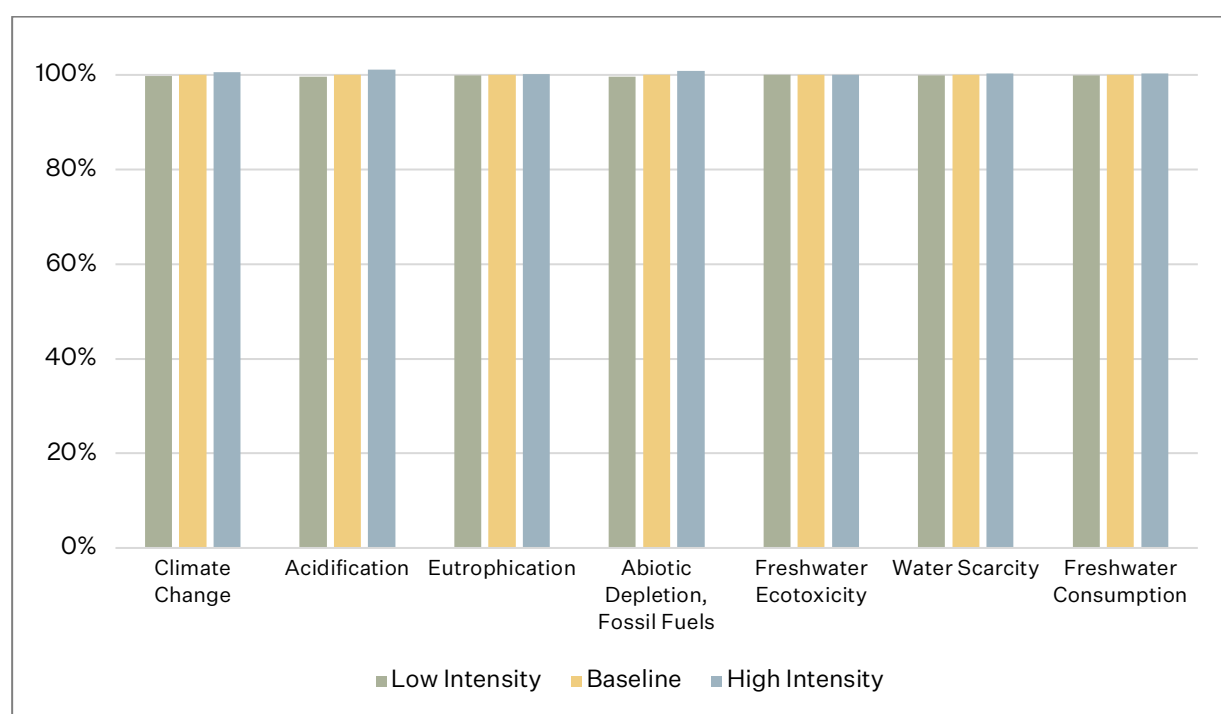
Table 134: M3—thermomechanically recycled staple fiber—Scenario "Transport—High Intensity"

Impact category	Flake production			Staple fiber production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	1.01	1.03	2%	2.03	2.03	0%	3.04	3.06	1%
AP	3.99×10^{-3}	4.13×10^{-3}	3%	7.82×10^{-3}	7.82×10^{-3}	0%	1.18×10^{-2}	1.19×10^{-2}	1%
EP	4.34×10^{-3}	4.38×10^{-3}	1%	1.13×10^{-2}	1.13×10^{-2}	0%	1.57×10^{-2}	1.57×10^{-2}	0%
AD	8.94	9.21	3%	24.9	24.9	0%	33.8	34.1	1%

Impact category	Flake production			Staple fiber production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
FE	2.69×10^{-2}	2.70×10^{-2}	0%	0.147	0.147	0%	0.174	0.174	0%
WS	0.184	0.186	1%	0.401	0.401	0%	0.585	0.587	0%
FC	5.25×10^{-3}	5.29×10^{-3}	1%	1.10×10^{-2}	1.10×10^{-2}	0%	1.62×10^{-2}	1.63×10^{-2}	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 56: Comparison of transport scenarios for thermomechanically recycled staple fiber produced by data provider M3



6.3. Upstream chemical production scenarios

Chemical sensitivity analyses were performed to address uncertainty regarding the origin and production methods of key chemicals used in chemical recycling (ethylene glycol and methanol) and virgin PET production (purified terephthalic acid and monoethylene glycol). These chemicals contribute significantly to the overall environmental impacts of both processes. Although data providers provided names, locations, or both, for their chemical suppliers, it is unclear whether these sites are manufacturing plants, warehouses, distribution centers, or other non-production facilities.

The ecoinvent database contains multiple production datasets for the same chemical, differentiated by manufacturing location and technology, as well as market-average datasets (for example, global, European, Asian), representing average production within a given region. Production in different regions uses varying technologies and electricity mixes, which lead to different environmental impacts. In the baseline results presented in sections 3.5, 4.5, and 5.5, either a global average dataset, or a regional dataset corresponding to the reported production location, was used.

For the sensitivity analysis, ecoinvent market datasets with the lowest and highest environmental impacts for methanol and purified terephthalic acid were selected, in order to establish the minimum–maximum range of impacts and assess how this variability influences the overall results for chemical recycling and virgin PET production; when impact results across different impact categories did not show a consistent pattern, the climate change impact category was used to guide which dataset was chosen as the minimum or maximum.

In addition to using ecoinvent market datasets for ethylene glycol and monoethylene glycol, LCIA data taken from a published journal article on the impacts of coal-to-ethylene glycol (Qian et al., 2022), which uses coal syngas, was included; ecoinvent does not contain any data on coal-to-ethylene glycol production. Ethylene glycol (EG) is the same substance as monoethylene glycol (MEG) in this report, with EG used by the chemical recyclers (section 3) and MEG used by the virgin PET producer (section 5). EG is commonly produced through the direct hydration of ethylene oxide (Zhang et al., 2024), which is typically derived from oil or natural gas, but can also use coal. This pathway is the standard practice globally and is reflected in the ecoinvent EG datasets (Ecoinvent, 2024b). However, EG can also be produced using a different and more energy-intensive process that utilizes coal syngas. This coal-to-ethylene glycol (CtEG) process is conducted in China along with the traditional EG production route (Qian et al., 2022).

6.3.1. Chemical recycling analysis (ethylene glycol, methanol)

6.3.1.1. Modeling approach

For chemical recycling, the sensitivity analysis focuses on two key chemical inputs: ethylene glycol (EG) and methanol, which are used by data providers C1 and C2. Data provider C3 does not use methanol and, instead, uses EG and an organic (confidential) solvent. However, C3 was unable to provide any information on its confidential solvent, and it was modeled as a generic organic chemical, which prevents any useful sensitivity analyses from being conducted on it.

Based on this, three scenarios were calculated for C1, C2, and C3:

- Ecoinvent low-intensity scenario, using the lowest impact EG (European market) and methanol (China, natural gas-based) datasets from ecoinvent
- Ecoinvent high-intensity scenario, using the highest impact EG (Rest-of-World market) and methanol (China, coal-based) datasets from ecoinvent

- Coal scenario, using LCIA results taken from Qian et al. (2022) for coal-to-ethylene glycol (CtEG) production using coal-derived syngas, and the highest impact methanol dataset (China, coal-based) from ecoinvent

In ecoinvent, Rest-of-World (RoW) datasets represent production in regions where no specific regional dataset exists. The composition of RoW differs by chemical, depending on which regional datasets (for example, China, Europe) are defined separately.

Ethylene glycol (EG)

As noted in the previous section, ethylene glycol (EG) is commonly produced through the direct hydration of ethylene oxide (Zhang et al., 2024), which is the standard practice in Europe and is reflected in the ecoinvent RER dataset. Ethylene oxide is primarily obtained from petroleum and natural gas, while coal is a possible, but less common, feedstock (Qian et al., 2022). In China, both the ethylene oxide pathway and a separate coal-to-ethylene glycol (CtEG) route are employed. The CtEG process uses coal-derived syngas to produce dimethyl oxalate as an intermediate, which is then converted to EG (Qian et al., 2022). This pathway has gained prominence due to China's abundant coal reserves and cost advantages. In 2018, CtEG accounted for roughly 42% of domestic EG production capacity and was projected to remain a major contributor (Qian et al., 2022). Historically, China relied heavily on EG imports, but import dependence fell from 67% in 2013 to 29% in 2023, following the commissioning of domestic CtEG production lines in 2020 (Liang et al., 2025).

Given this context, the CtEG pathway is highly relevant for the Chinese data providers (C1 and C2). For C3, based in the EU, CtEG is less relevant—as the EU imports less than 1% of EG from China (World Bank, 2023)—but it is still considered here for completeness.

Ecoinvent does not include datasets for CtEG production. To address this gap, a literature review was conducted, but suitable life cycle inventory (LCI) data could not be identified. Instead, a high-intensity coal scenario (scenario 3) was developed using life cycle impact assessment (LCIA) results for climate change, eutrophication, and freshwater consumption reported by Qian et al. (2022). Although Qian et al. provided an LCI in their supplementary materials, attempts to reconstruct their results produced substantial deviations, likely due to differences in background datasets, methodological assumptions, and unreported modeling choices. For this reason, the published LCIA results were adopted directly. Qian et al. (2022) based their modeling on the Chinese Life Cycle Database (CLCD, 2006), (Sichuan University and IKE Environmental Technology Co., Ltd., n.d.), supplemented with ecoinvent v3.1 (Ecoinvent, 2014; Qian et al., 2022).

Only selected impact categories—climate change, eutrophication, and freshwater consumption—were used, as these were reported with LCIA methods consistent (or at least similar, in the case of climate change) with those applied in this study. A key limitation is that Qian et al. used IPCC 2013 global warming potentials (IPCC, 2013), whereas this study applies IPCC 2021. Their other LCIA results were calculated with impact methods not aligned with this study's framework and, therefore, were not included.

While the methodological differences mean that results from the CtEG scenario should be interpreted with caution, the coal scenario is included in the sensitivity analysis to indicate the potential increase in impacts if coal-based EG substitutes for EG produced via the more common ethylene oxide pathway. The absolute values should not be overemphasized; rather, the scenario highlights the elevated environmental burdens associated with CtEG production.

In ecoinvent, only European and Rest-of-World (RoW) datasets are available for EG. C1 and C2 source EG from Chinese suppliers, and their baselines uses a RoW dataset from ecoinvent. C3 is based in Europe and uses the European dataset from ecoinvent as its baseline. Table 135–Table

136 show the percent differences in environmental impacts for 1 kg ethylene glycol production across sensitivity scenarios, relative to their respective baseline datasets.

Table 135: LCIA percent differences from 1 kg EG sensitivity scenarios (C1 and C2 baselines)

Impact category	Baseline (RoW)	Low intensity scenario (Europe)	High intensity scenario (RoW)	Coal scenario (CtEG)
Climate change	0%	-28%	0%	+92%
Acidification	0%	-39%	0%	-
Eutrophication	0%	-91%	0%	-92%
Abiotic depletion, fossil fuels	0%	-16%	0%	-
Freshwater ecotoxicity	0%	-55%	0%	-
Water scarcity	0%	0%	0%	-
Freshwater consumption	0%	0%	0%	+87%

Table 136: LCIA percent differences for 1 kg EG sensitivity scenarios (C3 baseline)

Impact category	Baseline (Europe)	Low intensity scenario (Europe)	High intensity scenario (RoW)	Coal scenario (CtEG)
Climate change	0%	0%	+40%	+168%
Acidification	0%	0%	+65%	-
Eutrophication	0%	0%	+997%	-12%
Abiotic depletion, fossil fuels	0%	0%	+19%	-
Freshwater ecotoxicity	0%	0%	+121%	-
Water scarcity	0%	0%	0%	-
Freshwater consumption	0%	0%	0%	+86%

Methanol

Data providers C1 and C2 source methanol from domestic suppliers in China, and the baseline model uses the China regional market average, which includes a weighted mix of coal- and natural-gas-based production; C3 does not use methanol in its chemical recycling process. Although China does import methanol, imports accounted for a relatively small percentage of total consumption (approximately 15% in 2019); the majority of methanol used is produced locally (China Association of Alcohol and Ether Fuel and Automobiles, 2020). Methanol production in China follows two pathways: coal gasification, which dominates the domestic supply, and natural gas reforming, which plays a smaller role (Zhang et al., 2024). These pathways form the basis of the scenario modeling approach.

To reflect a regionally appropriate supply chain, the analysis focuses onecoinvent China datasets. Other regional datasets exist but were not included in the analysis, as most show environmental impacts comparable to China's production pathway. One exception is the South Africa dataset, which uses a high-temperature Fischer-Tropsch process and results in much higher environmental impacts. Since China imports a negligible volume from South Africa (around 0.001% of total methanol imports in 2022), (World Bank, 2022), this dataset is excluded as it is not representative of China's supply chain.

Table 137 shows the percent differences in environmental impacts for 1 kg methanol production across sensitivity analysis scenarios, relative to their respective baseline datasets.

Table 137: LCIA percent differences for 1 kg methanol sensitivity scenarios (C1 and C2 baselines)

Impact category	Baseline (China, market average)	Low intensity scenario (China, natural gas)	High intensity and coal scenarios (China, coal)
Climate change	0%	-52%	+50%
Acidification	0%	-53%	+39%
Eutrophication	0%	+54%	-54%
Abiotic depletion, fossil fuels	0%	-5%	+3%
Freshwater ecotoxicity	0%	+23%	-30%
Water scarcity	0%	-52%	+50%
Freshwater consumption	0%	-52%	+50%

Table 138, below, summarizes the chemical datasets and references used in the baseline and each sensitivity scenario, organized by data provider.

Table 138: Sensitivity scenario data sources for chemical recycling product systems

Data provider	Region	Scenario name	Chemical datasets
C1	China	Baseline	EG: market for ethylene glycol ethylene glycol cutoff, U—RoW Methanol: market for methanol methanol cutoff, U—CN
		Low intensity scenario	EG: market for ethylene glycol ethylene glycol cutoff, U—RER Methanol: methanol production, from natural gas reforming methanol cutoff, U—CN
		High intensity scenario	EG: market for ethylene glycol ethylene glycol cutoff, U—RoW Methanol: methanol production, from coal gasification methanol cutoff, U—CN
		Coal scenario	EG: coal to ethylene glycol from Qian et al. 2022 (Ecoinvent, 2024b) Methanol: methanol production, from coal gasification methanol cutoff, U—CN
C2	China	Baseline	EG: market for ethylene glycol ethylene glycol cutoff, U—RoW Methanol: market for methanol methanol cutoff, U—CN
		Low intensity scenario	EG: market for ethylene glycol ethylene glycol cutoff, U—RER Methanol: methanol production, from natural gas reforming methanol cutoff, U—CN
		High intensity scenario	EG: market for ethylene glycol ethylene glycol cutoff, U—RoW Methanol: methanol production, from coal gasification methanol cutoff, U—CN
		Coal scenario	EG: coal to ethylene glycol from Qian et al. 2022 (Ecoinvent, 2024b) Methanol: methanol production, from coal gasification methanol cutoff, U—CN
C3	Europe	Baseline	EG: market for ethylene glycol ethylene glycol cutoff, U—RER
		Low intensity scenario	EG: market for ethylene glycol ethylene glycol cutoff, U—RER

Data provider	Region	Scenario name	Chemical datasets
		High intensity Scenario	EG: market for ethylene glycol ethylene glycol cutoff, U—RoW
		Coal scenario	EG: coal to ethylene glycol from Qian et al. 2022 (Ecoinvent, 2024b)

6.3.1.2. Results

The sensitivity analysis demonstrates that differences in the production region and technology for chemicals affect the results differently across data providers. C3 shows minimal changes (Figure 59–Figure 60), while C1 and C2 only exhibit large increases in the coal scenario and decreases in the low-intensity scenario, with little change in the high-intensity scenario (Figure 57–Figure 58). The direction and magnitude of change depend on two factors: (1) how much the chemicals contribute to the products' baseline impacts, and (2) the magnitude of difference between the different chemical datasets.

C1 and C2 have a relatively high contribution from ethylene glycol (EG) and methanol, making their results more sensitive to differences in supplier location and production technology. For C1, the climate change impact shifted -11% in the low-intensity scenario to +32% in the coal scenario (Table 139–Table 141, Figure 57). For C2, the climate change impact shifted -4% in the low-intensity scenario to +8% in the coal scenario (Table 142–Table 144, Figure 58). The smaller change for C2 is explained by its lower use of virgin EG compared to C1. In the high-intensity scenario, the EG dataset is identical to the baseline (RoW), with the only change being methanol shifting from a China market average dataset to coal-based production. This explains the relatively small shifts and indicates that substantial increases in impacts are only observed when coal-to-ethylene glycol (CtEG) is used.

C3 substitutes only the EG datasets across scenarios. EG is used in the depolymerization stage for both types of chip, and its contribution to total impacts across all impact categories is less than 1%, mainly due to the small quantity of virgin EG used per functional unit. As a result, C3 exhibits limited sensitivity to the change in sources of EG among scenarios (within $\pm 5\%$, Table 145–Table 150, Figure 59–Figure 60).

While this study relies on the most recent ecoinvent datasets, future assessments could be refined by obtaining supplier-specific information on upstream chemical production routes to reduce uncertainty.

6.3.2.1.1. Data provider C1 results

Table 139: C1—chemically recycled chip—Scenario "Chemicals—Low Intensity"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.304	0.304	0%	1.46	1.27	-13%	1.77	1.58	-11%
AP	1.36×10^{-3}	1.36×10^{-3}	0%	5.37×10^{-3}	4.51×10^{-3}	-16%	6.73×10^{-3}	5.87×10^{-3}	-13%
EP	4.12×10^{-4}	4.12×10^{-4}	0%	2.25×10^{-2}	2.26×10^{-2}	1%	2.29×10^{-2}	2.30×10^{-2}	1%
AD	3.96	3.96	0%	19.1	17.3	-9%	23.0	21.3	-8%
FE	2.51×10^{-4}	2.51×10^{-4}	0%	5.10×10^{-3}	4.69×10^{-3}	-8%	5.35×10^{-3}	4.94×10^{-3}	-8%
WS	2.86×10^{-2}	2.86×10^{-2}	0%	0.458	0.456	0%	0.487	0.485	0%

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
FC	6.66×10^{-4}	6.66×10^{-4}	0%	1.05×10^{-2}	1.04×10^{-2}	0%	1.12×10^{-2}	1.11×10^{-2}	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 140: C1—chemically recycled chip—Scenario "Chemicals—High Intensity"

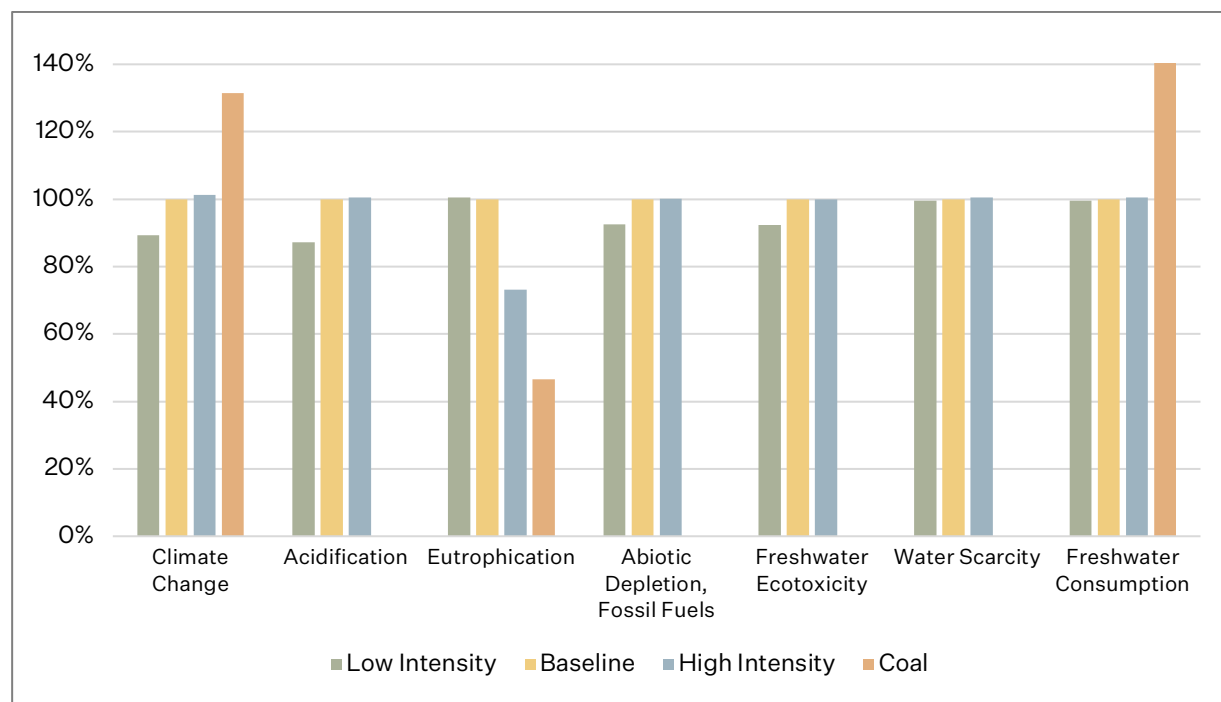
Impact category	Textile shreds production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	0.304	0.304	0%	1.46	1.48	1%	1.77	1.79	1%
AP	1.36×10^{-3}	1.36×10^{-3}	0%	5.37×10^{-3}	5.40×10^{-3}	1%	6.73×10^{-3}	6.76×10^{-3}	0%
EP	4.12×10^{-4}	4.12×10^{-4}	0%	2.25×10^{-2}	1.63×10^{-2}	-27%	2.29×10^{-2}	1.67×10^{-2}	-27%
AD	3.96	3.96	0%	19.1	19.1	0%	23.0	23.1	0%
FE	2.51×10^{-4}	2.51×10^{-4}	0%	5.10×10^{-3}	5.09×10^{-3}	0%	5.35×10^{-3}	5.34×10^{-3}	0%
WS	2.86×10^{-2}	2.86×10^{-2}	0%	0.458	0.461	0%	0.487	0.489	0%
FC	6.66×10^{-4}	6.66×10^{-4}	0%	1.05×10^{-2}	1.05×10^{-2}	0%	1.12×10^{-2}	1.12×10^{-2}	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 141: C1—chemically recycled chip—Scenario "Chemicals—Coal"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Coal	% Diff	Baseline	Coal	% Diff	Baseline	Coal	% Diff
CC	0.304	0.304	0%	1.46	2.02	38%	1.77	2.32	32%
AP	1.36×10^{-3}	1.36×10^{-3}	0%	5.37×10^{-3}	-	-	6.73×10^{-3}	-	-
EP	4.12×10^{-4}	4.12×10^{-4}	0%	2.25×10^{-2}	1.03×10^{-2}	-54%	2.29×10^{-2}	1.07×10^{-2}	-53%
AD	3.96	3.96	0%	19.1	-	-	23.0	-	-
FE	2.51×10^{-4}	2.51×10^{-4}	0%	5.10×10^{-3}	-	-	5.35×10^{-3}	-	-
WS	2.86×10^{-2}	2.86×10^{-2}	0%	0.458	-	-	0.487	-	-
FC	6.66×10^{-4}	6.66×10^{-4}	0%	1.05×10^{-2}	1.50×10^{-2}	43%	1.12×10^{-2}	1.57×10^{-2}	40%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 57: Comparison of chemical scenarios for chemically recycled chip produced by data provider C1

6.3.1.2.2. Data provider C2 results

Table 142: C2—chemically recycled chip—Scenario "Chemicals—Low Intensity"

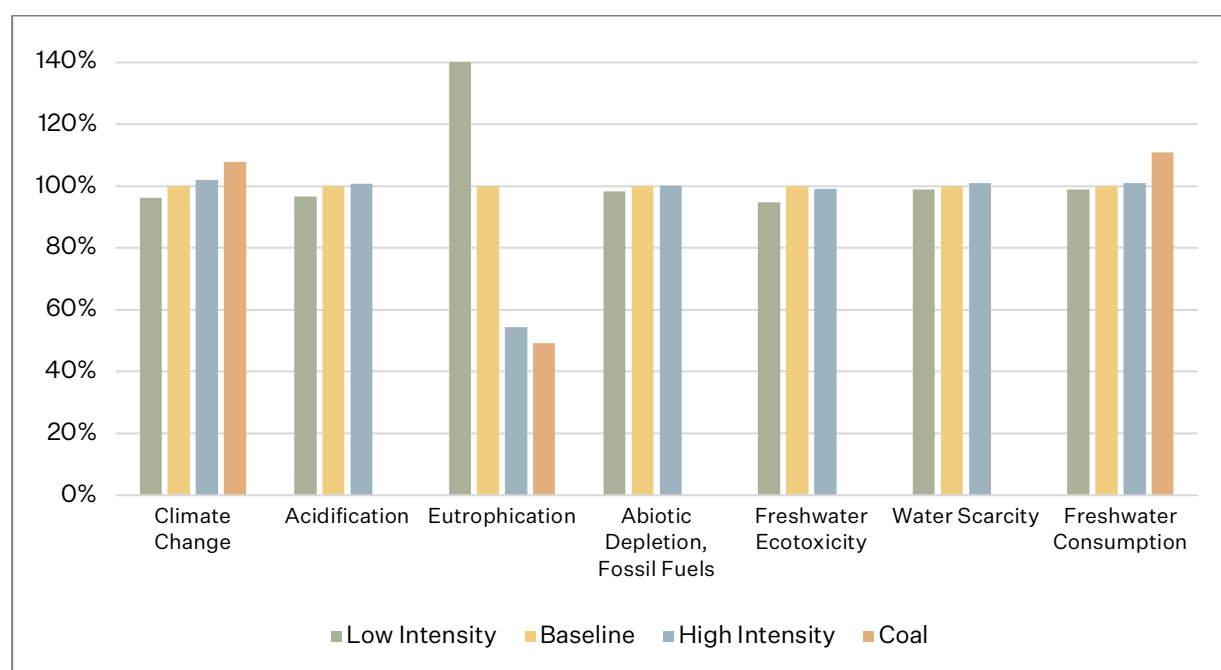
Impact category	Baseline	Low intensity	% Difference
Climate change (kg CO ₂ eq)	2.24	2.15	-4%
Acidification (mol H ⁺ eq)	8.63x10 ⁻³	8.34x10 ⁻³	-3%
Eutrophication (kg PO ₄ eq)	2.81x10 ⁻²	3.93x10 ⁻²	40%
Abiotic depletion, fossil fuels (MJ)	28.9	28.4	-2%
Freshwater ecotoxicity (PAF m ³ day)	1.67x10 ⁻³	1.58x10 ⁻³	-5%
Water scarcity (m ³ world eq)	0.468	0.463	-1%
Freshwater consumption (m ³)	1.07x10 ⁻²	1.06x10 ⁻²	-1%

Table 143: C2—chemically recycled chip—Scenario "Chemicals—High Intensity"

Impact category	Baseline	High intensity	% Difference
Climate change (kg CO ₂ eq)	2.24	2.28	2%
Acidification (mol H ⁺ eq)	8.63x10 ⁻³	8.70x10 ⁻³	1%
Eutrophication (kg PO ₄ eq)	2.81x10 ⁻²	1.53x10 ⁻²	-46%
Abiotic depletion, fossil fuels (MJ)	28.9	28.9	0%
Freshwater ecotoxicity (PAF m ³ day)	1.67x10 ⁻³	1.65x10 ⁻³	-1%
Water scarcity (m ³ world eq)	0.468	0.472	1%
Freshwater consumption (m ³)	1.07x10 ⁻²	1.08x10 ⁻²	1%

Table 144: C2—chemically recycled chip—Scenario "Chemicals—Coal"

Impact category	Baseline	Coal	% Difference
Climate change (kg CO ₂ eq)	2.24	2.41	8%
Acidification (mol H ⁺ eq)	8.63x10 ⁻³	-	-
Eutrophication (kg PO ₄ eq)	2.81x10 ⁻²	1.38x10 ⁻²	-51%
Abiotic depletion, fossil fuels (MJ eq)	28.9	-	-
Freshwater ecotoxicity (PAF m ³ day)	1.67x10 ⁻³	-	-
Water scarcity (m ³ world eq)	0.468	-	-
Freshwater consumption (m ³)	1.07x10 ⁻²	1.19x10 ⁻²	11%

Figure 58: Comparison of chemical scenarios for chemically recycled chip produced by data provider C2

6.3.1.2.3. Data provider C3 results

Table 145: C3—chemically recycled post-consumer chip—Scenario "Chemicals—Low Intensity"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.522	0.522	0%	0.364	0.364	0%	0.885	0.885	0%
AP	1.45x10 ⁻³	1.45x10 ⁻³	0%	6.69x10 ⁻⁴	6.69x10 ⁻⁴	0%	2.12x10 ⁻³	2.12x10 ⁻³	0%
EP	5.60x10 ⁻³	5.60x10 ⁻³	0%	5.37x10 ⁻⁴	5.37x10 ⁻⁴	0%	6.14x10 ⁻³	6.14x10 ⁻³	0%
AD	6.96	6.96	0%	3.06	3.06	0%	10.0	10.0	0%
FE	6.46x10 ⁻³	6.46x10 ⁻³	0%	1.42x10 ⁻⁴	1.42x10 ⁻⁴	0%	6.60x10 ⁻³	6.60x10 ⁻³	0%
WS	0.124	0.124	0%	7.27x10 ⁻²	7.27x10 ⁻²	0%	0.197	0.197	0%

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
FC	0.156	0.156	0%	0.112	0.112	0%	0.268	0.268	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 146: C3—chemically recycled post-consumer chip—Scenario "Chemicals—High Intensity"

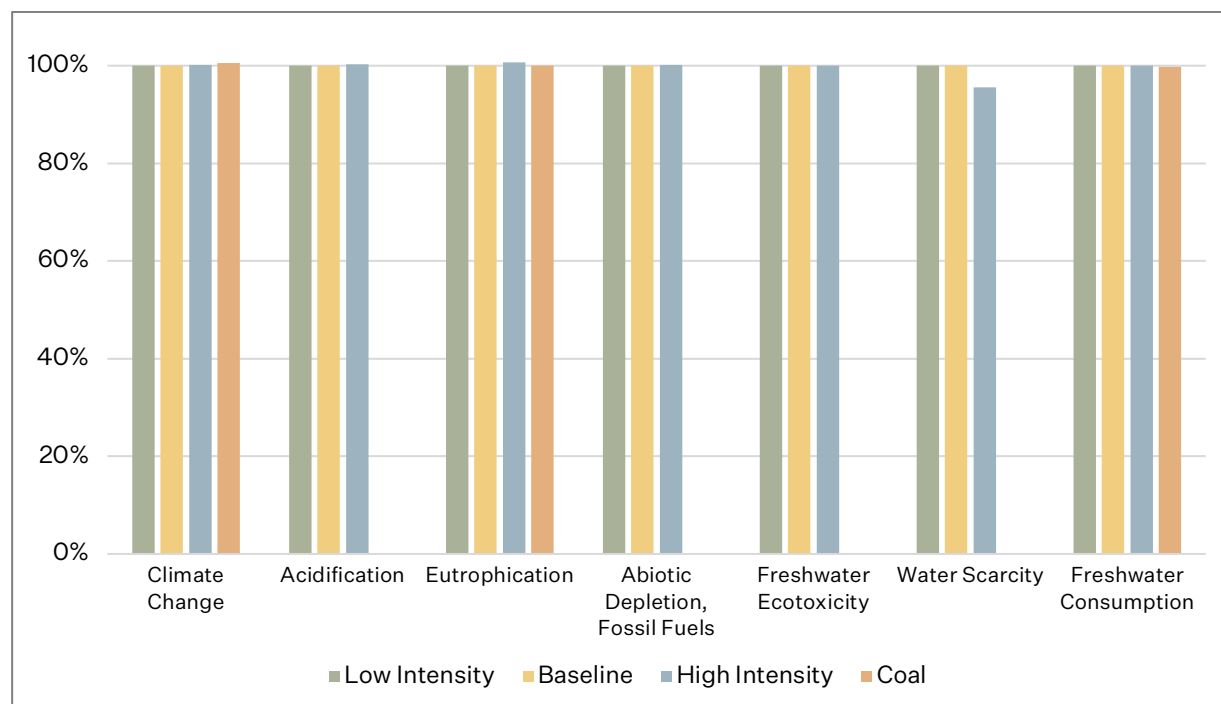
Impact category	Textile shreds production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	0.522	0.522	0%	0.364	0.365	0%	0.885	0.887	0%
AP	1.45×10^{-3}	1.45×10^{-3}	0%	6.69×10^{-4}	6.75×10^{-4}	1%	2.12×10^{-3}	2.12×10^{-3}	0%
EP	5.60×10^{-3}	5.60×10^{-3}	0%	5.37×10^{-4}	5.82×10^{-4}	8%	6.14×10^{-3}	6.19×10^{-3}	1%
AD	6.96	6.96	0%	3.06	3.08	0%	10.0	10.0	0%
FE	6.46×10^{-3}	6.46×10^{-3}	0%	1.42×10^{-4}	1.45×10^{-4}	2%	6.60×10^{-3}	6.60×10^{-3}	0%
WS	0.124	0.124	0%	7.27×10^{-2}	6.39×10^{-2}	-12%	0.197	0.188	-4%
FC	0.156	0.156	0%	0.112	0.112	0%	0.268	0.268	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 147: C3—chemically recycled post-consumer chip—Scenario "Chemicals—Coal"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Coal	% Diff	Baseline	Coal	% Diff	Baseline	Coal	% Diff
CC	0.522	0.522	0%	0.364	0.369	1%	0.885	0.891	1%
AP	1.45×10^{-3}	-	-	6.69×10^{-4}	-	-	2.12×10^{-3}	-	-
EP	5.60×10^{-3}	5.60×10^{-3}	0%	5.37×10^{-4}	5.36×10^{-4}	0%	6.14×10^{-3}	6.14×10^{-3}	0%
AD	6.96	-	-	3.06	-	-	10.0	-	-
FE	6.46×10^{-3}	-	-	1.42×10^{-4}	-	-	6.60×10^{-3}	-	-
WS	0.124	-	-	7.27×10^{-2}	-	-	0.197	-	-
FC	0.156	0.156	0%	0.112	0.112	-1%	0.268	0.268	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 59: Comparison of chemical scenarios for chemically recycled post-consumer chip produced by data provider C3**Table 148: C3—chemically recycled post-industrial chip—Scenario "Chemicals—Low Intensity"**

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	0.426	0.426	0%	0.257	0.257	0%	0.683	0.683	0%
AP	1.11×10^{-3}	1.11×10^{-3}	0%	5.48×10^{-4}	5.48×10^{-4}	0%	1.66×10^{-3}	1.66×10^{-3}	0%
EP	5.37×10^{-3}	5.37×10^{-3}	0%	4.16×10^{-4}	4.16×10^{-4}	0%	5.78×10^{-3}	5.78×10^{-3}	0%
AD	5.71	5.71	0%	2.59	2.59	0%	8.30	8.30	0%
FE	6.23×10^{-3}	6.23×10^{-3}	0%	1.08×10^{-4}	1.08×10^{-4}	0%	6.34×10^{-3}	6.34×10^{-3}	0%
WS	0.111	0.111	0%	6.53×10^{-2}	6.53×10^{-2}	0%	0.176	0.176	0%
FC	0.141	0.141	0%	0.109	0.109	0%	0.250	0.250	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 149: C3—chemically recycled post-industrial chip—Scenario "Chemicals—High Intensity"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	0.426	0.426	0%	0.257	0.258	0%	0.683	0.684	0%
AP	1.11×10^{-3}	1.11×10^{-3}	0%	5.48×10^{-4}	5.54×10^{-4}	1%	1.66×10^{-3}	1.67×10^{-3}	0%
EP	5.37×10^{-3}	5.37×10^{-3}	0%	4.16×10^{-4}	4.58×10^{-4}	10%	5.78×10^{-3}	5.82×10^{-3}	1%
AD	5.71	5.71	0%	2.59	2.61	0%	8.30	8.32	0%
FE	6.23×10^{-3}	6.23×10^{-3}	0%	1.08×10^{-4}	1.11×10^{-4}	3%	6.34×10^{-3}	6.34×10^{-3}	0%

Impact category	Textile shreds production			Chip production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
WS	0.111	0.111	0%	6.53×10^{-2}	5.64×10^{-2}	-14%	0.176	0.167	-5%
FC	0.141	0.141	0%	0.109	0.109	0%	0.250	0.250	0%

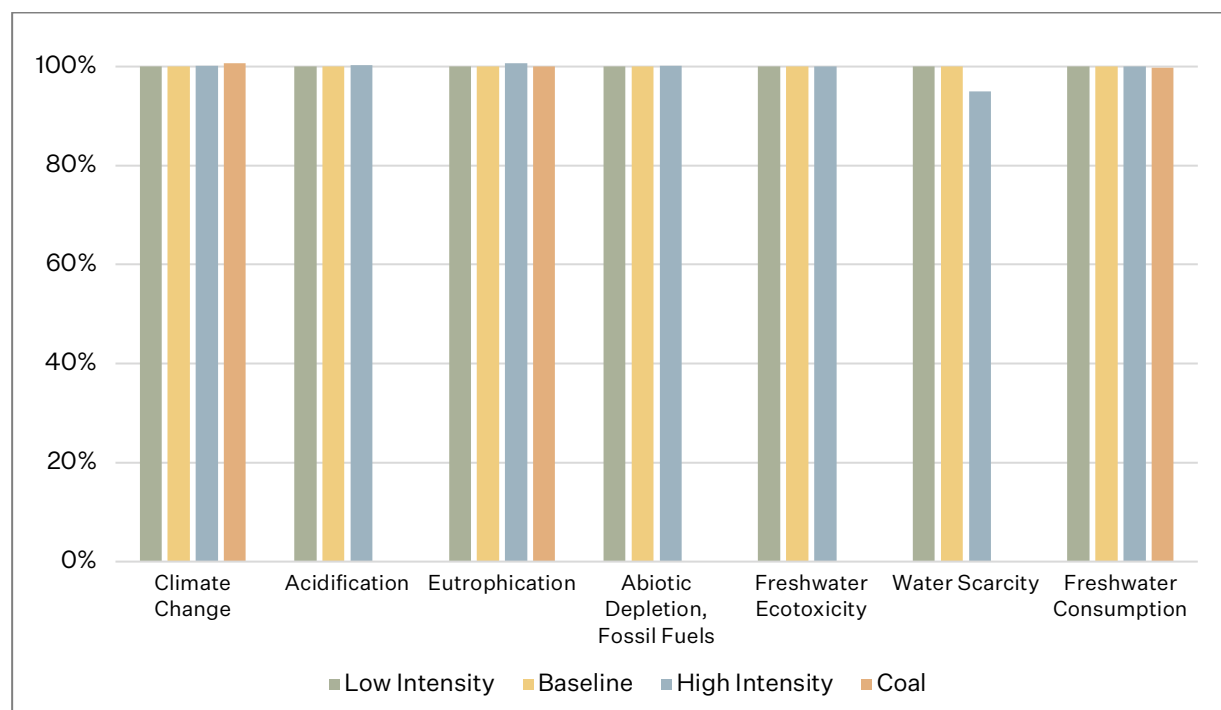
Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 150: C3—chemically recycled post-industrial chip—Scenario "Chemicals—Coal"

Impact category	Textile shreds production			Chip production			Total		
	Baseline	Coal	% Diff	Baseline	Coal	% Diff	Baseline	Coal	% Diff
CC	0.426	0.426	0%	0.257	0.262	2%	0.683	0.688	1%
AP	1.11×10^{-3}	-	-	5.48×10^{-4}	-	-	1.66×10^{-3}	-	-
EP	5.37×10^{-3}	5.37×10^{-3}	0%	4.16×10^{-4}	4.15×10^{-4}	0%	5.78×10^{-3}	5.78×10^{-3}	0%
AD	5.71	-	-	2.59	-	-	8.30	-	-
FE	6.23×10^{-3}	-	-	1.08×10^{-4}	-	-	6.34×10^{-3}	-	-
WS	0.111	-	-	6.53×10^{-2}	-	-	0.176	-	-
FC	0.141	0.141	0%	0.109	0.109	-1%	0.250	0.250	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 60: Comparison of chemical scenarios for chemically recycled post-industrial chip produced by data provider C3



6.3.2. Virgin production analysis (purified terephthalic acid, monoethylene glycol)

6.3.2.1 Modeling approach

Virgin PET production requires purified terephthalic acid (PTA) and monoethylene glycol (MEG) to polymerize PET. Both chemicals are globally traded commodities and were evaluated with sensitivity analyses due to market and environmental variability.

Three scenarios were created for V1:

- Ecoinvent low-intensity scenario, using the lowest impact PTA (European production mix) and MEG (European market) datasets from ecoinvent
- Ecoinvent high-intensity scenario, using the highest impact PTA (global market) and MEG (Rest-of-World market) datasets from ecoinvent
- Coal scenario, using the highest impact PTA dataset (global market) from ecoinvent and LCIA results taken from Qian et al. (2022), for coal-to-ethylene glycol (CtEG) production using coal-derived syngas

In ecoinvent, Rest-of-World (RoW) datasets represent production in regions where no specific regional dataset exists. The composition of RoW differs by chemical, depending on which regional datasets (for example, China, Europe) are defined separately.

The coal scenario was included to align with the chemical recycling analysis and to test the potential impacts of CtEG production. While V1 does not source MEG from China, incorporating this pathway allows a comparison of the potential influence of coal-based routes on virgin PET production results.

Purified Terephthalic Acid (PTA)

Ecoinvent market datasets for PTA include a global average, Europe, Canada, and RoW (excluding Europe and Canada). Among these, the European dataset generally shows the lowest environmental impacts across most categories, including climate change, acidification, and abiotic depletion. The global average dataset reflects the highest impacts across most impact categories. This is largely due to its weighting toward rest-of-world production, which has higher environmental burdens, and its inclusion of transport from producer to consumer or distributor. While Europe and Canada are included in the global average, their contributions are relatively small.

Although V1 sources PTA in Southeast Asia, the global average dataset was used as the baseline to conservatively reflect broader global production impacts and upstream transport. Table 151 shows the percent differences in environmental impacts for 1 kg PTA production across sensitivity scenarios, relative to their respective baseline datasets.

Table 151: LCIA percent differences for 1 kg PTA sensitivity scenarios (V1 baseline)

Impact category	Baseline (Global)	Low intensity scenario (Europe)	High intensity and coal scenarios (Global)
Climate change	0%	-14%	0%
Acidification	0%	-19%	0%
Eutrophication	0%	-3%	0%
Abiotic depletion, fossil fuels	0%	-6%	0%
Freshwater ecotoxicity	0%	-23%	0%
Water scarcity	0%	-1%	0%

Impact category	Baseline (Global)	Low intensity scenario (Europe)	High intensity and coal scenarios (Global)
Freshwater consumption	0%	-1%	0%

Monoethylene Glycol (MEG)

For MEG, the baseline was modeled using the ethylene glycol (EG) RoW market dataset from ecoinvent. Three sensitivity scenarios were applied: a low-intensity scenario (European market), a high-intensity scenario (RoW market), and a coal scenario based on Qian et al. (2022). While the virgin PET producer (V1) does not source MEG from China, the coal-to-ethylene glycol (CtEG) pathway was included to test its potential effect on virgin production results. Refer to section 6.3 for a detailed discussion of EG/MEG production pathways.

Table 152 shows the percent differences in environmental impacts for 1 kg MEG production across sensitivity analysis scenarios, relative to their respective baseline datasets.

Table 152: LCIA percent differences from 1 kg MEG sensitivity scenarios

Impact category	Baseline (RoW)	Low intensity scenario (Europe)	High intensity scenario (RoW)	Coal scenario (CtEG)
Climate change	0%	-28%	0%	+92%
Acidification	0%	-39%	0%	-
Eutrophication	0%	-91%	0%	-92%
Abiotic depletion, fossil fuels	0%	-16%	0%	-
Freshwater ecotoxicity	0%	-55%	0%	-
Water scarcity	0%	0%	0%	-
Freshwater consumption	0%	0%	0%	+87%

Table 153 summarizes the chemical datasets and references used in the baseline and each sensitivity scenario.

Table 153: Sensitivity scenario data sources for virgin PET production

Data provider	Region	Scenario name	Chemical datasets
V1	Southeast Asia	Baseline	PTA: market for purified terephthalic acid purified terephthalic acid cutoff, U—GLO MEG: market for ethylene glycol ethylene glycol cutoff, U—RoW
		Low intensity	PTA: purified terephthalic acid production purified terephthalic acid cutoff, U - RER MEG: market for ethylene glycol ethylene glycol cutoff, U—RER
		High intensity	PTA: market for purified terephthalic acid purified terephthalic acid cutoff, U - GLO MEG: market for ethylene glycol ethylene glycol cutoff, U—RoW
		Coal	PTA: market for purified terephthalic acid purified terephthalic acid cutoff, U—GLO

Data provider	Region	Scenario name	Chemical datasets
			MEG: coal to ethylene glycol from Qian et al. (Qian et al., 2022; Ecoinvent, 2024b)

6.3.2.2. Results

The sensitivity analysis shows that differences in the production of PTA and MEG affect results across all five virgin PET products (SF1, SF2, SF3, black POY, white DTY) under the low-intensity and coal scenarios. The baseline was modeled as identical to the high-intensity scenario, representing a conservative assumption for global production and resulting in no differences across impact categories between the two cases.

In the low-intensity scenario, climate change impacts decrease by 10–14% across all virgin PET products (Tables 154, 157, 160, 163, and 166). Other impact categories also decrease, while acidification, freshwater ecotoxicity, water scarcity, and freshwater consumption are relatively insensitive, with decreases of 7% or less.

The coal scenario increases climate change impacts by 15–21% across products (Tables 156, 159, 162, 165, and 168), demonstrating higher impacts when MEG is produced via the CtEG pathway. This Southeast Asian data provider (V1) is unlikely to source MEG from China, but this scenario is included to test the potential influence of coal-based production on results.

These findings align with the contribution analysis, which shows that PTA and MEG are the dominant contributors to impacts across all virgin PET products, accounting for 46–94% of all impact categories except freshwater ecotoxicity. Because these inputs play a large role, alternative sourcing of PTA and MEG can lead to meaningful shifts in results. At the same time, while this study relies on the most recent ecoinvent datasets, obtaining supplier-specific information on chemical production routes (for example, CtEG) would provide opportunities to further refine results in future assessments.

6.3.2.2.1. Staple fiber results (SF1, SF2, SF3)

Table 154: Virgin staple fiber SF1—Scenario "Chemicals—Low Intensity"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	3.41	2.90	-15%	1.34	1.34	0%	4.74	4.23	-11%
AP	1.69x10 ⁻²	1.41x10 ⁻²	-17%	8.06x10 ⁻³	8.06x10 ⁻³	0%	2.49x10 ⁻²	2.21x10 ⁻²	-11%
EP	2.74x10 ⁻²	1.83x10 ⁻²	-33%	3.75x10 ⁻³	3.75x10 ⁻³	0%	3.11x10 ⁻²	2.21x10 ⁻²	-29%
AD	65.1	59.9	-8%	17.3	17.3	0%	82.4	77.3	-6%
FE	6.23x10 ⁻³	4.56x10 ⁻³	-27%	0.138	0.138	0%	0.144	0.142	-1%
WS	0.665	0.663	0%	0.200	0.200	0%	0.865	0.863	0%
FC	1.55x10 ⁻²	1.54x10 ⁻²	0%	4.71x10 ⁻³	4.71x10 ⁻³	0%	2.02x10 ⁻²	2.02x10 ⁻²	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 155: Virgin staple fiber SF1—Scenario "Chemicals—High Intensity"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	3.41	3.41	0%	1.34	1.34	0%	4.74	4.74	0%
AP	1.69x10 ⁻²	1.69x10 ⁻²	0%	8.06x10 ⁻³	8.06x10 ⁻³	0%	2.49x10 ⁻²	2.49x10 ⁻²	0%
EP	2.74x10 ⁻²	2.74x10 ⁻²	0%	3.75x10 ⁻³	3.75x10 ⁻³	0%	3.11x10 ⁻²	3.11x10 ⁻²	0%
AD	65.1	65.1	0%	17.3	17.3	0%	82.4	82.4	0%
FE	6.23x10 ⁻³	6.23x10 ⁻³	0%	0.138	0.138	0%	0.144	0.144	0%
WS	0.665	0.665	0%	0.200	0.200	0%	0.865	0.865	0%
FC	1.55x10 ⁻²	1.55x10 ⁻²	0%	4.71x10 ⁻³	4.71x10 ⁻³	0%	2.02x10 ⁻²	2.02x10 ⁻²	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 156: Virgin staple fiber SF1—Scenario "Chemicals—Coal"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Coal	% Diff	Baseline	Coal	% Diff	Baseline	Coal	% Diff
CC	3.41	4.17	22%	1.34	1.34	0%	4.74	5.51	16%
AP	1.69x10 ⁻²	-	-	8.06x10 ⁻³	8.06x10 ⁻³	0%	2.49x10 ⁻²	-	-
EP	2.74x10 ⁻²	1.87x10 ⁻²	-32%	3.75x10 ⁻³	3.75x10 ⁻³	0%	3.11x10 ⁻²	2.24x10 ⁻²	-28%
AD	65.1	-	-	17.3	17.3	0%	82.4	-	-
FE	6.23x10 ⁻³	-	-	0.138	0.138	0%	0.144	-	-
WS	0.665	-	-	0.200	0.200	0%	0.865	-	-
FC	1.55x10 ⁻²	2.18x10 ⁻²	41%	4.71x10 ⁻³	4.71x10 ⁻³	0%	2.02x10 ⁻²	2.66x10 ⁻²	31%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

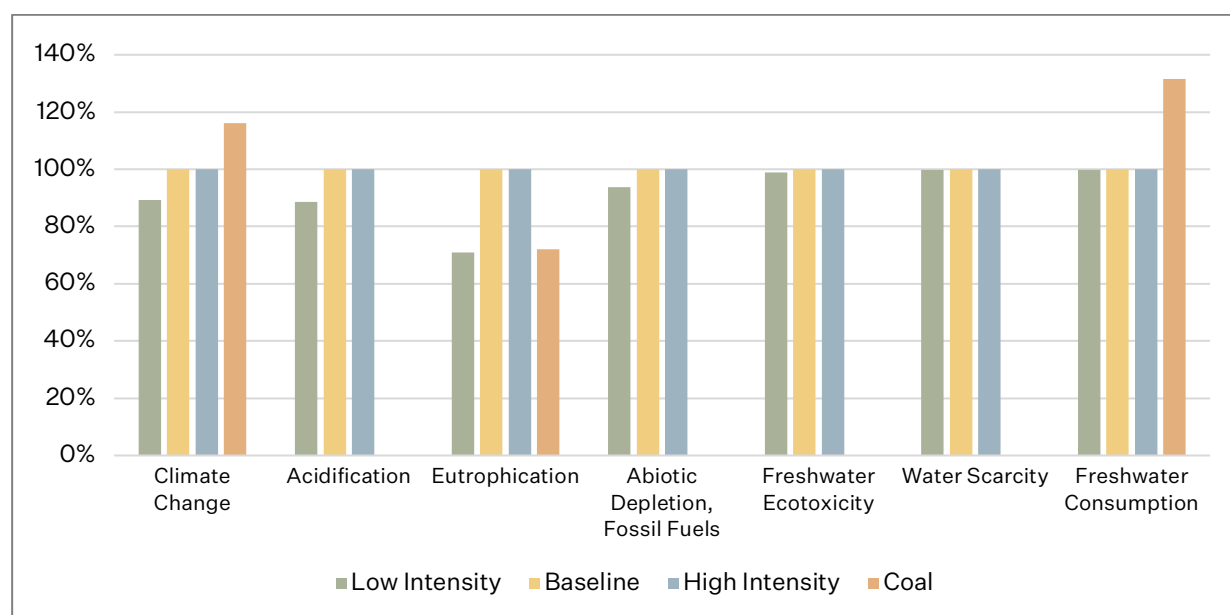
Figure 61: Comparison of chemical scenarios for virgin staple fiber SF1

Table 157: Virgin staple fiber SF2—Scenario "Chemicals—Low Intensity"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	3.74	3.18	-15%	1.19	1.19	0%	4.93	4.37	-11%
AP	1.85x10 ⁻²	1.54x10 ⁻²	-17%	7.63x10 ⁻³	7.63x10 ⁻³	0%	2.61x10 ⁻²	2.31x10 ⁻²	-12%
EP	3.01x10 ⁻²	2.01x10 ⁻²	-33%	5.35x10 ⁻³	5.35x10 ⁻³	0%	3.54x10 ⁻²	2.55x10 ⁻²	-28%
AD	71.4	65.8	-8%	11.8	11.8	0%	83.2	77.5	-7%
FE	6.84x10 ⁻³	5.00x10 ⁻³	-27%	0.105	0.105	0%	0.112	0.110	-2%
WS	0.730	0.728	0%	0.162	0.162	0%	0.892	0.890	0%
FC	1.70x10 ⁻²	1.69x10 ⁻²	0%	3.96x10 ⁻³	3.96x10 ⁻³	0%	2.10x10 ⁻²	2.09x10 ⁻²	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 158: Virgin staple fiber SF2—Scenario "Chemicals—High Intensity"

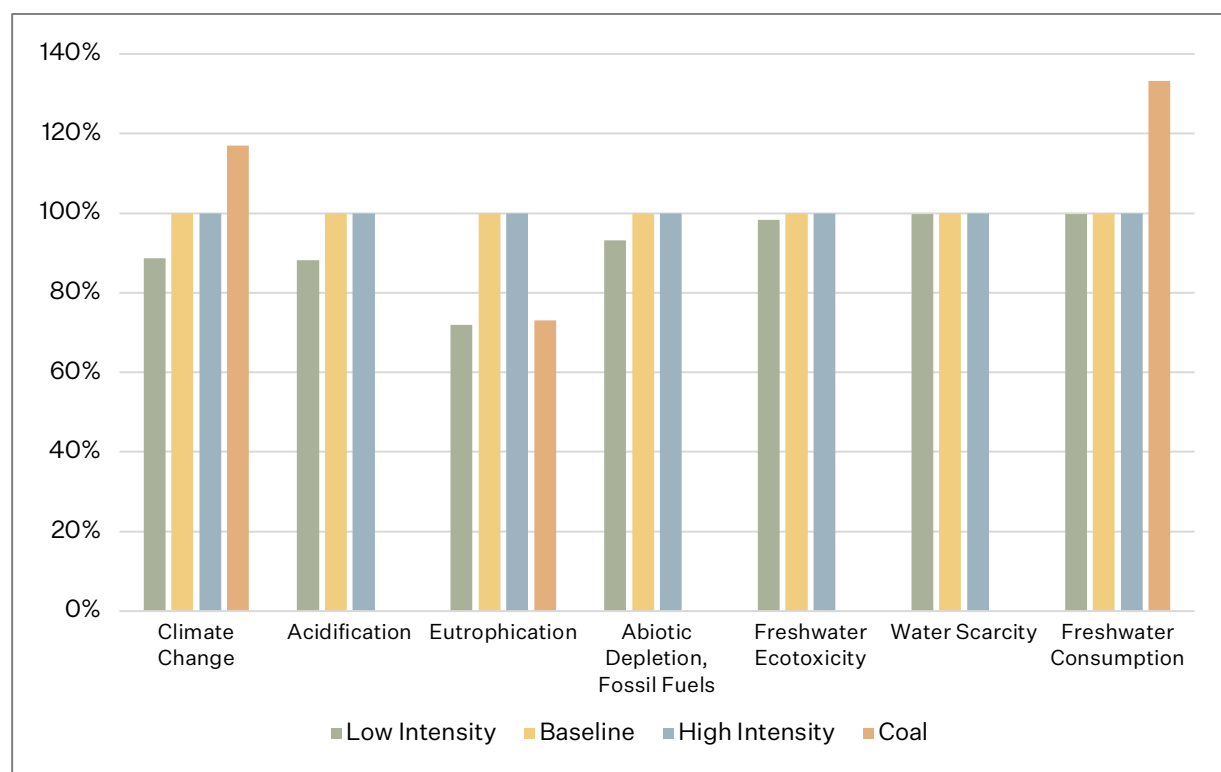
Impact category	Melt production			Staple fiber production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	3.74	3.74	0%	1.19	1.19	0%	4.93	4.93	0%
AP	1.85x10 ⁻²	1.85x10 ⁻²	0%	7.63x10 ⁻³	7.63x10 ⁻³	0%	2.61x10 ⁻²	2.61x10 ⁻²	0%
EP	3.01x10 ⁻²	3.01x10 ⁻²	0%	5.35x10 ⁻³	5.35x10 ⁻³	0%	3.54x10 ⁻²	3.54x10 ⁻²	0%
AD	71.4	71.4	0%	11.8	11.8	0%	83.2	83.2	0%
FE	6.84x10 ⁻³	6.84x10 ⁻³	0%	0.105	0.105	0%	0.112	0.112	0%
WS	0.730	0.730	0%	0.162	0.162	0%	0.892	0.892	0%
FC	1.70x10 ⁻²	1.70x10 ⁻²	0%	3.96x10 ⁻³	3.96x10 ⁻³	0%	2.10x10 ⁻²	2.10x10 ⁻²	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 159: Virgin staple fiber SF2—Scenario "Chemicals—Coal"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Coal	% Diff	Baseline	Coal	% Diff	Baseline	Coal	% Diff
CC	3.74	4.58	22%	1.19	1.19	0%	4.93	5.77	17%
AP	1.85x10 ⁻²	-	-	7.63x10 ⁻³	7.63x10 ⁻³	0%	2.61x10 ⁻²	-	-
EP	3.01x10 ⁻²	2.05x10 ⁻²	-32%	5.35x10 ⁻³	5.35x10 ⁻³	0%	3.54x10 ⁻²	2.59x10 ⁻²	-27%
AD	71.4	-	-	11.8	11.8	0%	83.2	-	-
FE	6.84x10 ⁻³	-	-	0.105	0.105	0%	0.112	-	-
WS	0.730	-	-	0.162	0.162	0%	0.892	-	-
FC	1.70x10 ⁻²	2.40x10 ⁻²	41%	3.96x10 ⁻³	3.96x10 ⁻³	0%	2.10x10 ⁻²	2.79x10 ⁻²	33%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 62: Comparison of chemical scenarios for virgin staple fiber SF2**Table 160: Virgin staple fiber SF3—Scenario "Chemicals—Low Intensity"**

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	3.39	2.82	-17%	0.577	0.577	0%	3.96	3.40	-14%
AP	1.40×10^{-2}	1.09×10^{-2}	-22%	2.13×10^{-3}	2.13×10^{-3}	0%	1.61×10^{-2}	1.30×10^{-2}	-19%
EP	2.98×10^{-2}	1.98×10^{-2}	-34%	1.35×10^{-3}	1.35×10^{-3}	0%	3.12×10^{-2}	2.12×10^{-2}	-32%
AD	69.8	64.0	-8%	6.56	6.56	0%	76.3	70.6	-7%
FE	8.24×10^{-3}	6.39×10^{-3}	-23%	2.26×10^{-2}	2.26×10^{-2}	0%	3.08×10^{-2}	2.90×10^{-2}	-6%
WS	0.714	0.712	0%	5.07×10^{-2}	5.07×10^{-2}	0%	0.765	0.763	0%
FC	1.66×10^{-2}	1.66×10^{-2}	0%	1.20×10^{-3}	1.20×10^{-3}	0%	1.78×10^{-2}	1.78×10^{-2}	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 161: Virgin staple fiber SF3—Scenario "Chemicals—High Intensity"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	3.39	3.39	0%	0.577	0.577	0%	3.96	3.96	0%
AP	1.40×10^{-2}	1.40×10^{-2}	0%	2.13×10^{-3}	2.13×10^{-3}	0%	1.61×10^{-2}	1.61×10^{-2}	0%
EP	2.98×10^{-2}	2.98×10^{-2}	0%	1.35×10^{-3}	1.35×10^{-3}	0%	3.12×10^{-2}	3.12×10^{-2}	0%
AD	69.8	69.8	0%	6.56	6.56	0%	76.3	76.3	0%

Impact category	Melt production			Staple fiber production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
FE	8.24×10^{-3}	8.24×10^{-3}	0%	2.26×10^{-2}	2.26×10^{-2}	0%	3.08×10^{-2}	3.08×10^{-2}	0%
WS	0.714	0.714	0%	5.07×10^{-2}	5.07×10^{-2}	0%	0.765	0.765	0%
FC	1.66×10^{-2}	1.66×10^{-2}	0%	1.20×10^{-3}	1.20×10^{-3}	0%	1.78×10^{-2}	1.78×10^{-2}	0%

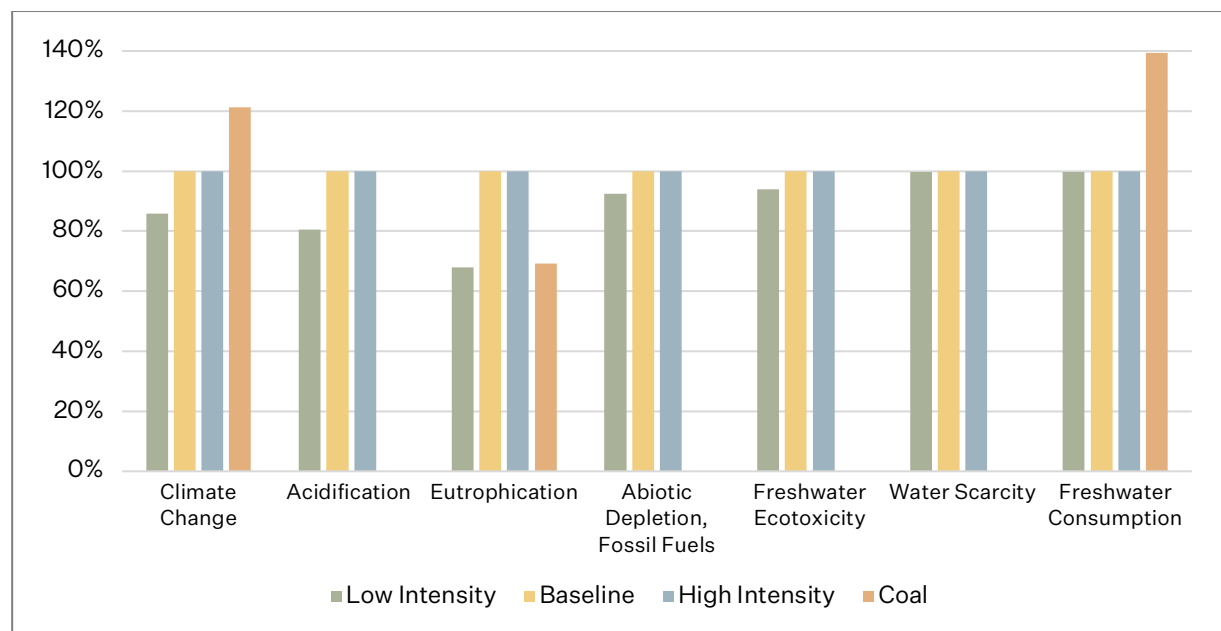
Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 162: Virgin staple fiber SF3—Scenario "Chemicals—Coal"

Impact category	Melt production			Staple fiber production			Total		
	Baseline	Coal	% Diff	Baseline	Coal	% Diff	Baseline	Coal	% Diff
CC	3.39	4.23	25%	0.577	0.577	0%	3.96	4.81	21%
AP	1.40×10^{-2}	-	-	2.13×10^{-3}	2.13×10^{-3}	0%	1.61×10^{-2}	-	-
EP	2.98×10^{-2}	2.02×10^{-2}	-32%	1.35×10^{-3}	1.35×10^{-3}	0%	3.12×10^{-2}	2.16×10^{-2}	-31%
AD	69.8	-	-	6.56	6.56	0%	76.3	-	-
FE	8.24×10^{-3}	-	-	2.26×10^{-2}	2.26×10^{-2}	0%	3.08×10^{-2}	-	-
WS	0.714	-	-	5.07×10^{-2}	5.07×10^{-2}	0%	0.765	-	-
FC	1.66×10^{-2}	2.36×10^{-2}	42%	1.20×10^{-3}	1.20×10^{-3}	0%	1.78×10^{-2}	2.48×10^{-2}	39%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 63: Comparison of chemical scenarios for virgin staple fiber SF3



6.3.2.2.2. Partially oriented yarn results (black POY)

Table 163: Black virgin POY—Scenario "Chemicals—Low Intensity"

Impact category	Chip production			POY production			Total		
	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff	Baseline	Low intensity	% Diff
CC	3.56	2.97	-17%	1.87	1.87	0%	5.44	4.84	-11%
AP	1.49x10 ⁻²	1.16x10 ⁻²	-22%	7.27x10 ⁻³	7.27x10 ⁻³	0%	2.21x10 ⁻²	1.88x10 ⁻²	-15%
EP	3.14x10 ⁻²	2.09x10 ⁻²	-34%	5.08x10 ⁻³	5.08x10 ⁻³	0%	3.65x10 ⁻²	2.59x10 ⁻²	-29%
AD	73.4	67.4	-8%	19.4	19.4	0%	92.8	86.8	-6%
FE	8.67x10 ⁻³	6.72x10 ⁻³	-23%	6.93x10 ⁻²	6.93x10 ⁻²	0%	7.79x10 ⁻²	7.60x10 ⁻²	-3%
WS	0.752	0.749	0%	0.204	0.204	0%	0.956	0.953	0%
FC	1.75x10 ⁻²	1.74x10 ⁻²	0%	4.76x10 ⁻³	4.76x10 ⁻³	0%	2.23x10 ⁻²	2.22x10 ⁻²	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 164: Black virgin POY—Scenario "Chemicals—High Intensity"

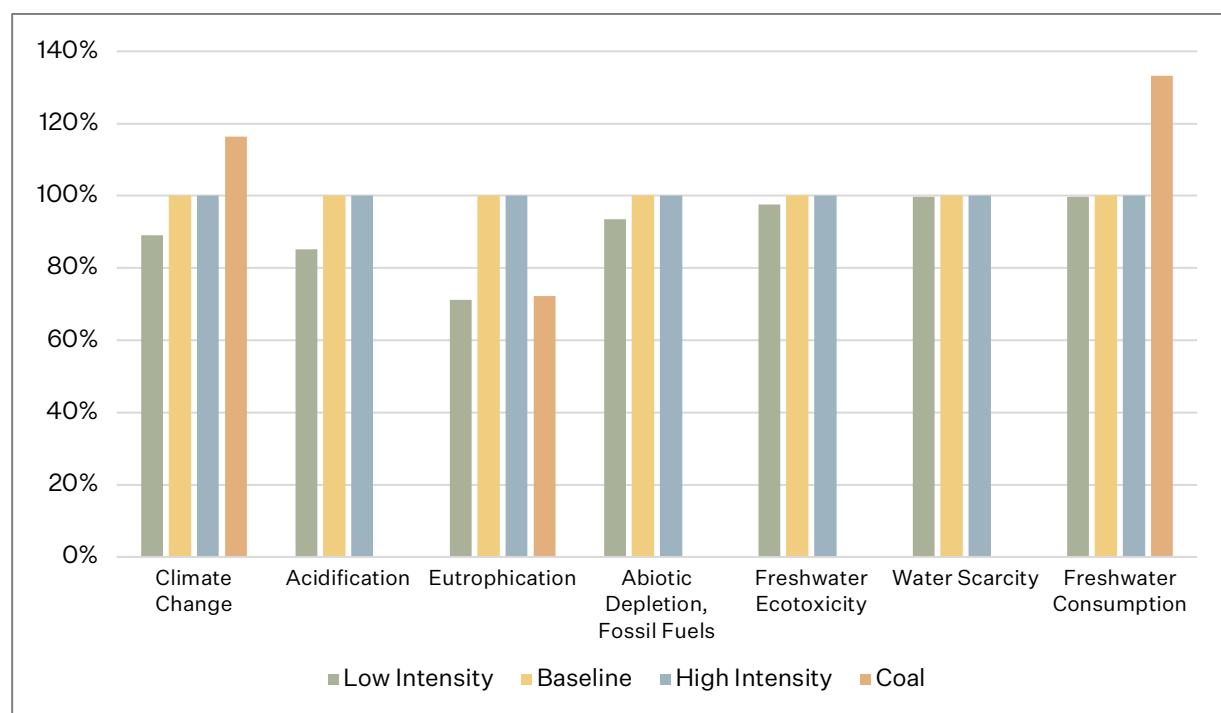
Impact category	Chip production			POY production			Total		
	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff	Baseline	High intensity	% Diff
CC	3.56	3.56	0%	1.87	1.87	0%	5.44	5.44	0%
AP	1.49x10 ⁻²	1.49x10 ⁻²	0%	7.27x10 ⁻³	7.27x10 ⁻³	0%	2.21x10 ⁻²	2.21x10 ⁻²	0%
EP	3.14x10 ⁻²	3.14x10 ⁻²	0%	5.08x10 ⁻³	5.08x10 ⁻³	0%	3.65x10 ⁻²	3.65x10 ⁻²	0%
AD	73.4	73.4	0%	19.4	19.4	0%	92.8	92.8	0%
FE	8.67x10 ⁻³	8.67x10 ⁻³	0%	6.93x10 ⁻²	6.93x10 ⁻²	0%	7.79x10 ⁻²	7.79x10 ⁻²	0%
WS	0.752	0.752	0%	0.204	0.204	0%	0.956	0.956	0%
FC	1.75x10 ⁻²	1.75x10 ⁻²	0%	4.76x10 ⁻³	4.76x10 ⁻³	0%	2.23x10 ⁻²	2.23x10 ⁻²	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 165: Black virgin POY—Scenario "Chemicals—Coal"

Impact category	Chip production			POY production			Total		
	Baseline	Coal	% Diff	Baseline	Coal	% Diff	Baseline	Coal	% Diff
CC	3.56	4.45	25%	1.87	1.87	0%	5.44	6.33	16%
AP	1.49x10 ⁻²	-	-	7.27x10 ⁻³	7.27x10 ⁻³	0%	2.21x10 ⁻²	-	-
EP	3.14x10 ⁻²	2.13x10 ⁻²	-32%	5.08x10 ⁻³	5.08x10 ⁻³	0%	3.65x10 ⁻²	2.64x10 ⁻²	-28%
AD	73.4	-	-	19.4	19.4	0%	92.8	-	-
FE	8.67x10 ⁻³	-	-	6.93x10 ⁻²	6.93x10 ⁻²	0%	7.79x10 ⁻²	-	-
WS	0.752	-	-	0.204	0.204	0%	0.956	-	-
FC	1.75x10 ⁻²	2.49x10 ⁻²	42%	4.76x10 ⁻³	4.76x10 ⁻³	0%	2.23x10 ⁻²	2.96x10 ⁻²	33%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 64: Comparison of chemical scenarios for black virgin POY

6.3.2.2.3. Drawn textured yarn results (white DTY)

Table 166: White virgin DTY—Scenario "Chemicals—Low Intensity"

Impact	Melt production			POY production			DTY production			Total		
	Base	Low	%	Base	Low	%	Base	Low	%	Base	Low	%
CC	3.43	2.86	-17%	0.719	0.719	0%	1.68	1.68	0%	5.83	5.26	-10%
AP	1.43×10^{-2}	1.11×10^{-2}	-22%	2.81×10^{-3}	2.81×10^{-3}	0%	6.63×10^{-3}	6.63×10^{-3}	0%	2.37×10^{-2}	2.06×10^{-2}	-13%
EP	3.02×10^{-2}	2.01×10^{-2}	-34%	2.07×10^{-3}	2.07×10^{-3}	0%	4.83×10^{-3}	4.83×10^{-3}	0%	3.71×10^{-2}	2.70×10^{-2}	-27%
AD	70.6	64.8	-8%	7.47	7.47	0%	17.2	17.2	0%	95.3	89.5	-6%
FE	8.35×10^{-3}	6.47×10^{-3}	-22%	1.22×10^{-2}	1.22×10^{-2}	0%	0.256	0.256	0%	0.277	0.275	-1%
WS	0.723	0.721	0%	7.37×10^{-2}	7.37×10^{-2}	0%	0.259	0.259	0.0%	1.06	1.05	0%
FC	1.68×10^{-2}	1.68×10^{-2}	0%	1.72×10^{-3}	1.72×10^{-3}	0%	6.02×10^{-3}	6.02×10^{-3}	0.0%	2.46×10^{-2}	2.45×10^{-2}	0%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 167: White virgin DTY—Scenario "Chemicals—High Intensity"

Impact	Melt production			POY production			DTY production			Total		
	Base	High	%	Base	High	%	Base	High	%	Base	High	%
CC	3.43	3.43	0%	0.719	0.719	0%	1.68	1.68	0%	5.83	5.83	0%
AP	1.43×10^{-2}	1.43×10^{-2}	0%	2.81×10^{-3}	2.81×10^{-3}	0%	6.63×10^{-3}	6.63×10^{-3}	0%	2.37×10^{-2}	2.37×10^{-2}	0%
EP	3.02×10^{-2}	3.02×10^{-2}	0%	2.07×10^{-3}	2.07×10^{-3}	0%	4.83×10^{-3}	4.83×10^{-3}	0%	3.71×10^{-2}	3.71×10^{-2}	0%
AD	70.6	70.6	0%	7.47	7.47	0%	17.2	17.2	0%	95.3	95.3	0%
FE	8.35×10^{-3}	8.35×10^{-3}	0%	1.22×10^{-2}	1.22×10^{-2}	0%	0.256	0.256	0%	0.277	0.277	0%
WS	0.723	0.723	0%	7.37×10^{-2}	7.37×10^{-2}	0%	0.259	0.259	0.0%	1.06	1.06	0%

Impact	Melt production			POY production			DTY production			Total		
	Base	High	%	Base	High	%	Base	High	%	Base	High	%
FC	1.68x10 ⁻²	1.68x10 ⁻²	0%	1.72x10 ⁻³	1.72x10 ⁻³	0%	6.02x10 ⁻³	6.02x10 ⁻³	0.0%	2.46x10 ⁻²	2.46x10 ⁻²	0%

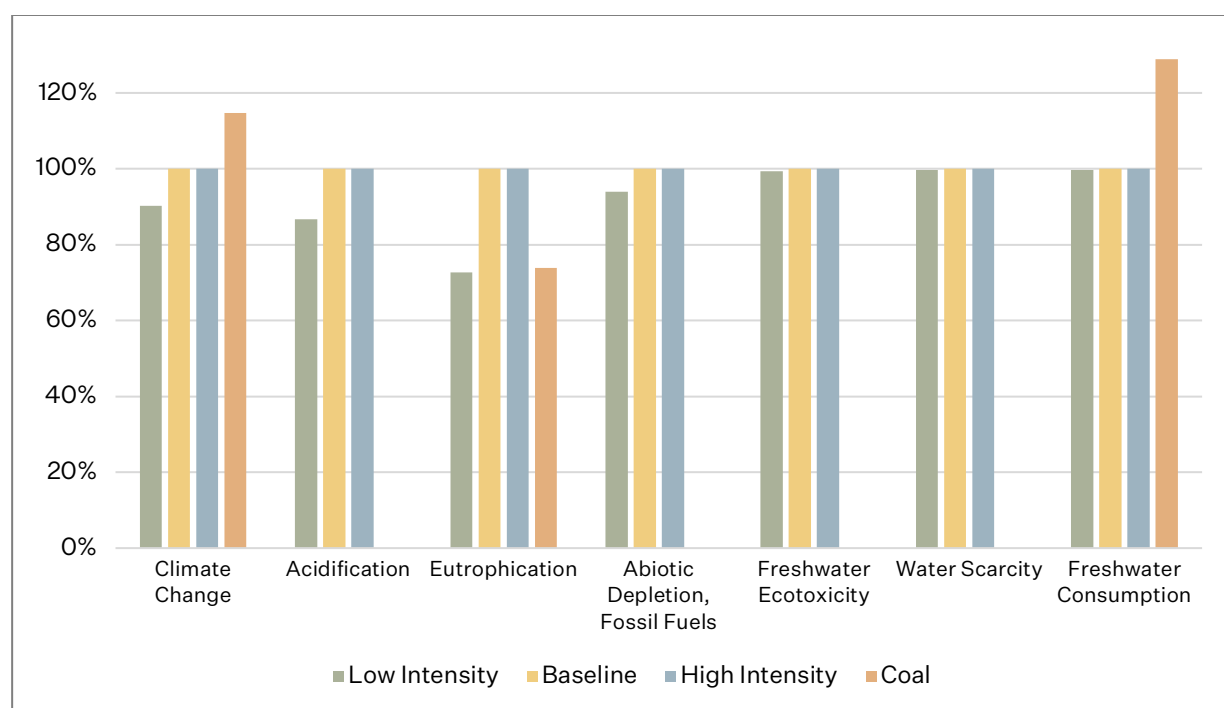
Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Table 168: White virgin DTY—Scenario "Chemicals—Coal"

Impact	Melt production			POY production			DTY production			Total		
	Base	Coal	%	Base	Coal	%	Base	Coal	%	Base	Coal	%
CC	3.43	4.28	25%	0.719	0.719	0%	1.68	1.68	0%	5.83	6.68	15%
AP	1.43x10 ⁻²	-	-	2.81x10 ⁻³	2.81x10 ⁻³	0%	6.63x10 ⁻³	6.63x10 ⁻³	0%	2.37x10 ⁻²	-	-
EP	3.02x10 ⁻²	2.05x10 ⁻²	-32%	2.07x10 ⁻³	2.07x10 ⁻³	0%	4.83x10 ⁻³	4.83x10 ⁻³	0%	3.71x10 ⁻²	2.74x10 ⁻²	-26%
AD	70.6	-	-	7.47	7.47	0%	17.2	17.2	0%	95.3	-	-
FE	8.35x10 ⁻³	-	-	1.22x10 ⁻²	1.22x10 ⁻²	0%	0.256	0.256	0%	0.277	-	-
WS	0.723	-	-	7.37x10 ⁻²	7.37x10 ⁻²	0%	0.259	0.259	0.0%	1.06	-	-
FC	1.68x10 ⁻²	2.39x10 ⁻²	42%	1.72x10 ⁻³	1.72x10 ⁻³	0%	6.02x10 ⁻³	6.02x10 ⁻³	0.0%	2.46x10 ⁻²	3.17x10 ⁻²	29%

Note: "% Diff" indicates the percentage difference between baseline and scenario results.

Figure 65: Comparison of chemical scenarios for white virgin DTY



7. Limitations

Due to the chosen study scope and LCIA methodologies, several important limitations should be considered to ensure the results are interpreted appropriately, as outlined below.

7.1. Limitations in the study scope

- Ecoinvent v3.11 datasets were used to model all primary and secondary life cycle inventory data, including the production of raw materials, packaging materials, ancillary materials, energy used, transport, and treatment of wastes. These datasets were selected based on how recent the data was collected, and how closely they match the actual technology used and the location in which the actual process occurred, if known. Except where noted, they are considered to be representative of the processes for which primary data was not available. However, they are not perfect matches to the actual operations that they represent.
- Several limitations in the study scope arose due to data uncertainties and constraints related to data availability. These have been discussed in detail below:
- Data provider C1 reported the use of confidential catalysts and additives, but only indicated whether they are organic or inorganic chemicals and the mass used. These chemicals are modeled using proxy ecoinvent datasets for average organic and inorganic chemical production, with quantities informed by literature review. These assumptions may not reflect the actual impacts of the proprietary catalysts and additives.
- Data provider C3 uses a confidential solvent during its shredding process, which they did not provide information on. A proxy dataset for the production of a mix of organic chemicals from ecoinvent was used to represent this solvent, and likely does not accurately represent the actual impacts of producing this solvent.
- For data provider M3, detailed information on flake production from external suppliers was not available. The model assumes that the externally sourced flake, representing 25% percent of the flake used for staple fiber production, was produced using the same manufacturing process as the internally produced flake. This assumption may not capture potential differences in external flake production.
- For all thermomechanical recyclers and virgin production, freshwater ecotoxicity is primarily driven by surfactant-related chemicals. However, upstream data on the exact sources and production methods of these different types of surfactant-related chemicals is not available. The modeled datasets are not exact matches to the actual chemistry of the surfactant-related chemicals.
- The electricity grid mix dataset from ecoinvent used to represent the (confidential) Southeast Asian country that M3 and V1 are located in, has a high freshwater ecotoxicity impact. This is due to the use of bagasse-based bioenergy within this country's grid mix. Bagasse-based bioenergy is modeled using global average sugarcane cultivation data from ecoinvent. The upstream sugarcane production may not be representative of this agricultural process in this country, and increases the uncertainty of the freshwater ecotoxicity results for M3 and V1.
- Primary data for the upstream waste collection distances for post-consumer and post-industrial PET waste was unavailable for some data providers (see details below). In these instances, distances from ecoinvent datasets and literature were used instead. Sensitivity analyses were conducted to test the assumptions, and results show that upstream waste collection distances can affect the total impacts related to recycled polyester.
- Data providers C1 and C2 were only able to provide a general area from which post-industrial waste was collected. The transport distances modeled are estimated, based on this information.

- The exact distance required to collect C2's post-consumer textile waste was unable to be provided. Instead, a list of all post-consumer waste suppliers used by C2 was provided. The farthest known post-consumer textile waste supplier location (1,200 km) was used as a conservative estimate. Given that post-consumer textile waste represents only 7% of the feedstock, its impact on the overall process is limited.
- The upstream collection distance for post-industrial waste used by data provider M1 is based on the ecoinvent transport of non-hazardous waste (Table 41).
- For data providers M1 and M2, the distance to collect post-consumer bottle waste is based on the ecoinvent dataset for post-consumer bottle collection and sorting (Table 41).
- Data provider M3 indicated that bottle collection occurs within the greater metropolitan area of the nearby city where the facility operates. As upstream transport data was not provided, a 100 km transport distance was assumed to represent bottle collection within the local area.
- Data provider C3's LCI data is based on engineering plans validated using detailed heat and mass balances based on pilot-scale recycling production, and this data does not represent commercial-scale process conditions. It is unclear how representative the provided data is of the commercial-scale operation of this technology.
- Given the use of specific facility modeling choices and the variability between suppliers, the LCA results reported here should not be used to extrapolate to an industry average for these types of processes, if better data is available. These facilities may represent better-than-average scenarios.

7.2. Limitations in the life cycle impact assessment phase

There may be additional impacts relevant to the production of virgin and recycled polyester at the manufacturing facility that are not captured by the impact categories used within this LCA. It should also be noted that LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

8. Conclusions and Recommendations

LCAs are used extensively to assess environmental impacts from the production of different materials; however, the accuracy of an LCA is only as good as the quality of data on which it is based. This assessment was conducted to better understand the environmental impact, logistics, and strengths and weaknesses of different mechanical recycling, chemical recycling, and virgin PET production pathways. Data was collected from five companies, representing: virgin production of five different PET products in Southeast Asia (PET chip, black and white staple fiber, partially oriented yarn, and drawn textured yarn); mechanical recycling of post-consumer PET bottles and post-industrial textile waste within the US, China, and Southeast Asia into PET chip and staple fiber; and chemical recycling of post-industrial and post-consumer textile waste in China and Europe into PET chip. These intermediate products are used to produce all other finished PET textile products (for example, yarn, clothing, shoes, upholstery, fill, etc.). In addition, as far as the authors are aware, this study provides the first publicly available LCI data and LCIA results on the virgin production of PET chip and staple fiber from Southeast Asia, which is significant given that Asia as a whole produces over half of the world's PET (Coherent Market Insights, 2025; Research and Markets, 2023; Intel Market Research, 2025). It also provides new LCIA results on PET chemical and thermomechanical recycling technologies. However, it is important to note that while this study includes chemical recycling of post-consumer textile waste, the extent of data available was limited. Only one commercial scale data provider (C2) recycled post-consumer waste, and this only represented 7% of the waste they recycled during the data collection period of its operations.

The sections below summarize the LCIA results and sensitivity analyses for each technology and provide some recommendations.

8.1. Chemical recycling results

Chemical recycling can be employed for both post-industrial and post-consumer textile waste feedstock. However, while both commercial chemical recyclers involved in this study claim their technology can be used to recycle post-consumer waste, C1 recycled <1% post-consumer waste during the data collection period, and C2 recycled approximately 7%. Given the additional challenges with sorting and cleaning post-consumer waste, this is expected and falls in line with what has been learned from other chemical recyclers interviewed in the scoping phase of this study; most chemical recyclers are currently focusing on post-industrial waste as it is much easier to collect and recycle, compared to post-consumer waste, due to its homogeneous nature and the ability to avoid dealing with challenges to sort textile blends. The three solvolytic recycling processes assessed in this study can decolor waste PET and, so, are not limited by the color of the waste feedstock. Current PET chemical recycling technologies can only accept small amounts (<4-15%)³ of impurities, such as cotton and elastane.

The LCIA results revealed that, for both commercially operating chemical recyclers (C1 and C2), electricity consumption and the use of chemicals are major environmental hotspots associated with the chemical recycling of polyester (Figure 6–Figure 7). In addition, C2's recycling process uses a substantial amount of energy for heat, which is a dominant contributor across many impact categories. For the pre-commercial recycler (C3), which provided LCI data on recycling 100% post-consumer and 100% post-industrial waste, the largest contributing inputs to impact were electricity, chemical use, and waste treatment (Figure 8–Figure 9).

³ Based on primary data from data providers included in this study.

8.2. Thermomechanical recycling results

Thermomechanical recycling is used mainly to recycle post-consumer PET bottle waste into textiles, but it can also be used to recycle post-industrial textile waste. It requires mostly homogeneous, high-quality waste inputs, as it is unable to remove contaminants or additives within the PET. It can only recycle PET waste a limited number of times before the PET becomes too degraded for further mechanical recycling (Patel et al., 2024). It is also unable to decolor PET, and so the recycled chip or staple fiber is generally the same color as the waste used, which may result in overdyeing downstream products like filament to colors such as black, which may limit end use.⁴

Electricity is a consistent contributor to climate change, acidification, eutrophication, and abiotic depletion of fossil fuels across all products and data providers (>11%). Feedstock collection also contributes notably to these impact categories, particularly for M2 where an ecoinvent default bottle collection distance of 990 km is used. In addition to transport, the production of low-density polyethylene (LDPE) collection containers—modeled using default data from ecoinvent—further contributes to the collection-related impacts.

Freshwater ecotoxicity is driven almost entirely (>79%) by surfactant-related chemicals, which are used to clean incoming waste in M1 and M2's recycling process. While upstream data on the exact sources and production methods of these different types of surfactant-related chemicals is not available, the closest representative LCA datasets were used to model them. For M3, chemicals and electricity together are responsible for >94% of its impact. The contribution from electricity is largely driven by upstream processes in the regional grid mix, particularly sugarcane cultivation associated with bagasse-based bioenergy. It is unclear how representative the ecoinvent sugarcane cultivation process is as it represents sugarcane grown in India, a different region than the one in which M3 operates.

Water scarcity and freshwater consumption impacts for thermomechanically recycled chip production are primarily influenced by electricity (9–52%), feedstock collection (9–55%)—mostly driven by the upstream production of the collection container—and chemicals (8–28%). Facility water use is also a main contributor, particularly for M3's freshwater consumption and for M1's water scarcity.

8.3. Virgin production results

The vast majority of PET is still produced from virgin materials and represented 87% of the 2024 textile polyester fiber market (Textile Exchange, 2024a). PET production begins with the extraction of crude oil and natural gas, which are ultimately processed into purified terephthalic acid (PTA) and monoethylene glycol (MEG); all of these upstream processes are accounted for within the LCA of this study. While dimethyl terephthalate (DMT) can be used in place of PTA, the vast majority of PET is polymerized using PTA and MEG, as was the case for the virgin data provider included in this assessment (V1).

The LCIA results show that the production of the PTA and MEG used to polymerize PET is the dominant contributor (46–94%) to all impact categories, except freshwater ecotoxicity, for all five virgin PET products (staple fiber 1, 2, and 3, black POY, and white DTY) (Figure 27–Figure 33). Energy use is another major contributor across most categories. Freshwater ecotoxicity is driven by the use of non-polymerization-related chemicals, such as surfactant-related spin finish.

⁴ Based on TAG expert feedback.

8.4. Sensitivity analyses

8.4.1. Electricity sensitivity analysis results

The results of the sensitivity analysis show that changing the grid mix used by any producer of PET, regardless of their pathway (chemical recycling, thermomechanical recycling, or virgin production), will affect the overall environmental impact of all impact categories, sometimes substantially. For instance, the climate change impact category decreased by as much as -54% under the renewable scenario and increased by up to 111%. The actual change in impact varied for each data provider, with the magnitude of change determined by the electricity intensity of the production process and the amount of renewable energy or coal used in each data providers' actual electricity mix.

Climate change, acidification, and abiotic depletion of fossil fuels are particularly sensitive, while eutrophication and freshwater ecotoxicity are more varied depending on the type of technology. For chemical recycling, eutrophication and freshwater ecotoxicity are only marginally affected by changes to their electricity mix. For thermomechanical recycling and virgin production, freshwater ecotoxicity is only affected if the baseline grid mix involves a source of electricity that has a high freshwater ecotoxicity impact, in this case, bagasse-based bioenergy used by M3 and V1 (the same company with both facilities located in the same country within Southeast Asia). The thermomechanical recyclers' and virgin producers' eutrophication impact is sensitive to changes in the electricity mix, where electricity makes a notable contribution. Finally, freshwater consumption and water scarcity impacts see large changes for either scenario when baseline electricity production involves large amounts of water use, as represented in the ecoinvent datasets. Hydroelectricity from reservoirs, and electricity generated using nuclear energy, have larger water-related impacts than coal and renewable electricity. This means that the removal of these sources of electricity in the coal and renewable energy scenarios will lead to a decrease in the water-related impacts for both scenarios. For instance, C3 uses imported alpine reservoir hydroelectricity in its baseline grid mix and sees a decrease of at least 22% for water scarcity and 83% for freshwater consumption impacts for both scenarios.

This analysis highlights that using renewable energy reduces the impact of electricity production. Companies looking to set up new recycling facilities should look for regions with large amounts of renewable energy in the grid mix, consider entering into contracts with renewable energy producers, or install onsite renewable energy to see lower environmental impacts.

8.4.2. Transport sensitivity analysis results

The truck transport sensitivity analysis shows that changes in the truck transport intensity (the distance and emissions from the combustion of fossil fuel) to collect waste feedstock can greatly affect the impact of results, particularly for climate change, acidification, freshwater ecotoxicity, and abiotic depletion of fossil fuels. For the climate change impact category, changes in truck intensity resulted in reductions as great as 13% and increases of up to 27%. The actual change in impact varied for each recycler and was dependent upon the distance required to collect the waste feedstock they used. The results also indicate that among changes in distance and emission standards, transport distance has a stronger influence across multiple impact categories. More stringent emission standards help reduce specific pollutant-related impacts (acidification, eutrophication, and freshwater ecotoxicity), but reductions in transport distances—such as through local sourcing—yield broader and more significant reductions across impact categories.

Therefore, both emission standards and transport distance should be considered, but the latter remains the dominant factor when assessing the environmental performance of upstream transport for recycled PET chip. When considering ways to minimize the environmental impact, upstream transport distances should be considered when determining the location of a recycling

facility or in deciding where to source recycled PET chip and options to decrease upstream transport should be examined.

8.4.3. Chemical sensitivity analysis results

The chemical sensitivity analysis demonstrates that changes in upstream chemical production can influence results for both chemical recycling and virgin production systems. Variations in the intensity of ethylene glycol (also referred to as monoethylene glycol (MEG)), methanol, and purified terephthalic acid (TPA) production were tested under low-intensity, high-intensity, and coal scenarios, with the latter reflecting ethylene glycol produced via the coal-to-ethylene-glycol (CtEG) pathway (Qian et al., 2022).

For climate change impacts, upstream chemical production changes led to reductions of up to 14% under the low-intensity scenario and increases of up to 32% under the coal scenario. The high-intensity scenario results in minimal or no change compared to the baseline, showing that the baseline already represents a conservative assumption or that the adjustments in upstream chemical datasets have limited influence on overall impacts. Substantial increases occur only under the coal scenario, while reductions are observed under the low-intensity scenario.

While this study relies on the most recent ecoinvent datasets, obtaining supplier-specific information on chemical production routes would allow further refinement of future assessments.

8.5. Recommendations

8.5.1. LCA methodology recommendations

8.5.1.1. Improve data quality on upstream waste collection and sorting, and chemical recycling

Primary data on upstream post-industrial and post-consumer waste collection and sorting was lacking for some data providers, requiring the use of secondary data and assumptions that might not be representative of the actual transport and operations involved. Gaining access to this data, particularly for post-consumer waste, would increase the accuracy of future LCAs on polyester recycling, given the collection and sorting of waste's contribution to the results.

In addition, the lack of existing data made it challenging to better understand why there is a variety in the energy (especially heat) required for commercial-scale chemical recycling of PET using glycolysis and transesterification using methanol. Acquiring more data will greatly improve our overall understanding of the life cycle impacts of chemical recycling.

8.5.1.2. Build upon existing relationships with recyclers and their supply chains to continue to improve data availability

As noted above, there were data gaps within this study. Establishing trusted relationships with recyclers and their supply chain would allow for better data to be collected, particularly around the chemistry of proprietary ingredients and the collection/sorting of textile waste. It would also make collecting this data easier, improving the efficiency of future LCA timelines.

8.5.2. LCA insights for business action

8.5.2.1. Invest in post-consumer sorting technologies

Textile brands can invest in sorting technology to improve the economic viability of post-consumer textile waste recycling. Existing technology struggles to identify interwoven fibers or multi-layered garments. Often, manual labor is used instead, which can greatly increase the cost of sorting. Creating new, automated technology to quickly identify, separate, and sort different types

of commonly used textile materials (for example, PET, nylon, spandex, and cotton) would greatly improve the post-consumer textile recycling markets.

8.5.2.2. Increase the use of renewable energy used to produce PET

The results from the electricity sensitivity analysis show that many environmental-impact categories, including climate change, are significantly affected by changing the source of electricity. Increasing the use of renewable electricity to produce PET will reduce its environmental impact. Companies should consider their source of electricity when designing and choosing locations for recycling facilities, and consider contracts with renewable producers. Textile brands should support waste recyclers with transitioning to renewable energy sources, especially post-consumer recyclers, to counteract the increased energy needed for the additional processing of post-consumer waste.

8.5.2.3. Reduce truck transport to lower environmental impacts and source waste locally

The results of the transport sensitivity analysis in this study show that the truck transport required to collect waste feedstock can have large effects on the results. Finding ways to reduce truck transport—such as placing recycling facilities near large sources of waste and utilizing cleaner (train or electric truck), or more efficient (ship) forms of transport—will reduce environmental impacts when other sources of emissions are constant. Sourcing waste locally also reduces transport distances and allows for better quality control and management of waste feedstock, since recycling companies are able to work directly with waste collection services to provide oversight. Recycling companies can also help incorporate standards and specifications of the waste collected, which ensures that it is processed and recycled more efficiently, reducing the economic costs of sorting and improving yields of recycled PET (Systemiq, 2024b).

8.5.2.4. Consider the trade-offs of different recycling technologies

Given the complexities of polyester recycling used in the textile industry, a wide variety of technologies have been developed that specialize in recycling certain types of post-industrial and post-consumer textile waste. Because the chemical recycling industry is still in its early stages, many of these technologies are newly invented and have yet to be tested at a commercial level. Out of the many different chemical recyclers interviewed for this study, of which three ultimately participated, few used the same chemical recycling technology. There are tradeoffs associated with these different technologies.

Thermomechanical recycling is generally less chemical and energy intensive and so, typically, has a lower environmental impact than chemical recycling; however, it is limited to recycling high-quality waste feedstock, as it is unable to remove additives and contaminants that have become chemically bound to waste PET. It is also unable to remove dyes, and so produces recycled products with a similar color as the waste it recycles, which may lead to overdyng of downstream products like filament.⁵ Finally, thermomechanical recycling is only able to recycle the same PET a limited number of times before the quality of the PET is too low to be thermomechanically recycled (Patel et al., 2024).

On the other hand, chemical recycling is generally more chemical and energy intensive, and so often has a higher environmental impact, but offers greater flexibility in the types of waste it can accept, as it is able to remove contaminants, additives, and dyes. There is a large variety of different types of chemical recycling technologies, with some designed to focus exclusively on post-industrial waste, some geared towards specific types of post-consumer waste, and still others designed to handle the significantly more complex task of recycling a broad range of post-consumer waste. Chemical recycling technologies that are able to handle diverse types of waste,

⁵ Based on TAG expert feedback.

with large amounts of additives and contaminants, are the most intensive recycling processes with the largest amount of impact (Closed Loop Partners, 2023).

Apart from thermomechanical and chemical recycling, dissolution recycling is an emerging recycling technology where solvents are used to dissolve plastic waste and extract target polymers to create new recycled plastic products (Recycling Today, 2024). This technology is still being developed, but is yet another recycling technology being explored in the chemical industry.

Much of this information is based on literature review (Closed Loop Partners, 2021; Closed Loop Partners, 2023), interviews with other recyclers who ultimately did not participate in this study, and the results of C3's pre-commercial chemical recycling technology. More data from commercially operating chemical recyclers is needed further verify these findings.

Appendix A—Circular Footprint Formula

This appendix explores how the thermomechanical and chemical recycling results, calculated using the recycled content allocation approach reported in the main body of this report, change when the Product Environmental Footprint (PEF) circular footprint formula (CFF) allocation approach is used instead. The results shown in section A.4, below, **do not conform to the PEF methodology and cannot be used as a PEF**. They are only intended to illustrate how the CFF allocation approach differs from the recycled content allocation approach.

A.1 Background and history

The CFF is an allocation approach developed by the European Commission's Joint Research Centre (JRC) to account for the environmental impacts of recycled and reused materials within the Product Environmental Footprint (PEF) framework. It shares the impact of recycling and perceived benefits of displacing primary (virgin) resource use between the product system that generates the waste and the product system that recycles this waste. The allocation of impacts and benefits is based on the supply and demand of recycled materials, with the aim to incentivize a circular economy.

A brief history of PEF and the CFF

- **2011**—The European Commission published the *Roadmap to a Resource Efficient Europe*, identifying the need for more consistent methods to assess the environmental performance of products and organizations.
- **2013**—The PEF Guide and the Organization Environmental Footprint (OEF) Guide were officially released. These guides provided the initial methodological framework based on Life Cycle Assessment (LCA), using standards such as ISO 14040/44, but expanding them with more specific modeling rules. The CFF was included in the initial PEF/OEF Guides and pilot phase documentation.
- **2013–2018**—The Environmental Footprint Pilot Phase was conducted. Over 280 organizations participated in developing Product Environmental Footprint Category Rules (PEFCRs) for 26 product groups, and OEF Sector Rules (OEF SRs) for several sectors. This phase aimed to test the methodology, improve data quality, and evaluate feasibility.
- **2019–2021**—The transition phase focused on refining the PEF methodology and integrating feedback from the pilot phase. The Commission also explored how to incorporate the PEF into EU policies, such as Green Public Procurement, Ecolabels, and Sustainable Product Policy. Revisions to the CFF were made based on pilot feedback. The JRC published updated reports, refining the mathematical formulation and addressing concerns about double counting and recyclability assumptions. By the end of the transition phase, the CFF became a mandatory part of Environmental Footprint-compliant studies, unless justified otherwise in category-specific rules.
- **2021–present**—The PEF methodology is being considered as part of broader legislative initiatives, including the Sustainable Products Initiative (SPI), Circular Economy Action Plan, and the Ecodesign for Sustainable Products Regulation (ESPR); PEF is also expected to be incorporated into Digital Product Passports. These initiatives aim to support the European Green Deal's goals by making PEF-based assessments a core part of product sustainability measures in the EU. Within the PEF, the CFF continues to serve as a foundational element in EU product policy, particularly in areas addressing material circularity, Ecodesign, and the Sustainable Products Initiative (SPI). It has also been integrated into Environmental Footprint-compliant databases and software tools such as openLCA and SimaPro.

(Carbonfact, 2024; European Commission, 2022; Zampori and Pant, 2019; European Commission, 2018).

A.2 Other recycling allocation approaches

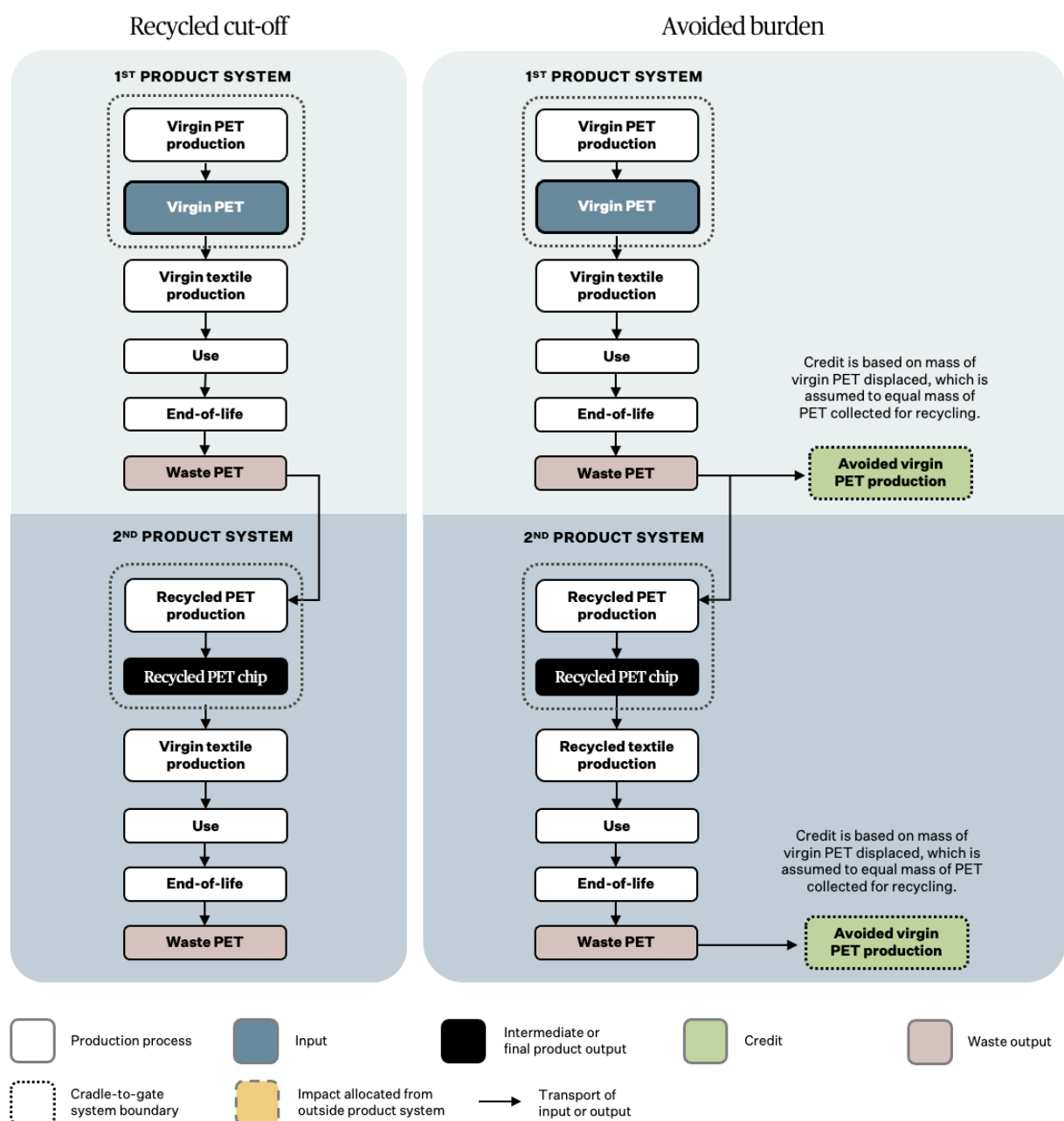
Within LCAs, different approaches exist to determine how to allocate the impacts from recycling and the benefits from any potential reduction of primary (virgin) resources between the generator of the waste and the recycler of this waste. Two of the most commonly used allocation approaches are the recycled content, also called the 100:0 or cut-off approach, and the avoided burden approach, commonly referred to as the closed-loop or 0:100 methodology.

- **Recycled content approach**—This methodology states that the primary user of a material is responsible for the impacts associated with its production and follows the “polluter-pays” principle. Impacts from the product system that generates the waste are allocated to this product system, while the impacts from recycling are allocated to the product system that uses the recycled material (also referred to as a secondary material) (Figure A-1). No benefits from any potential future reduction of primary (virgin) resources are included. This approach aims to incentivize the use of recycled materials as opposed to the generation of materials that may or may not be recycled. It is considered a straightforward approach to follow and communicate, and it avoids the use of credits from future activities. The results presented in the main body of this report follow the recycled content approach, which is also used by the Sustainability Apparel Coalition’s (SAC) Higg Material Sustainability Index (MSI) (Ecomatters, n.d.).
- **Avoided burden approach**—This methodology assumes that generating waste that can be recycled will lead to the reduction in the future of primary materials (often at a 1:1 ratio). As with the recycled content method, the product system that uses a material is responsible for the impact associated with producing it, regardless of whether it is primary or secondary (recycled) material. Unlike the recycled content method, the waste generated from a product system that is recycled, which is usually based on its recycling rate, is assumed to prevent an equivalent amount of primary material from being produced in the future (for example, generating 1 kg of aluminum waste, of which 70% is collected for recycling is assumed to displace 0.7 kg of primary aluminum from being produced). The impact from producing the mass of displaced primary material is subtracted from the impact of the product system that generated this waste; it is important to note that this credit is applied at the end-of-life stage of an LCA, which is not included within the cradle-to-gate studies conducted in this report. See Figure A-1, below, for more details. This allocation approach aims to incentive the production of waste that can be subsequently recycled and is supposed to encourage circularity. However, there are several key issues with this approach:
 - It is highly dependent upon assumptions about whether a waste material that can be recycled, will actually be recycled. Recycling rates measure the amount of material collected for recycling, not the actual amount of material that is recycled. These two values can be very different (Zink, 2023).
 - It can overestimate the credit if primary resources aren’t displaced at the assumed 1:1 ratio. There is a complex relationship between markets dealing with primary materials and markets dealing with secondary materials, such as used goods and scrap. Zink et al., (2015) created a model to estimate the effects that recycling aluminum has on displacing the production of primary aluminum when the prices of primary and secondary aluminum were considered. They found that only when buyers who commonly use primary material are, at least, as willing to substitute for secondary material as buyers of secondary material are willing to substitute for primary material, will a 1:1 ratio of displacement occur. Given that there are typically more constraints with using recycled materials than primary materials, and that recycling is typically more logistically and economically

challenging, this is often not true. These studies, and others like them, also demonstrate that it's incredibly challenging to predict the market interactions between primary and secondary materials (Zink and Geyer, 2017; Zink et al., 2015).

- It makes it challenging to understand the actual emissions released into the atmosphere from production, as credits based on potential future activities are included in the results.

Figure A-1. Recycled cut-off and avoided burden flow diagram



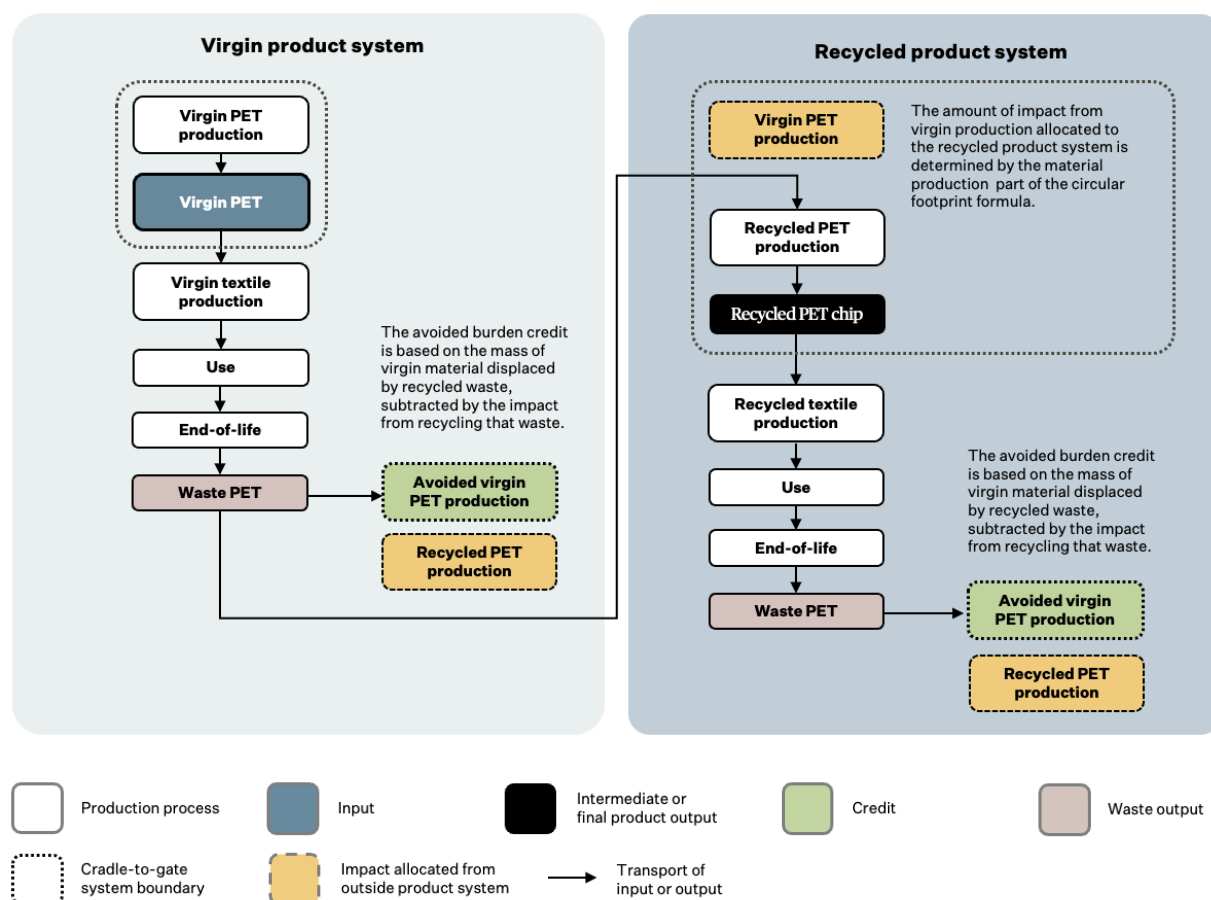
A.3 The circular footprint formula

As described by the PEF Method adopted by the Commission on December 16, 2021 (Recommendation 2279/2021) (European Commission, 2021b), the circular footprint formula (CFF) incorporates both aspects of the recycled content and avoided burden-allocation approaches by using the “A factor” to vary which allocation philosophy is emphasized: an “A factor” of 1 would be equivalent to the recycled content approach, while an “A factor” of 0 would be equivalent to the avoided burden approach. In reality, an “A factor” of between 0.2 and 0.8 is used and is based on the supply and demand of recycled materials within a given market:

- **A = 0.2:** low supply of recyclable materials and high demand by recyclers, the formula focuses on recyclability at end-of-life (avoided burden approach)
- **A = 0.8:** high supply of recyclable materials and low demand by recyclers (for example, the current situation with textile waste), the formula focuses on recycled content
- **A = 0.5:** equilibrium between supply of recyclable materials and demand by recyclers, the formula focuses both on recyclability at EoL and recycled content (for example, the PET bottle industry)

Specific “A values” are provided by PEF category rules (PEFCRs), standards created to provide additional provisions for a category of similar products, but a default value of 0.5 is used if a relevant PEFCR does not exist. The flexibility of the formula allows it to incentivize the development of recycling technologies within markets that have a high supply of waste but little to no recycling, and the opposite for markets that have robust recycling technologies but with limited supply of the materials they are designed to recycle. This means that when comparing different recycling processes that use different types of waste, it incentivizes recycling of wastes for which supply outpaces demand (for example, the recycling of textile waste receives a greater credit than the recycling of bottle waste). Another aspect that separates the CFF from the recycled content or avoided-burden approach, is its partial allocation of a secondary material’s first life (i.e., the virgin production of the material, which is then recycled) to the recycled product system (Figure A-2). Another difference between the CFF and the avoided-burden approach is that the avoided-burden credit within the end-of-life cycle stage includes the impact from the recycling of that material, which reduces the credit (Figure A-2).

Like the avoided-burden approach, the CFF relies on several assumptions, which has led to its critique by some within the LCA industry: 1) it assumes that waste materials will actually be recycled and will substitute virgin materials in future markets (Zampori and Pant, 2019); 2) it can be seen to incentivize the generation of waste in markets where demand outpaces supply as it gives a larger credit to waste generating product systems (Ekvall et al., 2021); 3) it is more complicated to implement than the recycled content or avoided-burden approach (Hecking and Muth, 2023; A.I.S.E, 2024); 4) it involves the use of credits based on future reductions of activity, which makes it challenging to determine the actual amount of impact generated.

Figure A-2. PEF Circular Footprint Formula flow diagram

The CFF formula itself consists of different parameters split into four different parts, as shown below.

Parameters

A: Allocation factor of burdens and credits applied between the supplier and the user of recycled materials.

B: Allocation factor of energy-recovery processes. It applies both to burdens and credits. It shall be set to 0 for all PEF studies.

Q_{sin} : Quality of the ingoing secondary material, i.e., the quality of the recycled material at the point of substitution.

Q_{sout} : Quality of the outgoing secondary material, i.e., the quality of the recyclable material at the point of substitution.

Q_p : Quality of the primary (virgin) material.

R_1 : The proportion of material in the input to the production that has been recycled from a previous system.

R_2 : The proportion of the material in the product that will be recycled or reused in a subsequent system. R_2 shall, therefore, take into account the inefficiencies in the collection and recycling (or reuse) processes. R_2 shall be measured at the output of the recycling plant.

R_3 : The proportion of the material in the product that is used for energy recovery at end-of-life (EoL).

$E_{recycled}$: Specific emissions and resources consumed per functional unit (FU) arising from the recycling process of the recycled (reused) material, including collection, sorting, and transportation processes.

$E_{recycledEoL}$: Specific emissions and resources consumed per FU arising from the recycling process at EoL, including collection, sorting, and transportation processes.

E_v : Specific emissions and resources consumed per FU arising from the acquisition and pre-processing of virgin material.

E_{*v} : Specific emissions and resources consumed per FU arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.

E_{ER} : Specific emissions and resources consumed per FU arising from the energy-recovery process (for example, incineration with energy recovery, landfill with energy recovery, etc.).

E_{SE} , E_{heat} , E_{elec} : Specific emissions and resources consumed per FU that would have arisen from the specific substituted energy source, heat, and electricity, respectively.

E_D : Specific emissions and resources consumed per FU arising from disposal of waste material at EOL of the analyzed product, without energy recovery.

X_{ERheat} , X_{ERelec} : The efficiency of the energy recovery process for both heat and electricity.

LHV: Lower heating value of the material in the product used for energy recovery.

Material production

$$(1 - R_1)E_v + R_1 \times (A \times E_{recycled} + (1 - A)E_v \times \frac{Q_{sin}}{Q_p})...$$

Waste recycling

$$+(1 - A)R_2 \times (E_{recycledEoL} - E_{*v} \times \frac{Q_{Sout}}{Q_p})$$

Energy recovery

$$(1 - B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

Disposal

$$(1 - R_2 - R_3)E_D$$

A.4 Application of the circular footprint formula

As stated by the PEF Method adopted by the Commission on December 16, 2021 (Recommendation 2279/2021) (European Commission, 2021b), cradle-to-gate studies set the R_2 , R_3 , and E_D parameters of the CFF to 0, effectively removing the parts of this formula related to waste recycling at EoL, energy recovery, or disposal. Instead, only the material production part of the CFF is used. In addition, a PEF requires results to be reported using two “A” values: an “A” value of 1, i.e., the recycled content allocation approach, which is already reported in the main body of this report; and the application- or material-specific “A” default value, for which we use the “A” and “ Q_{sin}/Q_{sout} ” values defined in the new 2025 Apparel and Footwear PEFCR (European Commission, 2025b), (Table A-1).

To use the material production part of the CFF, the point at which secondary (recycled) materials substitute primary (virgin) materials must be determined. Within this study, none of the product systems include a point of substitution, instead they produce the intermediate products (for example, virgin chip or recycled chip), which could be used to substitute each other in subsequent steps of the supply chain. For instance, chip is often spun and extruded into yarn, and either recycled or virgin chip could be used.

For the results presented in section A.5, below, (Tables A-2–A1-9) we use the hypothetical scenario of 1 kg of recycled chip or staple fiber intended for use in a subsequent yarn spinning process that can use either virgin or recycled chip or staple fiber; to simplify this scenario and to focus on the changes to the chip and staple fiber production results when using the CFF, we don’t include the environmental impacts from this hypothetical yarn spinning process and assume a 100% recycled content of the chip. We then apply this formula nine different times, using the life cycle inventory (LCI) data of the three chemical recyclers (C1, C2, and C3, shown in section 3.5) and the three thermomechanical recyclers (M1, M2, and M3, shown in section 4.5) for the $E_{recycled}$ parameter. V1’s cradle-to-chip and average cradle-to-staple fiber LCI data (Table 67, Table 74, Table 76) are used for the E_V parameters.

To further understand how the material production part of the CFF is applied in this hypothetical scenario, we break down this part of the CFF into two parts:

Environmental impacts associated with the mass of virgin chip: $(1 - R_1)E_V + \dots$

The first part of the formula determines the environmental impacts of the virgin chip used by the functional unit (in this case, 1 kg of yarn produced from either 1 kg of recycled or virgin chip). It does this by first multiplying the percent of the total virgin chip used by the functional unit ($1 - R_1$), which, in this case, is 100%) by the impact of producing virgin chip (E_V).

For our hypothetical scenario, we assume the $R_1 = 100\%$, so this part of the formula becomes 0.

Allocated environmental impact: $R_1 \times (A \times E_{recycled} + (1 - A)E_V \times \frac{Q_{sin}}{Q_p})$

The next part of the formula multiplies the recycled content (R_1 , which equals 100%) by the allocated environmental impacts— $(A \times E_{recycled} + (1 - A)E_V \times \frac{Q_{sin}}{Q_p})$ —using the “A” value and taking into account the quality of the recycled material compared to the quality of the virgin material at the point of substitution ($\frac{Q_{sin}}{Q_p}$); note that $E_{recycled}$ represents the impact from producing 1 kg of recycled chip.

As shown in Table A-1, an “A” value of 0.5 is used for post-consumer PET bottles recycled into chip used for textile applications (indicating that the demand for waste PET bottles for recycling is

equal to the supply of waste PET bottles) and an “A” value of 0.8 is used for post-industrial PET textile waste recycled into chip also used for textile applications (indicating that the demand for textile waste for recycling is lower than the supply of waste textiles). A $\frac{Q_{sin}}{Q_p}$ of 1 is used for mechanically recycled chip produced from PET bottles and chemically recycled chip produced from textile waste, while a value of 0.75 is used for mechanically recycled chip produced from textile waste, indicating that mechanically recycled chip from textile waste is of lower quality than the virgin PET chip it is substituting.

Table A-1: 2025 Apparel and Footwear PEFCR “A”, “Q_{sin}”, and “Q_p” values

(European Commission, 2025b)

Scope for E _v	Flow of recycled material	Origin of recycled material	A value	Q _{sin} / Q _p value	Applicable data provider
Production of virgin polyester fibers	Recycled polyester fibers	PET textile waste (via chemical recycling)	0.8	1	C1, C2, C3
		PET bottles	0.5	1	M1, M2, M3
		Textile PET fibers (via mechanical recycling)	0.8	0.75	M1

Applied formula

Chemically recycled post-consumer and post-industrial textile waste

$$(1 - 1)E_v + 1 \times (0.8 \times E_{recycled} + (1 - 0.8)E_v \times 1)$$

Mechanically recycled post-consumer PET bottles

$$(1 - 1)E_v + 1 \times (0.5 \times E_{recycled} + (1 - 0.5)E_v \times 1)$$

Mechanically recycled post-industrial textile waste

$$(1 - 1)E_v + 1 \times (0.8 \times E_{recycled} + (1 - 0.8)E_v \times 0.75)$$

A.5 Circular footprint formula results

Table A-2: C1—chemically recycled chip Higg MSI results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (kg CO ₂ eq)	1.77	2.09	15%
Acidification (mol H ⁺ eq)	6.73x10 ⁻³	8.20x10 ⁻³	18%
Eutrophication (kg PO ₄ eq)	2.29x10 ⁻²	2.43x10 ⁻²	6%
Abiotic depletion, fossil fuels (MJ eq)	23.0	32.3	29%
Freshwater ecotoxicity (PAF m ³ day)	5.35x10 ⁻³	5.92x10 ⁻³	10%
Water scarcity (m ³ world eq)	0.487	0.532	8%
Freshwater consumption (m ³)	1.12x10 ⁻²	1.22x10 ⁻²	9%

Table A-3: C1—chemically recycled chip EF 3.1 results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	6.73x10 ⁻³	8.20x10 ⁻³	18%
Climate change (kg CO ₂ eq)	1.77	2.09	15%
Climate change (biogenic) (kg CO ₂ eq)	1.23x10 ⁻³	1.50x10 ⁻³	18%
Climate change (fossil) (kg CO ₂ eq)	1.76	2.08	15%
Climate change (land use) (kg CO ₂ eq)	2.33x10 ⁻³	2.36x10 ⁻³	1%
Ecotoxicity freshwater (CTUe)	12.7	12.8	0%
Ecotoxicity freshwater (inorganics) (CTUe)	12.6	12.6	0%
Ecotoxicity freshwater (organics) (CTUe)	0.120	0.170	29%
Eutrophication freshwater (kg P eq)	3.99x10 ⁻⁴	4.72x10 ⁻⁴	15%
Eutrophication marine (kg N eq)	1.57x10 ⁻³	1.77x10 ⁻³	11%
Eutrophication terrestrial (mol N eq)	1.68x10 ⁻²	1.88x10 ⁻²	11%
Human toxicity cancer (CTUh)	5.89x10 ⁻¹⁰	6.11x10 ⁻¹⁰	4%
Human toxicity cancer (inorganics) (CTUh)	2.53x10 ⁻¹⁰	2.61x10 ⁻¹⁰	3%
Human toxicity cancer (organics) (CTUh)	3.36x10 ⁻¹⁰	3.50x10 ⁻¹⁰	4%
Human toxicity non-cancer (CTUh)	9.74x10 ⁻⁹	1.27x10 ⁻⁸	23%
Human toxicity non-cancer (inorganics) (CTUh)	9.08x10 ⁻⁹	1.12x10 ⁻⁸	19%
Human toxicity non-cancer (organics) (CTUh)	6.56x10 ⁻¹⁰	1.44x10 ⁻⁹	54%
Ionizing radiation (human health) (kBq U235 eq)	6.56x10 ⁻²	7.81x10 ⁻²	16%
Land use (dimensionless (pt))	6.52	6.88	5%
Ozone depletion (kg CFC11 eq)	2.54x10 ⁻⁸	2.98x10 ⁻⁶	99%
Particulate matter (disease incidence)	8.71x10 ⁻⁸	9.63x10 ⁻⁸	10%
Photochemical ozone formation (human health) (kg NMVOC eq)	6.21x10 ⁻³	7.82x10 ⁻³	21%

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Resource use fossils (MJ (net calorific))	24.4	34.0	28%
Resource use minerals and metals (kg Sb eq)	6.18×10^{-6}	9.83×10^{-6}	37%
Water use (m ³ world eq)	0.487	0.532	8%

Table A-4: C2—chemically recycled Higg chip MSI results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (kg CO ₂ eq)	2.24	2.47	9%
Acidification (mol H ⁺ eq)	8.63×10^{-3}	9.72×10^{-3}	11%
Eutrophication (kg PO ₄ eq)	2.81×10^{-2}	2.84×10^{-2}	1%
Abiotic depletion, fossil fuels (MJ eq)	28.9	37.0	22%
Freshwater ecotoxicity (PAF m ³ day)	1.67×10^{-3}	2.97×10^{-3}	44%
Water scarcity (m ³ world eq)	0.468	0.516	9%
Freshwater consumption (m ³)	1.07×10^{-2}	1.19×10^{-2}	10%

Table A-5: C2—chemically recycled chip EF 3.1 results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	8.63×10^{-3}	9.72×10^{-3}	11%
Climate change (kg CO ₂ eq)	2.24	2.47	9%
Climate change (biogenic) (kg CO ₂ eq)	1.17×10^{-3}	1.45×10^{-3}	20%
Climate change (fossil) (kg CO ₂ eq)	2.24	2.46	9%
Climate change (land use) (kg CO ₂ eq)	2.42×10^{-3}	2.43×10^{-3}	0%
Ecotoxicity freshwater (CTUe)	11.1	11.5	3%
Ecotoxicity freshwater (inorganics) (CTUe)	11.0	11.3	3%
Ecotoxicity freshwater (organics) (CTUe)	0.105	0.158	34%
Eutrophication freshwater (kg P eq)	3.62×10^{-4}	4.42×10^{-4}	18%
Eutrophication marine (kg N eq)	1.91×10^{-3}	2.03×10^{-3}	6%
Eutrophication terrestrial (mol N eq)	2.05×10^{-2}	2.18×10^{-2}	6%
Human toxicity cancer (CTUh)	6.18×10^{-10}	6.34×10^{-10}	3%
Human toxicity cancer (inorganics) (CTUh)	1.22×10^{-10}	1.56×10^{-10}	22%
Human toxicity cancer (organics) (CTUh)	4.95×10^{-10}	4.78×10^{-10}	-4%
Human toxicity non-cancer (CTUh)	1.14×10^{-8}	1.40×10^{-8}	19%
Human toxicity non-cancer (inorganics) (CTUh)	9.89×10^{-9}	1.19×10^{-8}	17%
Human toxicity non-cancer (organics) (CTUh)	1.47×10^{-9}	2.09×10^{-9}	29%
Ionizing radiation (human health) (kBq U235 eq)	6.54×10^{-2}	7.80×10^{-2}	16%
Land use (dimensionless (pt))	6.56	6.92	5%

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Ozone depletion (kg CFC11 eq)	3.24×10^{-8}	2.99×10^{-6}	99%
Particulate matter (disease incidence)	1.14×10^{-7}	1.18×10^{-7}	3%
Photochemical ozone formation (human health) (kg NMVOC eq)	7.76×10^{-3}	9.06×10^{-3}	14%
Resource use fossils (MJ (net calorific))	30.5	38.9	22%
Resource use minerals and metals (kg Sb eq)	3.47×10^{-4}	2.83×10^{-4}	-23%
Water use (m ³ world eq)	0.467	0.516	9%

Table A-6: C3—100% post-consumer chemically recycled chip Higg MSI results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (kg CO ₂ eq)	0.885	1.38	36%
Acidification (mol H ⁺ eq)	2.12×10^{-3}	4.50×10^{-3}	53%
Eutrophication (kg PO ₄ eq)	6.14×10^{-3}	1.09×10^{-2}	43%
Abiotic depletion, fossil fuels (MJ eq)	10	21.9	54%
Freshwater ecotoxicity (PAF m ³ day)	6.60×10^{-3}	6.92×10^{-3}	5%
Water scarcity (m ³ world eq)	0.197	0.293	33%
Freshwater consumption (m ³)	0.268	0.218	-23%

Table A-7: C3—100% post-consumer chemically recycled chip EF 3.1 results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	2.12×10^{-3}	4.50×10^{-3}	53%
Climate change (kg CO ₂ eq)	0.886	1.38	36%
Climate change (biogenic) (kg CO ₂ eq)	6.45×10^{-4}	1.04×10^{-3}	38%
Climate change (fossil) (kg CO ₂ eq)	0.885	1.38	36%
Climate change (land use) (kg CO ₂ eq)	3.43×10^{-4}	7.68×10^{-4}	55%
Ecotoxicity freshwater (CTUe)	4.61	6.26	26%
Ecotoxicity freshwater (inorganics) (CTUe)	4.54	6.13	26%
Ecotoxicity freshwater (organics) (CTUe)	6.54×10^{-2}	0.126	48%
Eutrophication freshwater (kg P eq)	2.80×10^{-4}	3.76×10^{-4}	25%
Eutrophication marine (kg N eq)	5.94×10^{-4}	9.83×10^{-4}	40%
Eutrophication terrestrial (mol N eq)	6.31×10^{-3}	1.04×10^{-2}	39%
Human toxicity cancer (CTUh)	1.70×10^{-10}	4.11×10^{-10}	59%
Human toxicity cancer (inorganics) (CTUh)	5.51×10^{-11}	1.56×10^{-10}	65%
Human toxicity cancer (organics) (CTUh)	1.15×10^{-10}	2.55×10^{-10}	55%

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Human toxicity non-cancer (CTUh)	2.54×10^{-9}	7.97×10^{-9}	68%
Human toxicity non-cancer (inorganics) (CTUh)	2.31×10^{-9}	6.83×10^{-9}	66%
Human toxicity non-cancer (organics) (CTUh)	2.25×10^{-10}	1.15×10^{-9}	80%
Ionizing radiation (human health) (kBq U235 eq)	3.96×10^{-2}	8.39×10^{-2}	53%
Land use (dimensionless (pt))	3.55	6.26	43%
Ozone depletion (kg CFC11 eq)	1.27×10^{-8}	2.98×10^{-6}	100%
Particulate matter (disease incidence)	1.56×10^{-8}	4.27×10^{-8}	63%
Photochemical ozone formation (human health) (kg NMVOC eq)	1.66×10^{-3}	4.67×10^{-3}	64%
Resource use fossils (MJ (net calorific))	7.81	23.7	67%
Resource use minerals and metals (kg Sb eq)	1.74×10^{-6}	6.95×10^{-6}	75%
Water use (m ³ world eq)	0.124	0.293	58%

Table A-8: C3—100% post-industrial chemically recycled chip Higg MSI results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (kg CO ₂ eq)	0.683	1.22	44%
Acidification (mol H ⁺ eq)	1.66×10^{-3}	4.14×10^{-3}	60%
Eutrophication (kg PO ₄ eq)	5.78×10^{-3}	1.06×10^{-2}	45%
Abiotic depletion, fossil fuels (MJ eq)	8.3	20.5	60%
Freshwater ecotoxicity (PAF m ³ day)	6.34×10^{-3}	6.71×10^{-3}	6%
Water scarcity (m ³ world eq)	0.176	0.276	36%
Freshwater consumption (m ³)	0.25	0.203	-23%

Table A-9: C3—100% post-industrial chemically recycled chip EF 3.1 results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	1.68×10^{-3}	4.14×10^{-3}	59%
Climate change (kg CO ₂ eq)	0.683	1.22	44%
Climate change (biogenic) (kg CO ₂ eq)	5.87×10^{-4}	9.89×10^{-4}	41%
Climate change (fossil) (kg CO ₂ eq)	0.682	1.22	44%
Climate change (land use) (kg CO ₂ eq)	2.93×10^{-4}	7.26×10^{-4}	60%
Ecotoxicity freshwater (CTUe)	2.84	4.84	41%
Ecotoxicity freshwater (inorganics) (CTUe)	2.78	4.72	41%
Ecotoxicity freshwater (organics) (CTUe)	5.80×10^{-2}	0.12	52%
Eutrophication freshwater (kg P eq)	2.34×10^{-4}	3.37×10^{-4}	31%

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Eutrophication marine (kg N eq)	4.47×10^{-4}	8.66×10^{-4}	48%
Eutrophication terrestrial (mol N eq)	4.75×10^{-3}	9.16×10^{-3}	48%
Human toxicity cancer (CTUh)	2.02×10^{-10}	3.02×10^{-10}	33%
Human toxicity cancer (inorganics) (CTUh)	6.60×10^{-11}	1.11×10^{-10}	40%
Human toxicity cancer (organics) (CTUh)	1.36×10^{-10}	1.91×10^{-10}	29%
Human toxicity non-cancer (CTUh)	2.97×10^{-9}	7.25×10^{-9}	59%
Human toxicity non-cancer (inorganics) (CTUh)	2.74×10^{-9}	6.15×10^{-9}	55%
Human toxicity non-cancer (organics) (CTUh)	2.31×10^{-10}	1.10×10^{-9}	79%
Ionizing radiation (human health) (kBq U235 eq)	6.54×10^{-2}	7.79×10^{-2}	16%
Land use (dimensionless (pt))	4.85	5.55	13%
Ozone depletion (kg CFC11 eq)	1.60×10^{-8}	2.98×10^{-6}	99%
Particulate matter (disease incidence)	1.40×10^{-8}	3.78×10^{-8}	63%
Photochemical ozone formation (human health) (kg NMVOC eq)	1.69×10^{-3}	4.22×10^{-3}	60%
Resource use fossils (MJ (net calorific))	9.67	22.23	57%
Resource use minerals and metals (kg Sb eq)	2.13×10^{-6}	6.58×10^{-6}	68%
Water use (m ³ world eq)	0.167	0.276	40%

Table A-10: M1—100% post-consumer thermomechanically recycled chip Higg MSI results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (kg CO ₂ eq)	0.959	2.17	56%
Acidification (mol H ⁺ eq)	4.89×10^{-3}	9.47×10^{-3}	48%
Eutrophication (kg PO ₄ eq)	5.10×10^{-3}	1.74×10^{-2}	71%
Abiotic depletion, fossil fuels (MJ eq)	11.4	40.4	72%
Freshwater ecotoxicity (PAF m ³ day)	7.20×10^{-3}	7.71×10^{-3}	7%
Water scarcity (m ³ world eq)	0.294	0.479	39%
Freshwater consumption (m ³)	5.05×10^{-2}	3.30×10^{-2}	-53%

Table A-11: M1—100% post-consumer thermomechanically recycled chip EF 3.1 results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	4.89×10^{-3}	9.47×10^{-3}	48%
Climate change (kg CO ₂ eq)	0.959	2.17	56%
Climate change (biogenic) (kg CO ₂ eq)	0.114	5.82×10^{-2}	-96%
Climate change (fossil) (kg CO ₂ eq)	0.845	2.11	60%

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (land use) (kg CO ₂ eq)	8.99x10 ⁻⁴	1.68x10 ⁻³	46%
Ecotoxicity freshwater (CTUe)	5.17	9.01	43%
Ecotoxicity freshwater (inorganics) (CTUe)	5.08	8.78	42%
Ecotoxicity freshwater (organics) (CTUe)	9.07x10 ⁻²	0.23	61%
Eutrophication freshwater (kg P eq)	2.80x10 ⁻⁴	5.22x10 ⁻⁴	46%
Eutrophication marine (kg N eq)	1.47x10 ⁻³	2.01x10 ⁻³	27%
Eutrophication terrestrial (mol N eq)	1.45x10 ⁻²	2.06x10 ⁻²	30%
Human toxicity cancer (CTUh)	7.17x10 ⁻¹⁰	7.08x10 ⁻¹⁰	-1%
Human toxicity cancer (inorganics) (CTUh)	1.39x10 ⁻¹⁰	2.15x10 ⁻¹⁰	35%
Human toxicity cancer (organics) (CTUh)	5.77x10 ⁻¹⁰	4.93x10 ⁻¹⁰	-17%
Human toxicity non-cancer (CTUh)	8.32x10 ⁻⁹	1.63x10 ⁻⁸	49%
Human toxicity non-cancer (inorganics) (CTUh)	7.70x10 ⁻⁹	1.38x10 ⁻⁸	44%
Human toxicity non-cancer (organics) (CTUh)	6.12x10 ⁻¹⁰	2.58x10 ⁻⁹	76%
Ionizing radiation (human health) (kBq U235 eq)	0.256	0.192	-33%
Land use (dimensionless (pt))	6.29	7.31	14%
Ozone depletion (kg CFC11 eq)	1.23x10 ⁻⁸	7.41x10 ⁻⁶	100%
Particulate matter (disease incidence)	9.72x10 ⁻⁸	1.15x10 ⁻⁷	16%
Photochemical ozone formation (human health) (kg NMVOC eq)	4.88x10 ⁻³	9.58x10 ⁻³	49%
Resource use fossils (MJ (net calorific))	15.6	44.05	65%
Resource use minerals and metals (kg Sb eq)	3.82x10 ⁻⁶	1.41x10 ⁻⁵	73%
Water use (m ³ world eq)	0.246	0.479	49%

Table A-12: M1—50-50 blended thermomechanically recycled chip Higg MSI results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (kg CO ₂ eq)	1.07	1.79	40%
Acidification (mol H ⁺ eq)	8.10x10 ⁻³	9.83x10 ⁻³	18%
Eutrophication (kg PO ₄ eq)	3.36x10 ⁻³	1.18x10 ⁻²	72%
Abiotic depletion, fossil fuels (MJ eq)	13.4	31.3	57%
Freshwater ecotoxicity (PAF m ³ day)	1.62x10 ⁻²	1.32x10 ⁻²	-23%
Water scarcity (m ³ world eq)	0.305	0.430	29%
Freshwater consumption (m ³)	3.58x10 ⁻²	2.87x10 ⁻²	-25%

Table A-13: M1—50-50 blended thermomechanically recycled chip EF 3.1 results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	8.10x10 ⁻³	9.83x10 ⁻³	18%
Climate change (kg CO ₂ eq)	1.07	1.79	40%
Climate change (biogenic) (kg CO ₂ eq)	4.33x10 ⁻²	2.90x10 ⁻²	-49%
Climate change (fossil) (kg CO ₂ eq)	1.03	1.76	42%
Climate change (land use) (kg CO ₂ eq)	1.58x10 ⁻³	1.83x10 ⁻³	14%
Ecotoxicity freshwater (CTUe)	3.24	6.29	48%
Ecotoxicity freshwater (inorganics) (CTUe)	3.15	6.10	48%
Ecotoxicity freshwater (organics) (CTUe)	9.70x10 ⁻²	0.183	47%
Eutrophication freshwater (kg P eq)	3.51x10 ⁻⁴	4.76x10 ⁻⁴	26%
Eutrophication marine (kg N eq)	2.05x10 ⁻³	2.16x10 ⁻³	5%
Eutrophication terrestrial (mol N eq)	2.14x10 ⁻²	2.26x10 ⁻²	5%
Human toxicity cancer (CTUh)	3.37x10 ⁻¹⁰	4.46x10 ⁻¹⁰	25%
Human toxicity cancer (inorganics) (CTUh)	1.10x10 ⁻¹⁰	1.66x10 ⁻¹⁰	34%
Human toxicity cancer (organics) (CTUh)	2.27x10 ⁻¹⁰	2.80x10 ⁻¹⁰	19%
Human toxicity non-cancer (CTUh)	6.19x10 ⁻⁹	1.19x10 ⁻⁸	48%
Human toxicity non-cancer (inorganics) (CTUh)	5.77x10 ⁻⁹	1.02x10 ⁻⁸	43%
Human toxicity non-cancer (organics) (CTUh)	4.15x10 ⁻¹⁰	1.75x10 ⁻⁹	76%
Ionizing radiation (human health) (kBq U235 eq)	0.455	0.338	-35%
Land use (dimensionless (pt))	5.97	6.59	9%
Ozone depletion (kg CFC11 eq)	1.25x10 ⁻⁸	4.82x10 ⁻⁶	100%
Particulate matter (disease incidence)	5.15x10 ⁻⁸	7.67x10 ⁻⁸	33%
Photochemical ozone formation (human health) (kg NMVOC eq)	6.65x10 ⁻³	8.97x10 ⁻³	26%
Resource use fossils (MJ (net calorific))	20.7	37.01	44%
Resource use minerals and metals (kg Sb eq)	2.89x10 ⁻⁶	9.81x10 ⁻⁶	71%
Water use (m ³ world eq)	0.305	0.430	29%

Table A-14: M2—thermomechanically recycled chip Higg MSI results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (kg CO ₂ e)	1.20	2.29	47%
Acidification (mol H ⁺ eq)	5.69x10 ⁻³	9.87x10 ⁻³	42%
Eutrophication (kg PO ₄ eq)	5.44x10 ⁻³	1.76x10 ⁻²	69%
Abiotic Depletion, fossil fuels (MJ eq)	13.6	41.5	67%
Freshwater ecotoxicity (PAF m ³ day)	2.67x10 ⁻²	1.75x10 ⁻²	-53%

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Water scarcity (m ³ world eq)	0.266	0.489	46%
Freshwater consumption (m ³)	6.05x10 ⁻³	1.13x10 ⁻²	46%

Table A-15: M2—thermomechanically recycled chip EF 3.1 results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	5.69x10 ⁻³	9.87x10 ⁻³	45%
Climate change (kg CO ₂ eq)	1.20	2.29	50%
Climate change (biogenic) (kg CO ₂ eq)	9.71x10 ⁻²	4.99x10 ⁻²	-94%
Climate change (fossil) (kg CO ₂ eq)	1.10	2.23	53%
Climate change (land use) (kg CO ₂ eq)	3.08x10 ⁻³	2.77x10 ⁻³	-9%
Ecotoxicity freshwater (CTUe)	9.51	11.18	19%
Ecotoxicity freshwater (inorganics) (CTUe)	9.37	10.93	18%
Ecotoxicity freshwater (organics) (CTUe)	0.144	0.26	46%
Eutrophication freshwater (kg P eq)	2.56x10 ⁻⁴	5.11x10 ⁻⁴	53%
Eutrophication marine (kg N eq)	1.52x10 ⁻³	2.03x10 ⁻³	29%
Eutrophication terrestrial (mol N eq)	1.53x10 ⁻²	2.11x10 ⁻²	31%
Human toxicity cancer (CTUh)	6.85x10 ⁻¹⁰	6.92x10 ⁻¹⁰	5%
Human toxicity cancer (inorganics) (CTUh)	1.56x10 ⁻¹⁰	2.23x10 ⁻¹⁰	34%
Human toxicity cancer (organics) (CTUh)	5.29x10 ⁻¹⁰	4.69x10 ⁻¹⁰	-9%
Human toxicity non-cancer (CTUh)	1.06x10 ⁻⁸	1.75x10 ⁻⁸	43%
Human toxicity non-cancer (inorganics) (CTUh)	9.94x10 ⁻⁹	1.49x10 ⁻⁸	37%
Human toxicity non-cancer (organics) (CTUh)	6.82x10 ⁻¹⁰	2.62x10 ⁻⁹	76%
Ionizing radiation (human health) (kBq U235 eq)	4.31x10 ⁻²	8.56x10 ⁻²	52%
Land use (dimensionless (pt))	8.95	8.64	1%
Ozone depletion (kg CFC11 eq)	8.38x10 ⁻⁷	7.83x10 ⁻⁶	90%
Particulate matter (disease incidence)	1.20x10 ⁻⁷	1.27x10 ⁻⁷	9%
Photochemical ozone formation (human health) (kg NMVOC eq)	5.16x10 ⁻³	9.73x10 ⁻³	50%
Resource use fossils (MJ (net calorific))	14.4	43.42	69%
Resource use minerals and metals (kg Sb eq)	4.44x10 ⁻⁶	1.44x10 ⁻⁵	71%
Water use (m ³ world eq)	0.266	0.489	48%

Table A-16: M3—thermomechanically recycled chip Higg MSI results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (kg CO ₂ eq)	1.31	2.34	44%

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	5.73x10 ⁻³	9.89x10 ⁻³	42%
Eutrophication (kg PO ₄ eq)	4.85x10 ⁻³	1.73x10 ⁻²	72%
Abiotic depletion, fossil fuels (MJ eq)	12.6	41.0	69%
Freshwater Ecotoxicity (PAF m ³ day)	4.64x10 ⁻²	2.73x10 ⁻²	-70%
Water scarcity (m ³ world eq)	0.239	0.475	50%
Freshwater Consumption (m ³)	6.92x10 ⁻³	1.17x10 ⁻²	41%

Table A-17: M3—thermomechanically recycled chip EF 3.1 results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	5.73x10 ⁻³	9.89x10 ⁻³	42%
Climate change (kg CO ₂ eq)	1.31	2.34	44%
Climate change (biogenic) (kg CO ₂ eq)	9.76x10 ⁻²	5.01x10 ⁻²	-95%
Climate change (fossil) (kg CO ₂ eq)	1.21	2.29	47%
Climate change (land use) (kg CO ₂ eq)	2.56x10 ⁻³	2.51x10 ⁻³	-2%
Ecotoxicity freshwater (CTUe)	7.70	10.28	25%
Ecotoxicity freshwater (inorganics) (CTUe)	6.63	9.56	31%
Ecotoxicity freshwater (organics) (CTUe)	1.06	0.72	-48%
Eutrophication freshwater (kg P eq)	4.94x10 ⁻⁴	6.30x10 ⁻⁴	21%
Eutrophication marine (kg N eq)	1.17x10 ⁻³	1.86x10 ⁻³	37%
Eutrophication terrestrial (mol N eq)	1.08x10 ⁻²	1.88x10 ⁻²	43%
Human toxicity cancer (CTUh)	7.01x10 ⁻¹⁰	7.00x10 ⁻¹⁰	0%
Human toxicity cancer (inorganics) (CTUh)	1.51x10 ⁻¹⁰	2.21x10 ⁻¹⁰	32%
Human toxicity cancer (organics) (CTUh)	5.50x10 ⁻¹⁰	4.79x10 ⁻¹⁰	-15%
Human toxicity non-cancer (CTUh)	1.00x10 ⁻⁸	1.72x10 ⁻⁸	42%
Human toxicity non-cancer (inorganics) (CTUh)	9.25x10 ⁻⁹	1.45x10 ⁻⁸	36%
Human toxicity non-cancer (organics) (CTUh)	7.88x10 ⁻¹⁰	2.67x10 ⁻⁹	71%
Ionizing radiation (human health) (kBq U235 eq)	1.45x10 ⁻²	7.13x10 ⁻²	80%
Land use (dimensionless (pt))	4.74	6.54	28%
Ozone depletion (kg CFC11 eq)	1.98x10 ⁻⁸	7.42x10 ⁻⁶	100%
Particulate matter (disease incidence)	1.26x10 ⁻⁷	1.30x10 ⁻⁷	3%
Photochemical ozone formation (human health) (kg NMVOC eq)	3.67x10 ⁻³	8.98x10 ⁻³	59%
Resource use fossils (MJ (net calorific))	13.1	42.79	69%
Resource use minerals and metals (kg Sb eq)	2.99x10 ⁻⁶	1.37x10 ⁻⁵	78%
Water use (m ³ world eq)	0.241	0.476	49%

Table A-18: M3—thermomechanically recycled staple fiber Higg MSI results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Climate change (kg CO ₂ eq)	3.04	3.79	20%
Acidification (mol H ⁺ eq)	1.18x10 ⁻²	1.71x10 ⁻²	31%
Eutrophication (kg PO ₄ eq)	1.57x10 ⁻²	2.41x10 ⁻²	35%
Abiotic depletion, fossil fuels (MJ eq)	33.8	57.2	41%
Freshwater ecotoxicity (PAF m ³ day)	0.174	0.135	-29%
Water scarcity (m ³ world eq)	0.585	0.713	18%
Freshwater consumption (m ³)	1.62x10 ⁻²	1.79x10 ⁻²	10%

Table A-19: M3—thermomechanically recycled staple fiber EF 3.1 results calculated using the CFF

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Acidification (mol H ⁺ eq)	1.18x10 ⁻²	1.71x10 ⁻²	31%
Climate change (kg CO ₂ eq)	3.04	3.79	20%
Climate change (biogenic) (kg CO ₂ eq)	0.113	5.83x10 ⁻²	-93%
Climate change (fossil) (kg CO ₂ eq)	2.92	3.73	22%
Climate change (land use) (kg CO ₂ eq)	8.86x10 ⁻³	7.90x10 ⁻³	-12%
Ecotoxicity freshwater (CTUe)	31.0	25.28	-23%
Ecotoxicity freshwater (inorganics) (CTUe)	28.4	23.39	-21%
Ecotoxicity freshwater (organics) (CTUe)	2.66	1.89	-41%
Eutrophication freshwater (kg P eq)	1.08x10 ⁻³	1.13x10 ⁻³	5%
Eutrophication marine (kg N eq)	2.43x10 ⁻³	3.04x10 ⁻³	20%
Eutrophication terrestrial (mol N eq)	2.30x10 ⁻²	3.08x10 ⁻²	25%
Human toxicity cancer (CTUh)	1.62x10 ⁻⁹	1.29x10 ⁻⁹	-25%
Human toxicity cancer (inorganics) (CTUh)	2.74x10 ⁻¹⁰	3.28x10 ⁻¹⁰	17%
Human toxicity cancer (organics) (CTUh)	1.34x10 ⁻⁹	9.59x10 ⁻¹⁰	-40%
Human toxicity non-cancer (CTUh)	1.89x10 ⁻⁸	2.75x10 ⁻⁸	31%
Human toxicity non-cancer (inorganics) (CTUh)	1.72x10 ⁻⁸	2.27x10 ⁻⁸	24%
Human toxicity non-cancer (organics) (CTUh)	1.74x10 ⁻⁹	4.78x10 ⁻⁹	64%
Ionizing radiation (human health) (kBq U235 eq)	3.59x10 ⁻²	8.54x10 ⁻²	58%
Land use (dimensionless (pt))	14.7	13.03	-13%
Ozone depletion (kg CFC11 eq)	1.09x10 ⁻⁵	1.34x10 ⁻⁵	19%
Particulate matter (disease incidence)	2.09x10 ⁻⁷	2.39x10 ⁻⁷	13%
Photochemical ozone formation (human health) (kg NMVOC eq)	8.37x10 ⁻³	1.31x10 ⁻²	36%
Resource use fossils (MJ (net calorific))	35.2	59.54	41%
Resource use minerals and metals (kg Sb eq)	7.38x10 ⁻⁶	7.76x10 ⁻⁴	99%

Impact category	Total impact— recycled content	Total impact— CFF	% Difference
Water use (m ³ world eq)	0.588	0.715	18%

A.6 Discussion of results

When applying the CFF and comparing it to the recycled cut-off results, the impacts increase across nearly all impact categories for all recyclers. When focusing on the climate change impact category, the CFF formula results in a 15% increase for C1, a 9% increase for C2, a 36% increase for C3's post-consumer recycling, a 44% increase for C3's post-industrial recycling, a 56% increase for M1's 100% post-consumer recycling, a 40% increase for M1's 50-50 blended chip, a 47% increase for M2, a 44% increase for M3's chip, and a 20% increase for M3's staple fiber.

The outcome of these results can be explained by understanding the difference in impact between the recycled chip and staple fiber, and their virgin counterparts when using the recycled cut-off allocation approach, and comprehending how the CFF combines the life cycle inventory data of the recycled and virgin product systems.

The CFF works by combining the LCI data of the recycled and virgin product systems. As the LCI data is used to calculate the life cycle impact assessment (LCIA), the bigger the difference in impact between the recycled and virgin product systems when using the recycled content allocation approach, the bigger the change in the LCIA results when using the CFF, since the CFF combines the LCI data of both product systems. If the impact of the virgin product system is lower than the impact of the recycled product system when using the recycled content method, then the results calculated using the CFF will result in a lower impact compared to the recycled content method, and vice versa.

The "A" and " $Q_{\text{sin}}/Q_{\text{sout}}$ " parameters also determine the magnitude of change when switching from the recycled content approach to the CFF. For chemically recycled textile waste, the " $Q_{\text{sin}}/Q_{\text{sout}}$ " parameter equals 1, and the "A" factor equals 0.8, resulting in a coefficient of 0.2 applied to the virgin LCI data and a coefficient of 0.8 applied to the chemically recycled LCI data; the virgin and chemically recycled LCI data is then summed. For thermomechanically recycled PET bottle waste, the "A" and " $Q_{\text{sin}}/Q_{\text{sout}}$ " parameters result in a coefficient of 0.5 applied to each set of LCI data, which is then summed. For thermomechanically recycled textile waste, the "A" and " $Q_{\text{sin}}/Q_{\text{sout}}$ " parameters result in a coefficient of 0.15 applied to the virgin LCI data and a coefficient of 0.8 applied to the thermomechanical LCI data, with the resulting product summed. The more virgin LCI data that is integrated with the recycling LCI data, the bigger the difference. This helps explain why, for the most part, recycled PET bottles have a bigger change than recycled textile waste, as more virgin LCI data is combined with the recycling LCI data.

Appendix B—Examining Human Rights Impacts in Polyester Production: Social Assessment for Polyester

B.1 About this appendix

Important disclaimer:

This study provides a foundational overview of some of the most common social impacts associated with polyester fiber production. It is intended to serve as a general reference, highlighting key themes and offering useful resources for further exploration. It does not represent an in-depth assessment and should not be treated as such.

For those seeking to understand the social impacts of a specific supply chain or location, a more detailed human rights impact assessment should be conducted. This should include direct stakeholder engagement on the ground, as social impacts can vary significantly by geography and site. These variations depend on a range of factors, including socio-political context, the demographics of local workers and communities, and the extent of human rights due diligence in place.

Numerous high-quality, in-depth resources on this topic are referenced throughout the report. Readers are encouraged to consult these materials to complement and deepen their understanding.

Polyester is the most widely used fiber in the world, accounting for 57% of global fiber production in 2023, or 71 million tonnes (Textile Exchange, 2024b). Of this polyester, 12.5% was produced through recycling (Textile Exchange, 2024b). Similarly to other industrial activities, the production of these materials consumes natural and human resources, and creates both environmental and social impacts. While the life cycle assessment (LCA) methodology captures impacts related to the environment, it does not cover impacts on people, such as those that may affect workers' and communities' human rights. Textile Exchange, as well as its project partners, believe it is important to consider the impacts of fiber and material production more holistically. This is linked to Textile Exchange's "LCA+" approach, where impact measurement goes beyond "carbon tunnel vision" to also account for biodiversity, soil health, water, animal welfare, and social livelihoods. For the polyester LCA study, the most relevant LCA+ impact area was identified as social impact and livelihoods. As a result, this document has been developed to capture some essential human rights impact elements related to polyester fiber production.

It is important to highlight that the LCA+ portion of this work does not go into the same level of depth in assessing human rights impacts as the LCA study does with environmental impacts. While there are well-established social life cycle assessment methodologies similar to environmental LCAs, the social assessment for polyester does not follow these methodologies fully and does not aim to provide a comprehensive analysis of the social footprint of polyester. Rather, this assessment aims to highlight the importance of understanding the social impacts alongside the environmental impacts, and provide readers with a foundational understanding of the key human rights impacts related to this production system.

This report explains the research methodology used and explores some common human rights impacts associated with the production of virgin and recycled polyester. It also makes

recommendations for brands, retailers, and manufacturers on how to build on the first level of information with more in-depth assessment, in line with existing human rights due diligence frameworks such as the UN Guiding Principles of Business and Human Rights (United Nations, 2011) and the OECD Due Diligence Guidance for Responsible Business Conduct (OECD, 2018).

B.2 Definitions

Note about scope: The scope of this study is limited to a specific segment of the polyester value chain—namely, from raw material extraction to chip and staple fiber production for recycled polyester and yarn for virgin polyester. Other segments of the value chain, which may involve different affected populations, are outside the scope of this report.

Note about responsibility: This report focuses on human rights impacts caused by business actors within the polyester supply chain, such as oil companies, feedstock providers, and polyester producers. It applies a business responsibility lens, emphasizing the duty of companies to respect human rights. While the role of states in protecting human rights is acknowledged—particularly in relation to contextual risk factors like corruption, poverty, and rule of law—this report does not assess state responsibilities in detail. Further details on respecting and protecting human rights can be found in the UNGPs. (United Nations, 2011)

Child Labor

The International Labour Organization (ILO) defines child labor as “work that deprives children of their childhood, their potential and their dignity, and that is harmful to physical and mental development.” The ILO refers to work that is a) mentally, physically, socially, or morally dangerous and harmful to children and/or b) interferes with their schooling by depriving them of the opportunity to attend school, obliging them to leave school prematurely, or requiring them to attempt to combine school attendance with excessively long and heavy work (International Labour Organization, 2025b).

Grievance Mechanisms

Grievance mechanisms are processes that allow individuals or communities who believe they have been harmed by a business activity to raise their concerns and seek remediation (United Nations, 2011)

Human Rights

Human rights are basic rights and freedoms belonging to every human being to ensure people can live their lives in dignity. There are 30 human rights outlined in the Universal Declaration of Human Rights (United Nations, 1948) and embedded in the Bill of Human Rights, an international law instrument. Human rights cover different aspects, from the most basic, such as the right to life or freedom, to economic rights, including labor rights, to political rights, such as the right to vote.

Human Rights Due Diligence

A continuous process carried out by businesses that involves setting clear human rights policies; identifying, addressing, and preventing the potential and actual human rights impacts associated with their own operations or value chain; ensuring the effectiveness of their actions; and communicating openly about their progress (United Nations, 1948).

Human Rights Impacts

In line with the United Nations Guiding Principles on Business and Human Rights (UNGPs) (United Nations, 2011) global terminology framework, this report defines human rights impacts as any actual or potential infringements on the rights of individuals or groups negatively affected by

polyester production. This includes both formal and informal workers across the supply chain, as well as communities living near production sites.

Informal Workers

Workers who are not formally registered as workers and therefore lack legal status and social protection in jobs that are not regulated, monitored, or taxed by governments. These are often workers who are also migrants (internal or cross-border) or otherwise disadvantaged in the job market and, therefore, are particularly vulnerable. Due to a lack of protections, informal workers cannot easily exercise their rights and are often found working in the most disadvantaged and low-paid jobs (United Nations, 2015).

Living Wage

A living wage is commonly defined as the wage level necessary to afford a decent standard of living for workers and their families. It takes into account country circumstances and is calculated for work performed during normal working hours. A living wage should be sufficient to cover basic needs such as food, housing, healthcare, education, transport, and clothing. It should be set using robust data and in consultation with worker and employer organizations (Global Living Wage Coalition, 2025). The ILO emphasizes that living wages should reflect local or regional differences and be regularly adjusted for changes in the cost of living (International Labour Organization, 2022).

Minimum Wage

According to the ILO, a minimum wage is defined as a minimum amount of compensation an employer is required to pay a worker for work performed during a certain period. It cannot be reduced by collective agreement or individual contracts (International Labour Organization, 2025a),

Rightsholders

This term includes groups and individuals whose human rights have been or may be affected by a company's operations, products, or services ("*affected people*"). A subset of stakeholders (Oxfam Business Advisory Services, 2023).

Waste Pickers

Informal workers who collect, sort, and sell waste materials for recycling or reuse (Tearfund, 2023), most commonly plastic waste.

B.3 Introduction

Understanding the structure of the supply chain is the first step in assessing human rights impacts in any context. All global supply chains inherently carry some social risks because they are complex and dynamic, which means achieving traceability is challenging and can take time. It is this lack of transparency, coupled with factors such as poverty, migration, and a weak rule of law (United Nations and the Rule of Law, 2025), which increases human rights risks as they contribute to people's vulnerability and create opportunities for exploitation.

This study aims to assess the impacts relevant to two types of supply chains: virgin and recycled polyester. The production of virgin polyester includes several upstream stages, starting with oil extraction. The human rights impacts of the oil and gas industry have been well documented and can negatively affect workers (Olsen et al., 2022) as well as local communities in countries of operation. The processing stages after oil extraction also carry some risks, especially in connection with working conditions in transport and manufacturing facilities.

Recycled polyester production typically begins with the processing of waste from several different sources and geographies, which can vary in number and risk, making the human rights impacts associated with its supply chains significantly more complicated. In some geographical regions, waste collection and sorting are largely informal, which means that mapping and understanding the supply chain network is more challenging (Barford and Beales, 2025). This is why many knowledge gaps still exist regarding the impacts on workers, waste pickers, and local communities where waste collection, transport, aggregation, and recycling take place. To account for this lack of information, this study supplemented desk-based research with primary data research, and triangulated with consultations with several human rights experts, particularly where data was missing, insufficient, or produced discrepancies.

This foundational research is intended to serve as a starting point for future, more in-depth studies—particularly those that include primary data collection through direct engagement with relevant rightsholder groups.

B.4 Scope

In line with the environmental LCA scope boundary, this study includes the following stages and processes:

Virgin polyester

- Stage 1
- Downstream feedstock sourcing (crude oil extraction)
- Refining and processing of the chemicals required to produce virgin PET
- Stage 2
- Manufacturing of PET yarn

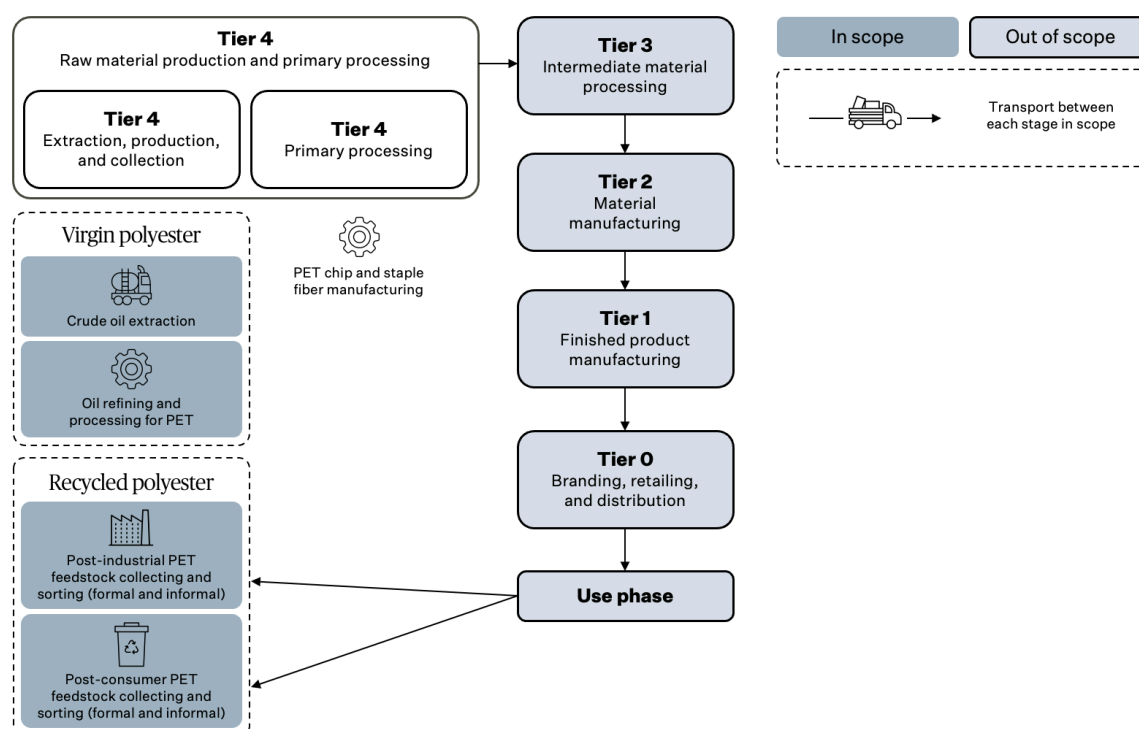
Recycled polyester

- Stage 1
- Upstream feedstock collection of post-industrial and post-consumer plastic waste (PET bottles, textile scraps, and textile garments)
- Stage 2
- Manufacturing of PET chip and staple fiber

The downstream life cycle stages after the production of the polyester chip, staple fiber, and yarn are outside the scope of this assessment. The graphic, Figure B-1 below, summarizes the different stages in and out of scope, noting the supply chain and processing differences between virgin and recycled PET.

Figure B-1: Supply chains stages of PET production in scope of this study

Please refer to the Textile Exchange Supply Chain Taxonomy for further information about supply chain tiers.



A note on transport:

Transport is part of every stage in the supply chain as it connects the various processing stages of a product into one journey. In regard to the above-mentioned stages in scope, different forms of transport may be needed—from road transportation to rail and sea shipping, or even the transport of raw materials by waste pickers on foot or bicycle.

While transport could be assessed as a sector on its own, for the purposes of this study, it is included as a sub-process of every stage and not explored separately. This means that the human rights impacts listed in the findings section cover the impacts found in the relevant forms of transport at that stage.

B.5 Methodology

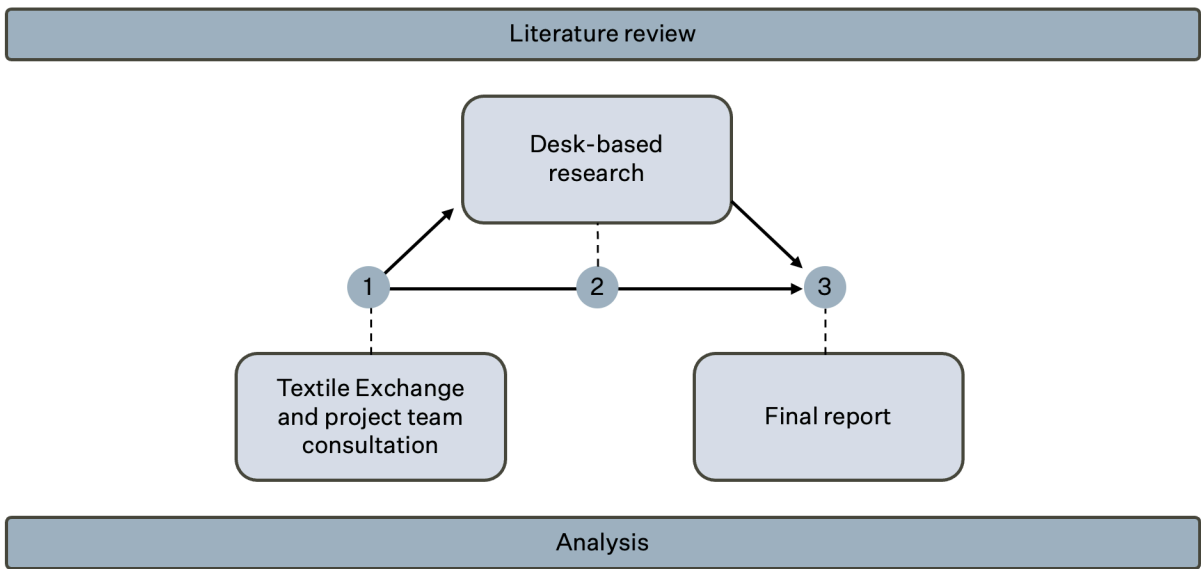
The study was written by an independent business and human rights advisor, Zuzana Mocilenkova and used a combination of research methods to collect data about human rights impacts. To begin, SCS Consulting Services led a consultation with project sponsors. Textile Exchange’s internal human rights team helped direct desk-based research to understand the known impacts, as well as the most recent and relevant sources of publicly available information on the topic (see References). The literature review was continuous throughout the duration of the study.

Due to the difference in supply chain structure and availability of data, two approaches were used for the two types of polyester in scope.

B5.1 Virgin polyester

All information was obtained through literature review only (see references).

Figure B-2: Methodology for virgin polyester

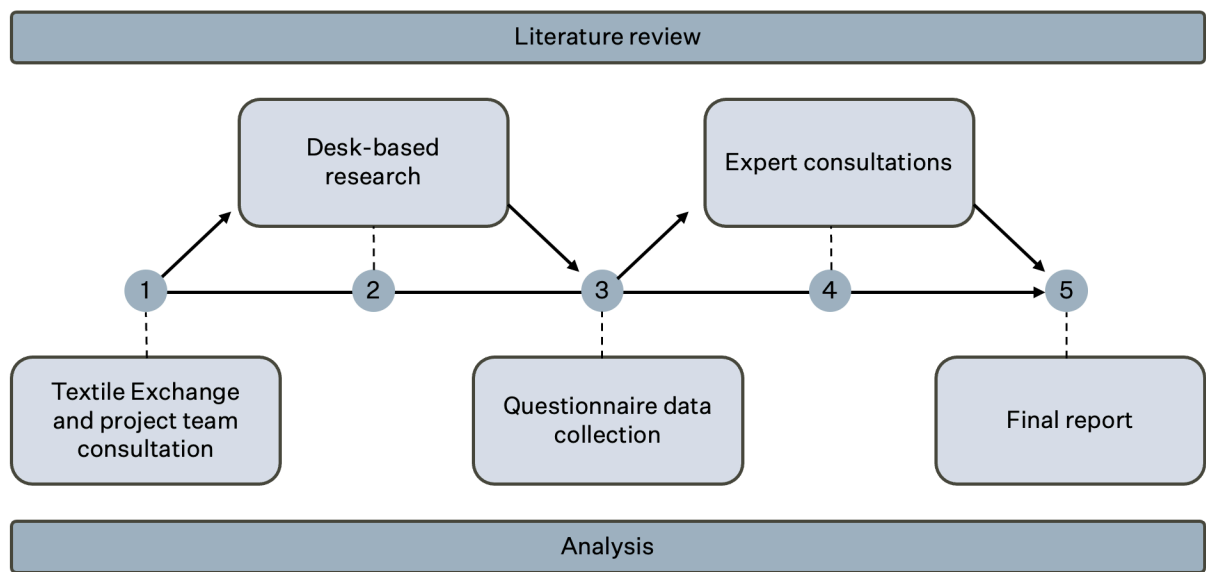


B5.2 Recycled polyester

Due to supply chain complexity and lack of available data, information was obtained through a combination of:

- Literature review
- Primary data collection through questionnaires (distributed to the recycled polyester chip and staple fiber manufacturers included in the Textile Exchange polyester LCA)
- Expert consultations

Figure B-3: Methodology for recycled polyester



B5.3 Questionnaire

The initial project team consultation and desk-based research informed the design of the questionnaire, which covered several key topic areas, from feedstock sources and supply chain traceability to awareness and mitigation of human and labor rights risks, to chemical management, stakeholder engagement, and grievance mechanisms (see a copy of the questionnaire in appendix A). Some questions were framed to collect information about the region the data providers were from, and some were asked to collect data about their operations and supply chains. This approach aimed to capture landscape trends and encourage respondents to provide authentic information about any potential or actual negative human rights impacts. The data collected through the questionnaire was provided on a voluntary basis and was self-reported by the data providers. The information was collected remotely (via email and calls with the data providers) and was not externally verified.

Through the questionnaire, we were able to collect primary data about human rights impacts directly from the commercial recycled polyester chip and staple fiber manufacturers included in the Textile Exchange polyester LCA. This comprised four data providers across three countries. One other data provider from the LCA was not operating at a commercial scale and was, therefore, unable to provide relevant information. The data providers were selected based on the type of processing they perform, as well as their willingness and availability to participate and share information. The data providers that were approached to take part in the study were identified through Textile Exchange and the polyester LCA project sponsors’ network of global contacts. Details of the data providers that were surveyed, including the region, technology, and feedstocks used, can be found in Table B-1.

Table B-1: Overview of data providers (recyclers) by region, technology type, and feedstock

No.	Country or region	Technology	Feedstock
1	China	Chemical recycling (two-stage depolymerization)	Post-industrial and post-consumer textile waste
2	China	Thermomechanical and chemical recycling (two-stage depolymerization)	Post-consumer PET bottles and post-industrial textile waste
3	Southeast Asia	Virgin (staple fiber, partially oriented yarn, drawn textured yarn), thermomechanical recycling (chip and staple fiber)	Post-consumer PET bottles
4	USA	Thermomechanical recycling	Post-consumer PET bottles and post-industrial textile waste

The findings from the questionnaires were reviewed and analyzed alongside the literature, helping to identify gaps and discrepancies in existing research. This process informed the selection of relevant human rights experts needed for consultations, leading to two expert consultations.

Additionally, since the initial responses offered limited insight beyond the manufacturer's own operations and labor compliance, it was decided to prioritize expert consultations and further desk-based research.

B5.4 Expert consultations

The experts were selected based on their focus and expertise in both recycling supply chains and human rights due diligence:

- **Vivien Luk**, of WORK, has worked globally with brands across industries, including the textile industry, and their supply chain actors, for several years on mapping, assessing, and addressing human rights impacts in recycled PET supply chains. Luk and the team have carried out hundreds of on-the-ground human rights impact assessments and engagements with PET manufacturers, processors, suppliers, pickers/collectors, aggregators, and other community members.
- **Sonia Dias**, of WIEGO, has worked in Brazil on supporting informal workers in organizing, including those in waste recycling supply chains. Dias has engaged with hundreds of workers and their families across different communities over the years to understand the human rights impacts of informal work and recycled PET collection, especially on women.

The human rights experts were asked to first review the primary data received through the questionnaires and then, guided by several questions from the project team, share written feedback for verbal presentation. This was an opportunity for the project team to ask the experts questions directly and clarify their comments. In some cases, the experts suggested further useful information sources, which were added to the ongoing literature review.

All information was triangulated and summarized in this report.

B5.5 Limitations

The study presented a number of limitations, which are important to acknowledge when using this report.

- This study was unable to collect information directly from rightsholders (such as workers or community members). While this is always the most preferred method for human rights impact assessment, it requires significant time, expertise, and investment, and was not possible as part of this study.
- As a result, the study relied mostly on secondary data about the impacts on rightsholders in the form of existing publicly available research, and proxy sources in the form of feedback from experts representing the rightsholders' viewpoints. While the experts were carefully selected, and this approach proved to be valuable, only two experts were consulted for this work.
- The study did collect some primary data from the supply chain through a questionnaire for recycled polyester producers, but there were several limitations with this approach:
 - The answers were provided by the PET chip or staple fiber manufacturer's management, not workers or communities (rightsholders) themselves. This means the answers likely didn't fully or accurately represent the impacts on rightsholders further down the supply chain.
 - The information collected through questionnaires was self-reported and not independently verified. The respondents decided how much detail they provided and which questions they answered, leaving some gaps.
 - The respondent's position in the company, the remote nature of data collection, and the fear of reprisal for disclosing issues may have influenced the level of transparency.

While the questionnaire sample was small, and only four out of five of the data providers were at a commercial scale and able to provide relevant information, it is worth noting that several of them are large corporations, playing a significant role in the global production of polyester. The small sample size should, however, be taken into consideration when interpreting this document.

Considering these limitations, this assessment is not meant to serve as a detailed, exhaustive analysis of the human rights impacts within the polyester recycling production systems. Instead, it is intended to support brands and retailers working with polyester by offering an overview of the most common and significant impacts associated with the production of virgin and recycled polyester chip and staple fiber, along with recommendations for addressing and managing these risks.

The results below are grouped by processing stage and include triangulated findings from all the research methods used. Furthermore, the findings matrix in appendix B provides a more visual and concise overview of the human rights impacts identified for the full scope of the study (all processing stages in scope).

The outcomes from this document should not be used for any claims or external communication, but rather to support the identification of the most relevant fields of action.

B.6 Findings

The findings have been grouped into three areas based on the activities involved and the human rights impacts associated with these three contexts:

- Extraction and refinement of crude oil and natural gas for virgin PET
- Feedstock sourcing for recycled PET
- Processing of feedstock and manufacturing of PET chip and fiber

Each of these areas contains several steps and activities. Virgin PET is produced by refining and chemically processing crude oil, which first needs to be extracted from the ground. The first stage of oil mining involves several steps, from exploration to construction, drilling, and transport of oil to refineries and chemical processing plants. All of these are high-risk activities, which create significant human rights impacts. The activities and impacts differ slightly from those involved in chemical processing in an industrial facility, which is why they are explored separately in this report.

Sourcing of recycled feedstock is explored as a standalone area, due to the unique context and impacts associated with those supply chains. This feedstock is sourced from existing waste streams, which can come from anywhere along the supply chain, from both formal (for example, municipal waste) or informal sources (for example, waste picking). The informal post-consumer waste sourcing can be a source of some of the most severe negative impacts on human rights in supply chains, hence informal supply chains are also explored separately.

Finally, the chemical processing of raw materials involves refining crude oil, processing recycled feedstock, or manufacturing polyester. Often, these activities are carried out in more mechanized facilities, requiring a higher-skilled workforce in order to operate machinery. These also carry their own risks and impacts but will have more in common with each other than oil drilling, for instance.

B6.1 Human rights impacts associated with the extraction of crude oil for virgin PET

The oil and gas sector is one of the biggest industries in the world (Ibisworld, n.d.) valued at USD761.1 billion in 2024 and expected to reach USD1.46 trillion in 2034 (Global Market Insights, n.d.). It plays an important role in international development and, if managed well, has the potential to contribute to job creation, poverty reduction, and helping people access and enjoy many of their human rights, such as right to work, adequate standard of living, and right to education (Institute for Human Rights and Business, n.d.). However, the industry sometimes operates without paying sufficient attention to human rights in contexts with corruption and a weak rule of law, which leads to increased human rights impacts (Ganesan, 2004).

There is evidence that oil and gas companies have caused or contributed to significant corporate human rights abuses, including abductions, torture, rape, slavery, and death (Tomlinson, 2018). There is a documented history of violence by law enforcement against local communities in efforts to secure access to oil and gas extraction sites around the world. These communities often lose access to land they rely on for farming, grazing, forestry, or fishing, which can severely impact their livelihoods. In many cases, they also lack access to critical information about project timelines, technical details, compensation procedures, and associated social and environmental risks (Bogrand et al., 2020). Accidental spills and pollution can severely, and sometimes irreversibly, affect the workers and the surrounding communities' health by polluting water, air, and soil (UNEA, 2017).

Even in the absence of the worst forms of impacts, the industry has been known to provide poor working conditions and drive inequality. One study found that while oil and gas projects might generate wealth for low- to middle-income countries, many communities affected by these

projects continue to live in poverty, and become worse off, due to the presence of oil and gas projects (Bogrand et al., 2020). While more and more oil and gas companies put human rights policies and due diligence systems into place meant to prevent these human rights abuses, these are not always effective or sufficient (Olsen et al., 2022).

The human rights impacts from the oil and gas industry can range depending on the specific location, site, and level of mitigation in place. However, the most common and most significant types of impacts based on the literature review are listed in Table B-2.

Table B-2: Human rights impacts associated with extraction of crude oil for virgin PET

	Human rights impacts	Details
Workers	Poor working conditions and impacts on labor rights in oil and gas operations and transport	Many oil and gas companies rely on the use of contractors with less oversight of their hiring and working conditions compared to direct hires. There is a higher risk of low wages, poor social security, and forced labor (such as payment of recruitment fees or withholding of identification documents) (Graham, 2010).
	Worker health and safety	For employees and contractors, accidents in oil and gas exploration, construction, and drilling are common due to the nature of operations involved and use of heavy machinery. Life-altering accidents and, in the worst case, loss of life are significant impacts. Other common health and safety risks include exposure to petrochemicals without training, lack of protective equipment, poor living conditions in worker accommodation, and long working hours (Graham, 2010).
	Forced labor and modern slavery	Workers in transport such as those working on ships or in ports necessary for raw material transport often suffer from abusive working conditions including forced labor, sexual harassment and abandonment, or loss at sea (International Transport Worker's Federation, 2025).
	Freedom of association and collective bargaining	In countries with emerging oil and gas industries, there can be a lack of effective worker representation (trade unions) or access to grievance mechanisms (Saha et al., 2023).
Communities	Indigenous Peoples and Local Communities' rights	According to Oxfam, Indigenous and community land covers more than 50% of the world's surface and supports up to 2.5 billion people who live, protect, and depend on it for their livelihood, but legally own only one fifth of it. (Oxfam, n.d.). Despite community land rights, lack of legal ownership and corruption makes this land vulnerable to land grabs by governments and corporations, including those involved in oil exploration and extraction (Sibaud, 2012). Free Prior and Informed Consent (FPIC) is a universally agreed process to ensure Indigenous communities are a rightful stakeholder and decision-maker in land acquisition projects and that any relocation is agreed by them and fairly compensated (UN Department of Economic and Social Affairs, 2016). However, this process is often not fully realized and can result in impacts on communities' human rights (including, but not limited to: right to self-determination; right to adequate standard of living; right to food, and housing; and minority, land and cultural rights) (Alvarado, 2022). While local communities' land rights status is not as well legally protected as that of Indigenous groups, the negative impact on their rights can be equally damaging.
	Conflict, violence, and societal disruption	Research has found a cross-national correlation between oil extraction and armed conflict (Blair et al., 2024). In many oil-rich countries in the world (such as Colombia), oil extraction projects have been linked to organized crime, armed conflict, and terrorist activity (Vélez-Torres and Méndez, 2021).

	Human rights impacts	Details
		Even in contexts without armed conflict, proposed exploration or drilling projects can divide and cause conflict in the surrounding community if there is disagreement on the project, lacking adequate consultation and engagement. Such disagreements can further divide ethnically and culturally diverse sub-groups, fueling instability. Private security forces used to protect the oil company staff and project location have been reported to resort to violence to break up peaceful community protests (Forester, 2022). In the worst cases, violence can lead to loss of life. In addition to increased risk of crime and gender violence outlined above, oil extraction projects can have other negative impacts on the local communities' infrastructure, such as transportation, education, or health systems (BSR, n.d.). Increased incomes of foreign workers living locally may increase the general cost of living, leaving the local population with less economic ability to meet their basic needs (BSR, n.d.). Finally, some locations with extractive activity have also seen increases in alcoholism, drug use, prostitution, gambling, and domestic abuse (BSR, n.d.).
	Discrimination, harassment, and abuse	There is evidence of connection between oil extraction projects and surges in sexual and physical violence against women and other gender minorities, both in the workplace and surrounding communities (Euronews, 2023). Crime including sexual assault and rape, as well as sex trafficking have been documented impacts within this context, with Indigenous women and children being particularly at risk (Tallgrass Institute, University of Colorado Boulder, 2020). Human rights defenders are a particularly vulnerable group with many facing harassment, threats, and even death as a result of speaking up against the government and big corporations. Discrimination in hiring and pay of women and minority groups is also common, as is harassment of and violence against human rights and environmental defenders. Threats, detention, torture, disappearances, and murders have all been documented impacts on individuals who stand up and speak up for many of the abuses publicly (DefendDefenders, 2012).
	Safe and healthy living conditions	Oil drilling and extraction releases some harmful chemicals and volatile compounds, contributing to pollution. Furthermore, operating the machinery requires a large amount of energy, which when powered by coal, creates additional impacts on the workers and local population due to the soot from burning coal (as is largely still the case in China) (Wang et al., 2020). However, oil spill accidents are also an inextricable part of the industry and can have significant, and sometimes irreversible, impact on the local population. The severe impacts the local communities in Niger Delta have faced is one of the most devastating examples in recent history (BHRC, n.d.). In this region alone, over 7,000 oil spill incidents have been reported over a 50-year period (UNDP, 2006). The human rights impacts on the local communities include but are not limited to: lack of access to clean drinking water, clean air, and clean soil; eating polluted crops; malnutrition; cancer; infertility and birth defects (affecting the communities' right to health); loss of livelihoods and decreasing food security due to displacement, failed crops, livestock loss, and fish stock decline (affecting the communities' right to housing, decent standard of living and right to work); as well as health and safety risk of fires near the spills (Ordinioha and Brisibe, 2013).

B6.2 Human rights impacts associated with feedstock sourcing for recycled PET

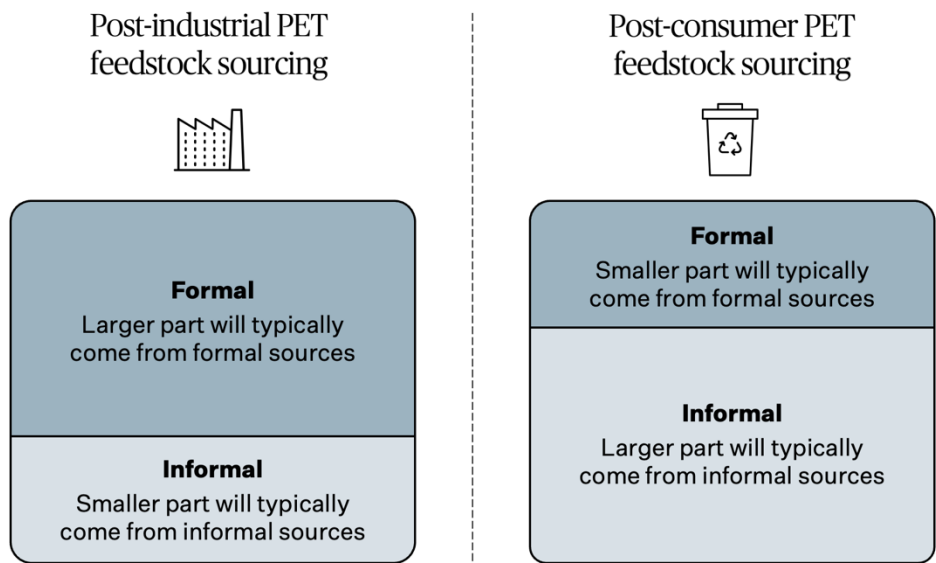
Feedstock sourcing for recycled PET consists of two main sub-sources:

- Post-industrial feedstock involves materials discarded during the manufacturing process (for example, off cuts, scrap, etc.) or products after manufacturing that are discarded before being used by consumers (for example, overstocked textile garments).
- Post-consumer feedstock are products that have been used and then discarded by consumers (for example, plastic bottles, clothing, linens, and other textiles).

Often, feedstock sourcing will require collection, sorting, and transport processes before arriving at the recycling facilities. Depending on the specific type of feedstock, further processing (for instance, shredding of fabric or finished goods) may be necessary before it is ready for the production of PET fiber.

Additionally, both types of sub-sources can also come from either formal or informal sources (The Circulate Initiative, 2023c). While this study was not able to find reliable statistics on the proportion of formal versus informal sources in these two types of feedstock for the textile industry specifically, it is estimated that around 60% of plastic waste is collected by informal waste pickers globally (Tearfund, 2023). Based on this, this research assumes that, in the textile industry, the picture is similar, and that the post-industrial waste is largely collected through formal means while the majority of the post-consumer waste is collected informally.

Figure B-4: Types of feedstock for recycled PET—estimated proportion of formal versus informal sources



While it is useful to explore the specific characteristics of formal and informal feedstock supply chains—especially given their distinct human rights risk profiles—it is important to recognize that these systems are intrinsically connected. In practice, no supply chain is likely to be entirely formal or entirely informal.

Due to the limitations outlined in this study, the data obtained through the questionnaire provided very little insight into the human rights impacts across the deeper levels of the supply chain, before the feedstock reaches the recyclers. The recyclers who filled out the survey were able to comment on some impacts relevant to their own operations and how they are managed, but not their supply chain, leaving the most severe impacts undetected. The responses also pointed to the recyclers’ focus on legal labor compliance, a more limited scope than human rights due diligence, which looks at all human rights (not only labor rights) and covers impacts on anyone who is

negatively affected by the business (unlike labor compliance, which only takes responsibility for directly employed workers/employees). These data gaps were pointed out by both experts, who commented that, because of this, even if the sample of this study was much bigger, the questionnaire results alone are not, and would not have been, representative of the true human rights impacts in the recycled PET supply chains. This is why the questionnaire results are not being presented alone in this report.

Despite limited research available on the human rights impacts in polyester recycling for the textile industry specifically, the human rights impacts in PET bottles recycling more generally (such as for the food and beverage industry) are relatively well documented, especially in light of global plastics treaty developments (O'Hare and Nøklebye, 2024). These sources point to several serious impacts on the most vulnerable workers. The most common and significant impacts identified in the desk-based research, and confirmed by the expert consultations, are listed in Table B-3.

B6.2.1 Formal sourcing of feedstock for recycled PET

Formal sourcing of feedstock refers to supply chains where all entities are officially registered businesses. This means they will typically have a certain level of oversight from the government and/or other supply chain actors, such as their direct buyers or brands further up the supply chain. Formal entities producing post-industrial waste may be factories or other intermediaries, such as traders, who sell the waste to recyclers. These can also be formal government schemes for collecting, sorting, and selling post-consumer waste for recycling. The level of formalization of waste recycling varies greatly by country, with many recent developments in Extended Producer Responsibility (EPR) schemes, an environmental policy that makes producers responsible for the entire life cycle of their products, coming into place (Valpak, 2025).

While it is reasonable to assume that because this feedstock comes from official or industrial sources it should be more easily traceable and carry fewer human rights risks, this is not always the case. Firstly, the existing human rights impacts will depend on the level of awareness the facilities producing or collecting the waste have about human rights and international standards, as well as the level of effectiveness of mitigation of these impacts have put into place. For instance, a recently built, modern recycling facility in the Global North may have strong health and safety protocols in place, yet still unknowingly employ foreign workers through an agency, where some may be in situations of forced labor due to having paid recruitment fees. Or, waste collection may be managed by a local municipality in the Global South, but due to resource strain and lack of awareness of human rights due diligence, the responsible local authority may have no mitigation in place, resulting in poor working conditions and human rights impacts for their staff.

Secondly, when it comes to waste produced by industrial factories, their level of awareness of human rights due diligence will usually depend on several factors, from their size and location (including the effectiveness of local law enforcement) to their position in the supply chain and exposure to pressures from their buyers to manage this area. Generally speaking, the further upstream in the supply chain these entities are, the less buyer pressure and therefore awareness they are likely to have. Additionally, the fact that a source of feedstock is a formal entity does not eliminate the possibility that it may use informal subcontractors, such as homeworkers, something that is common practice in textile supply chains (WIEGO, n.d.).

Even in cases when some level of human rights risk mitigation is in place at the factories producing post-industrial waste, the waste still needs to be transported and sorted. These processes can be carried out by informal workers, increasing the human rights impacts. Further research is needed to understand this scenario in more depth.

B6.2.2. Informal sourcing of feedstock for recycled PET

A significant proportion of the recycled PET supply chains is informal. According to one report, informal workers, largely rural migrants, recovered 20% of China’s municipal solid waste (Chen et al., 2023). In Southeast Asia, the majority of the plastic waste collected for recycling is collected and sorted by informal workers (The Circulate Initiative, 2023a).

The informal supply chains consist of a network of unregistered, self-employed individuals or, sometimes, cooperatives without any safety nets, such as a minimum wage guarantee or basic health and safety provisions. Informal supply chains may be organized, as there are often strong relationships among the entities involved, as well as much supply chain and waste sorting knowledge. Some informal waste activities have also been known to be linked to organized crime (United Nations Office on Drugs and Crime, 2024). As a result, these supply chains are significantly more complex and more opaque than the formal part of the PET recycling supply chains, which are usually run by governments or municipalities. The informal nature makes this type of feedstock sourcing substantially higher risk when it comes to human rights impacts.

For demonstration, Figure B-2 represents an example supply chain map of a polyester recycler. The map shows several layers of collection, aggregation, transport, and sorting before the feedstock reaches the recycler. While the recycler may be a formal business with mechanized processing, not heavily reliant on directly employed labor, and have some level of human rights due diligence in place, the other stages are likely to be largely informal and labor intensive, posing more severe human rights risks. Waste pickers or collectors are usually individuals who collect waste from the street, dumps, or any other available source. Sometimes they work alone, and sometime these are adults with their children accompanying or helping them. Traders, aggregators, and sorters are still usually informal individuals or entities, but have the means to collate larger quantities of waste, and store and sort it before passing it onto the recycler.

The “map” can look different for every recycler (and will usually contain both formal and informal sources), although it is reasonable to expect at least several layers of multiple relationships, as was confirmed by the desk-based research and the expert consultations.

Figure B-5: An example supply-chain map for a polyester recycler, showing the numerous sub-levels and complexity involved

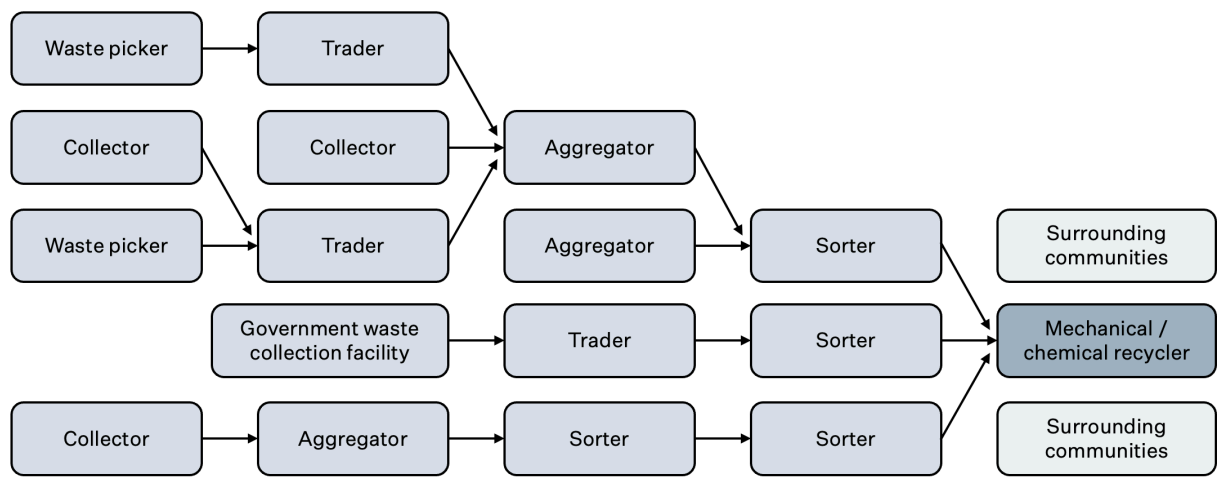


Table B-3: Human rights impacts associated with informal sourcing of feedstock for recycled PET

	Human rights impacts	Details
Workers	Worker health and safety	Exposure to waste and waste dump sites can severely impact waste pickers' health, infringing on their right to health and a healthy environment. Waste pickers are exposed to dangerous objects and substances (sharp objects, chemicals, contaminated material, etc.) daily, usually without any training or adequate personal protective equipment (PPE). Many waste pickers are internal or external migrants without easy access to healthcare and necessary treatment, which means that even small injuries can lead to serious infections and long-lasting consequences (Luk, 2024). Working in the vicinity of waste dumps means waste pickers are often inhaling the fumes of open burning of plastics, known to cause respiratory, heart, skin, and neurological difficulties and are linked to increased risk of cancer (Pathak et al., 2023) Lack of access to clean drinking water or safe and hygienic toilets, exposure to excessive heat (in light of climate change and increasing global temperatures), as well as risk of accidents in unmanaged areas are other common health impacts (GRID-Arendal, 2022).
	Social protection and precarious work	Most waste pickers' earnings are far off from a living income while also being unpredictable and unstable (Systemiq, 2024a), impacting several of their rights (including, but not limited to, right to adequate standard of living and right to housing). As reported by the experts interviewed, waste pickers' income hugely depends on working hours, location, experience and buyer relationships, family and dependents' status, market rates, seasonality, and competition (density of other waste pickers in the area). Storage space in large cities is limited, which reduces the amount of waste they can collect and store, affecting their income (The Circulate Initiative, 2023a). For instance, a male without a family may work 18 hours a day when he has access to quality material and has good buyers, earning better income on some days. However, if any of the variables change or he gets injured, he will not have any safety nets such as sick pay. In contrast, a female waste picker may have children whom she needs to look after. She may need to bring them with her, not being able to work as long hours or as fast, or access some of the waste locations, leading to lower earnings while needing to cover more expenses. Additionally, the rates paid by recyclers for the collected waste are not regulated or transparent, meaning the individual collectors, traders, and aggregators can be paid different rates, leading to inequality and further exploitation. Informal workers involved in other stages of PET recycling such as transport or ad hoc jobs, employed by chip or staple fiber manufacturers for instance, are likely to face similar challenges when it comes to income.
	Discrimination, harassment, and abuse	The reason people resort to waste picking is usually because of their vulnerable status and inability to earn income in other ways, such as lack of education or poverty. It is these statuses and the related vulnerability that also make waste pickers a target of discrimination and harassment by the government, and the community, leading to further social exclusion, with informal workers being the most affected. To illustrate, research conducted in Bengaluru, India showed that while the local community showed sympathy and appreciation toward formal waste collectors, informal waste pickers were often seen as uneducated and dirty and associated with homelessness, problems with addiction, and contributing to the spreading of diseases (Gambhir and Gupta, 2021). In addition to impacting their dignity and psychological well-being, such stigma is also likely to prevent waste pickers from gaining access to

	Human rights impacts	Details
		locations with better quality waste or building relationships with local residents, impacting their earnings.
	Lack of recognition and representation for informal workers	Even though waste pickers are an essential part of recycled plastics supply chain, they do not have the recognition and voice they are entitled to. This lack of recognition is at the root cause of all the other impacts they face, such as discrimination and poor working conditions. Exclusion from decision-making processes that affect them is one example where lack of recognition is creating further impacts. For instance, in many places waste pickers are not included in the development of EPR schemes, resulting in them losing livelihoods when they come into force. Or there is an expectation that waste pickers can, and want, to enter formal employment, when in reality their status may prevent them from doing so, or they may not be able to due to inflexible working arrangements. All these scenarios put waste pickers into a more vulnerable position with less job and income security.
	Child labor	Research shows that children working and/or accompanying adults is extremely common in the context of waste picking, exposing them to severe impacts on their health and safety as well their development and education, affecting several of their human rights. These include their right to health, decent standard of living, and education, but also rights specifically assigned to children, such as the right to be safe, to relax, and to play (UNICEF, n.d.). For example, in Dhaka, Bangladesh, half of all waste pickers are children (Child Hope, n.d. –b). Even in cases when adult waste pickers decide not to take their children with them to work, the children and adolescents face a bleak outlook. The nearest schools are far to walk to, exposing the children to dangerous traffic and human trafficking, often leading the youth to petty theft, exposure to drug taking, sexual exploitation, and arrest by the police within their community (Child Hope, n.d. –a).

Table B-4: Human rights impacts associated with formal sourcing of feedstock for recycled PET

	Human rights impacts	Details
Workers	Worker health and safety	For directly employed staff in formal waste collection or PET processing, there are health and safety impacts due to exposure to waste, chemicals, or heavy machinery, as well as potentially long working hours, low pay, and weak social protection. Discrimination based on gender (including pregnancy status), age, religion, or other status, as well as harassment in the workplace, are common impacts.
	Social protection and precarious work	Workers employed through contractors or labor agencies with little oversight of their hiring and working conditions, such as temporary, casual, or informal workers, are particularly vulnerable to poor working conditions in any context. For example, low skilled and low paid manual laborers carrying out cleaning or security staff and migrant workers are particularly at risk of instances of forced labor (such as payment of recruitment fees, withholding of identification documents, or unlawful wage deductions).
	Freedom of association and collective bargaining	Lack of effective worker representation (trade unions) or access to grievance mechanism means workers have little to no access to remedy when impacts at work occur, affecting their right to safe, just, and favorable conditions at work including freedom of association, among other rights.

B6.3 Human rights impacts associated with processing of polyester feedstock and production of polyester chip and staple fiber

The processing of polyester feedstock and production of PET chips and fiber generally requires a higher level of mechanization and occurs in a factory, rather than in the community or mining context. The human rights impacts at this stage, therefore, mostly relate to labor rights, with some impacts on the surrounding communities. The level of human rights due diligence—and, therefore, the potential impacts—can vary significantly across facilities, depending on factors such as their size and location, local legal requirements, the degree of supply chain formalization, and expectations from buyers.

The data collected through the study’s questionnaire provided some interesting insights in regard to this. All recyclers based in the Global South had some human rights due diligence in place for their own operations and their direct suppliers, quoting third-party audits of their direct feedstock suppliers. While audits have not proven to be reliably effective at managing human rights impacts, it still shows a certain level of awareness and investment into this topic. However, the recycler based in the Global North did not report due diligence in the supply chain at all and quoted its publicly traded status, country of operation, and strong labor laws as the reason. Despite the small sample, this is an interesting observation and learning, because the assumption that the location or laws themselves prevent human rights impacts is a common misconception, as severe human rights impacts exist in every country.

Another interesting observation was that while the respondents mentioned human rights due diligence, their answers mostly related to labor compliance in their own facilities and direct suppliers, not all human rights impacts or the full supply chain. None of the recyclers had visibility of feedstock sources beyond their direct relationships, nor did they do any human rights due diligence beyond this point, even though it is known that the most severe human rights impacts happen upstream in supply chains.

Location is also an interesting factor in this context for another reason. Most of the polyester produced globally is made by a small number of large corporations, concentrated in a few countries, with the majority being produced in China (Statista, 2024). The remaining volume is spread across Taiwan, Korea, India, Japan, Indonesia, and the United States (US) (Sewport, 2025). It is, therefore, relevant to consider the human rights profiles of these countries when assessing the impacts of polyester fiber production.

Table B-5: Common impacts associated with processing polyester

	Human rights impacts	Details
Workers	Worker health and safety	Exposure to chemicals without adequate training or PPE and its impacts on long-term health has been a documented risk for factory workers, especially in chemical processing plants such as those manufacturing PET chips through polymerization. Unsafe handling or storage of chemicals can also pose risk of fire and explosions. Similarly, use of dangerous machinery without adequate training can cause life-altering accidents or death. According to one study, workers in recycling facilities are twice as likely to be injured at work than an average worker in industries in the United States (Graham et al., 2015). Exposure to extreme temperatures in facilities is common and creates direct impacts on workers’ health, as well as often makes many workers not want to wear PPE due to discomfort, increasing other impacts. Long working hours and production pressures further increase the risk of serious health and safety impacts on workers.

	Human rights impacts	Details
	Child labor	It is not uncommon to find children working in manufacturing or processing factories, especially upstream in textile supply chains. Young workers, even when legally employed, are often found doing hazardous labor illegally, such as operating machinery, working with chemicals, or working at night. Child labor can be the result of individual circumstances such as poverty or lack of access to education as well as poor hiring practices and bigger trends such as labor shortages. Contrary to common assumptions, child labor is not only relevant to countries with weak economic or development status. For example, research shows that while China has undergone fast development over the last few decades, the child labor has risen during this time due to economic disparities between rural and urban areas and demand for low-cost labor (Sukmatika, 2024). In the US, since 2019, there has been an 88% increase in cases where children were found working in violation of child labor laws (US Department of Labor, 2024).
	Forced labor and modern slavery	According to the 2023 Global Slavery Index, instances of forced labor are found at all stages of textile supply chains, including polyester production (Walk Free Foundation, 2023). Instances of forced labor impacts relevant to the scope of this study include payment of recruitment fees and related situations of debt bondage, especially common in third party and/or informal recruitment of foreign and migrant workers; withholding of identification documents such as passports; withholding of wages and/or illegal wage deductions; and restriction of movement, as well as instances of state-imposed forced labor. A recent report on working conditions of migrant workers in Taiwan found all of these instances of forced labor present, in addition to other indicators of forced labor such as intimidation, threat and discipline fines, excessive overtime, and abuse of vulnerability (Transparentem, 2025). Forced labor impacts infringe on several basic human rights of workers (including, but not limited to, right to freedom of movement and right to freely choose one's work). In addition, several companies blacklisted from importing goods into the US due to forced labor concerns are also manufacturers of polyester fiber (US Homeland Security, 2025).
	Wages and working hours	Worker earnings in textile supply chains can often be low across the globe, which pushes many workers to work longer hours to make ends meet. In some countries, including China and Vietnam, working excessive overtime has become the norm and the means to earn enough to live on, resulting in workers leaving a workplace if they cannot get enough overtime hours (Nguyen et al., 2024). In many South Asian production countries, it is common for workers to regularly work in excess of 10 hours a day, with only 1 or 2 days off per month. This endemic overtime is exacerbated by the common working situation where workers migrate for work, leaving their family behind. In such cases, workers often want to maximize working time and earnings and build savings, potentially creating negative impacts on their mental and physical health and well-being.
	Freedom of association and collective bargaining	Lack of effective worker representation (trade unions) or access to grievance mechanisms mean workers may have little to no access to remedy when impacts at work occur, affecting their right to safe, just, and favorable conditions at work including freedom of association, among other rights.
	Discrimination, harassment, and abuse	Many female workers in textile manufacturing face discrimination in hiring, verbal abuse, sexual harassment in the workplace, and gender-based violence, the extent of which is rarely acknowledged (Niebank, 2018). The precarious work situation of many female workers, such as informal

	Human rights impacts	Details
		employment, coupled with lack of effective grievance mechanisms means these impacts are rarely reported and remediated. Lack of childcare and caring responsibilities mean many women can't work full time in formal employment or leave it and enter the informal sector when they have a family, pushing them further into economic inequality. Migrant, minority, and education status of women further exacerbate these impacts.
Communities	Safe and healthy living conditions	The chemicals used in manufacturing may not always be safely disposed of by factories, polluting local water systems and potentially affecting local communities' rights to clean water (CDP, 2022). Water pollution, in turn, affects the soil and in many cases the communities' crops and therefore livelihoods.

As demonstrated in this section, the human rights impact of polyester production can have severe implications on people's lives and dignity. They impact not only workers and those physically and directly in contact with polyester production, but also the wider communities around the sites of production. This is why it is important to look beyond labor rights and consider the full spectrum of human rights when assessing impacts on people.

Furthermore, the local context, along with the historical, political, and socio-economic background, is hugely important when trying to understand the root causes of these impacts and identify the best remediation actions. The recommendations in the next section point brands, retailers, and manufacturers toward the key considerations when working with these findings and acting on them.

B.7 Recommendations

The recommendations below summarize the industry best practices and feedback received from the expert consultations. Brands, retailers, and manufacturers wishing to take action on the impacts discussed in the findings section of this report are encouraged to consider the following list as the main areas where action is needed.

B7.1 Recommendations for brands, retailers, and manufacturers

Internal Procedures

Brands, retailers, and manufacturers should begin by conducting deeper research into their own supply chains, using this report as a foundation. This includes building internal commitment by ensuring leadership support, allocating budgets, and enhancing awareness and capacity across teams. Companies should engage qualified human rights specialists, either in-house or external, to support their work. When making sourcing decisions, businesses must consider the most severe human rights impacts and their own capacity to address them.

Supply chain mapping

Companies should work toward full traceability of their polyester supply chains by engaging with supply chain actors and progressively mapping upstream to the origin. It is important to assume that informal actors—such as temporary workers, subcontractors, and waste pickers—are part of the supply chain, even if not immediately visible. Building relationships with suppliers is essential before requesting sensitive information, especially on informal labor and human rights impacts.

Addressing human rights impacts

Human rights due diligence must be carried out on an ongoing basis, following the UN Guiding Principles on Business and Human Rights (United Nations, 2011) and the OECD Due Diligence Guidance (OECD, 2018). Companies need to understand that human rights impacts vary by local context, and they should not assume that the same issues affect all workers equally. They should avoid a compliance-based approach, particularly in relation to informal workers, and instead focus on building better practices over time, which also reduces the risk of unintended consequences. Prioritization should be based on the severity of risk, with informal workers and supply chains being a key focus. Effective due diligence also requires appropriate tools; social audits and self-assessments alone are insufficient. Field-based human rights impact assessments and mixed-methods approaches are more reliable.

Stakeholder engagement

Engagement should include rightsholders directly or through legitimate representatives, such as trade unions, associations, or cooperatives. Companies must be mindful of how and when they engage, respecting rightsholders' time and preferences. A gender and vulnerability lens should be applied throughout all activities, recognizing that different groups—such as women, children, and migrant workers—are affected in different ways. Engagement with other brands, suppliers, governments, and civil society should be continuous to improve the transparency and quality of supply chain data.

Grievance mechanisms and access to remedy

Companies must ensure that rightsholders in their polyester supply chains, including informal workers and local communities, have access to grievance mechanisms and appropriate remedies. If a company's own mechanism is unsuitable, it should help rightsholders access other existing systems or collaborate to create new ones.

Collaboration

Participating in industry initiatives can accelerate progress and increase collective impact. Companies should also be transparent about their challenges and progress to help the wider sector learn and improve.

Recommendations specifically for virgin polyester supply chains

Companies should presume that human rights impacts on Indigenous communities are likely unless there is clear evidence to the contrary. These communities must be included in human rights due diligence, and respect for free, prior, and informed consent (FPIC) should be assessed during human rights impact assessments. Industry efforts supporting Indigenous Peoples and Local Communities on the ground should be actively supported.

Recommendations specifically for recycled polyester supply chains

Informal workers are likely involved in recycled polyester supply chains and must be included in due diligence efforts. Mapping informal supply chains requires trust and sensitivity due to the potential impact on commercial relationships. Companies should ask about cooperatives or worker organizations as indicators of access to rights. Supporting the recognition and organization of waste pickers helps strengthen the circular economy and protect vulnerable workers.

It is essential that companies understand and verify these common human rights risks in their supply chains to meet legal obligations and voluntary frameworks. Stakeholder engagement, especially with rightsholders themselves, is crucial, along with collaboration with government, civil society, and other companies.

B7.2 Recommendations for the textile industry as a whole

As recycled options for polyester continue to evolve and scale, the industry should continue its efforts to invest in recycled polyester materials, rather than relying on virgin polyester options. The industry should conduct further research into polyester recycling specifically for the textile sector to address existing data gaps. This includes verifying the extent of informal sourcing in post-industrial recycling and assessing human rights impacts in textile-to-textile recycling. On-the-ground data collection is necessary and should involve direct engagement with rightsholders or their legitimate representatives. Human rights experts with the appropriate experience must be involved in this process, as sustainability expertise alone is not sufficient. Adequate time must be allocated for trust-building and quality data collection. Additionally, increasing the sample size of research initiatives will help enhance the relevance and reliability of findings across the industry.

B.8 Conclusion

Polyester production creates impacts on both people and the environment, therefore understanding them alongside one another is vitally important.

Despite the limitations and need for further research, this report highlights the common human rights impacts associated with the production of virgin and recycled polyester fiber, bringing some important insights into the impacts on the most vulnerable groups of people in these supply chains, such as informal workers, Indigenous communities, women, and children.

The findings show that both virgin and recycled polyester can have severe impacts on human rights, including harassment, violence, and abuse. However, recycled polyester, in particular, holds much promise for the future, playing an important part in tackling the world's textile waste crisis.

While there is much work yet to be done to better map and understand these supply chains and address the severe impacts on human rights, there are also many opportunities. Recycling supply chains create some of the most severe human rights impacts due to their informality and lack of regulation, meaning they also hold many potential solutions.

For instance, informal workers hold great knowledge about the structure of the supply chains that need to be mapped more closely, as well as feedstock quality and recycling. Safeguarding their rights, empowering them to organize, and including them in decision-making will not only improve their lives, but it provides the potential to solve many supply chain challenges associated with feedstock quality and availability for the other supply chain actors, including brands, retailers, and manufacturers.

The purpose of this report is to highlight the main impact themes. Human rights impacts exist globally, across industries, so there is a need for human rights due diligence to identify and address impacts that do exist and prevent, mitigate, and remediate these.

Brands, retailers, and manufacturers are encouraged to use this report as a starting point—not a definitive guide—on human rights impacts in polyester production. This resource should be built upon through further research, especially by incorporating on-the-ground primary data collection and direct engagement with relevant rightsholder groups.

B.9 Primary data questionnaire for recyclers

1. General information

Company name and location
Company size (total number of workers)
Permanent workers: • What percentage of workers at your facility are employed directly on a permanent basis? • What activities do they perform? • What percentage are women?
Short-term workers: • What percentage of workers at your facility are employed on a short-term basis (e.g., daily or seasonal workers)? • What activities do they perform? • What percentage of these short-term workers are women?
Indirect workers: • What percentage of workers at your facility are employed indirectly, through an agent or contractor? • What activities do they perform? • What percentage of these indirect workers are women?
Are the workers mostly local or migrant? Please indicate the %

Type of worker	%
Local	
Internal migrants	
Cross-border migrants	
Please add further comments:	

(Next section: Feedstock sourcing)

2. Feedstock sourcing

What is the composition of feedstock processed at your facility?
What are the internal procedures you have established for traceability and transparency in procuring raw materials?
Please provide a list of suppliers you source your raw materials from. For each supplier, include: • The type of material provided • The percentage of total raw material received from that supplier • Their geographic location.
Do you have visibility into your upstream supply chain beyond your direct (Tier 1) suppliers?

If yes, please provide an upstream supplier map representing feedstock collection through delivery to the recycling facilities. Please refer to the example in “General Instructions” on page 1.

Document any gaps.

How is this feedstock collected?

Provide as much detail as possible, including all possible sources, (traders, local collectors, etc.,).

Does feedstock undergo any sorting or pre-treatment before being recycled?

If yes, provide a description of all the steps involved and whether those processes are manual or automated.

Does your organization have a supplier policy that includes requirements for the social welfare and safety of the vendors collecting recycled materials?

(Next section: Human and labor rights)

3. Human and labor rights

Do you have a policy commitment to respect human and labor rights?

Does your organization carry out a human rights risk (or impact) assessment?

Does your organization remediate (or participate in remediation of) the identified risks or impacts?	
How often do workers get days off?	
Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.). Please select your answer with an x against the applicable row:	
At least 2 days off per week	
At least 1 day off per week	
At least 1 day off every 2 weeks	
At least 1 day off in a month	
Please add further comments:	
How often do workers exceed 40 hours per week?	
Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.). Please select your answer with an x against the applicable row:	
Never	
Rarely	
Sometimes	
Often	
Always	
Please add further comments:	

Do you feel that workers are able to freely refuse working overtime? If no, please explain what happens in a situation where they refuse overtime. Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.,). Please select your answer with an x against the applicable row:	
Yes	
No	
Please add further comments:	
What are the peak season working hours like? What is the highest overtime you have seen? Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.,). Please select your answer with an x against the applicable row:	
60–70 hours per week in total	
70–80 hours per week in total	
80–90 hours per week in total	
over 90 hours per week in total	
Please add further comments:	
How often do you see under-18s working in the polyester supply chain in your region? Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.,). Please select your answer with an x against the applicable row:	
Never	
Rarely	
Sometimes	
Often	

Always	
Please add further comments:	
What is the youngest age of children you see working in the polyester supply chain in your region? Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.,). Please select your answer with an x against the applicable row:	
Less than 10	
10–12 years old	
13–15 years old	
16–18 years old	
Please add further comments:	
Are you aware of under-18s ever doing work that could be considered hazardous? (Please mention what in the comment). Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.,). Please select your answer with an x against the applicable row:	
Yes	
No	
Please add further comments:	
Do your workers and workers in your supply chain have contracts or work informally? Please give more details in the comments (benefits can include sick pay, maternity pay, pension, etc.,). Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.,). Please indicate the %:	

Most have contracts with benefits	
Most have contracts but no benefits	
Some work informally, some have contracts	
Only informal work	
Other:	
Please add further comments:	
Do your workers and workers in your supply chain earn at least the local minimum wage? Please state the local minimum wage in the comments. Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.,). Please select your answer with an x against the applicable row:	
Never	
Rarely	
Sometimes	
Often	
Always	
Please add further comments, including the local minimum wage:	
How often do workers at your facility and in your supply chain earn a living wage (enough to cover their basic needs for themselves and their families, including unexpected expenses)? Please state the local living wage in the comments. Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.,). Please select your answer with an x against the applicable row:	
Never	
Rarely	

Sometimes	
Often	
Always	
Please add further comments, including the local living wage:	
How often do women and men in your facility and supply chain, who do the same job, earn the same money? Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.). Please select your answer with an x against the applicable row:	
Never	
Rarely	
Sometimes	
Often	
Always	
Please add further comments:	
How often do you hear about things like workers working in polyester production facilities, or the supply chain, being required to pay recruitment fees, or being unable to terminate employment due to owing money to their employer? Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.). Please select your answer with an x against the applicable row:	
Never	
Rarely	
Sometimes	
Often	
Always	
Please add further comments:	

Where workers in your facility or supply chain are provided with accommodation by their employer, what are the conditions of the accommodation? Please give more details in the comments. Please give more details in the comments if this differs for facility workers and other types of workers (such as pickers, aggregators, etc.,). Please select your answer with an x against the applicable row:	
Good—there are no issues	
Satisfactory—there may be minor issues	
Poor—there are many issues	
Dangerous—there are serious issues	
Please add further comments:	

(Next section: Stakeholder engagement)

4. Stakeholder engagement

<i>Stakeholder identification</i> Does your facility identify and analyze the range of stakeholders directly or potentially affected by your production-related activities? (For instance, employees and workers, suppliers and their workers, local communities, etc.,). If yes, how is this process conducted?
<i>Local community identification</i> Does your facility identify local communities that may be directly affected by your operations? If yes, has your facility identified local communities that may be directly affected by your operations?

What is your documented process for engaging with stakeholders? (By engaging, we mean talking with, listening, and responding to the stakeholders and considering their needs and opinions in your decision-making.)
Does your organization have a policy to provide relevant information in a timely manner about issues of concern requested by stakeholders, ensuring sufficient detail and substance for stakeholders to engage effectively on these issues? (In other words, is your engagement a two-way process, benefiting the stakeholders as well as you?)
What is your organization's policy for meaningful engagement with local communities in regions where your raw material procurement and production-related activities occur?
Does your facility engage in, document, and maintain regular consultations and planning with representatives of local communities at least annually to support community development?

(Next section: Chemical management)

5. Chemical management

Please describe the established chemical management strategy at your facility.

Do you use toxic or hazardous chemicals at your facility?	
What measures are in place to protect workers and the community from exposure to hazardous or toxic chemicals?	
Does your facility comply with local environmental or safety standards? If yes, please provide documentation.	
How would you rate the Health & Safety in your own facilities and supply chain? Please provide examples in the comments. Please select your answer with an x against the applicable row:	
Good—there are no issues	
Satisfactory—there may be minor issues	
Poor—there are many issues	
Dangerous—there are serious issues	
Please add further comments:	
What do you think are the main Health & Safety concerns for workers in polyester production facilities and the surrounding community? Please give more details in the comments. Please select as many answers that apply with an x against the applicable row:	

Chemical exposure	
Dangerous machinery	
Heat exposure	
Overtime and/or lack of breaks	
No access to sufficient PPE or training	
Please add further comments:	

(Next section: Grievance mechanisms)

6. Grievance mechanisms

Do you have a grievance mechanism for workers to raise workplace concerns or grievances, with the right to remain anonymous? If so, what does it consist of, and how can they access it?	
What is your grievance mechanism for external parties, such as business partners or community members, to lodge complaints or grievances with your company? How can they access it?	
To what extent can workers who work in polyester production facilities (or in their surrounding communities) advocate for themselves if they are negatively impacted by polyester production in any way (such as labor issues or water scarcity)? Please select your answer with an x against the applicable row:	
Concerns or grievances are usually effectively resolved in the workplace, or through a worker's union or another grievance channel	

Concerns or grievances are sometimes effectively resolved in the workplace, or through a worker's union or another grievance channel	
Although there are channels available, concerns or grievances are never effectively resolved in the workplace, or through a worker's union or another grievance channel	
There is NO channel in the workplace, a worker's union, or external grievance channel for workers or communities to use to resolve grievances or concerns	
Please add further comments:	
Is there anything you would like to add in relation to social impacts on workers or communities in relation to polyester production facilities within your area?	

(End of survey)

B.10 Matrix of common human rights impacts in polyester chip, staple fiber, and yarn production

Please note that while some of the impacts below are highlighted as “more severe”, this should be interpreted as a general guide. The actual severity of impacts can vary depending on the specific context or site. For example, if the extraction stage of a supply chain involves well-managed and closely monitored engagement with Indigenous Peoples or Local Communities—including a robust FPIC process—while a fatal accident occurs due to poor health and safety practices at a fiber production facility further upstream, the latter would clearly represent a more severe impact and should be prioritized for immediate action. This is the case even if, in general, the extraction stage is typically considered higher risk in the matrix below.

The matrix below was drafted considering the value chain steps covered by the polyester LCA, from extraction to production of PET chip, staple fiber, and yarn. The assessment considered the likely activities and actors at each stage, followed by evaluating sector-specific risk factors such as weak labor protections, environmental degradation, or displacement of communities. Special attention is given to vulnerable groups, including migrant workers and women. Risks are categorized based on severity (scale, scope, and irremediability) and likelihood. The impacts included are based on the research conducted for this study and should be considered a starting point for a company’s own risk assessment procedure.

Key:		Highest likelihood of severe impacts		Medium likelihood of severe impacts		Lower likelihood of severe impacts	
Potential and actual human rights impacts	Tier 4					Tier 3	
	Sourcing of feedstock for virgin PET			Sourcing of feedstock for recycled PET		Production of PET fiber	
							
	Virgin PET feedstock extraction (crude oil mining)	Virgin PET feedstock processing (chemical)	Recycled PET feedstock collection (pre-consumer)	Recycled PET feedstock collection (post-consumer)	Virgin and recycled PET chip and staple fiber production		
	Infringement of Indigenous Peoples and Local Communities' Rights		As the nature of the processes involved at these stages is different to those in oil extraction, the risk to people's land rights/right to FPIC is lower than at the extraction stage. However, these potential impacts are still relevant when land is obtained for other industrial purposes, such as construction of facilities, storage, etc.				
Communities	Conflict, Violence, and Societal Disruption		Violence used by security forces to get access to land, forcibly relocate residents or break up peaceful community protests. Persecution of environmental and human rights defenders.				
	Discrimination, Harassment, and Abuse		Threats, violence, and in the worst case, murder of human rights and environmental defenders have been documented impacts.				
	Safe and Healthy Living Conditions		Pollution of air, land, and waterways can have significant impact on the local population's health and ability to earn a livelihood (ability to fish, grow crops, etc.)				
			Waste recycling typically has a positive impact on the environment. Isolated incidents of bad waste management or storage may have impacts on the community members, but this is not considered a significant risk in this context.				

Key:	Highest likelihood of severe impacts	Medium likelihood of severe impacts	Lower likelihood of severe impacts

	Tier 4				Tier 3
	Sourcing of feedstock for virgin PET		Sourcing of feedstock for recycled PET		Production of PET fiber
Potential and actual human rights impacts	 Virgin PET feedstock extraction (crude oil mining)	 Virgin PET feedstock processing (chemical)	 Recycled PET feedstock collection (pre-consumer)	 Recycled PET feedstock collection (post-consumer)	 Virgin and recycled PET chip and staple fiber production
Workers	Forced Labor and Modern Slavery	Use of migrant labor is common in the oil and gas industry and polyester supply chain and can increase the risk of forced labor (retention of passports, payment of recruitment fees and restriction of movement among other types of forced labor).			
	Child Labor	Due to weak recruitment checks, poverty, and lack of employment, children and young workers are at risk of being involved in less formal and lower-skilled jobs.		Children can often be found accompanying their parent and/or working, impacting on their physical health, wellbeing, and development.	Due to weak recruitment checks, poverty, and lack of employment, children and young workers are at risk of being involved in less formal and lower-skilled jobs.
	Worker Health and Safety	Life-altering accidents due to the use of heavy machinery, and in the worst case, loss of life. Exposure to petrochemicals, poor living conditions in worker accommodation, and extreme overtime.	Health issues due to exposure to chemicals, lack of PPE, and long working hours, or accidents due to use of heavy machinery.	Use of machinery and long working hours can create impacts. The risk is higher where informal workers and involved.	Accidents, exposure to dangerous substances and chemicals, risk of contracting diseases in combination with lack of access to healthcare for informal pickers and their families, especially children.
	Societal Protection and Precarious Work	Labor hired through agencies and contractors is common with workers not earning a living wage or receiving benefits such as sick pay. Marginalized groups (women, ethnic minorities, foreign workers, etc.) are often discriminated against in hiring and pay.		Income of informal pickers is extremely low, can vary seasonally, and includes no safety nets (such as social benefits).	Women, migrants, and agency workers not earning a living wage or receiving benefits. Marginalized groups being discriminated against in hiring and pay.
	Freedom of Association and Collective Bargaining	Limited opportunities to join effective trade union, dependent on geography and context, and lack of effective grievance mechanisms mean workers have no access to remedy when impacts occur.			
	Discrimination, Harassment, and Abuse	Sexual harassment in the workplace and gender-based violence in communities with influx of migrant male workforce, especially in Indigenous context.	Sexual harassment and gender-based violence in the workplace impacting women and LGBTQA+ community.	Sexual harassment, lack of safety and gender-based violence impacting female pickers and children in the community.	Sexual harassment and gender-based violence in the workplace impacting women and LGBTQA+ community.

Appendix C: Critical Review Statement

Critical Review of the Study “Life Cycle Assessment of Virgin and Recycled Polyester Production Systems”, December 12, 2025:

Commissioned by:	Textile Exchange
Performed by:	SCS Consulting Services
Critical Review Panel⁶:	Dr. Roland Geyer, Professor, (Chair) University of California, Santa Barbara, CA, USA Dr. Ashley Holding, Principal Consultant, Circuvate, Elz, Germany Joel Mertens, Director, Cascale, Oakland, CA, USA Dr. Matthias Stratmann, Head of Department, nova Institute, Hürth, Germany
Date:	January 7, 2026
Reference	ISO 14044: 2006. Environmental management—Life cycle assessment—Requirements and guidelines ISO 14071: 2024. Environmental management—Life cycle assessment— Critical review processes and reviewer competencies

The Scope of the Critical Review

The review panel had the task to assess whether:

- The methods used to carry out the LCA are consistent with ISO 14044:2006
- The methods used to carry out the LCA are scientifically and technically valid
- The data used is appropriate and reasonable in relation to the goal of the study
- The interpretations reflect the limitations identified and the goal of the study
- The study report is transparent and consistent.

This critical review was performed by a panel of external independent experts according to ISO 14044 and ISO 14071, as the results of the study are intended to be disclosed to the public.

The extent to which the unit process data is appropriate and reasonable, given the goal and scope of the study, was determined by a critical review of the available material, which included the LCA Report and spreadsheets with additional primary LCI data. As usual, the reviewer did not have access to the full inventory models and data. The appropriateness of the primary LCI data was reviewed based on the reviewers’ expertise and available benchmarks. The appropriateness of the secondary LCI data was reviewed based on the reviewers’ expertise and available metadata.

⁶ While the professional affiliations of the peer reviewers have been provided, their effort was personally compensated. Thus, their reviews do not represent any endorsements by their organizations.

Critical Review Process

The Critical Review started on June 10, 2025, with the delivery of the first draft of the LCA report. Three rounds of reviews were conducted via online meetings, email exchanges, and a review worksheet. The critical review process was open and constructive. The LCA commissioner and practitioner were cooperative and forthcoming, and addressed all questions, comments, and requests of the review panel to its full satisfaction. This Review Statement summarizes the review process and its outcome.

The full review process is documented in the Review Report, which is available as a separate document, and contains all reviewer comments and practitioner responses.

General Evaluation

The defined scope for this LCA study was found to be appropriate to achieve the defined goals. The Life Cycle Inventory models are suitable for the purpose of the study and are thus capable of supporting the goal of the study. Apart from the remaining concerns listed below, all primary and secondary data is adequate in terms of quality, and technological, geographical, and temporal coverage. The data quality is found to be mostly high for the most important processes and at least adequate for all others.

The study uses the impact indicators required by the Higg Materials Sustainability Index (Higg MSI) and the Environmental Footprint (EF) 3.1 reference package. This selection was found to be appropriate and reasonable in relation to the goal of the study. As a result, the report is deemed to be representative and complete. The study is reported in a transparent manner. Various assumptions were addressed by uncertainty and sensitivity analyses of critical data and methodological choices. The interpretations of the results reflect the identified limitations of the study.

Remaining Concerns

The review panel has some remaining concerns regarding the primary inventory data for the modeled chemical recycling technologies (C1–C3), in particular, the high variability of the energy inputs. As a result, caution should be used when comparing the studied chemical recycling technologies with each other or with other primary or secondary PET production technologies.

Conclusion

The study has been carried out in conformance with ISO 14044. The critical review panel found the overall quality of the report high and its methods scientifically and technically valid. Apart from the remaining concerns described above, the used data is found to be appropriate and reasonable. The study report is transparent and consistent, and the interpretation of the results reflects the goal and the identified limitations of the study.



Roland Geyer



Ashley Holding



Joel Mertens



Matthias Stratmann

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