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Possibilities for **reducing microplastics emissions** from textiles

A dynamic probabilistic material flow analysis study on clothing and footwear aimed at the Netherlands

RIVM letter report 2025-0152
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Colophon

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Synopsis

Possibilities for reducing microplastics emissions from textiles

A dynamic probabilistic material flow analysis study on clothing and footwear aimed at the Netherlands

Microplastics from clothing and shoes are an ever-growing environmental problem. These small plastic particles pollute surface water, the air and the soil and may be harmful to environmental and human health. The particles are released when clothing is worn, washed and dried (particularly the first few times) and when shoes are worn.

Emissions of microplastics from clothing and shoes amounted to 430 tonnes in the Netherlands in 2022. This is expected to increase if no action is taken. RIVM believes that it is possible to reduce these emissions. Four measures would appear to be the most effective to achieve this.

The first measure would be to have manufacturers produce clothing that sheds fewer fibres. The second measure would be to use decomposable materials. Fewer synthetic fibres would mean fewer microplastics. The third measure would be to encourage people to use their clothing for a longer period of time. The final measure would be to have consumers use the delicate wash cycle more often. This would reduce wear while still cleaning synthetic clothing.

The first two measures would be the most effective, but a combination from the entire chain would yield even greater results. It is up to the parties, such as policymakers and clothing and washing machine manufacturers, to come up with a plan. Voluntary measures are not nearly as effective; statutory obligations and clear standards are required to achieve the greatest effect.

RIVM only calculated the emissions of microplastics from clothing and shoes. It did not consider the costs of the measures or the effects of other production processes and materials on, for example, the climate.

RIVM recommends assessing these aspects in order to properly weigh the effects of the measures against each other. For example, cotton production needs more pesticides and more land to grow cotton plants. A second recommendation is to use this study to encourage the parties involved to innovate and collaborate.

Keywords: microplastics, measures, environment, emissions, clothing, shoes, textile, material flow analysis

Publiekssamenvatting

Mogelijkheden om minder microplastics uit textiel uit te stoten

Een dynamische probabilistische materiaalstroomanalyse van kleding en schoenen gericht op Nederland

Microplastics uit kleding en schoenen zijn een steeds groter probleem in het milieu. Deze kleine plastic deeltjes vervuilen oppervlaktewater, de lucht en de bodem en kunnen schadelijk zijn voor de natuur en gezondheid. Ze komen vrij bij het dragen, wassen en drogen (vooral bij de eerste beurten) van kleding en het dragen van schoenen.

De uitstoot van microplastics door kleding en schoenen was in Nederland in 2022 430 ton. Dat zal naar verwachting meer worden als er geen maatregelen worden genomen. Volgens het RIVM is het mogelijk om deze uitstoot te verminderen. Vier maatregelen lijken daarvoor het meest effectief.

Als eerste kunnen fabrikanten kleding maken die minder vezels verliezen. De tweede mogelijkheid is andere materialen te gebruiken die afbreekbaar zijn. Minder synthetische vezels betekent minder microplastics. Ten derde kan worden gestimuleerd dat mensen kleding langer gebruiken. Ten slotte kunnen consumenten vaker wasmachineprogramma's voor fijne was gebruiken. Synthetische kleding wordt daarmee schoon en slijt er minder door.

De eerste twee maatregelen hebben het meeste effect, maar een combinatie vanuit de hele keten levert nog meer op. Het is aan de partijen, zoals beleidsmakers en producenten van kleding of wasmachines, om dat samen te gaan uitwerken. Vrijwillige maatregelen hebben veel minder effect; wettelijke verplichtingen en duidelijke normen zijn nodig om het meeste effect te bereiken.

Het RIVM rekende alleen de uitstoot van microplastics uit kleding en schoenen uit. Er is niet gekeken naar de kosten van de maatregelen, of naar de effecten van andere productieprocessen en materialen op bijvoorbeeld klimaat.

Het RIVM beveelt aan om deze punten wel mee te nemen om het effect van maatregelen goed tegen elkaar te kunnen afwegen. Zo zijn voor kleding van katoen meer pesticiden en land nodig om katoenplanten te laten groeien. Een tweede aanbeveling is om dit onderzoek te gebruiken om te stimuleren dat betrokken partijen innoveren en samenwerken.

Kernwoorden: microplastics, maatregelen, milieu, emissie, kleding, schoenen, textiel, materiaal stroom analyse

Contents

Summary

Microplastics from clothing and footwear are part of the growing plastics pollution problem. Policymakers, industry and consumers can contribute towards reducing emissions of microfibres from clothing. This would help reduce plastics pollution and promote the transitioning towards a more circular economy. In this study thirteen mitigation measures aimed at reducing clothing microfibre emission to the environment are assessed for their effect on reducing microplastic pollution. The effect is quantified using a previously developed material flow analysis model with key updates specific to clothing. For the first time footwear is included, although not the aim of the mitigation measures. Clothing is calculated to have released 290 ton (250 – 340 ton) and Footwear 140 ton (120 – 160 ton) of microplastics to the environment in the Netherlands for 2022. In Europe consumption and manufacturing of clothing is calculated to release 8100 ton (7100-9200 ton) and footwear 3100 ton (2600 – 3700 ton) of microplastics to the environment. This excludes emissions outside of Europe, e.g. due to manufacturing or end of life textile exports.

The thirteen mitigation measures are selected based on literature and were refined during a stakeholder workshop, see list below.

Description of Measures aimed at reducing microplastics emissions from clothing in the Netherlands:

1. Develop and use alternatives to synthetic glitters, trims and fringes
2. Develop and use alternatives for synthetic clothing (such as natural fibres)
3. Improve textile production methods to reduce microfibre losses, increasing quality of the textile fabric
4. Optimize recycling of clothing (clothing to fibre)
5. Lengthen lifetime of clothing (less fast fashion), including reuse of clothing
6. Industrial pre-washing of clothing
7. Use of external or extra microplastic filters in washing machines and alert consumers not to wash the filter in the sink (for consumers or industrial laundromats)
8. Reduce rinsing of dryer lint filters by increasing disposal in mixed waste
9. Increase removal of microfibres in washer-dryer combinations using a filter
10. Optimise cleaning of homes aimed at reducing microfibres in wastewater, e.g. by vacuum before mopping
11. Optimize washing procedure, e.g. using a more delicate (synthetics) washing programme
12. Drying on a clothesline instead of using a tumble dryer
13. Increase efficiency of microplastics removal from wastewater at treatment plants

The effect on reduction of microplastics emissions is quantified using a low and high implementation scenario for the year 2050 in the

Netherlands. These represent for instance the voluntary implementation (low scenario) of a measure or making this obligatory (high scenario).

The four measures with the highest potential for reducing microplastics emissions are the same for the high and low implementation scenario. These measures are:

- Replace materials with non-synthetic alternatives.
- Improve material quality using optimized product methods that reduce release of microfibres.
- Increase lifetime of clothing products, combating fast fashion.
- Optimise the use of tailored washing machine programs, resulting on average in a more delicate washing cycle.

Furthermore, the measures on filtration of microfibres from washing water using external filters, reducing the release of microfibres from the first wash by industrial scale pre-washing and not using synthetic polymers in fringes and trims of clothing articles are also estimated to reduce microplastics emissions. The other mitigation measures are expected to contribute less or not at all as the calculated effect is small or not certain given the error margin of this modelling study.

Overall, we recommend following up this study with a reflective workshop with stakeholders to further refine the potential scenarios and define a combination of mitigation measures that are deemed feasible or relevant to combine. For instance, extending the effective lifetime of clothing, optimizing production methods, and transitioning to alternative materials could be combined for estimating the combined effect on reducing microplastics emissions. Furthermore, prioritisation of mitigation measures should also be based on assessing the cost effectiveness and the broader environmental impact, e.g. using life cycle assessment for including impact of water and pesticide use. The study could also be extended to reporting on the whole EU, as regional differences, such as sludge application in agriculture, can have large effects on effectivity of different measures.

Samenvatting

Microplastics uit kleding en schoeisel maken deel uit van het groeiende probleem van plasticvervuiling. Beleidsmakers, industrie en consumenten kunnen bijdragen aan het verminderen van de uitstoot van microvezels uit kleding. Dit helpt om plasticvervuiling te verminderen en de overgang naar een meer circulaire economie te bevorderen. In deze studie worden dertien mitigatiemaatregelen gericht op het verminderen van de uitstoot van microvezels naar het milieu door kleding beoordeeld op hun effect hierop. Dit wordt gekwantificeerd met behulp van een eerder ontwikkeld materiaalstroomanalysemodel met verschillende updates specifiek voor kleding. Voor het eerst is ook schoeisel inbegrepen. Geschat wordt dat kleding in 2022 290 ton (250 – 340 ton) en schoeisel 140 ton (120-160 ton) microplastics naar het milieu hebben uitgestoten in Nederland. In Europa wordt geschat dat het verbruik en de productie van kleding 8100 ton (7100-9200 ton) en schoeisel 3100 ton (2600 – 3700 ton) microplastics naar het milieu heeft uitgestoten. Dit is exclusief uitstoot buiten Europa, bijvoorbeeld door productie of de export van textiel aan het einde van hun levensduur.

De dertien mitigatiemaatregelen zijn geselecteerd op basis van bestaande literatuur en werden verfijnd tijdens een stakeholderworkshop, zie onderstaande tabel.

Beschrijving van maatregelen voor reduceren microplastics uitstoot door kleding in Nederland:

1. Ontwikkel en gebruik van alternatieven voor synthetische glitters, franjes en andere afwerkingen
2. Ontwikkel en gebruik van alternatieven voor synthetische kleding (zoals natuurlijke en bio-afbreekbare vezels)
3. Verbeter textiel productiemethoden om microvezelverliezen te verminderen, waardoor de kwaliteit van de textielstof wordt verhoogd
4. Optimaliseer de recycling van kleding (kleding naar vezel)
5. Verleng de levensduur van kleding (minder ‘fast fashion’), inclusief hergebruik van kleding
6. Industrieel voorwassen van kleding
7. Gebruik externe of extra microplastic filters bij wasmachines en waarschuw consumenten om het filter niet in de gootsteen te wassen (voor consumenten of industriële wasserettes)
8. Verminder het afspoelen van drogerfilters door meer weg te gooien via restafval
9. Verhoog het verwijderen van microvezels in wasmachine-drogercombinaties met behulp van een filter
10. Optimaliseer de schoonmaak van huizen om microvezels in afvalwater te verminderen, bijvoorbeeld (meer) stofzuigen voor het dweilen
11. Optimaliseer de wasprocedure, bijvoorbeeld met een fijn (synthetisch) wasprogramma
12. Drogen aan een waslijn in plaats van een droger

13. Verhoog de efficiëntie van microplasticverwijdering uit afvalwater bij waterzuiveringsinstallaties

De vier maatregelen met het grootste potentieel om de uitstoot van microplastics te verminderen zijn hetzelfde voor het scenario met hoge en lage implementatie. Deze maatregelen zijn:

- Vervang materialen door niet-synthetische alternatieven
- Verbeter de materiaalkwaliteit met geoptimaliseerde productiemethoden die de afgifte van microvezels verminderen
- Verleng de levensduur van kledingproducten, terugdringen 'fast fashion'
- Optimaliseer het gebruik van op maat gemaakte wasmachineprogramma's, wat gemiddeld resulteert in een delicatere was cyclus, zoals voor fijne was.

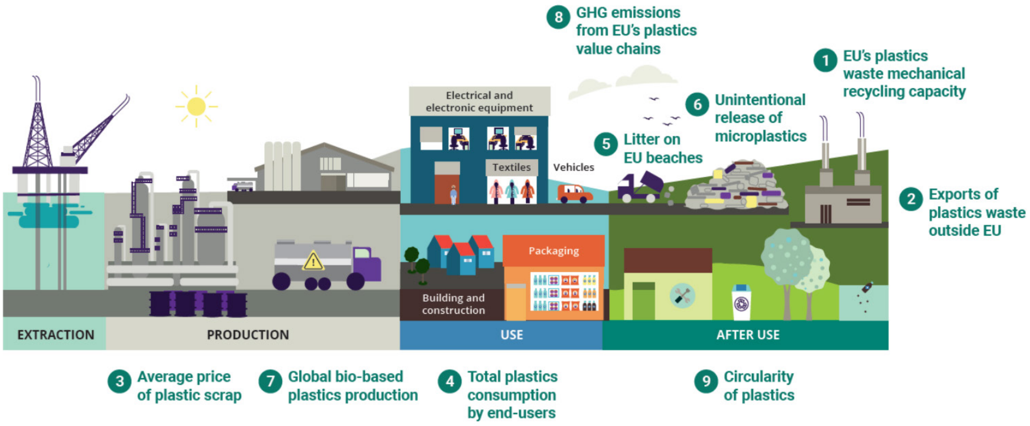
Verder blijkt uit de berekeningen dat de filtratie van microvezels uit waswater met externe filters, het verminderen van de afgifte van microvezels bij de eerste wasbeurt door industrieel voorwassen en het uitbannen van synthetische polymeren in franjes en afwerkingen op kledingstukken ook bijdraagt aan een verminderde microplastics uitstoot. Andere mitigatiemaatregelen zullen naar verwachting minder of niet bijdragen, aangezien het berekende effect niet aantoonbaar was en binnen de foutmarge zit van deze modelleringsstudie.

We raden aan om deze studie op te volgen met een reflectieve workshop met belanghebbenden om de mogelijke scenario's verder te verfijnen en een combinatie van mitigatiemaatregelen te definiëren die als haalbaar of relevant worden beschouwd. Zo kunnen bijvoorbeeld het verlengen van de effectieve levensduur van kleding, het optimaliseren van productiemethoden en de overgang naar alternatieve materialen worden gecombineerd om het gecombineerde effect op het verminderen van de uitstoot van microplastics te schatten. Bovendien moet de prioritering van mitigatiemaatregelen ook gebaseerd zijn op het beoordelen van de kosteneffectiviteit en het bredere milieu-effect, bijvoorbeeld door gebruik te maken van levenscyclusanalyse om de impact van water en pesticiden gebruik mee te nemen. De berekening van het effect van maatregelen kan ook worden uitgebreid naar de hele EU, aangezien regionale verschillen, zoals het gebruik van slib in de landbouw, grote effecten kunnen hebben op de effectiviteit.

1 Introduction

To tackle plastics pollution, the use of plastic materials needs to be safe and sustainable, which we see as part of the transition to a circular economy (Waaijers-van der Loop et al., 2022). The unintentional release of microplastics is one of the issues affecting this transition as it leads to material losses and causes pollution, see Figure 1 (EEA, 2024). There are numerous sources of microplastics release of which tyres, pre-production pellets, litter, textiles, intentionally produced polymer microparticles, packaging, paint and agriculture are the largest contributors (EC, 2023; Quik et al., 2024).

Figure 1 The nine components of the circularity metrics lab plastics module aimed at assessing Europe's plastics circularity. Source: (EEA, 2024).



Clothing is seen by Dutch national policy makers as an important source of microplastics for which they would like to set in place measures to reduce microplastics pollution (IenW, 2024). The approach in their policy brief mentions that all different stakeholders should play a part in reducing microplastics release. They mention specifically the support for prewashing textiles as part of the production process and setting a maximum microplastics release rate. In this study we aim to quantify the effect of these and other measures in order to reduce plastics pollution.

Several studies have reported on the role of clothing in microplastic pollution (Thompson et al., 2024; Verschoor and de Valk, 2018). The major sources of microplastics are (i) from washing and drying of clothing with the main releases going through the wastewater and solid waste disposal systems and (ii) from wear and tear due to everyday use of clothing with the main releases directly to indoor and outdoor air. In previous research RIVM already identified several mitigation measures against release of microplastics from clothing relevant for a range of stakeholders in the Netherlands, namely textile producers and retailers, government, consumers, water managers and producers of washing machines, dryers and detergents (Zwart and De Valk, 2019). Recently, RIVM quantified the release of microplastics from the largest contributors of microplastics to the environment, including clothing (Quik et al., 2024). This included quantification of two categories of mitigation measures, which for clothing were a measure to transition to alternative materials and reduce emissions to wastewater. In this work we aim to quantify the release of microplastics for a broader range of thirteen different mitigation measures as prioritized by a relevant group of stakeholders using the previously developed emissions model (Quik et al., 2024). This can support the Ministry for Infrastructure and Water Management in their aim to reduce microplastics pollution and transition to a circular economy.

2 Modelling approach

2.1 Overview

The basis for the emissions modelling approach is the same Dynamic Probabilistic Material Flow Analysis (DPMFA) model as in our previous study (Quik et al., 2024), reporting yearly emissions. The reference year for estimating baseline emissions is 2022, while including historic consumption starting in 1950 and extrapolating consumption of clothing and footwear up to 2050 based on the OECD global plastics outlook (OECD, 2022). This is relevant for keeping track of clothing being in use, e.g. with lifetimes longer than 1 year and subsequent discarding at end of life. Further details on the scope of this study are given in section 2.2, specification of the model and updates for clothing are given in section 2.3 and in the appendices.

To quantify the effect of relevant mitigation measures first a selection of potential measures was made based on those already described in literature. These measures were discussed during a workshop with invited stakeholders relevant to the clothing value chain in order to come to a more realistic and feasible selection of measures for quantification. For more information see section 2.4.

In brief, the effect of each mitigation measure is quantified in terms of the reduction in environmental emission compared to the baseline scenario with the updated DPMFA model for textiles. The mitigation measure scenario's are based on (i) the potential performance of a measure, e.g. the technical performance of a washing filter and (ii) the expected degree of implementation, e.g. the fraction of consumers eventually using such a filter. This combination of performance and degree of implementation was used to create a scenario for each measures reflecting a high and low degree of implementation. For instance, voluntary use of washing filters is not likely to lead to a high fraction of consumers using it, compared to when it would be a mandatory part of a washing machine installation. As such the results provide the bandwidth of potential emission reduction (% reduction compared to baseline in 2050) per mitigation measure. This should help policy makers in their decision on the type of policy measure to develop. The model results include uncertainty and are reported as the median with the 25^{th} and 75^{th} percentiles reported in brackets (median (p25 – p75)) for the sum of all plastics emissions (microplastics and macroplastics).

2.2 Scoping

This study includes the different textile product categories as defined under the textile Extended Producer Responsibility regulation. This means that clothing and footwear are considered. Compared to our previous study, (Quik et al., 2024), this does not include technical or home textiles, although they are also considered large sources of microplastics. New is the addition of footwear (shoes).

Please note that this study focusses solely on microplastics emissions, and for final choices on prioritization and implementation of mitigation measures we recommend including factors such as environmental and human health effects, and costs of implementation of a measure. For instance, analysis of potential trade-offs between reducing microplastic emissions versus reduction of health effects or environmental impacts are out of scope, e.g. between use of plastics versus other materials such as cotton.

2022 was chosen as references year as this is the reference year of the latest textile mass balance report for the Netherlands (FFact, 2024). The modelling is based on available literature data. This was a limiting factor in estimating abrasion of footwear, which is based on several assumptions as described in Appendix 2 as no measured abrasion rates were found in literature.

In this study we generally use the term microplastics. This relates to particles which are smaller than 5 mm in length, width or height or shorter than 15 mm in length, when their aspect ratio is larger than 3 (ECHA, 2020). For other aspects of the definition, we consider microplastics to be solid, insoluble and generally consisting of synthetic polymers. We include the emission of larger pieces of clothing to also contribute to microplastics in the environment as larger items are expected to degrade to microplastics in the long term (Rillig et al., 2021). Although in principle, no lower size limit should be set when considering microplastics, the reality is that the most commonly used detection methods have lower size limits between 100 nanometre and 100 micrometre, spanning several orders of magnitude. Most of the data used in this study relates to microplastics larger than about 10 micrometres. Attention should be given to the smaller size fraction in future studies.

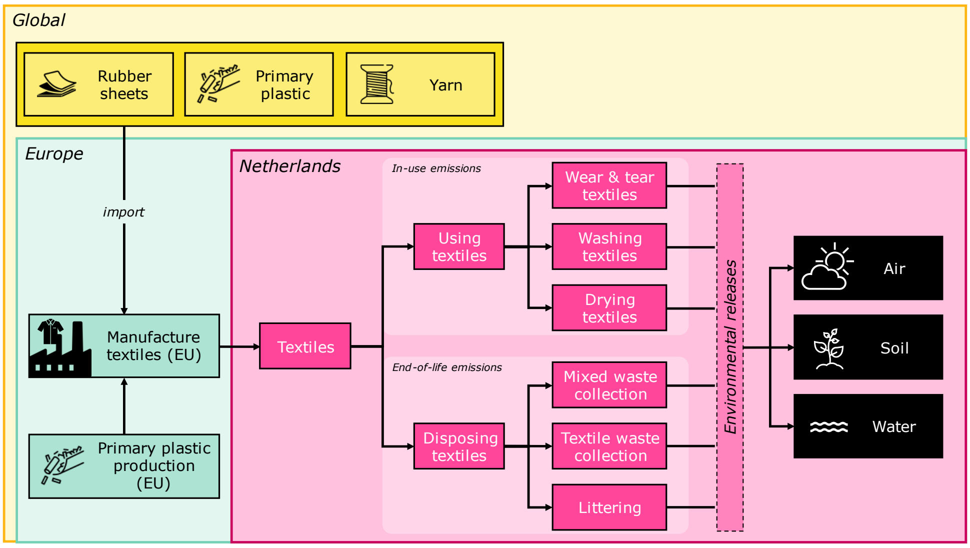
The original model distinguishes different polymers per clothing type (Quik et al., 2024), however abrasion rates are currently not differentiated per polymer, but per process step only, e.g. washing or drying. This is due to lack of data. No polymer specific results are reported.

2.3 Detailed model description

2.3.1 Model introduction

The model used in this study is a dynamic probabilistic material flow analysis (DPMFA) model described in Quik et al. (2024). In general material flow analyses are used to track the flow of materials through a system using an initial input, e.g. mass consumed. This initial input is combined with transfer coefficients which describe the flow of materials through the system until they reach their eventual sink, e.g. an environmental compartment. The dynamic part of the model relates yearly input data with product lifetimes in years by which the in use emission are spread out of the lifetime of the product category and end of life or waste emission are only emitted after disposal. Changes in time of process efficiency (transfer coefficients) are not taken into account. The past consumption of textiles is taken into account based on historic data with an extrapolation up to 1950 and for the future up to 2050 based on the OECD global plastics outlook (OECD, 2022). The probabilistic part of the model refers to the uncertainty included in the modelling. This uncertainty is based on the reliability of the input data, following several criteria. The DPMFA model is refined with more details relevant for microplastics emission from textile, see section 2.3.2 (Figure 2). The other product categories where not updated and for details on those and the base model see our previous report (Quik et al., 2024).

Figure 2 Simplified schematic representation of the material flow analysis model as applied for textiles (clothing and footwear) for estimating environmental release of microplastics and macroplastics at national (NL) and Europe scale.



2.3.2 Emission model refinements

2.3.2.1 Consumption data

The input data (tonnages) for textile was aggregated in accordance with the textile definition of the draft PEFCR (Quantis, 2021) for apparel and footwear, which is a slight change compared to the previous version of the model by Quik et al. (2024). More recent and detailed consumption data for clothing in the Netherlands and the EU were used from EUROSTAT. Clothing is now subdivided in several categories and footwear and apparel categories were added. These changes resulted in a clothing consumption about 5 times higher than in the previous study (Quik et al., 2024). Historical consumption data from 2011 to 2022 for both the Netherlands and the EU were used. For more information on the consumption data used and subdivision in clothing categories, see Appendix 1.

2.3.2.2 Process updates

Key parts of the modelled processes, using transfer coefficients, relevant for clothing are refined as detailed in Appendix 1. In summary novel components are:

- Specific methods of drying are included: outdoor, indoor clothing lines, vented tumble dryer, condenser heater pump tumble dryer and condenser heat element tumble dryer, see Figure S.2, Figure S.3 and Figure S.4.

- Washing by hand or machine and (potential) use of external washing machine filters, see Figure S.5.
- Three regimes of washing (frequent, rarely and not washed), see Figure S.6.
- Refinement of separate textile waste collection with updated data on recycling and reuse (FFact, 2024).
- Update of efficiency of wastewater treatment processes for the Netherlands (Bertelkamp et al., 2025b) and the EU (Iyare et al., 2020), see Figure S.8.

2.3.2.3 Footwear

Microplastic release from footwear is caused by the wear of the upper part of shoes and the shoe soles. The upper part of shoes is estimated to release microplastics from wear similar to other clothing articles, so an average wear rate is taken from clothing wear, based on Kawecki and Nowack (2019).

The wear rate of shoe soles was estimated based on several assumptions as detailed data on wear are not available in literature. In a study by (Lassen et al., 2015) 10% abrasion of shoe soles during the lifetime of a pair of shoes was assumed. And in another study, different experts reported an average shoe sole wear rate between 17.5 and 175.4 g/person/year, with an average of 109 g/person/year (Bertling et al., 2018).

The estimation of shoe sole wear is explained in detail in Appendix 2 and was made based on the following assumptions:

- Wear between 1 and 2 mm of the part of the sole that touches the ground (a third of the whole sole surface area).
- Average EU shoe size of 40 resulting in a volume of between 7.9 cm^3 and 16 cm^3 of shoe sole released.
- In relation to the consumption of shoes only 1/16th of the pairs of shoes are worn at any one time based on the assumption that one person possesses on average of 16 pairs of shoes.

This resulted in the lifetime shoe sole wear rate between 7.5g and 23.8 g per shoe. This is a relatively crude first estimate and does not compare to the estimate of clothing wear and tear which is based on several studies and measurements.

2.3.2.4 Model limitations

Although the model was improved, limitations remain. Many of the underlying data have varying levels of geographical, temporal, material representativeness, different levels in completeness and reliability of estimates. This is taken into account by using a probabilistic approach which estimates levels of uncertainty based on a screening of input data on the aforementioned aspects. For details see our previous report (Quik et al., 2024) and the original work by Kawecki and Nowack (2019). As such we report mainly the median together with the 25th and 75th percentiles to indicate the degree of uncertainty in the model outcomes.

Other model limitations are:

- Emissions outside of the Netherlands and Europe are not quantified within the model. For instance 88% of our clothing is

estimated to be produced outside of the EU, which cause emissions there.
- Emissions related to the export of textile waste collection outside NL/EU are not quantified. For instance, about 40% of all textile is exported for reuse or recycling after use in the Netherlands.

2.3.3 *Application and analysis*

The updated DPMFA model, version 2025.11.1 was used (Hids et al., 2025)(https://github.com/rivm-syso/DPMFA_NL_EU) . Our analysis are conducted on a high-performance cluster to cope with the computational demands of such a dynamic and probabilistic analysis. The DPMFA model itself is run using Python version 3.11.7. The packages Numpy, Pandas, dpmfa and SQlite are required for running the model. Further analysis of output data is done in R (R Core Team, 2025) making use mainly of the tidyverse (Wickham et al., 2019) and ggplot2 (Wickham, 2016) packages. In order to support our understanding of the model we conducted a (limited) global sensitivity analysis on the uncertainty of the input transfer coefficients, see details in Appendix 4.

2.4 Selection and quantification of mitigation measures

2.4.1 *Selection, specification and prioritization*

To select, specify and prioritize measures, input from both literature and stakeholders was gathered. To make the quantification of measures more realistic and take into account considerations from both practice and theory, stakeholders were involved. This follows the solution-focused sustainability assessment approach which supports stakeholder and science supported solutions for complex problems such as reducing microplastic emissions (Zijp et al., 2016).

The following steps were followed to come to a selection, specification and prioritization of possible measures to reduce microplastic emission from textile to the environment which were used as an input for quantification:

- Desk research: compiling an overview of the most relevant mitigation measures for clothing from literature including their theoretical or measured technical efficiency;
- Stakeholder mapping: identifying stakeholders from across the textile value chain covering parts of the value chain from production to recycling as well as relevant knowledge institutes, NGO's and government stakeholders.
- Participatory workshop and interviews with professionals from the textile sector to identify, specify and prioritise mitigation measures according to their potential effectiveness. Almost all parts of the value chain were represented with the exception of recyclers.

These steps are further discussed below.

2.4.1.1 Desk research

To make an overview of measures for the workshop, we first selected them from literature. We scanned the following reports and policy guidelines to compile a first overview of measures. As a starting point we used the report of Zwart and De Valk (2019) on measures to reduce microplastic release on plastics. Furthermore, we looked at the measures identified and prioritized for textiles from the previous study on all microplastic sources by Quik et al. (2024). We also scanned relevant policy documents to identify which measures are currently prioritized in policy, specifically the *Policy Programme for Circular Textile 2025-2030* (IenW, 2024).

We categorized the measures according to the following categories:
- *Circularity*: is the measure aimed at strategies of Reduce, Redesign, Recycling, Lifetime/Reuse or Recovery.
- *Place in the supply chain*: (1) production and retail (including recycling), (2) producers of washing machines and dryers, (3) consumers (4) sewage treatment

To make the measures fit for further prioritization and quantification, the measures were combined into 15 measures to reduce microplastics emissions (see Table 1*). This overview was used as input for the workshop with stakeholders.

To include relevant stakeholders in the workshop a stakeholder analysis for microplastics in textiles was performed. The stakeholder overview was based on the report of Zwart and De Valk (2019), participants in the network set up by the ministry of Infrastructure and Water Management (IenW) *"Everybody participates" (Iedereen draagt bij),* that aimed to bring together stakeholders from across the chain to reduce microplastic release from plastics but stopped in 2020 (RWS, 2020). Stakeholders related to footwear were not specifically included as focus on quantification of the mitigation measures is solely aimed at clothing.

2.4.1.2 Workshop

On the seventeenth of June 2025 we organized a hybrid workshop of half a day to get input from stakeholders on possible measures, their refinement and prioritization. The aim was to better assess the reduction potential of the selected measures. This was done together with experts and stakeholders to ensure that the proposed measures are both scientifically sound and practically feasible. Fourteen stakeholders participated in the workshop and came from different parts of the textile value chain from textile production to waste water treatment. These were in alphabetical order: Anton Advies, BSH Hausgeräte, Consumentenbond, Electrolux, Lavans, Milieucentraal, Ministry of Infrastructure and Water Management, Studio Anneloes, Plastic Soup Foundation, University of Amsterdam, Het Waterlaboratorium, Waternet, Zeeman and one person on personal title. No textile recyclers were able to join the workshop. The input of knowledge institute TNO was gathered through a separate interview.

The workshop consisted of the following parts:
a) Introduction to the project, purpose of the workshop and general framework of the mitigation measures

* This table only includes the final selection, which excludes the measure on developing alternatives to synthetic fleece (measure ID 3) and the measure on developing washing detergents aimed to reducing release of microplastics which was not selected for quantification (measure ID 11).

b) Examining the measures presented (see Table 1* for an overview and categorization), allowing for adding measures and discussing their applicability.
c) Prioritizing measures based on effectiveness to reduce microplastic release (the performance). Participants were invited to identify the 5 most important mitigation measures to implement.
d) Inventory of data availability relevant for modelling
e) Reflection on the workshop

Overall, the workshop was very positively received. Participants rated the session with an average score of 5.1 out of 7 in the reflection form. Satisfaction with the meeting was high (5.7), as was the desire to stay informed about follow-up steps (6.5). The session provided new insights (4.6) and contributed to a better understanding of the problem (4.8) and of other participants' perspectives (5.2), although the feeling that others understood one's own viewpoint was somewhat lower (3.2). Most participants felt that their presence added value (5.6) and indicated interest in attending a follow-up session (6.0). The efficiency of time use received a somewhat lower score (4.0), suggesting room for improvement in future sessions.

From the open responses, it emerged that participants particularly valued gaining a deeper appreciation of the complexity of the microplastics issue and learning from the diverse perspectives across the value chain. Several noted ongoing knowledge gaps, for example in data availability and modelling of measures, while others mentioned concrete takeaways such as the influence of spin speed on fibre shedding and the user challenges of external filters.

Looking ahead, participants expressed interest in being kept informed of results and in contributing relevant data or expertise, such as on washing behaviour, filtration pilots, or retail measurement approaches. Several offered to share reports, datasets, or contacts. The organization of the session was widely praised as well-structured, open, and inclusive, with ample space for all perspectives. At the same time, it is important to note that the workshop was not designed as a statistically representative consultation of all stakeholders in the textile value chain. Participation was by invitation and constrained by the available time and budget, and no open consultation was organised. Within these project constraints, the workshop served as a pragmatic way to qualitatively collect input and to prioritise which mitigation measures to take forward for quantification, recognising that not all options could be analysed in depth within the scope of this study. We therefore recommend a follow-up workshop or broader consultation to further discuss the quantified effects of each mitigation measure, increase common understanding of the assumptions and scenarios used, and explore how these measures could be implemented in practice, in line with the solution-focused sustainability assessment approach.

2.4.2 *Selected measures for quantification*

Based on the workshop and expert consultation the final list of mitigation measures was identified for quantification, see Table 1. Two mitigation measures were not selected for quantification based on outcome of the workshop (lower prioritisation) and due to model related arguments. The measure on developing alternatives for synthetic fleece was deemed to overlap in quantification with the other two measures already aimed at developing alternatives for synthetic trims and general clothing. The measure on developing washing machine detergents aimed at reducing microplastics release lacked data on the potential technical performance of this measure and the quantification approach would also overlap with the measure on optimizing the washing procedure (Measure ID 13).

The top 4 mitigation measures from the prioritization activity receiving more than 10 votes are:
- Industrial prewashing of clothing before they are sold to consumers (measure ID 7).
- Improve the production methods to reduce release of microfibers (measure ID 4).
- Increase lifetime of clothing (less fast fashion) including reuse due to clothing exchanges or resale (measure ID 6).
- Increase removal efficiency of microplastics during wastewater treatment (measure ID 15).

Table 1 Selection of mitigation measures for quantification of reduction potential for microplastics emissions to the environment in the Netherlands.

ID	Place in the supply chain	Description of Measure	Short name	Type
1	Production and retail	Develop and use alternatives to synthetic glitters, trims and fringes	Fringes	Redesign
2	Production and retail	Develop and use alternatives for synthetic clothing (such as natural fibres)	Replace	Redesign
4	Production and retail	Improve production methods to reduce microfibre losses, increasing quality of the clothing fabric	Production method	Redesign
5	Production and retail	Optimize recycling of clothing (clothing to fibre)	Recycling	Recycling
6	Production and retail	Lengthen lifetime of clothing (end fast fashion) including reuse of clothing	Lifetime	Lifetime/reuse
7	Production and retail	Industrial pre-washing of clothing	Prewashing	Reduce
8	Manufacturers of washers and dryers	Add external or extra microplastic filters in washing machines and alert consumers not to wash the filter in the sink (for consumers or industrial laundromats)	External filter	Recover

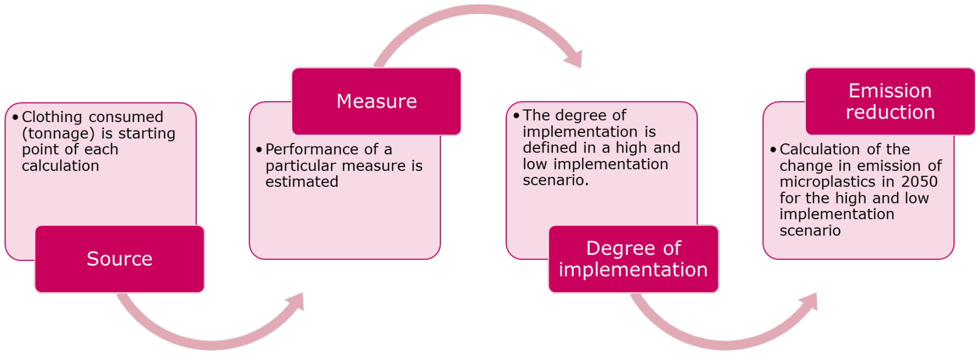
ID	Place in the supply chain	Description of Measure	Short name	Type
9	Manufacturers of washers and dryers	Reduce rinsing of dryer lint filters by increasing disposal in mixed waste.	Clean dryer filter	Reduce
10	Manufacturers of washers and dryers	Increase removal of microfibres in washer-dryer combinations using a filter	Washer dryer filters	Reduce
12	Consumers	Optimise cleaning of homes for reducing microfibres in wastewater, e.g. vacuum before mopping	Vacuuming	Recover
13	Consumers	Optimize washing procedure, e.g. using more delicate (synthetics) washing programme	Delicate washing cycle	Reduce
14	Consumers	Drying on a clothesline instead of using an tumble dryer	Clothesline instead of dryer	Reduce
15	Wastewater treatment	Increased efficiency of microplastics removal from wastewater at treatment plants	Wastewater	Recover

2.4.3 *Quantification of performance and degree of implementation*

The effectiveness of measures to reduce microplastics emissions depends on the technical performance of a measure and on the way in which a measure is implemented (Figure 3). The degree of implementation can vary from voluntary for the producer or consumer to decide on, to obligatory based on regulations. For this reason, we have chosen two scenarios for analysing the effects of each mitigation measure:

- *Low* scenario representing a more voluntary implementation or when available using existing implementation levels (e.g. for clothing recycling).
- *High* scenario representing a more obligatory implementation.

Figure 3 Overview of the quantification approach estimating the microplastic emission reduction from clothing sources for a range of mitigation measures.



For example the reduction of microplastics emissions of using an external washing machine filter is dependent on the technical efficiency of the filter and on the expected implementation, e.g. the fraction of consumers that will use such a filter. For instance, voluntary use of washing filters is not likely to lead to a high fraction of consumers using it, compared to when it would be a mandatory part of a washing machine installation. It should be clear that both options require very different policies.

The quantification of the implementation efficiency of each implementation approach making up the low and high scenarios is largely based on expert judgement as literature that could be used for quantification was not readily available. Several assumptions were taken and thus we included a large range of uncertainty in these estimates resulting in a minimum and maximum implementation efficiency for the low and high scenarios as described in Table 2.

The performance of each mitigation measure is estimated based on literature sources or on a combination of insights from the workshop and stakeholder interviews as described in Table 3. This estimate of performance combined with the implementation efficiency are used as input to alter the tonnages consumed (source flows) and processes (transfer coefficients) to reflect the low or high scenario of the mitigation measure. Further details on adjustment of the model are provided in Appendix 3, Table S.16.

The calculation results are compared to the baseline emissions in 2050 (Figure S.10) to calculate the emission reduction percentage based on the average of mass flows. For the high scenario this thus reflects the maximum potential emission reduction per mitigation measure. Whereas, the low scenario provides an estimate of the potential emission reduction which should be feasible with minimal enforcement. These two scenarios do not include feasibility of implementation of the measures as further economic, social, health and environmental aspects are not included here. These aspects are all expected to influence the adoption of these mitigation measures. This requires further analysis and depends on the choices of those implementing these mitigation measures. This could be part of follow up activities using the outcomes of this study.

Table 2 Approaches for implementing a mitigation measure with the estimated efficiency of implementation, largely reflecting the fraction of the population or companies implementing the measure. The numbers of the mitigation ID to which these are applied in either the low or high scenario are indicated between brackets. The combined low and high scenarios are given in Table 3.

Implementation approach (Mitigation ID)	Min. – max. implementation efficiency	Rationale
Information campaign aimed at consumers (1, 2, 6, 8, 9, 12, 13, 14)	0.0006% - 0.95%	Estimate based on a 1-17% of change in behaviour (Brick et al., 2025) and assumption of reaching 0.056-5.6% of the population with the campaign
Major campaign aimed at behavioural change (14)	1% - 17%	Estimate based on 1-17% of change in behaviour (Brick et al., 2025) with reaching majority of the population
Nudging of companies and voluntary application, could e.g. using research and development funding (4, 7, 10, 15)	1% - 10%	Assumption that companies can be reached more effectively compared to intervention aimed at consumers.
Clear division of responsibilities for recycling and reuse (5)	50% - 100%	Assumption that between 50% to 100% textile EPR goal is met
Obligations to increase recycling and reuse (5)	100% - 150%	Assumption that the textile EPR goal could be exceeded by 50%
Obligations for companies to implement measures with specific criteria (1, 6, 7, 8, 10, 15)	75% - 100%	Assumption for the most optimistic case, but taking into account that up to 25% could still circumvent such an approach.
Regulations in combination with standardization of approaches (2, 4, 12, 13)	37.5% - 50%	Assumption that at least for half of the textiles it is not possible to further reduce or change materials
Regulations introducing an extra label (9)	10% - 50%	Assumption that still more than half of people would neglect this

Table 3 Performance of each measure and the applied implementation efficiency (Table 2) for the low and high scenario. The effect of each measure is based on the combination of the performance and implementation efficiency, details in Table S.16.

ID	Short name, (used in figures)	Performance	Rationale / assumption	Implementation efficiency (low/high scenario)
1	Fringes	100%	All synthetic polymer glitters, trims and fringes are exchanged for alternatives (Quantis, 2021)	Low: 0.006‰-0.95% High: 75%-100%
2	Replace	~98%	All PET and PA, excluding workwear can be replaced. Workwear categories identified from product descriptions of Prodcom codes (Table S.17)	Low: 0.006‰-0.95% High: 37.5%-50%
4	Production method	90%	Alternative production methods of fabrics incl. coatings and finishings can cause a maximum reduction of 90% in microfiber loss during the lifetime of clothing (Periyasamy and Tehrani-Bagha, 2022)	Low: 1%-10% High: 37.5%-50%
5	Recycling	75%	Based on Textile UPV goals in 2030 and max 25% reuse and 33% recycling (Stichting UPV Textiel, 2025)	Low: 50%-100% High: 100%-150%
6	Lifetime	1 year	Assuming a 1 year lifetime increase for all clothing types combined with linear reduction in consumption (*Mass consumed = Original Mass – Original Mass/new lifetime*)	Low: 0.006‰-0.95% High: 75%-100%
7	Prewashing	~22%	Avoiding release during the first wash and dry cycle (Pric et al. 2016 and (Kawecki and Nowack, 2019))	Low: 1%-10% High: 75%-100%
8	External filter	8%-89%	Assuming 99% of households implement such an external filter (Consumentenbond, 2025; Kimmel et al., 2024)	Low: 0.006‰-0.95% High: 75%-100%

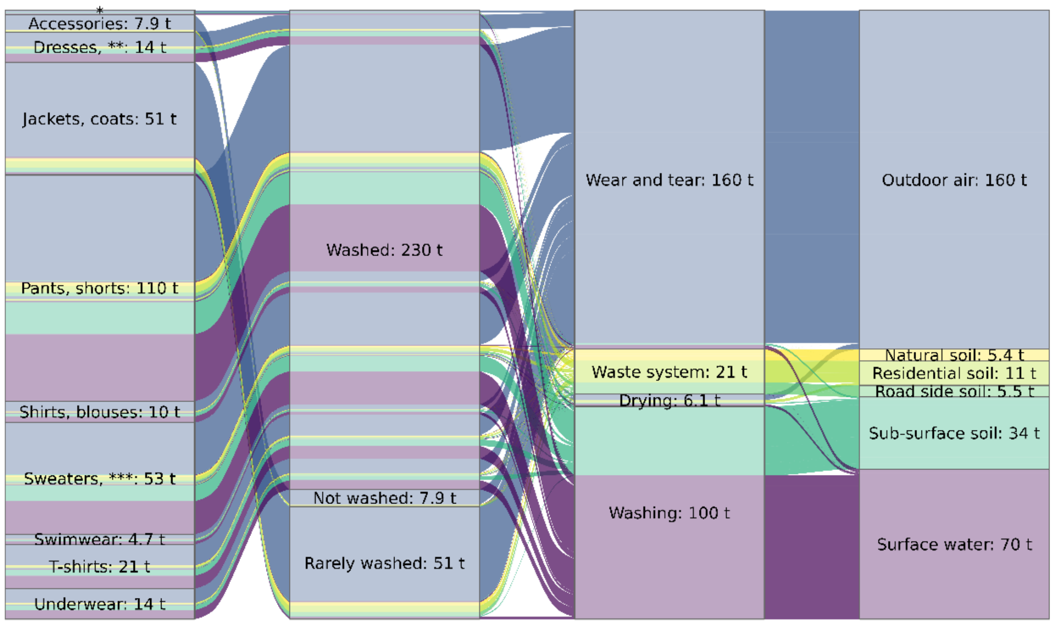
ID	Short name, (used in figures)	Performance	Rationale / assumption	Implementation efficiency (low/high scenario)
9	Clean dryer filter	99%	Assuming switching from rinsing to disposal in mixed waste.	Low: 0.006‰-0.95% High: 10%-50%
10	Washer dryer filters	50%	Based on same estimate for performance of other dryer filters (Kawecki and Nowack, 2019)	Low: 1%-10% High: 75%-100%
12	Vacuuming	100%	Assuming no more release to wastewater.	Low: 0.006‰-0.95% High: 37.5%-50%
13	Delicate washing cycle	79.7%	Maximum possible reduction using a delicate washing cycle (Eemrat et al. 2025)	Low: 0.006‰-0.95% High: 37.5%-50%
14	Clothesline instead of dryer	90%	Assumption that it is possible to dry on clothing lines with (50% in or outside)	Low: 0.006‰-0.95% High: 1%-17%
15	Wastewater	99.9%	Expected total removal after treatment	Low: 1%-10% High: 75%-100%

Multiplication of the performance and implementation efficiency results in a low and high scenario which each consist of a maximum and minimum resulting in a trapezoidal distribution in the input or TC's in the DPMFA model. The exact results of this and further details of implementation are provided in Table S.16 in Appendix 3.

3 Results and discussion

3.1 Emission estimates of current clothing consumption

Figure 4 Sankey diagram for median microplastic emissions to environmental compartments from clothing in the Netherlands (2022) as calculated using the DPMFA model. Waste system represent the end of life flows.

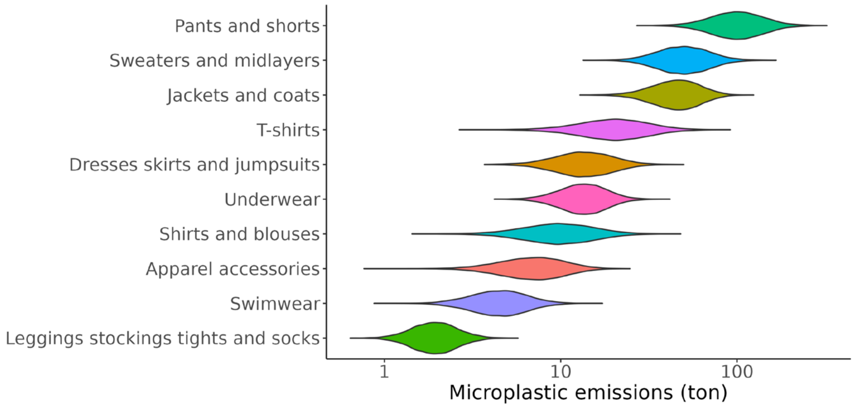


*Leggings, stockings, tights and socks: 2.1 t
**Dresses, skirts and jumpsuits
***Sweaters and midlayers

The Dutch textile consumption is calculated to have released 430 ton (390 ton – 490 ton) of microplastics to the environment in 2022. Clothing is estimated to contribute 290 ton (250 – 340 ton, Figure 4), and Footwear 140 ton (120 – 160 ton, Figure 6) to these emissions. Overall this is a ~2 times higher emission compared to our previous study on clothing for 2019 in which we estimated a 180 ton (120 – 240 ton) emission (Quik et al., 2024). Apart from being a different references year and not including footwear, the increase is due to updates and data refinements made to the model (See Chapter 2).

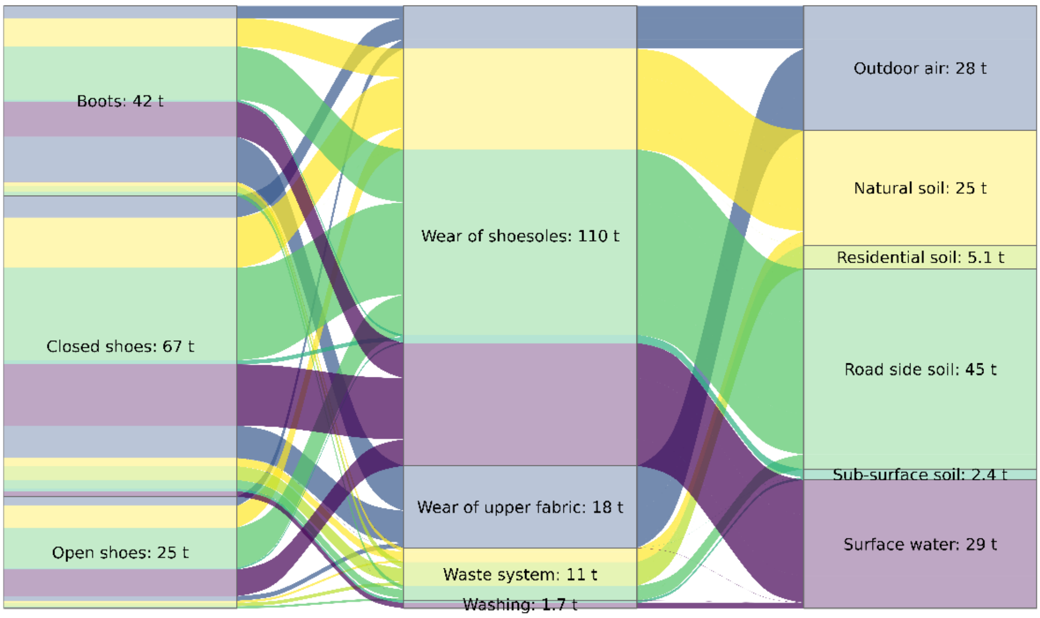
From the different clothing categories, the heaviest and most used clothing types contribute the largest fraction of microplastics emissions to the environment (Figure 4 and Figure 5). The mass of polymers in these different clothing types combined with the number of clothing articles consumed directly relates to the emission estimates. For this reason, Pants and Shorts, emit the most microplastics to the environment, as these are some of the heaviest clothing articles, followed by Sweaters and midlayers and Jackets and coats.

Figure 5 Microplastic emissions to the environment from clothing categories in the Netherlands as calculated using the DPMFA model. Violin plot with reference year 2022, the thickness of the curves indicate the frequency of data points: thicker means less uncertainty.



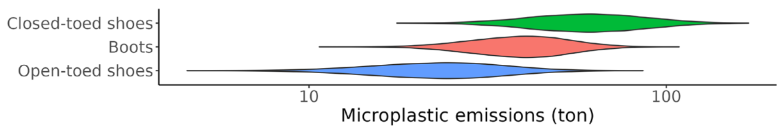
3.1.1 *Footwear*

Figure 6 Sankey diagram for median microplastic emissions to the environment from footwear in the Netherlands (2022) as calculated using the DPMFA model. Waste system represent the end of life flows.



Footwear contributes 33% to the microplastics emission from textiles, 140 ton (120 – 160 ton) to the environment (Figure 6 and Figure 7). To our knowledge this is the first estimate of microplastics emissions from footwear. Most microplastics emissions come from closed-toed shoes followed by boots and open-toed shoes. Due to lack of empirical data on abrasion rates of shoe soles (e.g. de release of microplastics from shoe soles due to walking or running), the emission estimates are less robust compared to those for clothing articles. The abrasion rates are estimated based on a lot of assumptions, related to sole wear depth (1-2 mm) and degree of use of the consumed shoes, (e.g. 1 in 16 shoes being worn, see Section 2.3.2.3 and Appendix 2). These estimates should be updated when empirical data on the abrasion of shoe soles becomes available and other estimates can be based on more robust sources and arguments.

Figure 7 Microplastic emissions to the environment from footwear categories in the Netherlands as calculated using the DPMFA model. Violin plot with reference year 2022, the thickness of the curves indicate the frequency of data points: thicker means less uncertainty.



3.1.2 *Distribution across Soil, Air and Water*

The DPMFA results show that air is the largest receiving compartment for microplastic emissions from clothing (Figure 4 and Table 4). This is in line with earlier studies reporting on the importance of microfibre release to air (Quik and Waaijers-van der Loop, 2021). For footwear the largest receiving compartment is Soil (Figure 6 and Table 4).

For both clothing and footwear similar fractions, 24.5% and 21.1%, are emitted to surface water, respectively. However, the route leading there is different. For clothing microplastics mainly travel through sewers and the wastewater treatment system. The 11.8% microplastics from clothing released to sub-surface soils is due to leaks in the sewer system, which plays a larger role for clothing compared to footwear. Footwear release microplastics to surface water through runoff from pavement, footpaths and roads due to wear of shoe soles. Through runoff and other transport processes from pavement and footpaths microplastics also end up in adjacent soils, leading to the much larger release to soils for footwear (56.4%) compared to clothing (7.91%). In Europe however the distribution across soil, air and water is different as sewage sludge is applied to agricultural soils and this is not the case in the Netherlands.

Attention should be paid to the applied removal efficiency of microplastics from wastewater treatment. This study used the most recent data from a study at two Dutch treatment plants (Waternet) which indicated a removal efficiency of 99.8% or even more than 99.9% (Bertelkamp et al., 2025b, 2025a). This is higher compared to the previous removal rate of 88.2% (Iyare et al., 2020; Quik et al., 2024) and which is still applied in the EU scale analysis. Although based on this one would expect a larger share of microplastics going to surface water, this is not the case as at EU scale the largest emission of microplastics is due to sludge application to soils (Table 4, Figure S.11 and Figure S.12).

This causes a much larger fraction of microplastics being emitted to soil at EU scale compared to NL scale. On average this also means that relative to the consumed clothing and shoes the unintentional release of microplastics is 0.57% of all End of Life mass flows at EU scale compared to 0.32% for the Netherlands. This should be representative of the circularity indicator for microplastics as developed by the European Environment Agency (EEA), see Figure 1.

Understanding the routes of emission is important for finding the most effective mitigation measures. The overall distribution of emissions across environmental compartments and thus the differences in major routes of emission can have an impact on the effectiveness of different mitigation measures as they target specific processes on these emission routes. This also means that refinements and updating data reflecting regional differences is important to include and should be part of these types of modelling studies. A recommendation is to extend the analysis of mitigation measures to other regions or whole EU. Here we focus on the Netherlands. For example, for certain EU member states reducing sludge application could be an effective measures for reducing microplastics emissions, but in the Netherlands this would not have an effect.

Table 4 Distribution of microplastics and macroplastics emissions from clothing and footwear between Soil, Air and Surface waters in the Netherlands and EU for 2022.

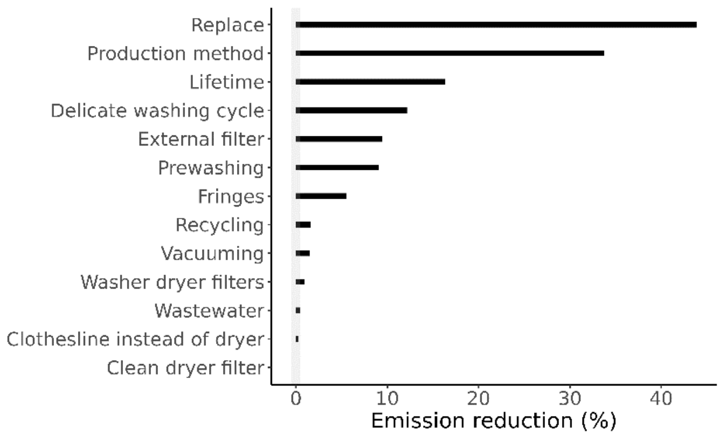
	NL		**EU**	
Compart-ment	**Clothing**	**Footwear**	**Clothing**	**Footwear**
Soil	7.91 %	56.4 %	47.6 %	62.9 %
Air	55.7 %	20.7 %	30.8 %	15.9 %
Subsurface soil	11.8 %	1.78 %	6.6 %	1.6 %
Surface water	24.5 %	21.1 %	15 %	19.6 %
Total env. Emission (ton)	290 (250 - 340)	140 (120 - 160)	8100 (7100 - 9200)	3100 (2600 - 3700)

3.2 Effect Mitigation Measures

All mitigation measures are aimed at reducing microplastics emissions to the environment from clothing. The reduction potential is estimated based on a high and low implementation scenario for the year 2050 in the Netherlands. The high scenario reflects an obligatory type of implementation of each mitigation measure, whereas the low scenario reflects a more voluntary implementation of each mitigation measure. This analysis shows data for clothing only and unless specifically mentioned does not include effects on emissions from footwear.

3.2.1 High implementation scenario

Figure 8 Percentage of baseline microplastics emission that can be reduced with each mitigation measure for the high implementation scenario as calculated using the DPMFA model for clothing. Shaded area indicates the margin of uncertainty ~1% in estimating the emission reduction.



The mitigation measures with the highest potential (>10%) to reduce microplastics emissions to the environment (Figure 8) are:

- *Replace* materials with non-synthetic alternatives.
- Improve material quality using optimized *product methods* that reduce release of microfibres.
- Increase *lifetime* of clothing products, combating fast fashion.
- Optimise the use of tailored washing machine programs, resulting on average in a more *delicate washing cycle*.

The mitigation measures that have a lower than 10% potential in reducing microplastics emissions are:

- Filtration of microfibres from washing water using *external filters.*
- Reducing the release of microfibres from the first wash by industrial scale *prewashing.*
- Not using synthetic polymers in glitters, trims and *fringes* on clothing articles.

The other mitigation measures have a much lower potential for reducing microplastics emissions compared to the rest, further discussed below.

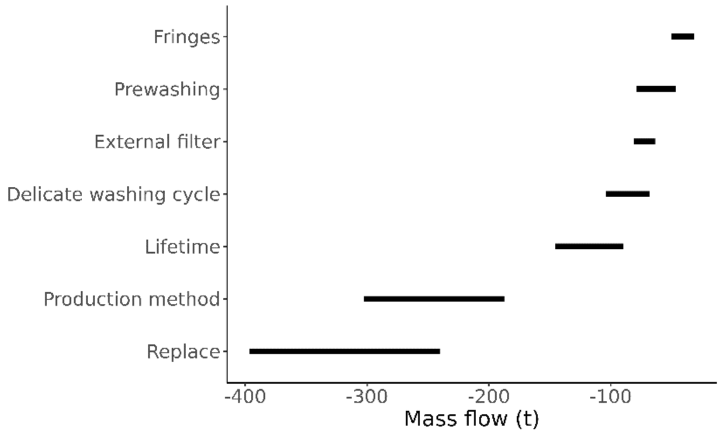
For the recycling measure, increasing the fraction of clothing going to recycling, following the existing goals for 2030 (Stichting UPV Textiel, 2025), will increase the emissions of microplastics, if adequate management of waste flows from recycling plants are not implemented, e.g. filtration of waste water. If they are, these filtration measures could additionally reduce emission by about 1.6%. This reduction comes solely from measures implemented at the recycling plant. The implementation degree applied here thus requires regulation at the recycling plants, which might fall under different regulations than those directly aimed at clothing.

The vacuuming measure, aimed at increasing household vacuuming of microfibres and discarding in mixed waste compared to moping them up and discarding them down the drain has a small potential for reducing microplastics emissions (<1.5%) in this scenario. However, both waste management systems in general eliminate the majority of microplastics, they only have leaks due to for instance dumping of waste or sewage overflows. The estimate of the size of these leaks is uncertain meaning that given the low percentage of reduction it remains unclear if this measure will result in actual reduction of releases to the environment. The uncertainty can be decreased by refining the source data for dumping and sewage overflows.

The measures on improving wastewater treatment, drying more clothes on clothing lines, using better filters for washing-dryer combination machines, and improving the way we handle dryer filters all have a lower than 1% estimate in emission reduction. Differences below 1% in this analysis are within the margin of uncertainty and thus their effect could not be estimated, e.g. below the limit of quantification. The main explanation for this is similar to the explanation for vacuuming as they largely depend on the same difference in performance of the water treatment system versus the solid waste systems and how people use these systems. Further refinement of the analysis is possible, but the benefit and goal of such refined analysis should be clear in comparison to the research efforts.

For shoes only the replacement of all polymers or only of fringes and trims results in a reduction in emissions of more than 1% (3 – 4 %) in the high scenario. This is logical as in selecting the mitigation measures only clothing was taken into account. Analysing mitigation measures aimed at footwear can be part of future studies which would then also need to consider the lack of empirical data on shoe sole wear.

Figure 9 Potential change in emission of microplastics (mass flow) to the environment (air, soil and water) from the high implementation scenario for the highest performing mitigation measures as calculated using the DPMFA model. The 25th to 75th percentiles are shown ordered from low to high change in emission.

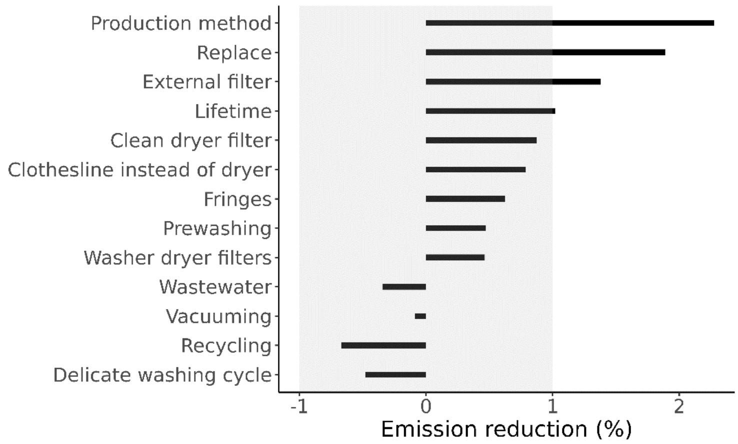


The mitigation measures with the highest potential for reducing microplastics emissions can avoid between 31 ton to 400 ton of microplastics (Figure 9). Although the emission estimates themselves are uncertain (e.g. Figure 5), the range in reduction of mass flows going to the environment are largely due to the range of the minimum and maximum change used in each intervention (Table 3). These combined with the estimated performance of each measure are used to calculate the potential emission reduction and result in the reduction of microplastics emissions mass flows as shown in Figure 9.

The reduced emissions of these seven measures are analysed individually, meaning that they cannot be combined as the measures would overlap, e.g. replacing synthetic fibres and introducing prewashing would not have the same reduction as the sum of these two as part of the removal due to prewashing is not possible as it was replaced by other materials not releasing microplastics. Analysis of a combination of measures is recommended in future studies.

3.2.2 Low implementation scenario

Figure 10 Percentage of baseline microplastics emissions that can be reduced with each mitigation measure for the low implementation scenario as calculated using the DPMFA model for clothing. Shaded area indicates the margin of uncertainty ~1% in estimating the emission reduction.

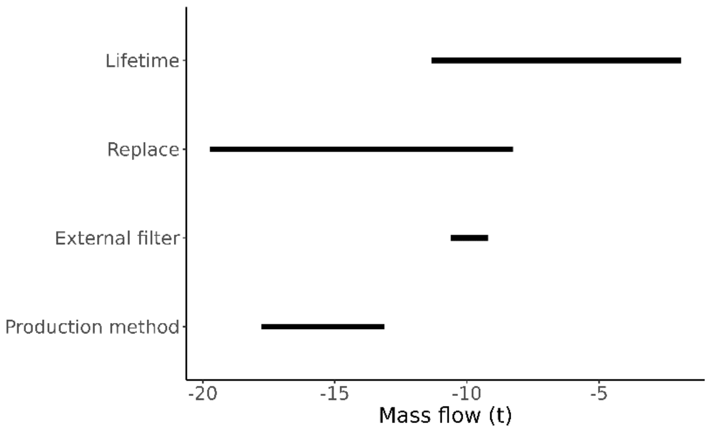


The four mitigation measures identified as having a high (>10%) potential for reducing microplastics emissions are also estimated to have the highest emission reduction in the low scenario (Figure 10). However, the fraction of reduction is at most ~2% for the measure on improvement of material quality using optimized production methods. The percentage of emission reduction gradually decreases to the margin of uncertainty of 1%. This means that overall, the effect on the reduction of microplastic pollution, when left as a voluntary measure, is not clear for most measures. This result illustrates that interventions such as an information campaign or nudging of companies, could contribute to reducing microplastics emissions for the top four measures, but not much for the others. It would be interesting to assess what combination of voluntary measures is more effective in synergy compared to the reduction potential of a single measure.

The effectiveness of the measure on improving production methods is largely due to the higher estimate of feasibility in the low scenario. This is due to the main actors being companies that would need to adjust their manufacturing processes, which is currently estimated to be implemented for 1 to 10% of market share. This 1%-10% level of implementation (Table 2) is based on the assumption that companies in the textile value chain can be reached more effectively compared to the general public and that they are willing to decrease their contribution towards environmental pollution. However, this might still be an over or underestimation because these estimates on level of implementation are not based on empirical data. This should be part of further research as well as verification activities with the textile sector, e.g. follow up workshops.

The Replace and Lifetime measures, as well as the production methods optimisation measures, also contribute towards the transition to a circular economy, as they are Redesign or Reduce types of measures. This would mean that in addition to reducing microplastics emissions they might have other benefits or impacts. The external filter measure is aimed at recovery of microfiber losses during washing, but still is able to potentially reduce the emission of microplastics by 9 – 11 tons (Figure 11). As already indicated above the effect of these single measures cannot be combined by summing up the reduction in emissions. It is possible to estimate this in new scenario studies.

Figure 11 Potential change in emission of microplastics (mass flow) to the environment (air, soil and water) from the low intervention scenario for different mitigation measures as calculated using the DPMFA model. The 25th to 75th percentiles are shown ordered from low to high change in emission.



4 Implications for further action

4.1 Stakeholder engagement

The workshop demonstrated the value of engaging stakeholders from across the textile and water chains in jointly identifying and assessing measures to reduce microplastic emissions. The active participation and positive feedback indicate a strong willingness among stakeholders to collaborate and share data for further quantification of measures. From a circular economy perspective, one notable gap was the absence of textile recyclers, whose input is essential to capture the full system perspective on circularity and end-of-life processes. However, from a purely microplastics emissions perspective, the role of the solid waste system is estimated to be responsible for only 7.5% of emissions from clothing. This means that for mitigating microplastics emissions, the role of textile recyclers is limited, but for the transition to a circular economy essential. Future sessions should thus aim to involve this part of the chain more explicitly and broaden the scope of assessing effectivity of mitigation measures to encompass other policy goals.

The discussions revealed that while stakeholders agreed on key measures, the quantification of effects and the interpretation of outcomes will require continued dialogue. This can improve the quality of the modelling approach by incorporating the latest insights from stakeholders while also increasing the understanding of the most effective mitigation measures for implementation.

4.2 Effectivity of mitigation measures

This study provides an overview of the reduction in microplastics emissions that can be achieved from thirteen individual mitigation measures. It is important that trade-offs between environmental impacts are explicitly considered, such as between synthetic and natural fibres (e.g. using plastic versus cotton, where the latter has higher water and land use) . This highlights the need for Life Cycle Assessment (LCA) to complement the current approach and to provide a more integrated view of sustainability impacts. The first assessment of this type are becoming available (Saadi and Boulay, 2025) and should be used to inform on further implementation of these measures, contributing to the circular economy goals as well as climate goals. Similarly, cost effectiveness should also be included, which can be done based one existing approaches (Gabbert et al., 2023).

4.3 Nanoplastics and particle properties

This study has included some key refinements and improvements to the model in order to estimate the emission of microplastics to the environment from clothing and footwear. Nevertheless, knowledge gaps still exist. Primarily on the polymer material characteristics of the source materials and the resulting microplastics. These are for instance the lack of data on the whole particle size distribution of microplastics coming from clothing, where data on nanoplastics (< 1 micrometre) is lacking. Furthermore, the size distribution and shape of microplastics released from clothing is likely relevant for human exposure as already known from other particle related health effect studies in air (Quik and Waaijers-van der Loop, 2021; van der Stel and Cassee, 2025). It is recommended to estimate the shape and size distribution of the microplastics emissions as calculated in this study.

4.4 Role of indoor air

The indoor air has a large role in release of microplastics to outdoor air from clothing and footwear (Quik and Waaijers-van der Loop, 2021). The process of microplastics either settling from indoor air to the floor or being transported to the outdoor air via ventilation are important. This is supported by a global sensitivity analysis which was conducted in order to assess to what degree different processes in the DPMFA model, as represented by transfer coefficients, explains the uncertainty in the model outcome (see Figure S.19 to Figure S.21). The exact distinction between what settles or remains in indoor air is dependent on the particle properties such as size, shape and density, which is not explicitly taken into account in this modelling exercise. Given that emissions to air are relevant for both clothing and footwear (Table 4, Figure 4, and Figure 6) it is important to investigate this further and take into account the variation in particle or fibre properties of microplastics going to indoor air in relation to them depositing to floors and other surfaces or remaining airborne. This is of particular relevance for further assessing human exposure to microplastics, as the impact of microplastics on indoor air quality is important to investigate further (van der Stel and Cassee, 2025). This could also lead to better assessment of mitigation measures, e.g. effectivity of using indoor air filters, like the measure on using an external washing machine filters.

5 Conclusions and recommendations

We calculated the emission of microplastics from textiles (clothing and footwear) with an improved modelling approach. This allowed for a comprehensive analysis of thirteen different mitigation measures aimed at reducing microplastic release from clothing. In the Netherlands, textiles alone cause 430 ton of microplastics emissions to the environment in 2022, and in Europe this is 11 200 ton. This makes up an annual microplastic loss of 0.32% and 0.57% of total consumed synthetic textiles in the Netherlands and EU respectively.

We found that the reduction potential of some mitigation measures can single handedly reduce microplastics emissions from clothing by up to ~40%. This naturally depends on the implementation approach used and if this is feasible. It is up to policymakers and other stakeholders to work together on implementation of the most effective and feasible measures.

We calculated that the highest emission reductions can be achieved by manufacturers. Manufacturers can produce clothing that releases less synthetic microfibres due to use of improved methods of production, resulting in less wear-induced material loss (up to 30% reduction). Naturally also by replacing synthetic materials with non-synthetic ones (up to 40% reduction). Additionally, consumers can reduce emissions by using their clothing for longer, thereby reducing consumption of new clothing articles (up to 15% reduction), or by using a more delicate washing machine programme (up to 10% reduction). Other mitigation measures can also play a role, such as using external washing machine filters and industrial prewashing. The interplay of these measures and assessment of cost-effectivity or environmental impact needs further analysis.

Prioritization of mitigation measures should depend on more than just release of microplastics to the environment. All sustainability related aspects need consideration: the economic, societal, health and environmental implications.

We recommend the following:

- Organize a follow up workshop(s) aimed at:
  - Identifying and extending the analysis to other sustainability related aspects that could lead to undesired trade-offs. This could be environmental ones such as greenhouse gas emissions or economic ones, such as monetary cost.
    - Developing new scenarios combining mitigation measures considering feasibility for implementation.
    - Increasing support for implementing measures and contributing to the reduction in plastics pollution and other sustainability goals.
- Refine the DPMFA model analysis based on:
    - Experimental measurements of microplastics release (abrasion) from shoe wear and tear.

    - Analysis of mitigation measures at the EU scale considering regional differences.
    - Including emissions and impacts outside of the EU related to manufacturing and textile exports.
- Extend the analysis using new tools for:
    - Conducting a cost effectivity analysis.
    - Conducting a Life Cycle Assessment, including the effects of microplastics release.
- Analyse and refine modelling of microplastics in indoor air in relation to human and environmental exposure to microplastics.

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Appendix 1 DPMFA model update for textiles

Eurostat data and the ESPR definition textiles

The ESPR definition for textiles is used which includes apparel and footwear. The previous clothing data (Quik et al., 2024) is now extended to include the commodity codes provided in Table S.1, with the exception of 4203 as it exclusively pertains to leather and this study only includes synthetic polymers. The commodity codes for apparel and shoes correspond to the first three digits of PRODCOM codes (Table S.2), which are used to identify product categories in the Eurostat databases for estimation of the import, production and export. Selecting the first three digits of PRODCOM codes (Table S.2) in the EUROSTAT database yields the selection of PRODCOM codes in Table S.6, which are each linked to a sub-category of apparel or footwear (link to database used: https://ec.europa.eu/eurostat/databrowser/view/DS-056120__custom_15192557/default/table?lang=en).

For each of the PRODCOM codes in Table S.6 the corresponding data was downloaded for EU-27 and NL. The units of this data was often 'number of items' instead of kg. The method by (Napolano et al., 2025) was used to convert data in 'number of items' to kg. This method involved using a conversion table that specified the kg per item for each PRODCOM subcategory (Table S.3). Consumption of clothing and footwear was calculated for each PRODCOM code, year and region as:

$$Consumption = import + production - export$$

*Table S.1 The definition of apparel and footwear used by the European Parliament expressed in commodity codes (*Regulation (EU) 2024/1781 of the European Parliament*, 2024).*

Commodity code	Description
1. Apparel and clothing accessories	
4203	Articles of apparel and clothing accessories, of leather or composition leather
61	Articles of apparel and clothing accessories, knitted or crocheted
62	Articles of apparel and clothing accessories, not knitted or crocheted
6504	Hats and other headgear, plaited or made by assembling strips of any material, whether or not lined or trimmed
6505	Hats and other headgear, knitted or crocheted, or made up from lace, felt or other textile fabric, in the piece (but not in stips), whether or not lined or trimmed; hairnets of any material, whether or not lined or trimmed

Commodity code	Description
2. Footwear	
6401	Waterproof footwear with outer soles and uppers of rubber or of plastics, the uppers of which are neither fixed to the sole nor assembled by stitching, riveting, nailing, screwing, plugging or similar processes.
6402	Other footwear with outer soles and uppers of rubber or plastics
6403	Footwear with outer soles of rubber, plastics, leather or composition leather and uppers of leather
6404	Footwear with outer soles of rubber, plastics, leather or composition leather and uppers of textile materials
6405	Other footwear

Table S.2 Commodity codes linked to PRODCOM codes ("StatLine - Verkopen; industriële producten naar productgroep (ProdCom)," 2025).

Commodity code	PRODCOM code	Description
61	143	Knitted or crochet clothing
62	141	Non knitted or crochet clothing
65	141/143	Accessories
64	152	Footwear

*Table S.3 PRODCOM codes and conversion factors. pa = pair, p/st = per item(Napolano et al., 2025). * Not present in PEFCR (2021); conversion factor the most similar PRODCOM category was used.*

Prodcom code	Prodcom unit	Conversion factor to kg	Source conversion factor
14111000	p/st	0.9	PEFCR (2021)
14121120	p/st	0.5	PEFCR (2021)
14121130	p/st	0.95	PEFCR (2021)
14121240	p/st	0.45	PEFCR (2021)
14121250	p/st	0.45	PEFCR (2021)
14122120	p/st	0.5	PEFCR (2021)
14122130	p/st	0.95	PEFCR (2021)
14122240	p/st	0.45	PEFCR (2021)
14122250	p/st	0.45	PEFCR (2021)
14123013	p/st	0.5	PEFCR (2021)
14123023	p/st	0.5	PEFCR (2021)
14131110	p/st	0.95	PEFCR (2021)

Prodcom code	Prodcom unit	Conversion factor to kg	Source conversion factor
14131120	p/st	0.95	PEFCR (2021)
14131230	p/st	0.95	PEFCR (2021)
14131260	p/st	0.5	PEFCR (2021)
14131270	p/st	0.45	PEFCR (2021)
14131310	p/st	0.95	PEFCR (2021)
14131320	p/st	0.95	PEFCR (2021)
14131430	p/st	0.95	PEFCR (2021)
14131460	p/st	0.5	PEFCR (2021)
14131470	p/st	0.3	PEFCR (2021)
14131480	p/st	0.25	PEFCR (2021)
14131490	p/st	0.45	PEFCR (2021)
14132115	p/st	0.5	PEFCR (2021)
14132130	p/st	0.95	PEFCR (2021)
14132200	p/st	0.5	PEFCR (2021)
14132300	p/st	0.95	PEFCR (2021)
14132442	p/st	0.45	PEFCR (2021)
14132444	p/st	0.45	PEFCR (2021)
14132445	p/st	0.45	PEFCR (2021)
14132448	p/st	0.45	PEFCR (2021)
14132449	p/st	0.45	PEFCR (2021)
14132455	p/st	0.45	PEFCR (2021)
14132460	p/st	0.45	PEFCR (2021)
14133115	p/st	0.5	PEFCR (2021)
14133130	p/st	0.95	PEFCR (2021)
14133200	p/st	0.5	PEFCR (2021)
14133330	p/st	0.95	PEFCR (2021)
14133470	p/st	0.3	PEFCR (2021)
14133480	p/st	0.25	PEFCR (2021)
14133542	p/st	0.45	PEFCR (2021)
14133548	p/st	0.45	PEFCR (2021)
14133549	p/st	0.45	PEFCR (2021)
14133551	p/st	0.45	PEFCR (2021)
14133561	p/st	0.45	PEFCR (2021)
14133563	p/st	0.45	PEFCR (2021)
14133565	p/st	0.45	PEFCR (2021)
14133569	p/st	0.45	PEFCR (2021)
14141100	p/st	0.25	PEFCR (2021)
14141220	p/st	0.08	PEFCR (2021)
14141230	p/st	0.15	PEFCR (2021)
14141240	p/st	0.3	PEFCR (2021)

Prodcom code	Prodcom unit	Conversion factor to kg	Source conversion factor
14141310	p/st	0.25	PEFCR (2021)
14141420	p/st	0.08	PEFCR (2021)
14141430	p/st	0.15	PEFCR (2021)
14141440	p/st	0.3	PEFCR (2021)
14141450	p/st	0.5	PEFCR (2021)
14142100	p/st	0.25	PEFCR (2021)
14142220	p/st	0.08	PEFCR (2021)
14142230	p/st	0.15	PEFCR (2021)
14142240	p/st	0.3	PEFCR (2021)
14142300	p/st	0.25	PEFCR (2021)
14142430	p/st	0.3	PEFCR (2021)
14142450	p/st	0.5	PEFCR (2021)
14142460	p/st	0.08	PEFCR (2021)
14142480	p/st	0.08	PEFCR (2021)
14142489	p/st	0.08	PEFCR (2021)
14142530	p/st	0.05	PEFCR (2021)
14142550	p/st	0.5	PEFCR (2021)
14143000	p/st	0.17	PEFCR (2021)
14191210	p/st	0.5	PEFCR (2021)
14191230	p/st	0.5	PEFCR (2021)
14191240	p/st	0.12	PEFCR (2021)
14191250	p/st	0.12	PEFCR (2021)
14191300	pa	0.1	PEFCR (2021)
14191930	p/st	0.1	PEFCR (2021)
14192210	p/st	0.5	PEFCR (2021)
14192220	p/st	0.5	PEFCR (2021)
14192230	p/st	0.5	PEFCR (2021)
14192240	p/st	0.12	PEFCR (2021)
14192250	p/st	0.12	PEFCR (2021)
14192310	p/st	0.5	PEFCR (2021)
14192333	p/st	0.15	PEFCR (2021)
14192338	p/st	0.15	PEFCR (2021)
14192353	p/st	0.15	PEFCR (2021)
14192358	p/st	0.15	PEFCR (2021)
14192370	pa	0.1	PEFCR (2021)
14193175	pa	0.1	PEFCR (2021)
14193180	p/st	0.1	PEFCR (2021)
14193200	p/st	0.1	PEFCR (2021)
14194130	p/st	0.1	PEFCR (2021)
14194150	p/st	0.1	PEFCR (2021)

Prodcom code	Prodcom unit	Conversion factor to kg	Source conversion factor
14194230	p/st	0.1	PEFCR (2021)
14194250	p/st	0.1	PEFCR (2021)
14194270	p/st	0.1	PEFCR (2021)
14311033	p/st	0.07	PEFCR (2021)
14311035	p/st	0.07	PEFCR (2021)
14311037	p/st	0.07	PEFCR (2021)
14311050	pa	0.01	PEFCR (2021)
14311090	pa	0.07	PEFCR (2021)
14391031	p/st	0.5	PEFCR (2021)
14391032	p/st	0.5	PEFCR (2021)
14391033	p/st	0.3	PEFCR (2021)
14391053	p/st	0.5	PEFCR (2021)
14391055	p/st	0.5	PEFCR (2021)
14391061	p/st	0.5	PEFCR (2021)
14391062	p/st	0.5	PEFCR (2021)
14391071	p/st	0.5	PEFCR (2021)
14391072	p/st	0.5	PEFCR (2021)
14391090	p/st	0.5	PEFCR (2021)
15201100	pa	0.9	PEFCR (2021)
15201210	pa	0.5	PEFCR (2021)
15201231	pa	0.9	PEFCR (2021)
15201237	pa	0.35	PEFCR (2021)
15201330	pa	0.9	PEFCR (2021)
15201351	pa	0.9	PEFCR (2021)
15201352	pa	0.9	PEFCR (2021)
15201353	pa	0.9	PEFCR (2021)
15201361	pa	0.5	PEFCR (2021)
15201362	pa	0.5	PEFCR (2021)
15201363	pa	0.5	PEFCR (2021)
15201370	pa	0.35	PEFCR (2021)
15201380	pa	0.9	PEFCR (2021)
15201444	pa	0.35	PEFCR (2021)
15201445	pa	0.9	PEFCR (2021)
15201446	pa	0.9	PEFCR (2021)
15202100	pa	0.9	PEFCR (2021)
15202900	pa	0.9	PEFCR (2021)
15203120	pa	0.9	PEFCR (2021)
15203150	pa	0.9	PEFCR (2021)
15203200	pa	0.9	PEFCR (2021)
14132110	p/st	0.5	14132115*

Prodcom code	Prodcom unit	Conversion factor to kg	Source conversion factor
14132116	p/st	0.95	14132130*
14132120	p/st	0.5	14132115*
14132210	p/st	0.5	14132200*
14132220	p/st	0.5	14132200*
14133110	p/st	0.5	14133115*
14133116	p/st	0.95	14131310*
14133120	p/st	0.5	14133115*
14133210	p/st	0.5	14133200*
14133220	p/st	0.5	14133200*
14194300	p/st	0.1	14194270*
14111033	p/st	0.07	14311033*
14311035	p/st	0.07	14311035*
14311050	pa	0.01	14311050*
14391031	p/st	0.5	14391031*
14391032	p/st	0.5	14391032*
14391033	p/st	0.3	14391033*

Polymer composition of categories

Quantis identified the average weight % of materials for several subcategories of clothing (Table S.4) and footwear (Table S.5) (Quantis, 2021). These tables were used to calculate the weight in kg for each PRODCOM code, region and year. One of the categories in Table S.4 and Table S5 was assigned to each PRODCOM code (Table S.6).

Calculation of consumption values

Once all Eurostat data was converted from number of items to kg and the category for each PRODOM code was known, the data was grouped by category. Consequently, the values in Table S.4 and Table S.5 were multiplied with the number of kg in each category. Next, only the synthetic materials were selected from this data. For every year and region, the number of kg per material was summed which resulted in the input values needed for the model.

Transfer coefficients

Calculation of TCs per clothing category

As not all categories have the same material composition and the same route to the environment, the input data must be distributed over the categories using transfer coefficients per material and per category. These TCs were calculated by taking Table S.4 and Table S.5, and removing the non-synthetic materials from them. Then the material fractions per category were recalculated (see MainInput excel file (v2025.11.1) available via [10.5281/zenodo.12636553](https://doi.org/10.5281/zenodo.12636553) and https://github.com/rivm-syso/DPMFA_NL_EU).

Table S.4 Average weight distribution between materials for different categories of clothing. Trims is assumed to consist of metal, PET and PES in equal parts. The first row provides the average weight per clothing category, the other rows the distribution across materials. Data source: (Quantis, 2021).

	T-shirts	Shirts & blouses	Sweaters & midlayers	Jackets & coats	Pants & shorts	Dresses, skirts and jumpsuits	Leggings, stockings, tights and socks	Underwear	Swimwear	Apparel accessories
Average weight (g/product)	**170**	**250**	**500**	**950**	**450**	**300**	**130**	**80**	**120**	**110**
List of materials										
Acrylic	0	0	0.05	0.11	0	0	0.07	0	0	0.16
Cashmere and camel hair	0	0	0.04	0.009	0	0	0	0	0	0
Cotton	0.7	0.55	0.34	0.15	0.47	0.54	0.22	0.705	0	0.15
Duck down	0	0	0	0.009	0	0	0	0	0	0
Elastane	0	0	0	0	0.04	0	0.09	0.07	0.09	0
Fur	0	0	0	0.003	0	0	0	0	0	0
Leather	0	0	0	0.009	0.01	0	0	0	0	0.07
Linen	0	0.05	0	0	0.04	0	0	0	0	0
Polyamide	0	0	0.02	0.15	0.07	0.04	0.27	0.1	0.51	0.04
Polyamide recycled	0	0	0	0	0	0	0.04	0.02	0	0
Polyester and other synthetics	0.213	0.232	0.217	0.356	0.309	0.245	0.188	0.051	0.376	0.303
Polyester recycled	0.02	0.03	0.04	0.04	0.03	0.02	0.02	0	0.02	0
PFTE	0	0	0	0.018	0	0	0	0	0	0
Silk	0	0	0	0	0	0	0	0	0	0.01
Viscose/Modal/Lyocell	0.06	0.13	0.05	0.04	0.02	0.13	0.08	0.05	0	0
Wool	0	0	0.24	0.09	0	0.02	0.02	0	0	0.26
Trims	0.007	0.008	0.03	0.016	0.011	0.005	0.002	0.004	0.004	0.007

Table S.5 Average weight distribution between materials for different categories of footwear. (Quantis, 2021). Trims is assumed to consist of metal, PET and PES in equal parts.

	Open-toed shoes	Closed-toed shoes	Boots
Average weight (g/product)	**350**	**900**	**1100**
List of materials			
Wood-based non-woven	0	0	0.02
Cork	0.05	0	0
Cotton	0	0.03	0
EVA	0.28	0.07	0
Leather	0.17	0.11	0.21
Metal	0	0	0.02
Polyamide	0	0.03	0.03
Polyester and other synthetics	0.03	0.26	0.13
Polyester recycled	0	0.03	0.02
Polyurethane	0.08	0.06	0.1
PVC	0.06	0.06	0.14
Rubber natural	0.13	0.08	0.05
Rubber synthetic	0.19	0.16	0.11
Thermoplastic polyurethane	0	0.03	0.14
Viscose/Modal	0	0.02	0
Wool	0	0.04	0
Trims	0.01	0.02	0.03

Table S.6 Material category per PRODCOM code for clothing and accessories.

PRODCOM code	Product description	Material category
14121120	Men’s or boys’ ensembles, of cotton or man-made fibres, for industrial and occupational wear	Jackets & coats
14121130	Men’s or boys’ jackets and blazers, of cotton or man-made fibres, for industrial and occupational wear	Jackets & coats
14121240	Men’s or boys’ trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear	Pants & shorts
14121250	Men’s or boys’ bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear	Pants & shorts
14122120	Women’s or girls’ ensembles, of cotton or man-made fibres, for industrial or occupational wear	Jackets & coats

PRODCOM code	Product description	Material category
14122130	Women’s or girls’ jackets and blazers, of cotton or man-made fibres, for industrial or occupational wear	Jackets & coats
14122240	Women’s or girls’ trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear	Pants & shorts
14122250	Women’s or girls’ bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear	Pants & shorts
14131110	Men’s or boys’ overcoats, car-coats, capes, cloaks and similar articles, of knitted or crocheted textiles (excluding jackets and blazers, anoraks, wind-cheaters and wind-jackets)	Jackets & coats
14131120	Men’s or boys’ waistcoats, anoraks, ski-jackets, wind-cheaters, wind-jackets and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)	Jackets & coats
14131230	Men’s or boys’ jackets and blazers, of knitted or crocheted textiles	Jackets & coats
14131260	Men’s or boys’ suits and ensembles, of knitted or crocheted textiles	Sweaters & midlayers
14131270	Men’s or boys’ trousers, breeches, shorts, bib and brace overalls, of knitted or crocheted textiles	Pants & shorts
14131310	Women’s or girls’ overcoats, car-coats, capes, cloaks and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)	Jackets & coats
14131320	Women’s or girls’ waistcoats, anoraks, ski-jackets, wind-cheaters, wind-jackets and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)	Jackets & coats
14131430	Women’s or girls’ jackets and blazers, of knitted or crocheted textiles	Jackets & coats
14131460	Women’s or girls’ suits and ensembles, of knitted or crocheted textiles	Sweaters & midlayers
14131470	Women’s or girls’ dresses, of knitted or crocheted textiles	Dresses, skirts and jumpsuits
14131480	Women’s or girls’ skirts and divided skirts, of knitted or crocheted textiles	Dresses, skirts and jumpsuits
14131490	Women’s or girls’ trousers, breeches, shorts, bib and brace overalls, of knitted or crocheted textiles	Pants & shorts
14132110	Men's or boys' raincoats	Jackets & coats

PRODCOM code	Product description	Material category
14132115	Men’s or boys’ raincoats, overcoats, car-coats, capes, etc.	Jackets & coats
14132116	Men's or boys' overcoats, car coats, capes, cloaks, anoraks (including ski-jackets), wind cheaters, wind-jackets and similar articles (excluding suits, ensembles, jackets, blazers, trousers, bib and brace overalls, breeches and shorts)	Jackets & coats
14132120	Men's or boys' overcoats, car-coats, capes, etc	Jackets & coats
14132130	Men’s or boys’ waistcoats, anoraks, ski-jackets, wind-jackets and similar articles (excluding jackets and blazers, knitted or crocheted, impregnated, coated, covered, laminated or rubberised)	Jackets & coats
14132200	Men’s or boys’ suits & ensembles (excluding knitted or crocheted)	Dresses, skirts and jumpsuits
14132210	Men's or boys' suits (excluding knitted or crocheted)	Dresses, skirts and jumpsuits
14132220	Men's or boys' ensembles (excluding knitted or crocheted)	Dresses, skirts and jumpsuits
14132300	Men’s or boys’ jackets and blazers (excluding knitted or crocheted)	Jackets & coats
14132442	Men’s or boys’ trousers and breeches, of denim (excluding for industrial or occupational wear)	Pants & shorts
14132444	Men’s or boys’ trousers, breeches and shorts, of wool or fine animal hair (excluding knitted or crocheted, for industrial or occupational wear)	Pants & shorts
14132445	Men’s or boys’ trousers and breeches, of man-made fibres (excluding knitted or crocheted, for industrial or occupational wear)	Pants & shorts
14132448	Men’s or boys’ trousers and breeches, of cotton (excluding denim, knitted or crocheted)	Pants & shorts
14132449	Men’s or boys’ trousers, breeches, shorts and bib and brace overalls (excluding of wool, cotton and man-made fibres, knitted or crocheted)	Pants & shorts
14132455	Men’s or boys’ bib and brace overalls (excluding knitted or crocheted, for industrial or occupational wear)	Pants & shorts
14132460	Men’s or boys’ shorts, of cotton or man-made fibres (excluding knitted or crocheted)	Pants & shorts
14133110	Woman's or girls' raincoats	Jackets & coats
14133115	Woman’s or girls’ raincoats and overcoats, etc	Jackets & coats

PRODCOM code	Product description	Material category
14133116	Women's or girls' overcoats, car-coats, capes, cloaks, anoraks (including ski jackets), wind-cheaters, wind-jackets and similar articles (excluding suits, ensembles, jackets, blazers, dresses, skirts, divided skirts, trousers, bib and brace overalls, breeches and shorts)	Jackets & coats
14133120	Woman's or girls' overcoats, etc	Jackets & coats
14133130	Women’s or girls’ waistcoats, anoraks, ski-jackets, wind-jackets and similar articles (excluding jackets and blazers, knitted or crocheted, impregnated, coated, covered, laminated or rubberised)	Jackets & coats
14133200	Women’s or girls’ suits & ensembles (excluding knitted or crocheted)	Dresses, skirts and jumpsuits
14133210	Women's or girls' suits (excluding knitted or crocheted)	Dresses, skirts and jumpsuits
14133220	Women's or girls' ensembles (excluding knitted or crocheted)	Dresses, skirts and jumpsuits
14133330	Women’s or girls’ jackets and blazers (excluding knitted or crocheted)	Jackets & coats
14133470	Women’s or girls’ dresses (excluding knitted or crocheted)	Dresses, skirts and jumpsuits
14133480	Women’s or girls’ skirts and divided skirts (excluding knitted or crocheted)	Dresses, skirts and jumpsuits
14133542	Women’s or girls’ trousers and breeches, of denim (excluding for industrial or occupational wear)	Pants & shorts
14133548	Women’s or girls’ trousers and breeches, of cotton (excluding denim, for industrial or occupational wear)	Pants & shorts
14133549	Women’s or girls’ trousers and breeches, of wool or fine animal hair or man-made fibres (excluding knitted or crocheted and for industrial and occupational wear)	Pants & shorts
14133551	Women’s or girls’ bib and brace overalls, of cotton (excluding knitted or crocheted, for industrial or occupational wear)	Pants & shorts
14133561	Women’s or girls’ shorts, of cotton (excluding knitted and crocheted)	Pants & shorts
14133563	Women's or girls' bib and brace overalls, of wool or fine animal hair and man-made fibres (excluding cotton, knitted or crocheted, for industrial or occupational wear) and women's or girls' shorts, of wool or fine animal hair (excluding knitted or crocheted)	Pants & shorts

PRODCOM code	Product description	Material category
14133565	Women’s or girls’ shorts, of man-made fibres (excluding knitted or crocheted)	Pants & shorts
14133569	Women’s or girls’ trousers, breeches, bib and brace overalls, of textiles (excluding cotton, wool or fine animal hair, man-made fibres, knitted or crocheted)	Pants & shorts
14141100	Men's or boys' shirts, knitted or crocheted	Shirts & blouses
14141220	Men’s or boys’ underpants and briefs, of knitted or crocheted textiles (including boxer shorts)	Underwear
14141230	Men’s or boys’ nightshirts and pyjamas, of knitted or crocheted textiles	Underwear
14141240	Men’s or boys’ dressing gowns, bathrobes and similar articles, of knitted or crocheted textiles	Underwear
14141310	Women’s or girls’ blouses, shirts and shirt-blouses, of knitted or crocheted textiles	Shirts & blouses
14141420	Women’s or girls’ briefs and panties, of knitted or crocheted textiles (including boxer shorts)	Underwear
14141430	Women’s or girls’ nighties and pyjamas, of knitted or crocheted textiles	Underwear
14141440	Women’s or girls’ negligees, bathrobes, dressing gowns and similar articles, of knitted or crocheted textiles	Underwear
14141450	Women’s or girls’ slips and petticoats, of knitted or crocheted textiles	Underwear
14142100	Men’s or boys’ shirts (excluding knitted or crocheted)	Shirts & blouses
14142220	Men’s or boys’ underpants and briefs (including boxer shorts) (excluding knitted or crocheted)	Underwear
14142230	Men’s or boys’ nightshirts and pyjamas (excluding knitted or crocheted)	Underwear
14142300	Women’s or girls’ blouses, shirts and shirt-blouses (excluding knitted or crocheted)	Shirts & blouses
14142430	Women’s or girls’ nightdresses and pyjamas (excluding knitted or crocheted)	Underwear
14142450	Women’s or girls’ slips and petticoats (excluding knitted or crocheted)	Underwear
14142530	Brassieres	Underwear
14142550	Girdles, panty-girdles and corselettes (including bodies with adjustable straps)	Underwear
14143000	T-shirts, singlets and vests, knitted or crocheted	T-shirts
14191210	Track-suits, of knitted or crocheted textiles	Sweaters & midlayers
14191240	Men’s or boys’ swimwear, of knitted or crocheted textiles	Swimwear
14191250	Women’s or girls’ swimwear, of knitted or crocheted textiles	Swimwear

PRODCOM code	Product description	Material category
14191290	Other garments, knitted or crocheted (including bodies with a proper sleeve)	Underwear
14191300	Gloves, mittens and mitts, of knitted or crocheted textiles	Apparel accessories
14192230	Ski-suits (excluding of knitted or crocheted textiles)	Jackets & coats
14192240	Men’s or boys’ swimwear (excluding of knitted or crocheted textiles)	Swimwear
14192250	Women’s or girls’ swimwear (excluding of knitted or crocheted textiles)	Swimwear
14192310	Handkerchiefs	Apparel accessories
14192333	Shawls, scarves, mufflers, mantillas, veils and the like (excluding articles of silk or silk waste, knitted or crocheted)	Apparel accessories
14192338	Shawls, scarves, mufflers, mantillas, veils and the like, of silk or silk waste (excluding knitted or crocheted)	Apparel accessories
14192353	Ties, bow ties and cravats (excluding articles of silk or silk waste, knitted or crocheted)	Apparel accessories
14192358	Ties, bow ties and cravats, of silk or silk waste (excluding knitted or crocheted)	Apparel accessories
14192370	Gloves, mittens and mitts (excluding knitted or crocheted)	Apparel accessories
14193175	Gloves, mittens and mitts, of leather or composition leather (excluding for sport, protective for all trades)	Apparel accessories
14193200	Garments made up of felt or non-wovens, textile fabrics impregnated or coated	Jackets & coats
14194130	Hat-forms, hat bodies and hoods, plateaux and manchons of felt (including slit manchons) (excluding those blocked to shape, those with made brims)	Apparel accessories
14194150	Hat-shapes, plaited or made by assembling strips of any material (excluding those blocked to shape, those with made brims, those lined or trimmed)	Apparel accessories
14194230	Felt hats and other felt headgear, made from hat bodies or hoods and plateaux	Apparel accessories
14194250	Hats and other headgear, plaited or made by assembling strips of any material	Apparel accessories
14194300	Other headgear (except headgear of rubber or of plastics, safety headgear and asbestos headgear); headbands, linings, covers, hat foundations, hat frames, peaks and chinstraps, for headgear	Apparel accessories
14311033	Panty hose and tights, of knitted or crocheted synthetic fibres, measuring per single yarn < 67 decitex	Leggings, stockings, tights & socks

PRODCOM code	Product description	Material category
14311035	Panty hose and tights, of knitted or crocheted synthetic fibres, measuring per single yarn >= 67 decitex	Leggings, stockings, tights & socks
14311037	Pantyhose and tights of textile materials, knitted or crocheted (excl. graduated compression hosiery, those of synthetic fibres and hosiery for babies)	Leggings, stockings, tights & socks
14311050	Women's full-length or knee-length knitted or crocheted hosiery, measuring per single yarn < 67 decitex	Leggings, stockings, tights & socks
14311090	Knitted or crocheted hosiery and footwear (including socks; excluding women's full-length/knee-length hosiery, measuring <67decitex, panty-hose and tights, footwear with applied soles)	Leggings, stockings, tights & socks
14391031	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of wool or fine animal hair (excluding jerseys and pullovers containing >= 50 % of wool and weighing >= 600 g)	Sweaters & midlayers
14391032	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of wool or fine animal hair (excluding jerseys and pullovers containing >= 50 % of wool and weighing >= 600 g)	Sweaters & midlayers
14391033	Jerseys and pullovers, containing >= 50 % by weight of wool and weighing >= 600 g per article	Sweaters & midlayers
14391053	Lightweight fine knit roll, polo or turtle neck jumpers and pullovers, of cotton	Sweaters & midlayers
14391055	Lightweight fine knit roll, polo or turtle neck jumpers and pullovers, of man-made fibres	Sweaters & midlayers
14391061	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of cotton (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	Sweaters & midlayers
14391062	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of cotton (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	Sweaters & midlayers
14391071	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of man-made fibres (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	Sweaters & midlayers
14391072	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of man-	Sweaters & midlayers

PRODCOM code	Product description	Material category
	made fibres (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	
14391090	Jerseys, pullovers, sweatshirts, waistcoats and cardigans, of textile materials (excluding those of wool or fine animal hair, cotton, man-made fibres)	Sweaters & midlayers

Table S.7 Material category per PRODCOM code for footwear.

PRODCOM code	Product description	Material category
15201100	Waterproof footwear, with uppers in rubber or plastics (excluding incorporating a protective metal toecap)	Closed-toed shoes
15201210	Sandals with rubber or plastic outer soles and uppers (including thong-type sandals, flip flops)	Open-toed shoes
15201231	Town footwear with rubber or plastic uppers	Closed-toed shoes
15201237	Slippers and other indoor footwear with rubber or plastic outer soles and plastic uppers (including bedroom and dancing slippers, mules)	Open-toed shoes
15201330	Footwear with a wooden base and leather uppers (including clogs) (excluding with an inner sole or a protective metal toe-cap)	Closed-toed shoes
15201351	Men’s town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)	Boots
15201352	Women’s town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)	Boots
15201353	Children’s town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)	Boots
15201361	Men’s sandals with leather uppers (including thong type sandals, flip flops)	Open-toed shoes
15201362	Women’s sandals with leather uppers (including thong type sandals, flip flops)	Open-toed shoes
15201363	Children’s sandals with leather uppers (including thong type sandals, flip flops)	Open-toed shoes
15201370	Slippers and other indoor footwear with rubber, plastic or leather outer soles and leather uppers (including dancing and bedroom slippers, mules)	Open-toed shoes
15201380	Footwear with wood, cork or other outer soles and leather uppers (excluding outer soles of rubber, plastics or leather)	Closed-toed shoes

PRODCOM code	Product description	Material category
15201444	Slippers and other indoor footwear (including dancing and bedroom slippers, mules) with uppers of textile materials	Open-toed shoes
15201445	Footwear with rubber, plastic or leather outer soles and textile uppers (excluding slippers and other indoor footwear, sports footwear)	Closed-toed shoes
15201446	Footwear with textile uppers (excluding slippers and other indoor footwear as well as footwear with outer soles of rubber, plastics, leather or composition leather)	Closed-toed shoes
15202100	Sports footwear with rubber or plastic outer soles and textile uppers (including tennis shoes, basketball shoes, gym shoes, training shoes and the like)	Closed-toed shoes
15202900	Other sports footwear, except snow-ski footwear and skating boots	Closed-toed shoes
15203120	Footwear (including waterproof footwear), incorporating a protective metal toecap, with outer soles and uppers of rubber or of plastics	Boots
15203150	Footwear with rubber, plastic or leather outer soles and leather uppers, and with a protective metal toe-cap	Boots
15203200	Wooden footwear, miscellaneous special footwear and other footwear n.e.c.	Open-toed shoes

Manufacturing losses
Losses during the manufacturing of fabric and clothing were reported (Table S.8). These factors were used to estimate the losses during the manufacturing process in the EU, as no clothing has been manufactured on a large scale in the Netherlands since 2011.

Table S.8 Manufacturing losses during apparel production (Quantis, 2021).

Manufacturing step	Losses
Spinning	5%
Knitting, flat	0.06%
Weaving	1%
Dyeing	0.15%
Finishing	0.4%
Garment assembly (cutting, sewing)	20%

Consumption data from import was multiplied by 0.9 and 1.1, to account for assumptions made during data preparation. This resulted in a high and low estimate for the net import mass of clothing.

For import:

$$Low\ import\ estimate\ (kt) = consumption\_imported\ (kt) * 0.9$$

$$High\ import\ estimate\ (kt) = consumption\_imported (kt) * 1.1$$

Consumption data from domestic production was also multiplied by 0.9 and 1.1 to account for assumptions made during data preparation. These values were added to the values for losses during production (Table S.8), because the mass of sold clothing originated from a higher mass of raw materials.

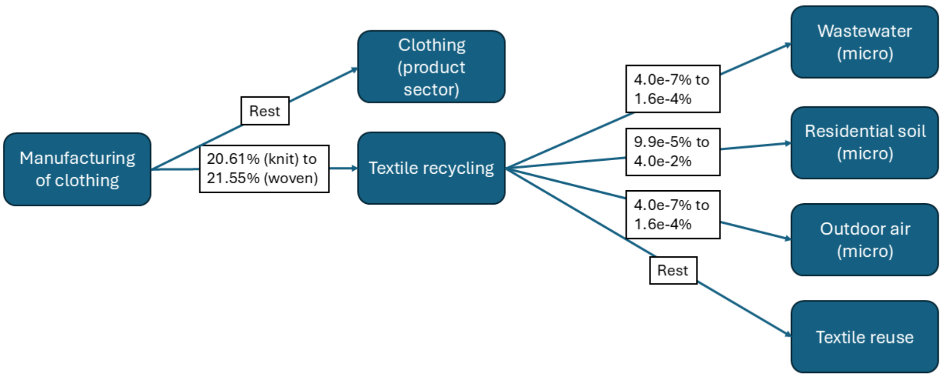
For production:

$$Low\ production\ estimate\ (kt) = consumption\_domestically\_produced\ (kt) * (0.9 + 0.2561)$$

$$High\ production\ estimate\ (kt) = consumption\_domestically\_produced\ (kt) * (1.1 + 0.2561)$$

The percentages of material lost during manufacturing (Table S8) were introduced in the model as transfer coefficients going from the compartment 'manufacturing of clothing' to 'textile recycling' (Figure S.1).

Figure S.1. Transfer coefficients from manufacturing of clothing to sinks. Only applies at EU scale as no clothing was manufactured at a large scale in the Netherlands from 2011.



Drying

Figure S.2 Refined clothing drying options included in the model with baseline fraction of use (Bakker et al., 2022; CBS, 2010; Cummins et al., 2023; Kawecki and Nowack, 2019; Zwart and De Valk, 2019).

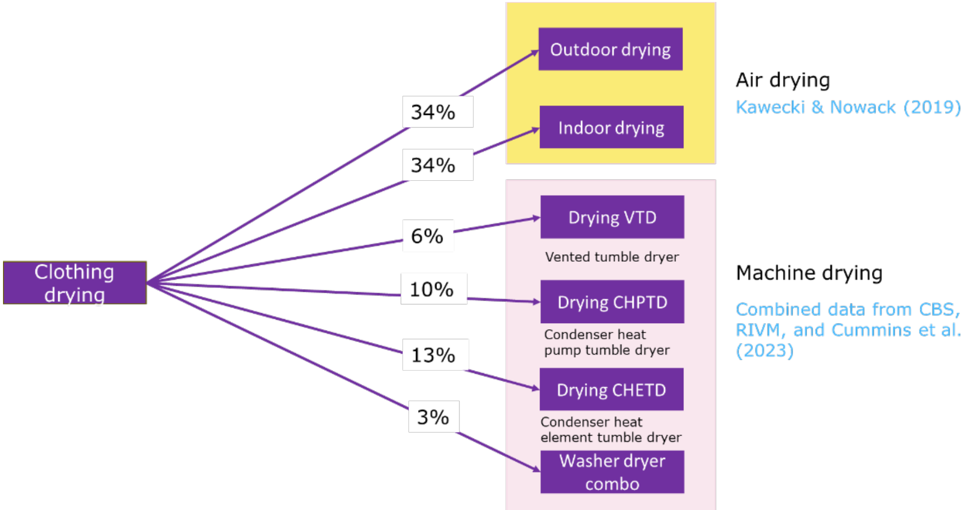


Figure S.3 Updated flows from indoor and outdoor drying (Kawecki and Nowack, 2019).

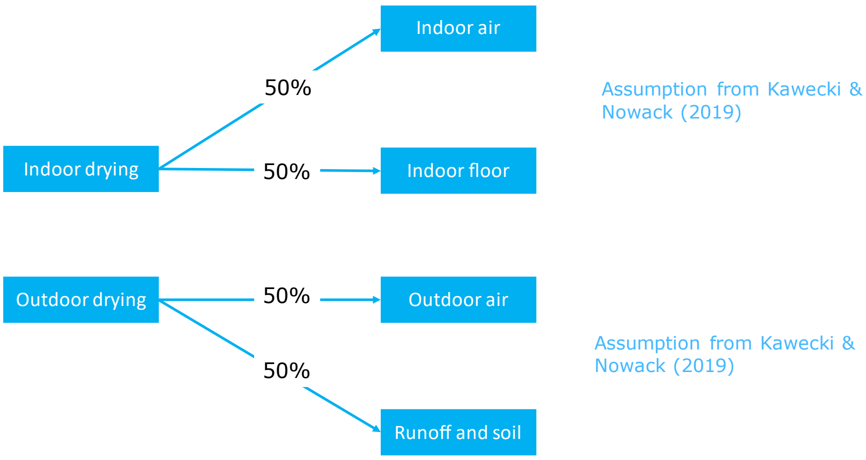
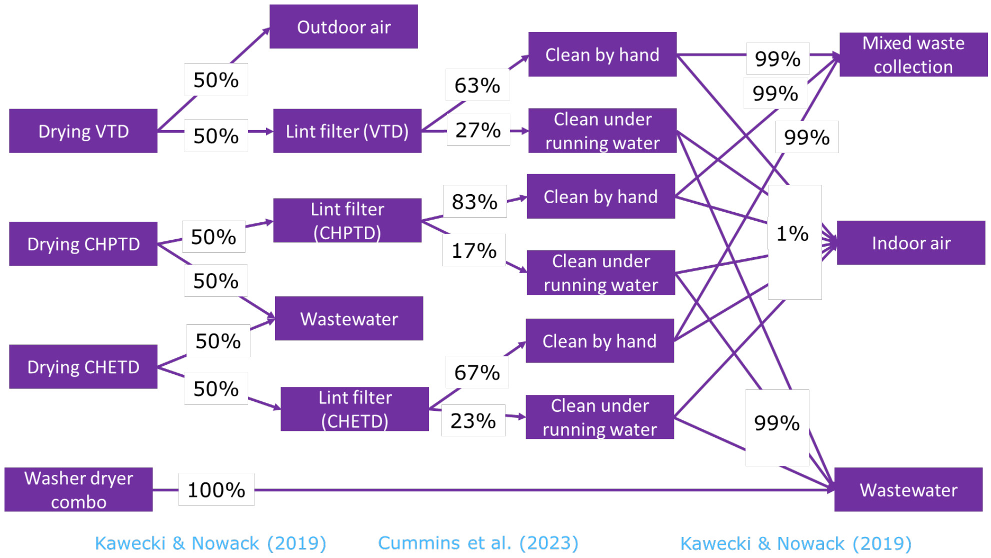


Figure S.4 Updated flows from machine drying (Cummins et al., 2023; Kawecki and Nowack, 2019).



Washing

Figure S.5 Refined washing options and use of extra fiber filter (Bakker et al., 2022; Kimmel et al., 2024).

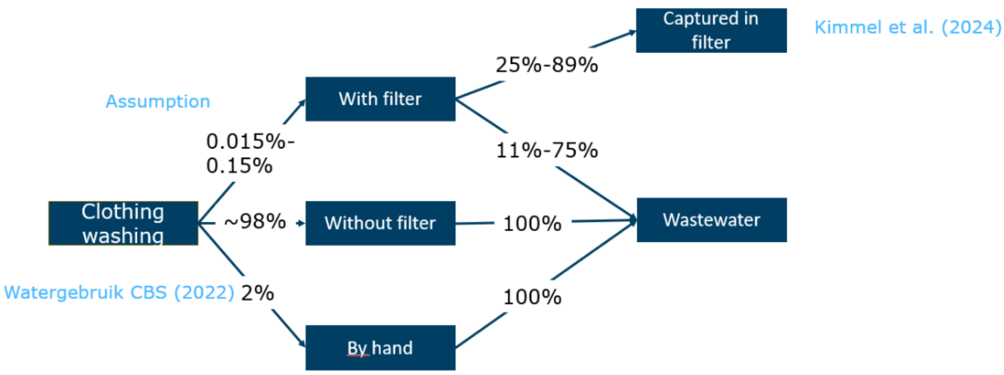
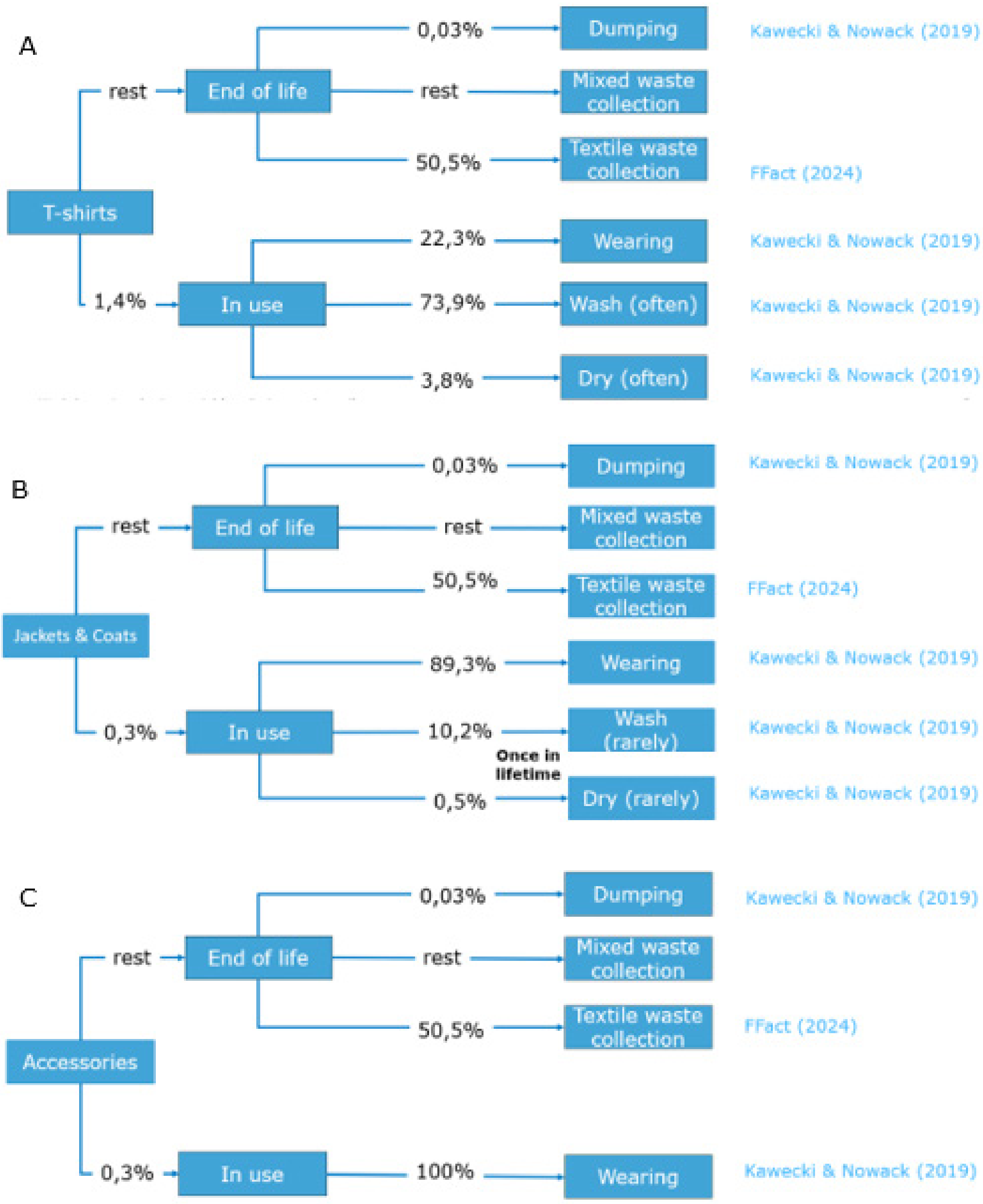
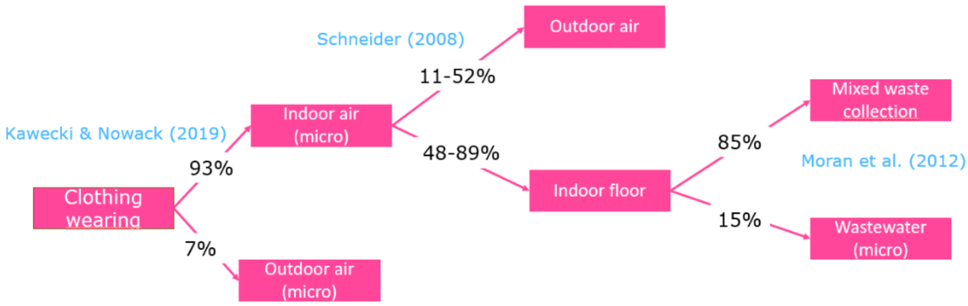


Figure S.6 Flows to and from in use/end of life compartments for clothing that is (A) washed often, (B) rarely washed and (C) not washed (FFact, 2024; Kawecki and Nowack, 2019).



Wearing and tear

Figure S.7 Flows for microfibers lost during wearing of clothes due to wear and tear (Kawecki and Nowack, 2019; Moran et al., 2012; Schneider, 2008).



Lifetimes

Table S.9 contains the average lifetime for each of the clothing and footwear categories. These lifetimes were calculated by taking the average lifetime per clothing and footwear category from Table SM4 by (Napolano et al., 2025). Napolano et al. in turn used the lifetimes from two sources (Drycleaning Institute of Australia Ltd, 2015; Laitala et al., 2018).

Table S.9 Lifetimes per clothing and footwear category.

Category	Years
Apparel accessories	2
Boots	5
Closed-toed shoes	5
Dresses, skirts and jumpsuits	8
Jackets & coats	7
Leggings, stockings, tights and socks	3
Open-toed shoes	5
Pants & shorts	4
Shirts & blouses	5
Sweaters & midlayers	6
Swimwear	2
T-shirts	5
Underwear	3

Textile waste collection

The aggregated textile waste collection compartment now distinguishes between clothing and other textile sources. In the previous version of the model, flows from "Technical textiles", "" and "Clothing" went to the same "Textile waste collection" compartment. From textile waste collection, there was one recycling and reuse rate for all textiles that entered the "Textile waste collection" compartment which should be specific to clothing and footwear. As different types of textile products have different rates of separate collection and recycling possibilities, new textile waste collection compartments were introduced to differentiate between types of textiles, see Table S.10.

Reuse and recycling rates were also updated with more recent and detailed data where available (Table S.11).

Table S.10 Transfer coefficients to textile waste collection compartments. Same TCs for NL and EU.

From	To	Data	Source
Clothing category	Clothing waste collection	50.5%	(FFact, 2024)
Home textiles (discarded)	Home textile waste collection	50.5%	(FFact, 2024)
Technical home textiles (discarded)	Technical textile waste collection	50.5%	(FFact, 2024)
Footwear category	Footwear waste collection	25.0%	(de Waart et al., 2023)

Table S 11 Transfer coefficients from textile waste collection to subsequent compartments. Same TCs for NL and EU.

From	To	Data	Source
Clothing waste collection	Textile reuse	6.73%	(FFact, 2024)
Clothing waste collection	Textile recycling	5.71%	(FFact, 2024)
Clothing waste collection	Residential soil (macro)	0.01%	Assumption based on similar losses estimated for other waste collection systems
Clothing waste collection	Landfill	0.30%	(FFact, 2024)
Clothing waste collection	Incineration	6.54%	(FFact, 2024)
Clothing waste collection	Export	rest	(FFact, 2024)
Home textile waste collection	Textile reuse	6.73%	(FFact, 2024)
Home textile waste collection	Textile recycling	5.71%	(FFact, 2024)
Home textile waste collection	Residential soil (macro)	0.01%	Assumption based on similar losses estimated for other waste collection systems
Home textile waste collection	Landfill	0.30%	(FFact, 2020)
Home textile waste collection	Incineration	6.54%	(FFact, 2024)
Home textile waste collection	Export	rest	(FFact, 2024)

From	To	Data	Source
Technical textile waste collection	Textile reuse	6.73%	(FFact, 2024)
Technical textile waste collection	Textile recycling	5.71%	(FFact, 2024)
Technical textile waste collection	Residential soil (macro)	0.01%	Assumption based on similar losses estimated for other waste collection systems
Technical textile waste collection	Landfill	0.30%	(FFact, 2020)
Technical textile waste collection	Incineration	6.54%	(FFact, 2024)
Technical textile waste collection	Export	rest	(FFact, 2024)
Footwear waste collection	Footwear reuse	10.00%	(de Waart et al., 2023)
Footwear waste collection	Incineration	rest	
Footwear waste collection	Landfill	0.30%	(FFact, 2020)
Footwear waste collection	Residential soil (macro)	0.01%	Assumption based on similar losses estimated for other waste collection systems
Footwear waste collection	Textile recycling	0.10%	Assume 0.01% recycling based on barely any collected footwear is recycled (de Waart et al., 2023)

Wastewater treatment system

Transfer coefficients for wastewater treatment were updated with more recent data for both the Netherlands and the EU. Most transfer coefficients were updated using the same data for NL and EU, but for the efficiency of the wastewater treatment plants two different sources were used (Table S.12).

Figure S.8 Wastewater treatment system for the Netherlands (Bertelkamp et al., 2025a; Hoeke, 2024; Kawecki and Nowack, 2019; van Egmond et al., 2021).

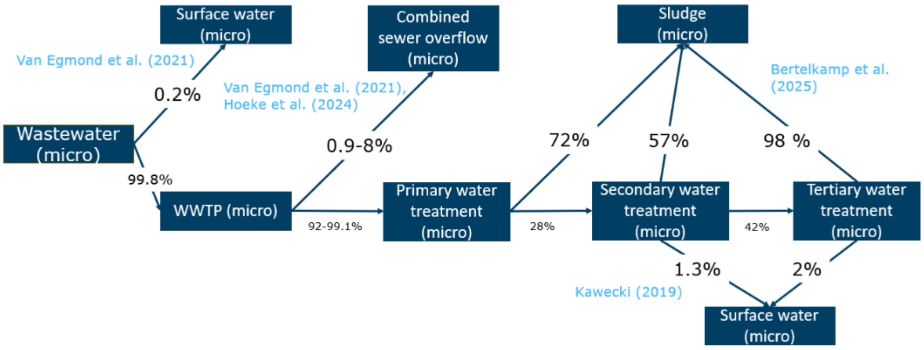


Table S.12 Updated transfer coefficients for waste water treatment plants.

From	To	Scale	Data	Source
Wastewater (micro)	On-site sewage facility (micro)	any	3.00%	(Dominguez et al., 2016)
Wastewater (micro)	Sub-surface soil (micro)	any	1.00%	(Rutsch et al., 2006)
Wastewater (micro)	Sub-surface soil (micro)	any	5.00%	(Rutsch et al., 2006)
Wastewater (micro)	Surface water (micro)	NL	0.20%	(van Egmond et al., 2021)
Wastewater (micro)	Surface water (micro)	EU	0.20%	(van Egmond et al., 2021)
Wastewater (micro)	Wastewater treatment plant (micro)	any	rest	
Wastewater (macro)	On-site sewage facility (macro)	any	3.00%	(Dominguez et al., 2016)
Wastewater (macro)	Surface water (macro)	NL	0.20%	(van Egmond et al., 2021)
Wastewater (macro)	Surface water (macro)	EU	0.20%	(van Egmond et al., 2021)
Wastewater (macro)	Wastewater treatment plant (macro)	any	rest	
Wastewater treatment plant (micro)	Combined sewer overflow (micro)	NL	8.00%	Hoeke 2024 and Liefting E and de Man 2014
Wastewater treatment plant (micro)	Combined sewer overflow (micro)	NL	0.90%	(van Egmond et al., 2021)
Wastewater treatment plant (micro)	Combined sewer overflow (micro)	EU	3.2%	(Sun et al., 2014)

From	To	Scale	Data	Source
Wastewater treatment plant (micro)	Combined sewer overflow (micro)	EU	3.0%	(Mutzner et al., 2016)
Wastewater treatment plant (micro)	Primary water treatment (micro)	any	rest	
Wastewater treatment plant (macro)	Combined sewer overflow (macro)	NL	8.00%	Hoeke 2024 and Liefting E and de Man 2014
Wastewater treatment plant (macro)	Combined sewer overflow (macro)	EU	3.2%	(Sun et al., 2014)
Wastewater treatment plant (macro)	Combined sewer overflow (macro)	EU	3.0%	(Mutzner et al., 2016)
Wastewater treatment plant (macro)	Combined sewer overflow (macro)	NL	0.90%	(van Egmond et al., 2021)
Wastewater treatment plant (macro)	Primary water treatment (macro)	any	rest	
Primary water treatment (micro/macro)	Secondary water treatment (micro/macro)	any	rest	
Primary water treatment (micro/macro)	Sludge (micro/macro)	any	72.0%	(Iyare et al., 2020)
Secondary water treatment (micro/macro)	Tertiary water treatment (micro/macro)	any	rest	
Secondary water treatment (micro/macro)	Sludge (micro/macro)	any	57.1%	(Iyare et al., 2020)
Secondary water treatment (micro/macro)	Surface water (micro/macro)	Any	1.4%	Private communication with Frederic Guhl from FOEN, Kawecki et al. (2019)
Tertiary water treatment (micro/macro)	Surface water (micro/macro)	any	rest	after primary and secondary removal results in 99.8% removal in NL and 88.2% removal in EU
Tertiary water treatment (micro/macro)	Sludge (micro/macro)	EU	50%	(Iyare et al., 2020)

From	To	Scale	Data	Source
Tertiary water treatment (micro/macro)	Sludge (micro/macro)	NL	98.3%	(Bertelkamp et al., 2025b)

Appendix 2 DPMFA model update on Footwear

Shoe soles

Footwear can release microplastics from shoe sole abrasion and due to abrasion of the upper part of shoes. The upper part of shoes is estimated to wear similar to other clothing articles, so an average is taken from Kawecki and Nowack (2019).

The wear rate of shoe soles was mentioned in two studies. In one study a 10% abrasion of shoe soles during the lifetime of a pair of shoes was assumed (Lassen et al., 2015). In another study, experts were asked to estimate the wear of shoe soles which resulted in an average of 109 g/person/year (Bertling et al., 2018). There were no lab studies available on the wear rate of shoe soles. Therefore, we made an estimate for each of the polymers shoe soles are made of.

The estimation of shoe sole wear was made based on an assumed height of the shoe sole that is abraded during wear (Table S.13) and the average number of shoes one might possess. This gives an very crude estimate of the release of microplastics from shoe soles. The calculations are detailed below in order to calculate the transfer coefficients from polymers (PUR, EVA, PVC and Rubber) used in shoes to the in_use wear compartment.

Table S.13 Assumed shoe sole height abrasion estimates.

	Height
Low estimate shoe sole height abrasion	0.1 cm
High estimate shoe sole height abrasion	0.2 cm

An average shoe size of EU40 was taken to measure the sole area in cm^2. This resulted in an area of 238 cm^2. It was assumed that 1/3 of the sole actually abrades during wear, because most pressure on the sole happens at the heel and ball of the foot. This results in an abradable surface of 79.3 cm^2. This surface area was used to calculate the volume of the sole that is worn for both the high and low estimates (Table S.14).

Table S.14 Volume of the sole that is abraded.

	Volume
Low estimate worn volume	7.93 cm^3
High estimate worn volume	15.87 cm^3

Most shoe soles are made of rubber, PUR, EVA or PVC (Rahimifard et al., 2007). To calculate the weight of the abraded shoe soles lost, the abraded volume is multiplied by the density of each material (Table S13).

As it is known from the input data how many pairs of shoes were sold, we can calculate the grams of sole lost during wear of all shoes, which can be converted to transfer coefficients (weight fraction lost during wear of shoes) for each polymer in Table S.15. Finally, these transfer coefficients are corrected by dividing the transfer coefficients by 16. This is the mean number of shoes that people possess based on a survey done executed by a footwear brand in the Netherlands (Nelson Schoenen, 2024).

Table S.15 Polymer densities and calculated weight of sole lost per shoe.

Polymer	**Density (g/cm^3)**	**Material lost, low estimate (g/shoe)**	**Material lost, high estimate (g/shoe)**
Rubber	1.5	11.9	23.8
PUR	1.1	8.7	17.4
EVA	0.95	7.5	15.0
PVC	1.39	11.0	22.0

Appendix 3 Details on quantification of the effect of mitigation measures

Table S.16 Model changes of input or transfer coefficients implemented for each measure relative to the baseline. This represents the actual performance of each scenario based on the combination of the intervention type, Table 2 and measure performance, Table 3.

ID	Short name	Alterations of the baseline for quantification of the low and high scenarios
1	Fringes	Low scenario, 0.000048% to 0.068% and high scenario, 6.1% to 8.1% of reduced mass of PET and Other polymer fringes used in clothing.
2	Replace	Low scenario, 0.00050% to 1.9% and high scenario, 31% to 56% of reduced mass of PET and PA used in clothing.
4	Production method finishes	Low scenario, 0.9% to 9% and high scenario, 34% to 45% reduction in release during clothing use (wearing, washing and drying)
5	Recycling	Low scenario, 24% to 48% and High scenario, 49 to 98 % increase in separate clothing waste collection. A 0% or 99% reduction in releases of microfibers to wastewater, air or soil due to the recycling process is included for the low and high scenario respectively.
6	Lifetime	Low scenario, 0.000072% to 0.27% and High scenario, 8.9% to 16% reductced mass of PET, PA, Acryl, PUR, PVC, Rubber and Other polymers due to 1 year longer use of clothing and consequent reduction in clothing consumption. Lifetimes of clothing released during the use and waste fase are also adjusted which leads to a longer timeframe over which these emissions occur.
7	Prewashing	Low scenario, 0.22% - 2.2%[a] and High scenario, 16% - 22%[a] reduction of in use (wearing, drying, washing) emissions for regularly washed clothes. Low scenario 0.03% – 0.3%[a] and High scenario 2.2% – 3.0 %[a] reduction of in use emissions for rarely washed clothes
8	External filter	Low scenario, 0.00055% to 0.94% and High scenario, 74% to 99% additional use of external filters. This is up to 6 and 670 times higher use of external filters compared to the baseline for the low and high scenarios, respectively.
9	Clean dryer filter	Low scenario, 0.00011% – 0.56%[b] and High scenario, 2% - 30%[b] increase in cleaning filters by disposal in mixed waste, instead of rinsing.

ID	Short name	Alterations of the baseline for quantification of the low and high scenarios
10	Washer dryer filters	Low scenario, 0.5% - 5% and High scenario, 38% - 50% increase in filter use for washer-dryer combinations with consequently reduced flows to wastewater.[c]
12	Vacuuming	Low scenario, 0.0006% - 0.95% and High scenario, 38% - 50% reduction in microplastics going to wastewater due to mopping.
13	Delicate washing cycle	Low scenario, 0.0003% - 0.56%[a] and High scenario, 22% - 29%[a] reduction of in use (wearing, drying, washing) emissions for regularly washed clothes. Low scenario 0.00005% – 0.08%[a] and High scenario 3.0% – 4.1 %[a] reduction of in use emissions for rarely washed clothes
14	Clothesline instead of dryer	Low scenario, 0.00067% - 1%, and high scenario, 1.1% - 21% increase in drying on clotheslines with the consequence that overall microfibre release due to not using a dryer is reduced (~0.000014%-0.43%)
15	Wastewater	Low scenario, 1.0% - 10% and High scenario, 75% - 99.9% reduction in releases from water treatment to surface water. Low scenario, 0.008% - 0.08% and High scenario, 0.64% - 0.85% increase in flow going to sludge from wastewater treatment.

a: The percentage is given for all in use releases, but the change only affects release during washing, e.g. the contribution of drying and wearing to in use releases goes up.
b: There are small differences between the VTD, CHPTD and CHETD type of dryers as the baseline estimate of rinsing the filters is estimated to differ (Mellink et al., in prep).
c: 30% of washer-dryer filters are still rinsed under running water based on average from Cummins et al. (2023).

Table S.17 Prodcom codes for workwear identified from the product description. Used for calculating the 'Replace' mitigation measure.

Prodcom code	Product_description	Category
14121120	Men's or boys' ensembles, of cotton or man-made fibres, for industrial and occupational wear	Jackets & coats
14121130	Men's or boys' jackets and blazers, of cotton or man-made fibres, for industrial and occupational wear	Jackets & coats
14121240	Men's or boys' trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear	Pants & shorts
14121250	Men's or boys' bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear	Pants & shorts

Prodcom code	Product_description	Category
14122120	Women’s or girls’ ensembles, of cotton or man-made fibres, for industrial or occupational wear	Jackets & coats
14122130	Women’s or girls’ jackets and blazers, of cotton or man-made fibres, for industrial or occupational wear	Jackets & coats
14122240	Women’s or girls’ trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear	Pants & shorts
14122250	Women’s or girls’ bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear	Pants & shorts

Appendix 4 Additional figures

Baseline emissions

Figure S.9 Micro- and macroplastic emissions to the environment for different major sources in the Netherlands, including updates for Clothing and Footwear as calculated using the DPMFA model. Violin plot with reference year 2022, the thickness of the curve indicates the frequency of data points: thicker means less uncertainty.

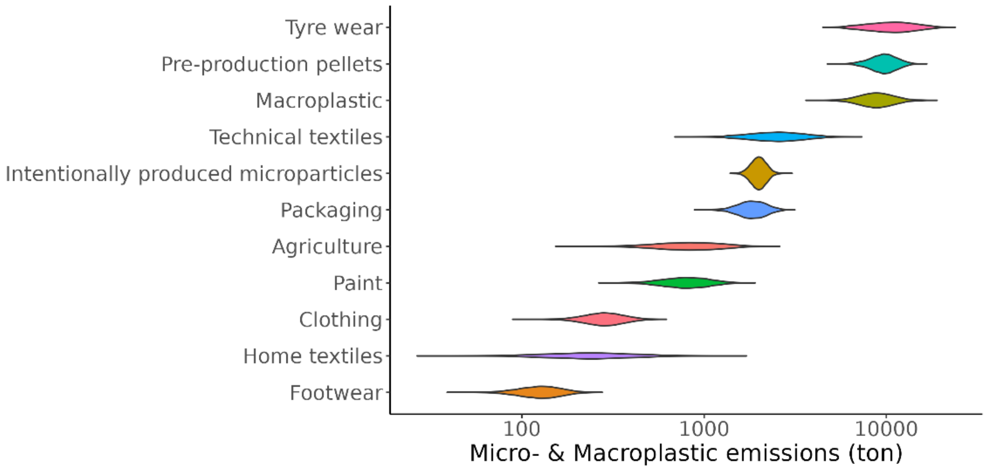


Figure S.10 Baseline emissions of microplastics from clothing and footwear categories to the environment for the Netherlands in 2050.

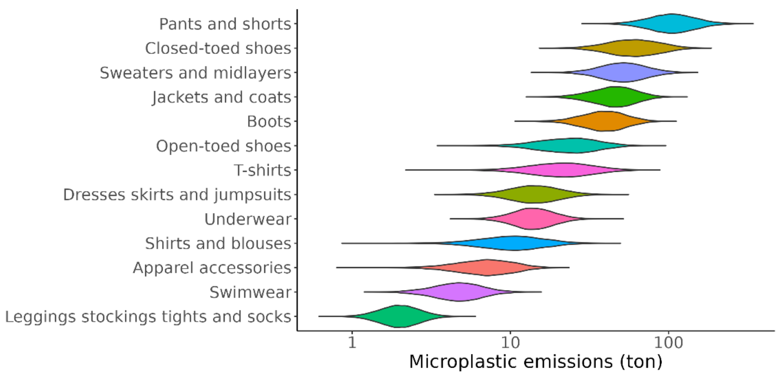
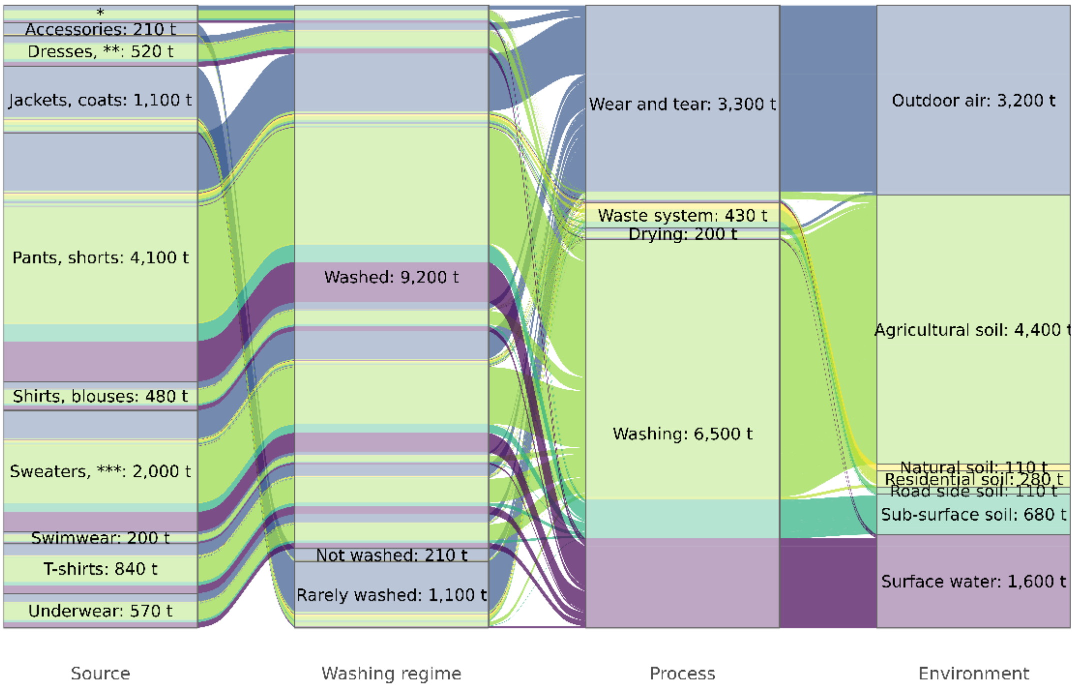


Figure S.11 Sankey diagram for median microplastic emissions to environmental compartments from clothing in the EU (2022) as calculated using the DPMFA model. Waste system represent the end of life flows.



*Leggings, stockings, tights and socks: 2.1 t
**Dresses, skirts and jumpsuits
***Sweaters and midlayers

Figure S.12 Sankey diagram for median microplastic emissions to the environment from footwear in the EU (2022) as calculated using the DPMFA model. Waste system represent the end of life flows.

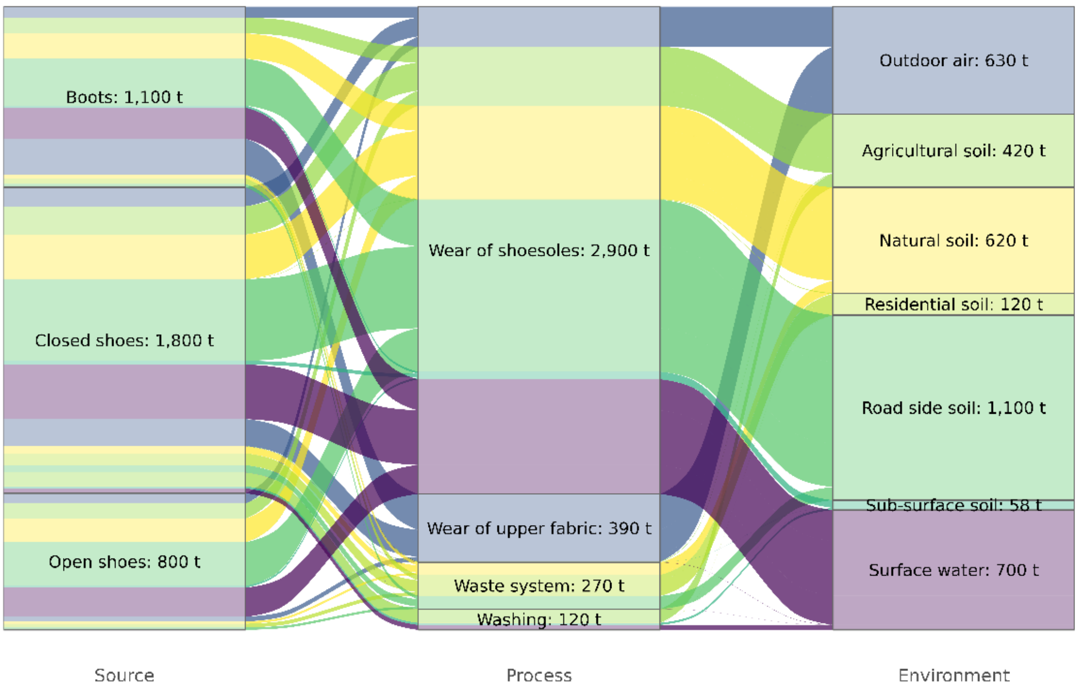


Figure S.13 Baseline emissions of micro- and macroplastics to the environment for the EU (2022).

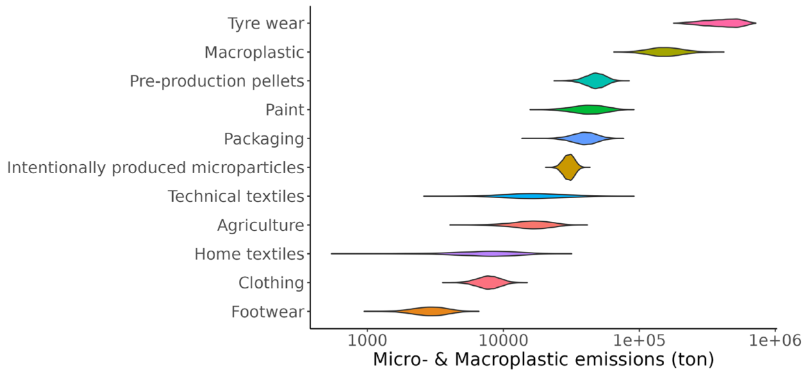


Figure S.14 Baseline emissions of microplastics from clothing categories to the environment for the EU (2022).

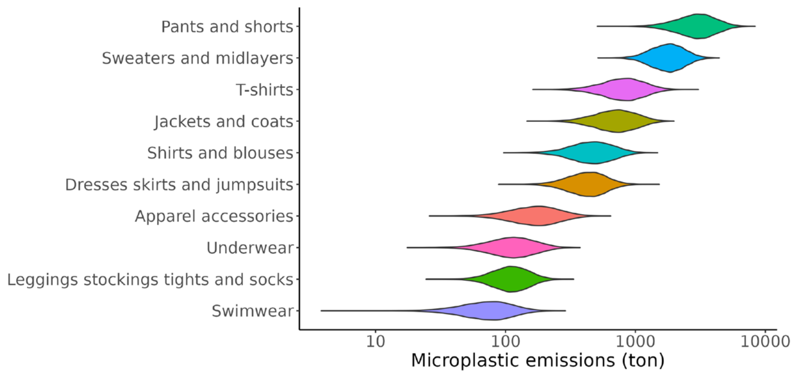


Figure S.15 Baseline emissions of microplastics from footwear categories to the environment for the EU (2022).

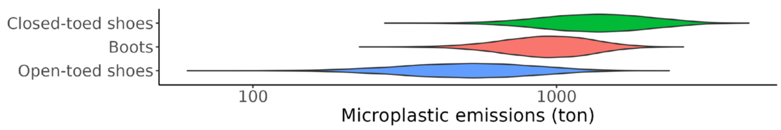
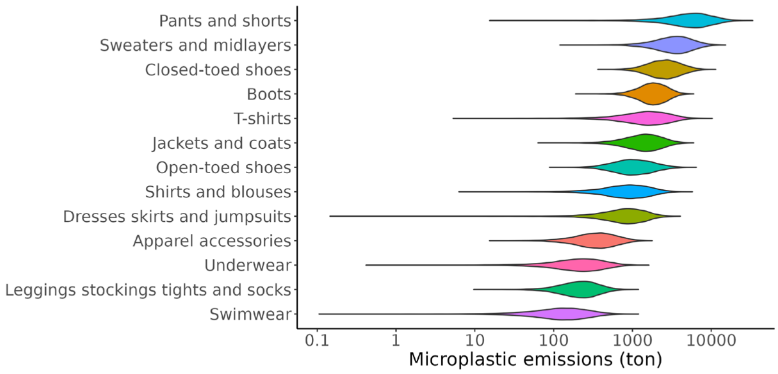


Figure S.16 Baseline emissions of microplastics from clothing and footwear categories to the environment for the EU (2050).



Mitigation measures

Figure S.17 Estimated reduction of microplastics emissions to the environment (air, soil and water) from the high intervention scenario for all mitigation measures. The 25th to 75th percentiles are shown ordered from low to high.

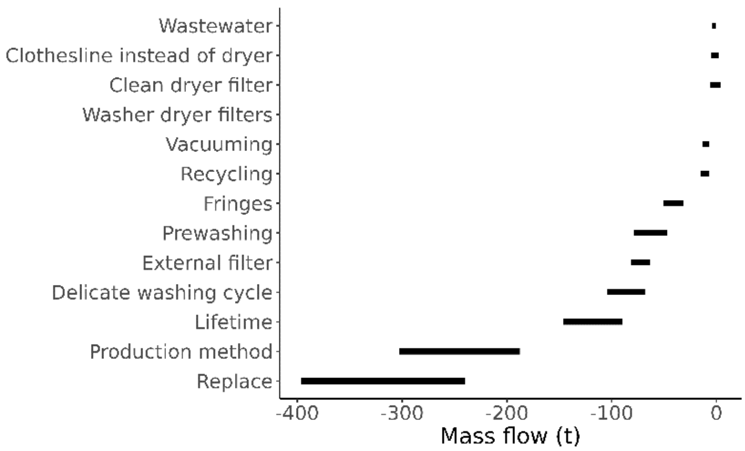
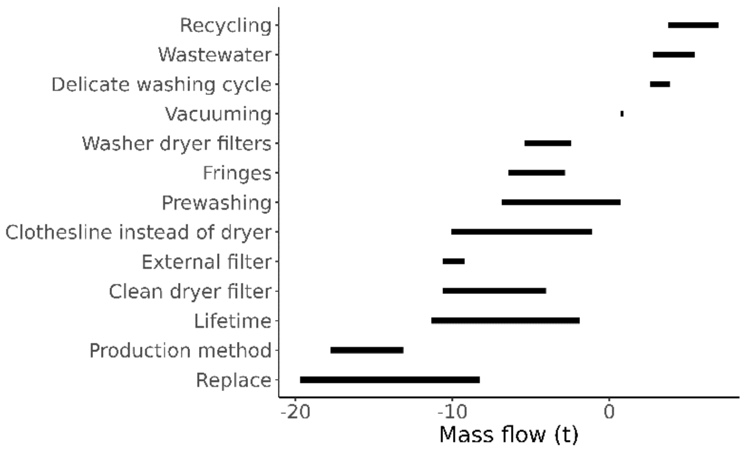


Figure S.18 Estimated reduction of microplastics emissions to the environment (air, soil and water) from the low intervention scenario for all mitigation measures. The 25th to 75th percentiles are shown ordered from low to high.



Global sensitivity analysis

A global sensitivity analysis was conducted using the Borgonovo moment-independent sensitivity importance measure (Borgonovo, 2007) to rank all uncertain transfer coefficients in terms of their contribution to uncertainty in the resulting mass flow of micro- and macro-plastics emitted to environmental compartments. This was done using the sensiFdiv function in the sensitivity package (Iooss et al., 2023) for R (R Core Team, 2025) as also applied in earlier work (Blanco et al., 2024; Quik et al., 2024). Future work should also include the uncertainty in input consumption and life time of different clothing categories.

Figure S.19 Part 1 Showing a heatmap of the Sobol indices (delta) from the global sensitivity analysis of input variation in transfer coefficient in relation to the sum of all masses emitted to environmental compartments (n=10.000). The higher the delta the higher the variation in the input explains the variation of the mass flows going to the environment.

Figure S.20 Part 2 Showing a heatmap of the Sobol indices (delta) from the global sensitivity analysis of input variation in transfer coefficient in relation to the sum of all masses emitted to environmental compartments (n=10.000). The higher the delta the higher the variation in the input explains the variation of the mass flows going to the environment.

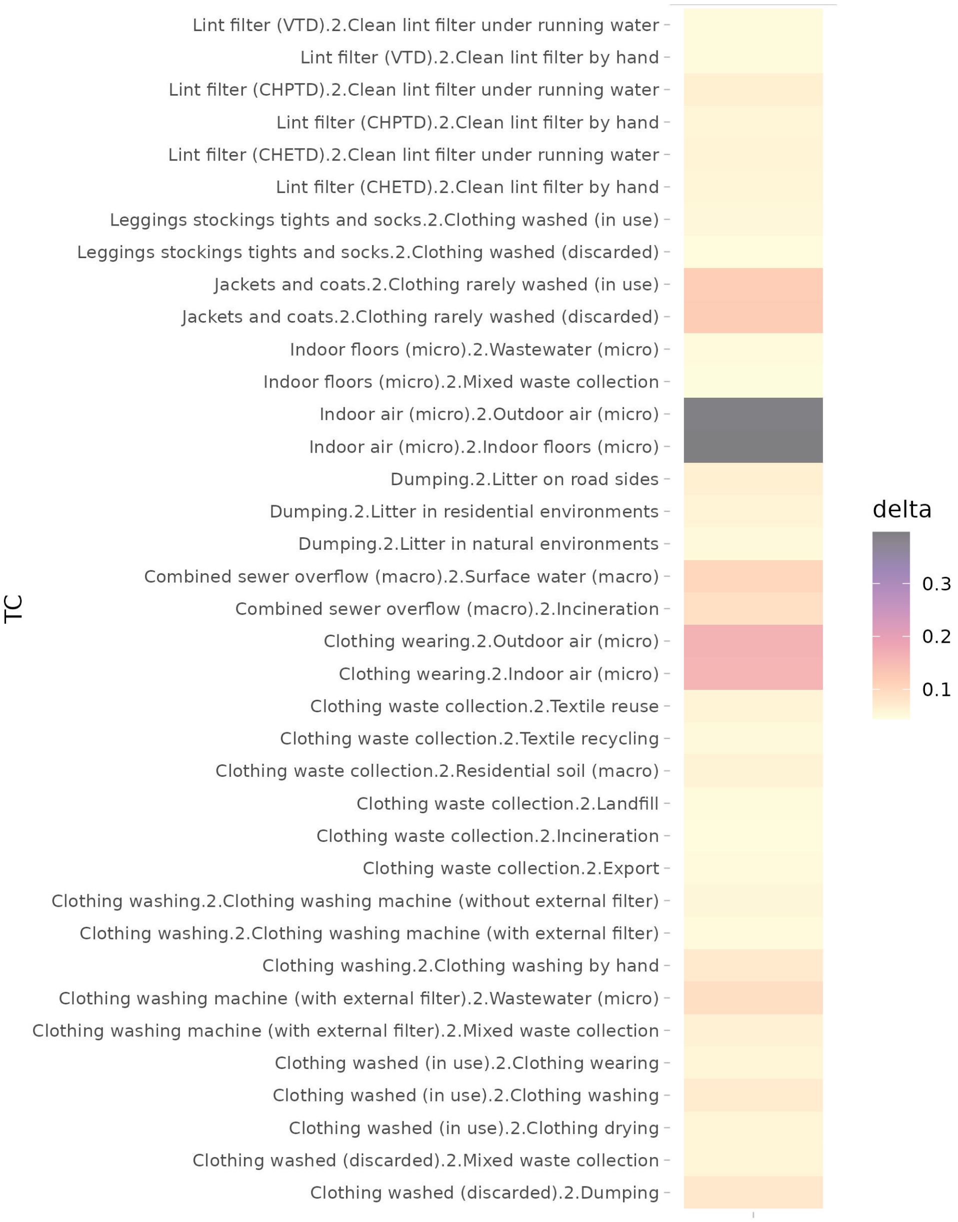
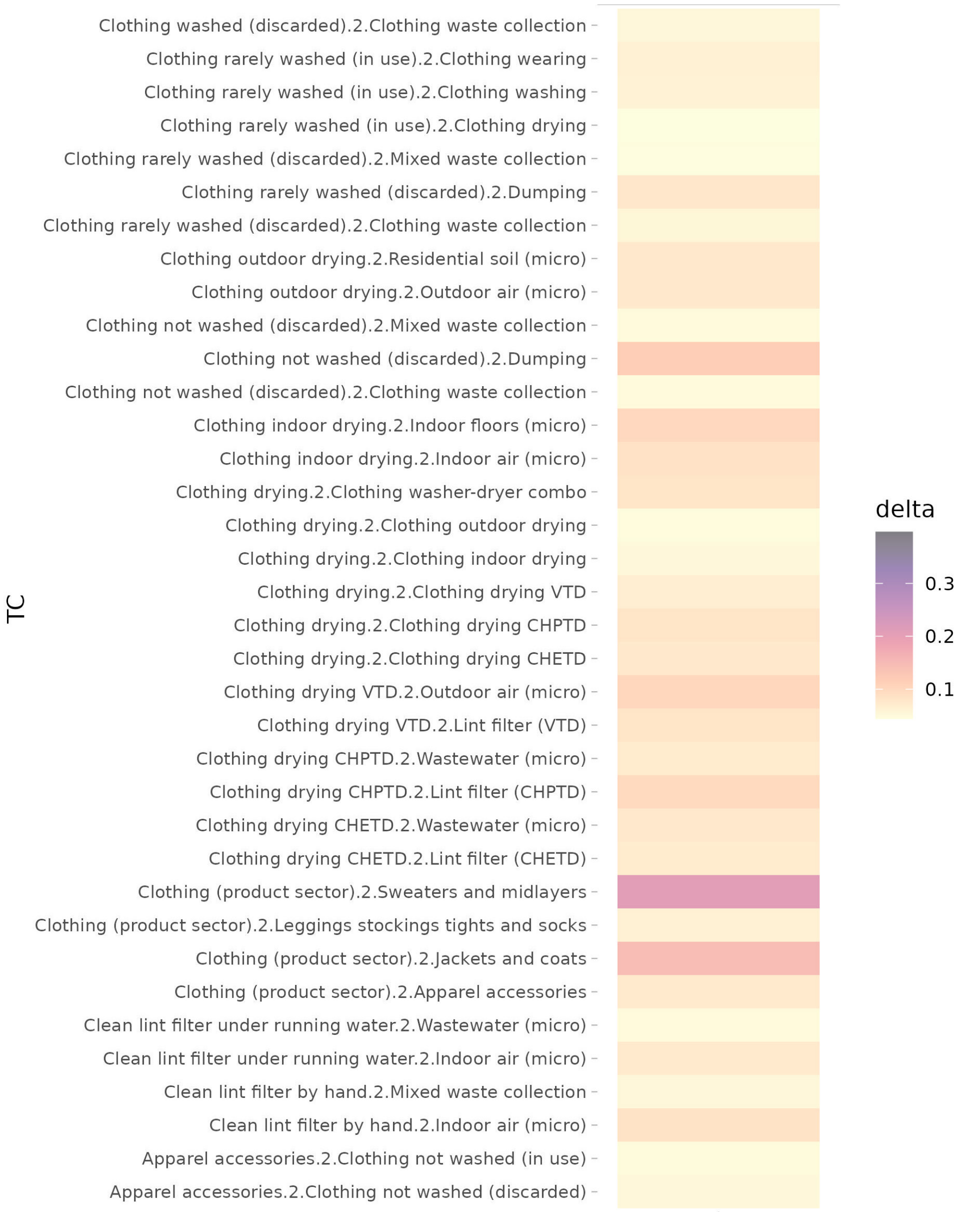


Figure S.21 Part 3 Showing a heatmap of the Sobol indices (delta) from the global sensitivity analysis of input variation in transfer coefficient in relation to the sum of all masses emitted to environmental compartments (n=10.000). The higher the delta the higher the variation in the input explains the variation of the mass flows going to the environment.



Appendix 5 Additional data tables

Table S.18 Data table for sankey (Figure 4). Each row in the table represents the median flow of plastics in tonnes from a clothing category, via a washing regime and process to a sink. Data for the Netherlands in 2022.

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Leggings, stockings, tights and socks	Washed	Drying	Outdoor air	2.44E-02
Leggings, stockings, tights and socks	Washed	Drying	Residential soil	1.15E-02
Leggings, stockings, tights and socks	Washed	Drying	Sub-surface soil	4.83E-03
Leggings, stockings, tights and socks	Washed	Drying	Surface water	1.02E-02
Leggings, stockings, tights and socks	Washed	Washing	Residential soil	3.48E-07
Leggings, stockings, tights and socks	Washed	Washing	Sub-surface soil	2.81E-01
Leggings, stockings, tights and socks	Washed	Washing	Surface water	5.94E-01
Leggings, stockings, tights and socks	Washed	Waste system	Natural soil	3.19E-02
Leggings, stockings, tights and socks	Washed	Waste system	Outdoor air	1.62E-05
Leggings, stockings, tights and socks	Washed	Waste system	Residential soil	5.84E-02
Leggings, stockings, tights and socks	Washed	Waste system	Road side soil	3.31E-02
Leggings, stockings, tights and socks	Washed	Waste system	Sub-surface soil	8.22E-07
Leggings, stockings, tights and socks	Washed	Waste system	Surface water	1.91E-04
Leggings, stockings, tights and socks	Washed	Wear and tear	Outdoor air	9.22E-01

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Leggings, stockings, tights and socks	Washed	Wear and tear	Residential soil	5.85E-05
Leggings, stockings, tights and socks	Washed	Wear and tear	Sub-surface soil	5.37E-03
Leggings, stockings, tights and socks	Washed	Wear and tear	Surface water	1.14E-02
Accessories	Not washed	Waste system	Natural soil	2.38E-01
Accessories	Not washed	Waste system	Outdoor air	1.21E-04
Accessories	Not washed	Waste system	Residential soil	4.45E-01
Accessories	Not washed	Waste system	Road side soil	2.42E-01
Accessories	Not washed	Waste system	Sub-surface soil	5.93E-06
Accessories	Not washed	Waste system	Surface water	1.42E-03
Accessories	Not washed	Wear and tear	Outdoor air	6.73E+00
Accessories	Not washed	Wear and tear	Residential soil	4.22E-04
Accessories	Not washed	Wear and tear	Sub-surface soil	3.81E-02
Accessories	Not washed	Wear and tear	Surface water	8.13E-02
Dresses, skirts and jumpsuits	Washed	Drying	Outdoor air	1.65E-01
Dresses, skirts and jumpsuits	Washed	Drying	Residential soil	7.43E-02
Dresses, skirts and jumpsuits	Washed	Drying	Sub-surface soil	3.26E-02
Dresses, skirts and jumpsuits	Washed	Drying	Surface water	6.71E-02
Dresses, skirts and jumpsuits	Washed	Washing	Residential soil	2.04E-06
Dresses, skirts and jumpsuits	Washed	Washing	Sub-surface soil	1.93E+00
Dresses, skirts and jumpsuits	Washed	Washing	Surface water	3.99E+00
Dresses, skirts and jumpsuits	Washed	Waste system	Natural soil	2.24E-01
Dresses, skirts and jumpsuits	Washed	Waste system	Outdoor air	1.12E-04
Dresses, skirts and jumpsuits	Washed	Waste system	Residential soil	4.18E-01

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Dresses, skirts and jumpsuits	Washed	Waste system	Road side soil	2.13E-01
Dresses, skirts and jumpsuits	Washed	Waste system	Sub-surface soil	5.15E-06
Dresses, skirts and jumpsuits	Washed	Waste system	Surface water	1.25E-03
Dresses, skirts and jumpsuits	Washed	Wear and tear	Outdoor air	6.38E+00
Dresses, skirts and jumpsuits	Washed	Wear and tear	Residential soil	3.81E-04
Dresses, skirts and jumpsuits	Washed	Wear and tear	Sub-surface soil	3.40E-02
Dresses, skirts and jumpsuits	Washed	Wear and tear	Surface water	7.04E-02
Jackets, coats	Rarely washed	Drying	Outdoor air	4.24E-02
Jackets, coats	Rarely washed	Drying	Residential soil	1.98E-02
Jackets, coats	Rarely washed	Drying	Sub-surface soil	8.44E-03
Jackets, coats	Rarely washed	Drying	Surface water	1.78E-02
Jackets, coats	Rarely washed	Washing	Residential soil	6.04E-07
Jackets, coats	Rarely washed	Washing	Sub-surface soil	5.04E-01
Jackets, coats	Rarely washed	Washing	Surface water	1.07E+00
Jackets, coats	Rarely washed	Waste system	Natural soil	1.54E+00
Jackets, coats	Rarely washed	Waste system	Outdoor air	7.78E-04
Jackets, coats	Rarely washed	Waste system	Residential soil	2.81E+00
Jackets, coats	Rarely washed	Waste system	Road side soil	1.55E+00
Jackets, coats	Rarely washed	Waste system	Sub-surface soil	3.82E-05
Jackets, coats	Rarely washed	Waste system	Surface water	9.11E-03
Jackets, coats	Rarely washed	Wear and tear	Outdoor air	4.23E+01
Jackets, coats	Rarely washed	Wear and tear	Residential soil	2.63E-03
Jackets, coats	Rarely washed	Wear and tear	Sub-surface soil	2.41E-01
Jackets, coats	Rarely washed	Wear and tear	Surface water	5.13E-01
Pants, shorts	Washed	Drying	Outdoor air	1.23E+00

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Pants, shorts	Washed	Drying	Residential soil	5.60E-01
Pants, shorts	Washed	Drying	Sub-surface soil	2.43E-01
Pants, shorts	Washed	Drying	Surface water	5.07E-01
Pants, shorts	Washed	Washing	Residential soil	1.58E-05
Pants, shorts	Washed	Washing	Sub-surface soil	1.45E+01
Pants, shorts	Washed	Washing	Surface water	3.01E+01
Pants, shorts	Washed	Waste system	Natural soil	1.64E+00
Pants, shorts	Washed	Waste system	Outdoor air	8.27E-04
Pants, shorts	Washed	Waste system	Residential soil	3.08E+00
Pants, shorts	Washed	Waste system	Road side soil	1.61E+00
Pants, shorts	Washed	Waste system	Sub-surface soil	3.93E-05
Pants, shorts	Washed	Waste system	Surface water	9.47E-03
Pants, shorts	Washed	Wear and tear	Outdoor air	4.76E+01
Pants, shorts	Washed	Wear and tear	Residential soil	2.86E-03
Pants, shorts	Washed	Wear and tear	Sub-surface soil	2.61E-01
Pants, shorts	Washed	Wear and tear	Surface water	5.46E-01
Shirts, blouses	Washed	Drying	Outdoor air	1.17E-01
Shirts, blouses	Washed	Drying	Residential soil	5.15E-02
Shirts, blouses	Washed	Drying	Sub-surface soil	2.33E-02
Shirts, blouses	Washed	Drying	Surface water	4.68E-02
Shirts, blouses	Washed	Washing	Residential soil	1.33E-06
Shirts, blouses	Washed	Washing	Sub-surface soil	1.39E+00
Shirts, blouses	Washed	Washing	Surface water	2.81E+00
Shirts, blouses	Washed	Waste system	Natural soil	1.61E-01
Shirts, blouses	Washed	Waste system	Outdoor air	7.91E-05
Shirts, blouses	Washed	Waste system	Residential soil	3.05E-01
Shirts, blouses	Washed	Waste system	Road side soil	1.50E-01

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Shirts, blouses	Washed	Waste system	Sub-surface soil	3.53E-06
Shirts, blouses	Washed	Waste system	Surface water	8.79E-04
Shirts, blouses	Washed	Wear and tear	Outdoor air	4.56E+00
Shirts, blouses	Washed	Wear and tear	Residential soil	2.68E-04
Shirts, blouses	Washed	Wear and tear	Sub-surface soil	2.34E-02
Shirts, blouses	Washed	Wear and tear	Surface water	4.76E-02
Sweaters, midlayers	Washed	Drying	Outdoor air	6.08E-01
Sweaters, midlayers	Washed	Drying	Residential soil	2.80E-01
Sweaters, midlayers	Washed	Drying	Sub-surface soil	1.22E-01
Sweaters, midlayers	Washed	Drying	Surface water	2.54E-01
Sweaters, midlayers	Washed	Washing	Residential soil	7.98E-06
Sweaters, midlayers	Washed	Washing	Sub-surface soil	7.12E+00
Sweaters, midlayers	Washed	Washing	Surface water	1.49E+01
Sweaters, midlayers	Washed	Waste system	Natural soil	8.24E-01
Sweaters, midlayers	Washed	Waste system	Outdoor air	4.08E-04
Sweaters, midlayers	Washed	Waste system	Residential soil	1.52E+00
Sweaters, midlayers	Washed	Waste system	Road side soil	8.01E-01
Sweaters, midlayers	Washed	Waste system	Sub-surface soil	1.96E-05
Sweaters, midlayers	Washed	Waste system	Surface water	4.71E-03
Sweaters, midlayers	Washed	Wear and tear	Outdoor air	2.34E+01
Sweaters, midlayers	Washed	Wear and tear	Residential soil	1.43E-03
Sweaters, midlayers	Washed	Wear and tear	Sub-surface soil	1.29E-01
Sweaters, midlayers	Washed	Wear and tear	Surface water	2.70E-01
Swimwear	Washed	Drying	Outdoor air	5.58E-02
Swimwear	Washed	Drying	Residential soil	2.59E-02

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Swimwear	Washed	Drying	Sub-surface soil	1.10E-02
Swimwear	Washed	Drying	Surface water	2.30E-02
Swimwear	Washed	Washing	Residential soil	7.62E-07
Swimwear	Washed	Washing	Sub-surface soil	6.43E-01
Swimwear	Washed	Washing	Surface water	1.35E+00
Swimwear	Washed	Waste system	Natural soil	7.26E-02
Swimwear	Washed	Waste system	Outdoor air	3.71E-05
Swimwear	Washed	Waste system	Residential soil	1.36E-01
Swimwear	Washed	Waste system	Road side soil	7.40E-02
Swimwear	Washed	Waste system	Sub-surface soil	1.84E-06
Swimwear	Washed	Waste system	Surface water	4.32E-04
Swimwear	Washed	Wear and tear	Outdoor air	2.12E+00
Swimwear	Washed	Wear and tear	Residential soil	1.32E-04
Swimwear	Washed	Wear and tear	Sub-surface soil	1.21E-02
Swimwear	Washed	Wear and tear	Surface water	2.56E-02
T-shirts	Washed	Drying	Outdoor air	2.39E-01
T-shirts	Washed	Drying	Residential soil	1.05E-01
T-shirts	Washed	Drying	Sub-surface soil	4.77E-02
T-shirts	Washed	Drying	Surface water	9.72E-02
T-shirts	Washed	Washing	Residential soil	2.79E-06
T-shirts	Washed	Washing	Sub-surface soil	2.86E+00
T-shirts	Washed	Washing	Surface water	5.77E+00
T-shirts	Washed	Waste system	Natural soil	3.26E-01
T-shirts	Washed	Waste system	Outdoor air	1.61E-04
T-shirts	Washed	Waste system	Residential soil	6.23E-01
T-shirts	Washed	Waste system	Road side soil	3.08E-01
T-shirts	Washed	Waste system	Sub-surface soil	7.21E-06

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
T-shirts	Washed	Waste system	Surface water	1.81E-03
T-shirts	Washed	Wear and tear	Outdoor air	9.38E+00
T-shirts	Washed	Wear and tear	Residential soil	5.47E-04
T-shirts	Washed	Wear and tear	Sub-surface soil	4.76E-02
T-shirts	Washed	Wear and tear	Surface water	9.80E-02
Underwear	Washed	Drying	Outdoor air	1.68E-01
Underwear	Washed	Drying	Residential soil	7.98E-02
Underwear	Washed	Drying	Sub-surface soil	3.33E-02
Underwear	Washed	Drying	Surface water	7.04E-02
Underwear	Washed	Washing	Residential soil	2.36E-06
Underwear	Washed	Washing	Sub-surface soil	1.94E+00
Underwear	Washed	Washing	Surface water	4.10E+00
Underwear	Washed	Waste system	Natural soil	2.21E-01
Underwear	Washed	Waste system	Outdoor air	1.12E-04
Underwear	Washed	Waste system	Residential soil	4.08E-01
Underwear	Washed	Waste system	Road side soil	2.28E-01
Underwear	Washed	Waste system	Sub-surface soil	5.68E-06
Underwear	Washed	Waste system	Surface water	1.33E-03
Underwear	Washed	Wear and tear	Outdoor air	6.42E+00
Underwear	Washed	Wear and tear	Residential soil	4.03E-04
Underwear	Washed	Wear and tear	Sub-surface soil	3.73E-02
Underwear	Washed	Wear and tear	Surface water	7.84E-02

Table S.19 Data table for sankey (Figure 6). Each row in the table represents the median flow of plastics in tonnes from a footwear category, via a process to a sink. Data for the Netherlands in 2022.

Footwear category	Process	Sink	Mean mass (tonnes)
Boots	Waste system	Natural soil	8.14E-01
Boots	Waste system	Outdoor air	3.58E-06
Boots	Waste system	Residential soil	1.36E+00
Boots	Waste system	Road side soil	8.57E-01
Boots	Waste system	Sub-surface soil	1.83E-07
Boots	Waste system	Surface water	4.95E-03
Boots	Wear of shoesoles	Natural soil	6.09E+00
Boots	Wear of shoesoles	Outdoor air	2.62E+00
Boots	Wear of shoesoles	Residential soil	1.62E-03
Boots	Wear of shoesoles	Road side soil	1.13E+01
Boots	Wear of shoesoles	Sub-surface soil	4.99E-01
Boots	Wear of shoesoles	Surface water	7.48E+00
Boots	Wear of upper fabric	Outdoor air	9.60E+00
Boots	Wear of upper fabric	Residential soil	1.34E-04
Boots	Wear of upper fabric	Sub-surface soil	1.21E-02
Boots	Wear of upper fabric	Surface water	2.56E-02
Closed shoes	Washing	Residential soil	6.69E-07
Closed shoes	Washing	Sub-surface soil	5.30E-01
Closed shoes	Washing	Surface water	1.13E+00
Closed shoes	Waste system	Natural soil	1.76E+00
Closed shoes	Waste system	Outdoor air	7.71E-06
Closed shoes	Waste system	Residential soil	2.94E+00
Closed shoes	Waste system	Road side soil	1.84E+00
Closed shoes	Waste system	Sub-surface soil	3.91E-07
Closed shoes	Waste system	Surface water	1.07E-02
Closed shoes	Wear of shoesoles	Natural soil	1.08E+01
Closed shoes	Wear of shoesoles	Outdoor air	4.57E+00
Closed shoes	Wear of shoesoles	Residential soil	2.83E-03
Closed shoes	Wear of shoesoles	Road side soil	1.97E+01
Closed shoes	Wear of shoesoles	Sub-surface soil	8.76E-01
Closed shoes	Wear of shoesoles	Surface water	1.31E+01

Footwear category	Process	Sink	Mean mass (tonnes)
Closed shoes	Wear of upper fabric	Outdoor air	6.90E+00
Closed shoes	Wear of upper fabric	Residential soil	1.05E-04
Closed shoes	Wear of upper fabric	Sub-surface soil	9.52E-03
Closed shoes	Wear of upper fabric	Surface water	2.01E-02
Open shoes	Waste system	Natural soil	4.38E-01
Open shoes	Waste system	Outdoor air	1.91E-06
Open shoes	Waste system	Residential soil	7.35E-01
Open shoes	Waste system	Road side soil	4.58E-01
Open shoes	Waste system	Sub-surface soil	9.74E-08
Open shoes	Waste system	Surface water	2.65E-03
Open shoes	Wear of shoesoles	Natural soil	4.65E+00
Open shoes	Wear of shoesoles	Outdoor air	1.99E+00
Open shoes	Wear of shoesoles	Residential soil	1.20E-03
Open shoes	Wear of shoesoles	Road side soil	8.59E+00
Open shoes	Wear of shoesoles	Sub-surface soil	3.75E-01
Open shoes	Wear of shoesoles	Surface water	5.66E+00
Open shoes	Wear of upper fabric	Outdoor air	9.93E-01
Open shoes	Wear of upper fabric	Residential soil	1.30E-05
Open shoes	Wear of upper fabric	Sub-surface soil	1.13E-03
Open shoes	Wear of upper fabric	Surface water	2.33E-03

Table S.20 Data table for sankey (Figure S 11). Each row in the table represents the median flow of plastics in tonnes from a clothing category, via a washing regime and process to a sink. Data for the EU in 2022.

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Leggings, stockings, tights and socks	Washed	Drying	Agricultural soil	2.24E+00
Leggings, stockings, tights and socks	Washed	Drying	Outdoor air	1.73E+00
Leggings, stockings, tights and socks	Washed	Drying	Residential soil	8.55E-01
Leggings, stockings, tights and socks	Washed	Drying	Sub-surface soil	3.41E-01

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Leggings, stockings, tights and socks	Washed	Drying	Surface water	7.93E-01
Leggings, stockings, tights and socks	Washed	Washing	Agricultural soil	1.30E+02
Leggings, stockings, tights and socks	Washed	Washing	Residential soil	1.48E+00
Leggings, stockings, tights and socks	Washed	Washing	Sub-surface soil	1.99E+01
Leggings, stockings, tights and socks	Washed	Washing	Surface water	4.59E+01
Leggings, stockings, tights and socks	Washed	Waste system	Agricultural soil	1.34E-03
Leggings, stockings, tights and socks	Washed	Waste system	Natural soil	2.28E+00
Leggings, stockings, tights and socks	Washed	Waste system	Outdoor air	1.14E-03
Leggings, stockings, tights and socks	Washed	Waste system	Residential soil	4.16E+00
Leggings, stockings, tights and socks	Washed	Waste system	Road side soil	2.36E+00
Leggings, stockings, tights and socks	Washed	Waste system	Sub-surface soil	5.80E-05
Leggings, stockings, tights and socks	Washed	Waste system	Surface water	1.37E-02
Leggings, stockings, tights and socks	Washed	Wear and tear	Agricultural soil	2.54E+00
Leggings, stockings, tights and socks	Washed	Wear and tear	Outdoor air	6.53E+01
Leggings, stockings, tights and socks	Washed	Wear and tear	Residential soil	3.33E-02
Leggings, stockings, tights and socks	Washed	Wear and tear	Sub-surface soil	3.80E-01

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Leggings, stockings, tights and socks	Washed	Wear and tear	Surface water	8.84E-01
Accessories	Not washed	Waste system	Agricultural soil	3.43E-03
Accessories	Not washed	Waste system	Natural soil	6.19E+00
Accessories	Not washed	Waste system	Outdoor air	3.07E-03
Accessories	Not washed	Waste system	Residential soil	1.15E+01
Accessories	Not washed	Waste system	Road side soil	6.31E+00
Accessories	Not washed	Waste system	Sub-surface soil	1.55E-04
Accessories	Not washed	Waste system	Surface water	3.72E-02
Accessories	Not washed	Wear and tear	Agricultural soil	6.69E+00
Accessories	Not washed	Wear and tear	Outdoor air	1.74E+02
Accessories	Not washed	Wear and tear	Residential soil	8.69E-02
Accessories	Not washed	Wear and tear	Sub-surface soil	9.96E-01
Accessories	Not washed	Wear and tear	Surface water	2.33E+00
Dresses, skirts and jumpsuits	Washed	Drying	Agricultural soil	3.93E+00
Dresses, skirts and jumpsuits	Washed	Drying	Outdoor air	2.92E+00
Dresses, skirts and jumpsuits	Washed	Drying	Residential soil	1.39E+00
Dresses, skirts and jumpsuits	Washed	Drying	Sub-surface soil	5.95E-01
Dresses, skirts and jumpsuits	Washed	Drying	Surface water	1.36E+00
Dresses, skirts and jumpsuits	Washed	Washing	Agricultural soil	2.33E+02
Dresses, skirts and jumpsuits	Washed	Washing	Residential soil	2.59E+00
Dresses, skirts and jumpsuits	Washed	Washing	Sub-surface soil	3.49E+01
Dresses, skirts and jumpsuits	Washed	Washing	Surface water	8.05E+01
Dresses, skirts and jumpsuits	Washed	Waste system	Agricultural soil	1.98E-03
Dresses, skirts and jumpsuits	Washed	Waste system	Natural soil	4.01E+00

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Dresses, skirts and jumpsuits	Washed	Waste system	Outdoor air	1.99E-03
Dresses, skirts and jumpsuits	Washed	Waste system	Residential soil	7.51E+00
Dresses, skirts and jumpsuits	Washed	Waste system	Road side soil	3.87E+00
Dresses, skirts and jumpsuits	Washed	Waste system	Sub-surface soil	9.39E-05
Dresses, skirts and jumpsuits	Washed	Waste system	Surface water	2.27E-02
Dresses, skirts and jumpsuits	Washed	Wear and tear	Agricultural soil	4.27E+00
Dresses, skirts and jumpsuits	Washed	Wear and tear	Outdoor air	1.15E+02
Dresses, skirts and jumpsuits	Washed	Wear and tear	Residential soil	5.54E-02
Dresses, skirts and jumpsuits	Washed	Wear and tear	Sub-surface soil	6.22E-01
Dresses, skirts and jumpsuits	Washed	Wear and tear	Surface water	1.44E+00
Jackets, coats	Rarely washed	Drying	Agricultural soil	1.06E+00
Jackets, coats	Rarely washed	Drying	Outdoor air	8.22E-01
Jackets, coats	Rarely washed	Drying	Residential soil	4.01E-01
Jackets, coats	Rarely washed	Drying	Sub-surface soil	1.63E-01
Jackets, coats	Rarely washed	Drying	Surface water	3.77E-01
Jackets, coats	Rarely washed	Washing	Agricultural soil	6.34E+01
Jackets, coats	Rarely washed	Washing	Residential soil	7.24E-01
Jackets, coats	Rarely washed	Washing	Sub-surface soil	9.75E+00
Jackets, coats	Rarely washed	Washing	Surface water	2.26E+01
Jackets, coats	Rarely washed	Waste system	Agricultural soil	1.67E-02
Jackets, coats	Rarely washed	Waste system	Natural soil	2.95E+01
Jackets, coats	Rarely washed	Waste system	Outdoor air	1.47E-02
Jackets, coats	Rarely washed	Waste system	Residential soil	5.39E+01
Jackets, coats	Rarely washed	Waste system	Road side soil	3.02E+01
Jackets, coats	Rarely washed	Waste system	Sub-surface soil	7.45E-04

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Jackets, coats	Rarely washed	Waste system	Surface water	1.77E-01
Jackets, coats	Rarely washed	Wear and tear	Agricultural soil	3.12E+01
Jackets, coats	Rarely washed	Wear and tear	Outdoor air	8.11E+02
Jackets, coats	Rarely washed	Wear and tear	Residential soil	4.09E-01
Jackets, coats	Rarely washed	Wear and tear	Sub-surface soil	4.66E+00
Jackets, coats	Rarely washed	Wear and tear	Surface water	1.09E+01
Pants, shorts	Washed	Drying	Agricultural soil	3.17E+01
Pants, shorts	Washed	Drying	Outdoor air	2.40E+01
Pants, shorts	Washed	Drying	Residential soil	1.15E+01
Pants, shorts	Washed	Drying	Sub-surface soil	4.77E+00
Pants, shorts	Washed	Drying	Surface water	1.11E+01
Pants, shorts	Washed	Washing	Agricultural soil	1.87E+03
Pants, shorts	Washed	Washing	Residential soil	2.08E+01
Pants, shorts	Washed	Washing	Sub-surface soil	2.81E+02
Pants, shorts	Washed	Washing	Surface water	6.52E+02
Pants, shorts	Washed	Waste system	Agricultural soil	1.73E-02
Pants, shorts	Washed	Waste system	Natural soil	3.25E+01
Pants, shorts	Washed	Waste system	Outdoor air	1.60E-02
Pants, shorts	Washed	Waste system	Residential soil	6.02E+01
Pants, shorts	Washed	Waste system	Road side soil	3.16E+01
Pants, shorts	Washed	Waste system	Sub-surface soil	7.68E-04
Pants, shorts	Washed	Waste system	Surface water	1.87E-01
Pants, shorts	Washed	Wear and tear	Agricultural soil	3.49E+01
Pants, shorts	Washed	Wear and tear	Outdoor air	9.26E+02
Pants, shorts	Washed	Wear and tear	Residential soil	4.54E-01
Pants, shorts	Washed	Wear and tear	Sub-surface soil	5.13E+00

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Pants, shorts	Washed	Wear and tear	Surface water	1.19E+01
Shirts, blouses	Washed	Drying	Agricultural soil	3.66E+00
Shirts, blouses	Washed	Drying	Outdoor air	2.68E+00
Shirts, blouses	Washed	Drying	Residential soil	1.23E+00
Shirts, blouses	Washed	Drying	Sub-surface soil	5.48E-01
Shirts, blouses	Washed	Drying	Surface water	1.25E+00
Shirts, blouses	Washed	Washing	Agricultural soil	2.18E+02
Shirts, blouses	Washed	Washing	Residential soil	2.42E+00
Shirts, blouses	Washed	Washing	Sub-surface soil	3.24E+01
Shirts, blouses	Washed	Washing	Surface water	7.48E+01
Shirts, blouses	Washed	Waste system	Agricultural soil	1.69E-03
Shirts, blouses	Washed	Waste system	Natural soil	3.73E+00
Shirts, blouses	Washed	Waste system	Outdoor air	1.83E-03
Shirts, blouses	Washed	Waste system	Residential soil	7.15E+00
Shirts, blouses	Washed	Waste system	Road side soil	3.50E+00
Shirts, blouses	Washed	Waste system	Sub-surface soil	8.31E-05
Shirts, blouses	Washed	Waste system	Surface water	2.04E-02
Shirts, blouses	Washed	Wear and tear	Agricultural soil	3.86E+00
Shirts, blouses	Washed	Wear and tear	Outdoor air	1.06E+02
Shirts, blouses	Washed	Wear and tear	Residential soil	5.00E-02
Shirts, blouses	Washed	Wear and tear	Sub-surface soil	5.42E-01
Shirts, blouses	Washed	Wear and tear	Surface water	1.28E+00
Sweaters, midlayers	Washed	Drying	Agricultural soil	1.55E+01
Sweaters, midlayers	Washed	Drying	Outdoor air	1.17E+01
Sweaters, midlayers	Washed	Drying	Residential soil	5.56E+00
Sweaters, midlayers	Washed	Drying	Sub-surface soil	2.35E+00

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Sweaters, midlayers	Washed	Drying	Surface water	5.41E+00
Sweaters, midlayers	Washed	Washing	Agricultural soil	9.13E+02
Sweaters, midlayers	Washed	Washing	Residential soil	1.02E+01
Sweaters, midlayers	Washed	Washing	Sub-surface soil	1.38E+02
Sweaters, midlayers	Washed	Washing	Surface water	3.15E+02
Sweaters, midlayers	Washed	Waste system	Agricultural soil	8.23E-03
Sweaters, midlayers	Washed	Waste system	Natural soil	1.59E+01
Sweaters, midlayers	Washed	Waste system	Outdoor air	7.88E-03
Sweaters, midlayers	Washed	Waste system	Residential soil	2.96E+01
Sweaters, midlayers	Washed	Waste system	Road side soil	1.56E+01
Sweaters, midlayers	Washed	Waste system	Sub-surface soil	3.79E-04
Sweaters, midlayers	Washed	Waste system	Surface water	9.11E-02
Sweaters, midlayers	Washed	Wear and tear	Agricultural soil	1.71E+01
Sweaters, midlayers	Washed	Wear and tear	Outdoor air	4.50E+02
Sweaters, midlayers	Washed	Wear and tear	Residential soil	2.21E-01
Sweaters, midlayers	Washed	Wear and tear	Sub-surface soil	2.49E+00
Sweaters, midlayers	Washed	Wear and tear	Surface water	5.86E+00
Swimwear	Washed	Drying	Agricultural soil	1.54E+00
Swimwear	Washed	Drying	Outdoor air	1.18E+00
Swimwear	Washed	Drying	Residential soil	5.75E-01
Swimwear	Washed	Drying	Sub-surface soil	2.34E-01
Swimwear	Washed	Drying	Surface water	5.42E-01
Swimwear	Washed	Washing	Agricultural soil	8.96E+01
Swimwear	Washed	Washing	Residential soil	1.02E+00
Swimwear	Washed	Washing	Sub-surface soil	1.36E+01
Swimwear	Washed	Washing	Surface water	3.15E+01

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Swimwear	Washed	Waste system	Agricultural soil	8.72E-04
Swimwear	Washed	Waste system	Natural soil	1.57E+00
Swimwear	Washed	Waste system	Outdoor air	7.77E-04
Swimwear	Washed	Waste system	Residential soil	2.89E+00
Swimwear	Washed	Waste system	Road side soil	1.60E+00
Swimwear	Washed	Waste system	Sub-surface soil	3.85E-05
Swimwear	Washed	Waste system	Surface water	9.32E-03
Swimwear	Washed	Wear and tear	Agricultural soil	1.73E+00
Swimwear	Washed	Wear and tear	Outdoor air	4.50E+01
Swimwear	Washed	Wear and tear	Residential soil	2.26E-02
Swimwear	Washed	Wear and tear	Sub-surface soil	2.56E-01
Swimwear	Washed	Wear and tear	Surface water	6.00E-01
T-shirts	Washed	Drying	Agricultural soil	6.37E+00
T-shirts	Washed	Drying	Outdoor air	4.69E+00
T-shirts	Washed	Drying	Residential soil	2.14E+00
T-shirts	Washed	Drying	Sub-surface soil	9.40E-01
T-shirts	Washed	Drying	Surface water	2.15E+00
T-shirts	Washed	Washing	Agricultural soil	3.79E+02
T-shirts	Washed	Washing	Residential soil	4.22E+00
T-shirts	Washed	Washing	Sub-surface soil	5.59E+01
T-shirts	Washed	Washing	Surface water	1.29E+02
T-shirts	Washed	Waste system	Agricultural soil	2.93E-03
T-shirts	Washed	Waste system	Natural soil	6.46E+00
T-shirts	Washed	Waste system	Outdoor air	3.17E-03
T-shirts	Washed	Waste system	Residential soil	1.24E+01
T-shirts	Washed	Waste system	Road side soil	6.05E+00

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
T-shirts	Washed	Waste system	Sub-surface soil	1.44E-04
T-shirts	Washed	Waste system	Surface water	3.57E-02
T-shirts	Washed	Wear and tear	Agricultural soil	6.78E+00
T-shirts	Washed	Wear and tear	Outdoor air	1.84E+02
T-shirts	Washed	Wear and tear	Residential soil	8.71E-02
T-shirts	Washed	Wear and tear	Sub-surface soil	9.54E-01
T-shirts	Washed	Wear and tear	Surface water	2.22E+00
Underwear	Washed	Drying	Agricultural soil	4.41E+00
Underwear	Washed	Drying	Outdoor air	3.42E+00
Underwear	Washed	Drying	Residential soil	1.68E+00
Underwear	Washed	Drying	Sub-surface soil	6.72E-01
Underwear	Washed	Drying	Surface water	1.56E+00
Underwear	Washed	Washing	Agricultural soil	2.55E+02
Underwear	Washed	Washing	Residential soil	2.91E+00
Underwear	Washed	Washing	Sub-surface soil	3.91E+01
Underwear	Washed	Washing	Surface water	9.08E+01
Underwear	Washed	Waste system	Agricultural soil	2.60E-03
Underwear	Washed	Waste system	Natural soil	4.48E+00
Underwear	Washed	Waste system	Outdoor air	2.24E-03
Underwear	Washed	Waste system	Residential soil	8.23E+00
Underwear	Washed	Waste system	Road side soil	4.68E+00
Underwear	Washed	Waste system	Sub-surface soil	1.12E-04
Underwear	Washed	Waste system	Surface water	2.71E-02
Underwear	Washed	Wear and tear	Agricultural soil	5.00E+00
Underwear	Washed	Wear and tear	Outdoor air	1.29E+02
Underwear	Washed	Wear and tear	Residential soil	6.52E-02

Clothing category	Washing regime	Process	Sink	Mean mass (tonnes)
Underwear	Washed	Wear and tear	Sub-surface soil	7.44E-01
Underwear	Washed	Wear and tear	Surface water	1.73E+00

Table S.21 Data table for sankey (Figure S 12). Each row in the table represents the median flow of plastics in tonnes from a footwear category, via a process to a sink. Data for the EU in 2022.

Clothing	Process	Sink	Mean mass (t)
Boots	Waste system	Agricultural soil	8.05E-03
Boots	Waste system	Natural soil	1.86E+01
Boots	Waste system	Outdoor air	8.07E-05
Boots	Waste system	Residential soil	3.08E+01
Boots	Waste system	Road side soil	1.94E+01
Boots	Waste system	Sub-surface soil	4.16E-06
Boots	Waste system	Surface water	1.12E-01
Boots	Wear of shoesoles	Agricultural soil	8.93E+01
Boots	Wear of shoesoles	Natural soil	1.42E+02
Boots	Wear of shoesoles	Outdoor air	6.10E+01
Boots	Wear of shoesoles	Residential soil	1.07E+00
Boots	Wear of shoesoles	Road side soil	2.63E+02
Boots	Wear of shoesoles	Sub-surface soil	1.16E+01
Boots	Wear of shoesoles	Surface water	1.75E+02
Boots	Wear of upper fabric	Agricultural soil	1.76E+00
Boots	Wear of upper fabric	Outdoor air	2.01E+02
Boots	Wear of upper fabric	Residential soil	2.27E-02
Boots	Wear of upper fabric	Sub-surface soil	2.53E-01
Boots	Wear of upper fabric	Surface water	5.98E-01
Closed shoes	Washing	Agricultural soil	7.65E+01
Closed shoes	Washing	Residential soil	8.76E-01
Closed shoes	Washing	Sub-surface soil	1.19E+01
Closed shoes	Washing	Surface water	2.74E+01
Closed shoes	Waste system	Agricultural soil	1.70E-02
Closed shoes	Waste system	Natural soil	3.96E+01
Closed shoes	Waste system	Outdoor air	1.71E-04
Closed shoes	Waste system	Residential soil	6.61E+01
Closed shoes	Waste system	Road side soil	4.10E+01
Closed shoes	Waste system	Sub-surface soil	8.88E-06
Closed shoes	Waste system	Surface water	2.38E-01
Closed shoes	Wear of shoesoles	Agricultural soil	1.59E+02
Closed shoes	Wear of shoesoles	Natural soil	2.50E+02

Clothing	Process	Sink	Mean mass (t)
Closed shoes	Wear of shoesoles	Outdoor air	1.06E+02
Closed shoes	Wear of shoesoles	Residential soil	1.88E+00
Closed shoes	Wear of shoesoles	Road side soil	4.58E+02
Closed shoes	Wear of shoesoles	Sub-surface soil	2.04E+01
Closed shoes	Wear of shoesoles	Surface water	3.07E+02
Closed shoes	Wear of upper fabric	Agricultural soil	1.40E+00
Closed shoes	Wear of upper fabric	Outdoor air	1.51E+02
Closed shoes	Wear of upper fabric	Residential soil	1.83E-02
Closed shoes	Wear of upper fabric	Sub-surface soil	2.05E-01
Closed shoes	Wear of upper fabric	Surface water	4.83E-01
Open shoes	Waste system	Agricultural soil	5.33E-03
Open shoes	Waste system	Natural soil	1.26E+01
Open shoes	Waste system	Outdoor air	5.50E-05
Open shoes	Waste system	Residential soil	2.10E+01
Open shoes	Waste system	Road side soil	1.31E+01
Open shoes	Waste system	Sub-surface soil	2.79E-06
Open shoes	Waste system	Surface water	7.61E-02
Open shoes	Wear of shoesoles	Agricultural soil	8.44E+01
Open shoes	Wear of shoesoles	Natural soil	1.33E+02
Open shoes	Wear of shoesoles	Outdoor air	5.68E+01
Open shoes	Wear of shoesoles	Residential soil	1.00E+00
Open shoes	Wear of shoesoles	Road side soil	2.45E+02
Open shoes	Wear of shoesoles	Sub-surface soil	1.09E+01
Open shoes	Wear of shoesoles	Surface water	1.63E+02
Open shoes	Wear of upper fabric	Agricultural soil	2.13E-01
Open shoes	Wear of upper fabric	Outdoor air	2.63E+01
Open shoes	Wear of upper fabric	Residential soil	2.75E-03
Open shoes	Wear of upper fabric	Sub-surface soil	2.92E-02
Open shoes	Wear of upper fabric	Surface water	7.01E-02

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