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Plastics in the environment – development of a classification for first estimates of the fate of waste and other plastic products in different environmental media

Final report

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Plastics in the environment – development of a classification for first estimates of the fate of waste and other plastic products in different environmental media

Final report

by

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Abstract: Plastics in the environment – development of a classification for first estimates of the fate of waste and other plastic products in different environmental media

Plastic emissions to the environment are an increasingly discussed issue. In this project, a first estimation of plastic emissions to the environment from littered plastic items as well as plastic applications has been made. Based on this, the most relevant sources could be identified and possible mitigation actions have been discussed. Major emissions result from the transportation sector with tyre wear as key source. In addition, the construction sector as well as the agriculture and horticulture sectors contribute significantly. Besides the quantification of entries from various sources, the data situation has been critically assessed and key points for improving the data situation have been identified. Finally, results from this study have been cross-checked with findings from related recent studies.

Kurzbeschreibung: Kunststoffe in der Umwelt – Erarbeitung einer Systematik für erste Schätzungen zum Verbleib von Abfällen und anderen Produkten aus Kunststoffen in verschiedenen Umweltmedien

Der Eintrag und Verbleib von Kunststoffen in die Umwelt ist seit einigen Jahren ein viel beachtetes und viel diskutiertes Thema. In diesem Vorhaben wurde eine Abschätzung des quantitativen Verbleibs von Kunststoffen in der Umwelt aus dem Bereich der achtlos weggeworfenen oder liegen gelassenen Kunststoffabfälle („Littering“) sowie der Kunststoffprodukte, die umweltoffen eingesetzt werden und aus denen Einträge in Form von Kunststoffpartikeln in die Umwelt hervorgehen können, vorgenommen. Auf dieser Basis wurden zum einen relevante Quellen für Kunststoffeinträge identifiziert und Handlungsmöglichkeiten diskutiert. Die größten Einträge ergeben sich aus dem Verkehrsbereich mit dem Reifenabrieb als größter Quelle. Daneben tragen der Baubereich und der Landwirtschafts- und Gartenbaubereich relevant zu den Gesamtmengen bei. Zum anderen ist eine kritische Betrachtung der Datenlage erfolgt und besonders zentrale Aspekte für eine Verbesserung der Datenlage wurden identifiziert. Die Berechnungsergebnisse wurden mit aktuellen einschlägigen Studien abgeglichen und eingeordnet.

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ABS	Acrylonitrile-Butadiene-Styrene Copolymer
AC	Acrylate Copolymer
ACS	Acrylate Crosspolymer
AM	Motorway maintenance authority (German: Autobahnmeisterei)
BASt	Federal Highway Research Institute (German: Bundesanstalt für Straßenwesen)
BMVI	Federal Ministry of Transport and Digital Infrastructure (German: Bundesministerium für Verkehr und digitale Infrastruktur)
BSR	Berlin City Cleaning Service (German: Berliner Stadtreinigung)
DTV	Average daily traffic volume (German: durchschnittliche tägliche Verkehrsstärke)
EP	Epoxy Resin
EPS	Expanded Polystyrene
EVA	Ethylen-Vinylacetat-Copolymer
GFK	Glass Fibre Reinforced Plastic
MV	Mecklenburg-Western Pomerania
NI	Lower Saxony
NRW	North Rhine-Westphalia
OSPAR	Oslo-Paris Convention
PA	Polyamide
PE	Polyethylene
PE-HD	Polyethylene - High Density
PE-LD	Polyethylene – Low Density
PES	Polyethersulfone
PET	Polyethylene terephthalate
POM	Polyoxymethylene
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
PVA	Polyvinyl acetate
PVC	Polyvinyl chloride

ABS	Acrylonitrile-Butadiene-Styrene Copolymer
RIGK	RIGK GmbH – Recycling of industrial and commercial plastic packaging
ReFoPlan	Departmental Research Plan (German: Ressortforschungsplan)
Roads.NRW	North Rhine-Westphalia state road construction company (Straßen.NRW cf. list of references)
SH	Schleswig-Holstein
SM	Road maintenance authority (German: Straßenmeisterei)
TPU	Thermoplastic polyurethane
UBA	German Environment Agency (German: Umweltbundesamt)
WPC	Wood-Plastics-Composites
XPS	Extruded Polystyrene

Summary

Plastics are used in a variety of applications. From many of these applications as well as from improperly disposed plastic waste, plastic entries into the environment may result.

While, recently, the input of plastics into the environment has received broad attention and has been a widely discussed topic for some time now, the actual state of knowledge on the subject is, so far, fragmentary. Only few estimations quantifying plastic entries from different sources are available to date. Against this background, it was the goal of this study to obtain a first structured estimation of the quantitative entries of plastics from different sources into the environment for Germany. In this regard, littered plastics (plastic items thrown away or left behind in places not intended or designated for such a purpose) as well as the sector of plastic products used in the environment were considered. From the plastic products used in the environment, plastic inputs can result both during the usage and after the end of use span.

Many of the plastics entering the environment through different pathways are removed by cleaning and removal measures.

The project particularly aims at estimating the share of plastic entries which remain in the environment after such measures.

Methodical approach

The scope of this study is the environment in Germany. The approach differentiates between two basic emission pathways:

- Emission from littering of plastic waste
- Emissions from plastic products and plastic containing products intended to be used in the environment.

For both pathways, models were built, allowing an estimation of the plastics remaining in the environment based on available information and expert assumptions.

The modelling of the pathway from littering is based on information on the plastics found in the environment. Here the main sinks have been differentiated according to their use (roads, service stations, parking lots, pedestrian zones, coasts, river sides and inland swimming areas).

For the pathway of plastic products and plastic containing products intended to be used in the environment, the modelling is based on the quantities placed on the market (POM) for 63 product groups and assumptions on the share remaining in the environment after the end of the use-phase.

From plastic products used in the environment, emissions often occur over a long time span (up to multiple decades) and also the permanent remain of entire products or product parts in the environment partly occurs only after long-time usage. In the developed model these emissions occurring in the future are counted "back" to the period of "the placing on market". For an even more exact depiction of the yearly emissions, time series analyses of the POM as well as the variance of the respective usage lengths over time would have to be considered in the modelling. For both aspects, so far no consistent databases are available.

The calculation results of both emission pathways were brought together and structured according to the following sites:

- Streets

- Rivers and river sides
- Settlement areas
- Agricultural areas
- Coastlines

Thus, for each of these sites/ land use types a quantification of plastic emissions can be found in the results.

Parallel to this project commissioned by the German Environment Agency (Umweltbundesamt), a quantification of the plastic emissions into to the environment in Germany has been subject to two other recent studies:

- Bertling, Jürgen; Hamann, Leandra; Bertling, Ralf (2018): Kunststoffe in der Umwelt. Unter Mitarbeit von Tatiana Bladier, Rodion Kopitzky, Daniel Maga, Nils Thonemann und Torsten Weber. Fraunhofer Umsicht. Oberhausen.
- Conversio (2018): Vom Land ins Meer - Modell zur Erfassung landbasierter Kunststoffabfälle. Unter Mitarbeit von Christoph Lindner und Thomas Jäger. Hg. v. Conversio und BKV. Frankfurt.

Considering the high environmental and political relevance of the subject, a systematic cross check with these other two studies has been performed. This check was done based on the published reports and documentation of the above-mentioned parallel studies with the present preliminary results of this project as well as in intensive expert discussions between the involved authors. For this purpose, a workshop between the authors of Fraunhofer Umsicht, Conversio and Ökopol was held in September 2018 in Hamburg.

Here, fundamental differences became apparent regarding the subject in question (from primary microplastics to secondary microplastics to large plastic products), the emission pathways considered (from careless littering to inevitable emissions from usage to tolerated remain in the environment) as well as the sinks in question (from the focus on the final emission into the sea to the entire environment of Germany). The knowledge about these differences is very important in order to interpret the respective conclusions and statements of the studies correctly. For this reason the present report includes a systematic comparison of central assumptions and limits of the three studies.

The three studies consistently show that all data and findings available to this date do not suffice to build a continuously valid framework for the quantitative plastic emissions into the environment. The current results are therefore based to a relevant extent on extrapolations of single data points as well as expert assumptions, which from a scientific point of view, leads to high uncertainties of the results.

Regardless of the systematic differences and the challenges concerning missing data, the differentiated analysis of the results of all three studies showed in many cases high accordance in the magnitude of emissions from different sources.

In those cases where relevant differences in the calculated emissions between the parallel studies and the preliminary results of this project were identified, the calculations, underlying data and assumptions made were examined in more detail. As far as viable these aspects were considered in the sensitivity analysis of the results presented in this report.

Results: Plastic emissions into the environment

The plastic waste identified in the project, which is introduced by littering into the various types of land use (roads, rest areas, parks, pedestrian zones, coasts, river sides and inland swimming areas) and remains permanently in the environment, amounts to 650 to 2,500 t/a. Without differentiation between littering and non-littering waste (i.e. waste from illegal deposition) this amount increases up to 3,750 t/a. If the assumptions are adjusted in consideration of the other current studies, the mass increases to about 13,100 t/a. This exemplifies the existing data uncertainties because of the lack of systematic statistical data regarding littered waste which is suited for extrapolation.

From plastic applications, plastic emissions amount from 150,540 t/a to 235,045 t/a. Of these, 132,790 t/a to 165,440 t/a originate from the transport sector with tyre abrasion as main source. Next to this the building sector (8,875 – 60,425 t/a) and the agricultural and horticultural sector (6,200 – 21,500 t/a) relevantly contribute to the total emissions. Here again the result ranges show considerable uncertainties. In addition to uncertainties in the distinction between the quantities of products used in an environmentally open manner and the total quantities placed on the market in many product areas, uncertainties exist in particular in the area of assumptions about the proportions of products used in an environmentally open manner that will remain in the environment in the long term even after the end of use.

With regard to the outlined uncertainties, the most relevant emissions of plastics remaining in the environment are summarized in the following table.

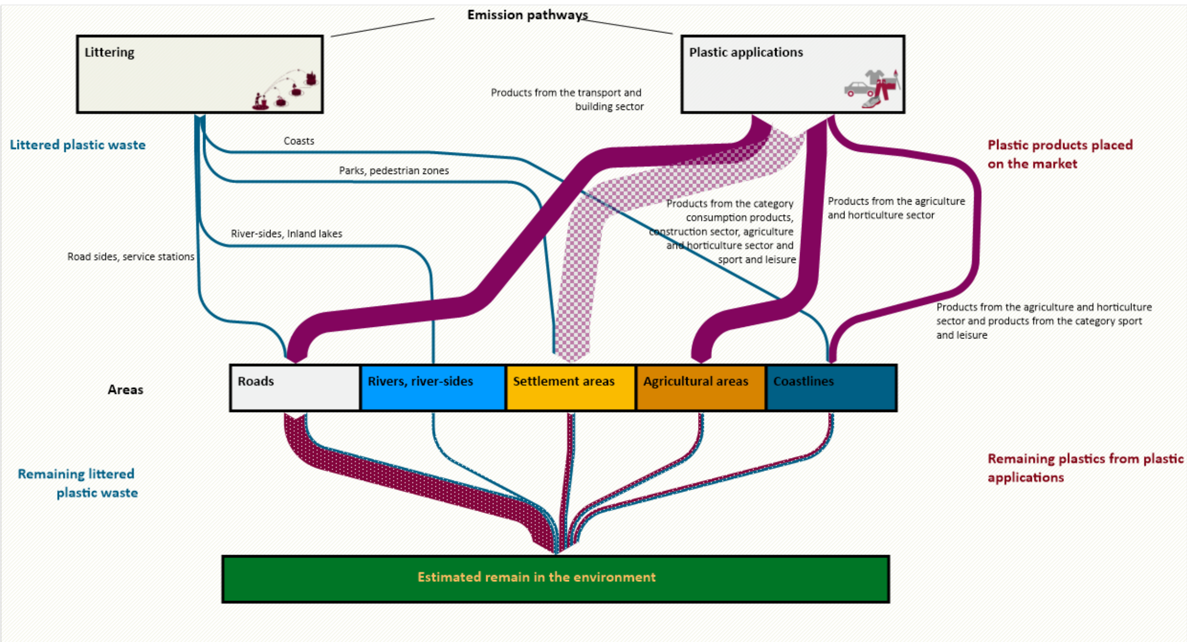
Table 1: The estimated yearly emissions of plastics permanently remaining in the environment for the 30 most mass-relevant emission sectors

Emission pathway	Source / emission sector	Plastic emission [t/a]
Emission from intended use of plastic products or plastic containing products	Tyres, motor vehicle (abrasion)	143,260 (129,000-158,000)
	Pipes	25,410 (4,620-46,200)
	Geotextiles	3,500 (2,500-4,500)
	Shoes (abrasion)	2,400 (1,600-3,200)
	Planting pots	2,285 (415-4,150)
	Sewage sludge	2,250 (1,500 – 3,000)
	Compost	2,230 (1,090 – 3,340)
	Fertilizers	2,025 (1,970-2,075)
	Granulate for artificial pitches	1,930 (1,545 – 2,315)
	Grass paver	1,790 (325 – 3,250)
	Road markings	1,760 (1,130-2,390)
	Agricultural foils	1,650 (300-3,000)
	Bicycle tyres	1,095 (820-1,370)
	Drainage channel (rain channel)	895 (165 – 1,625)
	Cigarette filters (butts)	890 (165 – 1,620)

Emission pathway	Source / emission sector	Plastic emission [t/a]
	Agricultural nets, tubes, fleeces	880 (160 – 1,600)
	Seepage blocs	825 (150 – 1,500)
	Baler twines	825 (150 – 1,500)
	Construction paints	700 (350 – 1,049)
	Palisades	650 (325-975)
	Base plates	500 (250-759)
	Toys / play equipment	500 (250-75)
	Cosmetics	490 (475-500)
	Silage films	460 (230-690)
	Pond liners	460 (83-830)
	Cable coatings	395 (200-590)
	Browsing protection	275 (50-500)
	Drainage	230 (40-415)
	Construction foil	200 (100—300)
Emissions from littering of plastic products	Carelessly disposed of ("littered") plastics including waste from illegal disposal, lost products, etc.	1,500 (650-13,100)

The mass flows of plastic emissions are furthermore depicted in the following graph structured by emission pathways. Here also an allocation to the emission site is made.

Figure 1: Plastic emissions to the environment - Summary of estimations



Source: Ökopol

In conclusion based on this data basis the following observations can be made:

- The emissions from various plastic applications dominate the overall picture. Next to the transport sector, which is dominated by tyre abrasion, particularly the construction sector is a relevant source for plastic emissions.
- Tyre abrasion represents the quantitatively largest (single) source for plastic emission. The uncertainties (or differences in the assumed abrasion factors) are below 30 %. There is strong consensus among experts on the quantitative relevance of this source.
- Next to the abrasion from the intended use of tyres, the source contributing the most to emissions remaining in the environment is the incomplete removal of plastic products after their use.
- Littering of mostly small plastic objects such as packaging is also a relevant source of plastic emissions into the environment. Regarding the total emissions, however, this source is one amongst many similarly important sources. In many areas, cleaning measures can reduce the permanent presence in the environment. Changes in the nature and intensity of such cleaning measures are reflected in the developed model as a change of the captured share of waste or rather as slippage. Main uncertainties and questions exist regarding:
  - The effectiveness of the existing cleaning measurements: Systematic data regarding cleaning measures, accounting for amounts with regard to different land use types, efficacy / slippage are missing here. The influence of the assumptions made on slip and plastic proportion has been depicted using the example of littering along roads. Parameter variations in line with the assumptions made in other studies can influence the results of the estimations by up to a factor of 10.
  - The differentiation between littering and non-littering: because this distinction cannot be made for the plastic products found in the environment, this differentiation brings an additional uncertainty into the total estimations, which according to expert's valuation is not countered by an added value regarding the conclusions.

Derivation of recommended actions

Based on the results of the modelling of the plastic emissions into the environment, recommendations for actions can be derived on two levels.

Firstly, the research as well as the analysis of the currently available data on plastic emissions into the environment showed that in many areas the data availability is insufficient. Here, need for action exists to improve the knowledge on the status quo and also improve the analysis of future developments.

Secondly, the estimations on plastic emissions already show quite clearly which sectors of emission are relevant with regard to future mitigation measurements.

These are:

- Emissions from sewage sludge and composts
- Emissions from roads: tyres, road markings, shoes

- Emissions from agriculture and horticulture: geotextiles, pipes, architectural paints, artificial grass, grass paver
- Emissions from the agricultural industry; foils etc.

Additionally the sector of waste water treatment is of importance because of its cross divisional function and the area of littered cigarette filters because of its attention in the media.

In the course of the project, these sectors were looked at in more detail with regard to existing mitigation measurements and approaches for future action.

Waste water treatment

Emissions of plastic parts and particles into waste water (sewage water and rainwater) are to be expected from various plastic applications. Findings on the quantity of plastic emissions in the different output streams and the resulting plastic emissions into the environment are only sparsely available. Multiple research projects with the focus on "plastics in the environment" are currently underway which could improve the state of knowledge. The results of these research projects should be systematically evaluated and taken into account when updating the overall emission model.

Emissions from roads

In the sector of road use, a closer look has been taken at tyre abrasion, road markings and shoe abrasions. For tyres a prospective adjustment of the regulation (EC) No 1222/2009 or 661/2009 may be an option for the reduction of the plastic emissions. Additionally, from the current research project "RAU – tyre abrasions into the environment" valuable findings on the emission and mitigation possibilities of tyre abrasions can be expected.

With regard to road markings the expert are of the opinion that there are currently no concise and reasonable approaches to action. In principle the kind of used road markings could be regulated via the public invitation for tender, however regarding the missing alternatives this remains a theoretical approach.

In the area of shoe abrasions an approach could be to make binding standards on abrasion resistance. Corresponding standards are to date available for the area of safety footwear and in voluntary eco labels (Blue Angel and EU-Ecolabel).

Construction and landscaping

Especially in the sector of civil engineering and road construction but also in buildings plastic products are increasingly being installed directly in the ground. These products are on the one hand plastic foils or plastic textiles which are being used as insulation, sealing or compensating membranes and on the other hand a broad variety of moulded plastic parts such as pipes, wastewater channels and cable ducts. Also supporting elements for terrain levels, road attachments and more are by now increasingly made out of plastic.

All of these plastic products are designed for long term use in their respective area of application. However, with regard to plastic emissions into the environment three main questions arise:

1. To which extent can emissions of plastic particles or parts be expected from the different conditions of installation and from the intended use?
2. To which extent can emissions of plastic be expected due to either damage from the use phase or from the installation or in the course of renovation and reconstruction measures?

3. Which share of the initially installed plastic products can be expected to remain in the environment permanently after their use phase, either because they remain entirely in the ground or because they are damaged during the dismantling of the building and remain partly in the ground?

Regarding to the total quantities especially questions 1 and 2 are relevant. For these sectors however, to date no systematically suitable basic information is available.

With respect to question 2 the challenge is the lack of routine maintenance for the plastic parts in question. Therefore damages of plastic parts and plastic emissions related to those are usually not detected or are accepted as long as they do not compromise the function of the building and are usually not recorded in a structured manner.

With respect to question 3 this is due to the fact that the intended overall usage time is not yet reached for the majority of the plastic products and that even if the plastic parts are removed during dismantling, no comparison is made of the initially installed parts and those plastic parts removed during dismantling of the building.

Because of the high quantitative relevance of this emission sector, in the experts' opinion it is indispensable to carry out detailed investigations on the current state of management and dismantling of plastic products used in an environmentally open manner in the building sector.

Sewage sludge and compost

Possible mitigation measures for the plastic quantities emitted with the sewage sludge output are either a reduction of the plastic quantities introduced into the waste water treatment plant (WWTP) or a reduction of the plastic content of the sewage sludge or a further reduction/total ban of the application of sewage sludge on land for agricultural purposes. The first measure would be desirable, however it requires changes in many other areas. A reduction of the plastic content in sewage sludge would only be feasible through an improved screening. To achieve this, either the legal threshold for sewage sludge intended for agricultural application could be strengthened or extended to particles smaller than 2 mm. It is however questionable whether it is possible to technically remove plastics from sludge to a sufficient degree, as the plastic particles in the sludge can be expected to be particularly small (from tyre abrasion, plastic fibres etc.). A further reduction or total ban of sewage sludge application on agricultural land is rather unlikely, as this regulation has only just been adopted for large WWTPs and has to be implemented now. Furthermore, an improvement of the data base is an important measure for action. A number of currently ongoing research projects are devoted to this topic.

Two fundamental mitigation measures can be distinguished for the reduction of plastic contents in composts: firstly the reduction of plastic contents in the input into composting facilities (in particular waste from the organic waste bin and garden waste), secondly the reduction of plastic contents in the output product (compost) through improved technology, stricter thresholds or enforcement. On the input side it would be useful to expand and develop consumer information tools, whereby an evaluation of the effectiveness of such campaigns is still pending. Further possible measures could be a polluter-pays pricing for biological waste as well as an adaption of the standards EN 13432 and EN 14995, which define conditions for the degradability of plastics, to the actual conditions in composting plants.

On the side of the treatment and outputs a possible measure could be to tighten the legal thresholds. In September 2018, at the request of a number of federal states, the Federal Council expressed its support for this. Today, most of the facilities are already significantly below the thresholds, however the thresholds do not cover particles smaller than the size of 2 mm. Whether it is technically and economically feasible to remove plastics more thoroughly (including smaller particles) during the biological treatment has to be clarified in detail with the composting plant operators and further experts. Moreover, the German bio waste ordinance as well as quality monitoring of fertilizers could be strengthened with regard to the foreign substance thresholds. This monitoring is the responsibility of the federal states and is done randomly, the situation however differs from state to state. Whether the monitoring with regard to plastic contents in composts is sufficient cannot be evaluated with the current information available.

On top of this, the improvement of the data base on plastic contents in compost is reasonable because most surveys and studies only record plastic particles larger than 2 mm thus the content of smaller particles remains unknown.

Agricultural industry

The range of agricultural films includes films intended for earlier harvesting and for fodder preservation. The emission into the environment results from remainders of entire foils or smaller foil parts in the soil due to drift or incomplete removal after usage. The main challenge is to guarantee a wide removal and recycling of the films. With the initiative ERDE of the RIGK GmbH such a collection and recycling and system already exists. The initiative ERDE (Erntekunststoffe Recycling Deutschland) is a collection system for agricultural films, initiated by the Industrievereinigung Kunststoffverpackungen e. V (IK). The system is currently financed by ten participating producers of agricultural plastics (RIGK 2018) in order to offer farmers a cost-effective service for collection of the films. Users of agricultural films (farmers) can bring the used films to collection points or have them collected.

Planting pots

The emission of plastic from planting pots stems from abrasion or chipping off of small plastic parts during the use or from remainders of the product in the environment i.e. by leaving the pots outside and blowing them away with the wind. The emission of plastic from this source could be entirely avoided if the pots were not made of plastic but of material that is degradable under given conditions. Such pots made of biologically degradable and compostable materials like straw, cork, sawdust and corn starch are available on the market.

The feasibility of this solution is however limited for plants offered for private use in retail markets. Suited and affordable alternatives are currently searched for. Another possible measure to reduce the emission is to give incentives to the consumers to collect the pots and return them (i.e. via a deposit system).

Cigarettes

For the avoidance of littering and remain of cigarette butts in the environment several measurements can be identified:

- Targeted information about the negative impacts on the environment of litter,
- Structured guidance for municipalities,
- Addressing the issue in “anti-litter campaigns”,
- Provision of “mobile” ashtrays (either free of charge or against payment) and
- Punishment of littering through regulations.

In Germany, such activities have so far taken place only rarely. In the experts opinion it should be assessed which of the identified mitigation measures lead to a reduction of littered cigarettes to further develop effective and equally efficient action measurements for Germany. For this purpose it should be determined whether data on the impact of these measures are collected in selected municipalities that have implemented measures against littering. In principle, it should be examined along the further legislative process of the EU-plastic strategy which kind of awareness raising measures specifically are intended in the proposal of the EU commission and how the proposed new instrument of extended producer responsibility could be designed in concrete terms.

Systematic further development of the overall modelling

As part of the project, an overall model was developed for the first time for all areas of plastic discharge into the environment in Germany. In view of the problems with the data bases outlined above, only initial estimates with correspondingly high uncertainties could be made for some areas. Nevertheless, this modelling allows a first rational derivation of the overall relevance of the topic of entries and the fate of plastic in the environment.

According to the authors, however, the representatives of the plastics industry, environmental administration and specialist science involved in the final expert discussion in June 2019 see this as opening up the perspective of a stronger fact-based debate on the topic, which has so far been quite controversial and emotional.

In order to be able to fulfil this function in the future, however, in the opinion of the named actors, a consistent updating of the overall model is required, in which the existing uncertainties and remaining data gaps must be specifically minimised.

For this it is relevant that the structured representation of all entry areas created in the developed modelling allows to overwrite the currently used (estimated) values with updated and/or better substantiated detailed data at any time. This would make it possible in future to improve and update the database in a transparent and, if necessary, also work-sharing process.

The comparison with other partial models on environmental inputs of plastics developed in parallel carried out in the course of the project and the discussions conducted with the actors involved also showed, however, that it is important in the context of updating and further developing an overall model to re-examine the objective, i.e. the expected answers.

Basically, with a modelling both

- precautionary orientation
  by creating a systematic factual situation as a rational basis for targeted action in the case of newly identified risks and precautionary reduction strategies and
- risk management/reduction
  through the (focused) pursuit of environmental quality impairments derived from concrete risk considerations in defined environmental compartments

may be under laid. However, there are questions regarding the type of preparation of the information, i.e., among other things:

- Input quantity into the environment and/or quantity remaining in the environment?
  => Leads to the question: are e.g. sealed (urban) areas part of the "environment"?

- Accumulated stock and/or annual (entry/remaining) increase?
  => Leads to the question: Period of observation (whereabouts after x years ...)?
- Amount of macro and/or micro plastics
  => is linked to the question of the time horizon and thus the formation of "secondary" micro-plastics.
- Accounting at the place of entry and/or whereabouts?
  => The questions of (permanent) retention relevant for precautionary and risk considerations make the integration of transport and degradation models necessary.
- Balancing of the basic polymer quantities and/or also the quantities of additives/functionalisation substances
  => Requires further knowledge/information on the material composition of different product groups

In view of these questions, which in some areas will presumably require longer discussion and coordination, the authors propose the following staged further procedure for the further development of the overall modelling.

Step 1: Update of the existing overall model as a uniform entry model on the basis of the product quantities used.

In this context

- result-related data references (i.e. the litter quantities currently found) are abandoned in favour of a uniform reference to usage quantities.
- a targeted invitation to the market players to participate in the improvement of the data base is issued. The focus is on those market players who (possibly) bring relevant products into use.

Step 2: Development and integration of transport and degradation models for plastics released into the environment.

Here

- such models have to be adapted systematically to the different entry pathways of plastic into the environment and the compartments where they are transported to.
- a targeted transfer of current research work and results will become necessary.

Step 3: Transparent performance of risk assessments and derivation of risk management measures for the identified environmental fate quantities.

This

- requires the combination of information on quantities with current findings on the (environmental and health-related) effects of (micro-)plastics in the various environmental compartments

- enables a targeted review of measures already taken (for precautionary reasons) with regard to risk management and their adjustment/update.

Zusammenfassung

Kunststoffe werden in einer Vielzahl von Anwendungen eingesetzt. Aus zahlreichen dieser Kunststoffanwendungen sowie aus nicht ordnungsgemäß entsorgten Kunststoffabfällen können Kunststoffeinträge in die Umwelt resultieren.

Während der Eintrag von Kunststoffen in die Umwelt seit einiger Zeit ein viel beachtetes und viel diskutiertes Thema darstellt, ist der tatsächliche Wissensstand zum Thema bislang lückenhaft. Abschätzungen zum mengenmäßigen Eintrag aus den verschiedenen Quellen gibt es bislang nur vereinzelt. Vor diesem Hintergrund war es Ziel des durchgeführten Vorhabens aus dem Ressortforschungsplan (ReFoPlan), eine erste strukturierte Abschätzung über den quantitativen Eintrag von Kunststoffen in die Umwelt in Deutschland zu erhalten. Dabei wurde sowohl der Bereich der achtlos weggeworfenen oder liegen gelassenen Kunststoffabfälle („Littering“) betrachtet als auch das Feld der Kunststoffprodukte, die in der Umwelt genutzt werden. Bei den in der Umwelt genutzten Kunststoffprodukten können sowohl während der Nutzung als auch nach deren Nutzungsende Einträge von Kunststoffe in die Umwelt resultieren.

Viele der auf den unterschiedlichen Wegen in die Umwelt eingetragenen Kunststoffe werden im Zuge von Reinigungs- und Rückbaumaßnahmen wieder aus der Umwelt entfernt.

Das Projekt zielt konkret darauf ab, eine Abschätzung derjenigen Masse an Kunststoffen vorzunehmen, die nach solchen üblichen Maßnahmen letztlich in der Umwelt verbleiben.

Methodisches Vorgehen

Der im Vorhaben untersuchte Betrachtungsraum ist die Umwelt in Deutschland. Die Herangehensweise unterscheidet zwischen den zwei grundlegenden Eintragspfaden:

1. Eintrag aus dem Littering von Kunststoffabfällen (Littering wird hier verstanden als das achtlose Wegwerfen oder Liegenlassen von Abfällen im öffentlichen Raum)[1]
2. Eintrag aus beabsichtigt in der Umwelt verwendeten („umweltoffen““ eingesetzten) Kunststoffprodukten und kunststoffhaltigen Produkten

Für beide Eintragspfade wurden Modelle gebildet, die auf Basis verfügbarer Informationen und fachlich begründeter Annahmen eine Abschätzung der in der Umwelt verbleibenden Kunststoffmengen erlauben.

Die Modellierung des Eintragspfades aus dem Littering basiert auf Informationen zu den in der Umwelt vorgefundenen Kunststoffmengen. Dabei erfolgt eine Differenzierung der Hauptfundorte nach Flächennutzungsarten/typen (Straßen, Rastanlagen, Parkanlagen, Fußgängerzonen, Küsten, Flussrandstreifen und Binnenbadestellen).

Beim Eintragspfad der beabsichtigt in der Umwelt verwendeten („umweltoffen““ eingesetzten) Kunststoffprodukte und kunststoffhaltigen Produkte erfolgt die Modellierung anhand der in Verkehr gebrachten Menge (iVgM) für 63 Produktgruppen und dem Ansatz der Kunststoffanteile, die während der Nutzung in die Umwelt emittierten sowie der Anteile der iVgM, die nach dem Ende der Nutzungsdauer in der Umwelt verbleiben.

Im Bereich der umweltoffenen Anwendungen erstreckt sich der Eintrag häufig über längere Zeiträume (bis zu mehreren Jahrzehnten) und auch der mögliche dauerhafte Verbleib von ganzen Produkten oder Produkt-Teilen findet erst nach den teilweise sehr langjährigen

[1] Entsprechend des vorgegebenen Untersuchungsrahmens für diese Studie werden illegale Abfallentsorgung, die nicht unter die achtlos weggeworfenen oder liegenliegen gelassenen Abfälle fallen, nicht mitbetrachtet. Es erfolgt jedoch eine zusätzliche abschätzende Betrachtung der mengenmäßigen Auswirkung auf die ermittelten Kunststoffeinträge dieser Setzung zum Untersuchungsrahmen; siehe hierzu insbesondere die Parametervariation in Abschnitt 6.3.6

Nutzungen statt. In der jetzt entwickelten Modellierung werden diese zukünftigen Umwelteinträge der Periode des „Inverkehrbringens“ angerechnet. Für eine noch exaktere Abbildung der jährlichen Eintragsmengen müssten Zeitreihenanalysen der iVgM sowie die Varianz der jeweiligen Nutzungsdauern im Zeitverlauf mit in die Betrachtungen einfließen. Für beide Aspekte fehlen bislang konsistente Datengrundlagen.

Die Berechnungsergebnisse der beiden Eintragspfade werden zusammengeführt und dabei nach folgenden Eintragsorten gegliedert:

- Straßen
- Flüsse und Gewässerrandstreifen
- Siedlungsflächen
- Landwirtschaftliche Flächen
- Küstenstreifen

Für jeden dieser Eintragsorte/Flächennutzungstypen findet sich also im Ergebnis eine Quantifizierung des in der Umwelt verbleibenden Kunststoffeintrags.

Parallel zu dem vorliegenden ReFoPlan-Vorhaben des Umweltbundesamtes erfolgte auch in den Studien anderer Auftraggeber eine Quantifizierung des Eintrags von Kunststoffen in die Umwelt in Deutschland. Zu benennen sind hier:

- Bertling, Jürgen; Hamann, Leandra; Bertling, Ralf (2018): Kunststoffe in der Umwelt. Unter Mitarbeit von Tatiana Bladier, Rodion Kopitzky, Daniel Maga, Nils Thonemann und Torsten Weber. Fraunhofer Umsicht. Oberhausen.
- Conversio (2018): Vom Land ins Meer - Modell zur Erfassung landbasierter Kunststoffabfälle. Unter Mitarbeit von Christoph Lindner und Thomas Jäger. Hg. v. Conversio und BKV. Frankfurt.

In Anbetracht der hohen umweltpolitischen Bedeutung der Gesamtthematik der Umwelteinträge von Kunststoffen wurde im Rahmen der Qualitätssicherung der Analyse- und Modellierungsergebnisse der vorliegenden Studie ein systematischer Querabgleich mit diesen beiden Studien durchgeführt. Dieser Abgleich erfolgte auf Grundlage der veröffentlichten Berichte und Dokumentationen der benannten Parallelstudien mit den vorliegenden Zwischenergebnissen des ReFoPlan-Vorhabens sowie einer vertiefenden Fachdiskussion zwischen den jeweiligen Autoren. Dafür wurde im September 2018 zwischen den Autoren von Fraunhofer Umsicht, Conversio und Ökopol ein entsprechendes Arbeitstreffen in Hamburg durchgeführt.

Dabei zeigten sich einige grundlegende Unterschiede im Bereich des betrachteten Sachgegenstandes (vom primären Mikroplastik über sekundäres Mikroplastik bis zu großen Kunststofferzeugnissen), der jeweils betrachteten Eintragsmechanismen (vom achtlosen „Littering“, über unvermeidbare Einträge aus der Nutzung bis zu hingenommenem Verbleib in der Umwelt) sowie auch der bilanzierten Umwelträume (von der Fokussierung auf den schlussendlichen Eintrag in das Meer bis hin zur Betrachtung des gesamten Umweltraumes in Deutschland). Die Kenntnis dieser Unterschiede ist sehr wichtig, um die jeweils getroffenen Aussagen und Ergebnisse der Studien korrekt zu interpretieren. Aus diesem Grund beinhaltet der vorliegende Bericht eine systematische Gegenüberstellung zentraler Grundannahmen und Grenzziehungen der drei Studien.

Übereinstimmend zeigen alle durchgeführten Studien, dass die bislang verfügbaren Grunddaten und Untersuchungsergebnisse nicht ausreichend sind, um ein durchgehend valides Mengengerüst der Umwelteinträge von Kunststoffen zu erstellen. In relevantem Maß sind die bisherigen Ergebnisse deshalb auf der Extrapolation von Einzelbefunden sowie begründeten Expertenschätzungen basiert, was aus wissenschaftlicher Sicht zu entsprechend hohen Unsicherheiten in den Endergebnissen führt.

Ungeachtet der systematischen Unterschiede und der skizzierten Herausforderungen im Bereich fehlender Grunddaten zeigte die differenzierte Analyse der Ergebnisse der drei Studien in Eintragsbereichen, die sachlich direkt vergleichbar sind, vielfach hohe Übereinstimmung in der Größenordnung der Ergebniswerte.

Dort, wo sich relevante Unterschiede zwischen den Parallelstudien und den Zwischenergebnissen des ReFoPlan-Vorhabens zeigten, wurden die jeweiligen fachlichen Ableitungen und Erwägungen der getroffenen Annahmen und Setzungen nochmals überprüft und, soweit begründet umsetzbar, bei der Sensitivitätsprüfung der Ergebnisse im Rahmen des vorliegenden Ergebnisberichtes berücksichtigt.

Ergebnisse: In der Umwelt verbleibende Kunststoffeinträge

Die im Vorhaben ermittelten dauerhaft in der Umwelt verbleibenden Kunststoffeinträge aus dem Littering-Pfad über die unterschiedenen Flächennutzungstypen (Straßen, Rastanlagen, Parkanlagen, Fußgängerzonen, Küsten, Flussrandstreifen und Binnenbadestellen) belaufen sich auf 650 bis 2.500 t/a. Ohne Unterscheidung zwischen Littering- und Nicht-Littering-Abfällen (bspw. Abfälle aus illegalen Ablagerungen) erhöht sich diese Menge auf bis zu 3.750 t/a. Werden die getroffenen Annahmen unter Berücksichtigung der anderen aktuellen Studien angepasst, so steigt die Menge auf rund 13.100 t/a an. Dies macht den Einfluss der bestehenden Datenunsicherheiten aufgrund des Fehlens systematischer und für eine Hochrechnung geeigneter statistischer Erfassungen gelitterter Mengen deutlich.

Im Bereich der umweltoffenen Kunststoffanwendungen ergeben sich dauerhaft in der Umwelt verbleibende Kunststoffeinträge von 150.540 t/a bis 253.045 t/a. Hierbei entstammen 132.790 t/a bis 165.440 t/a dem Verkehrsbereich mit dem Reifenabrieb als größter Quelle. Daneben tragen der Baubereich (8.875 - 60.425 t/a) und der Landwirtschafts- und Gartenbaubereich (6.200 - 21.500 t/a) relevant zu den Gesamtmengen bei. Auch hier zeigen die Ergebnisspannbreiten deutliche Unsicherheiten. Neben Unschärfen bei der Abgrenzung der umweltoffen verwendeten Produktmengen an den gesamten in Verkehr gebrachten Mengen in vielen Produktbereichen liegen diese Unsicherheiten insbesondere im Bereich der Annahmen zu den Anteilen der umweltoffen genutzten Produkte, die auch nach dem Ende der Nutzung langfristig in der Umwelt verbleiben.

Die unter Beachtung der skizzierten Unsicherheiten relevantesten, endgültig, in der Umwelt verbleibenden Einträge von Kunststoffen sind in nachfolgender Tabelle zusammengefasst.

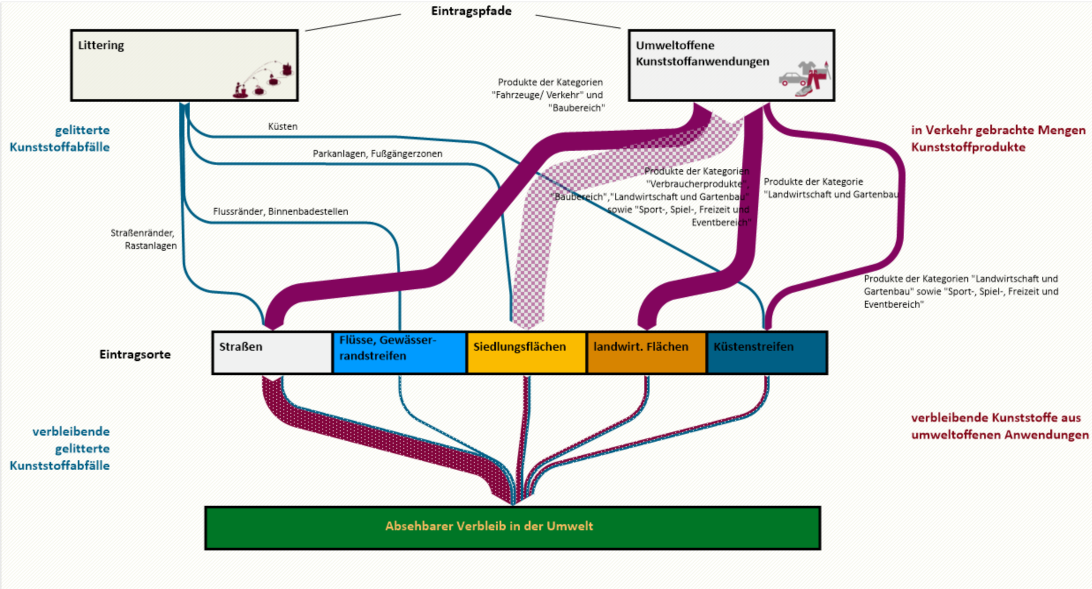
Table 1: Die abgeschätzten jährlichen Eintragsmengen, dauerhaft in der Umwelt verbleibenden Kunststoffmengen für die 30 mengenrelevantesten Eintragsbereiche

Eintragspfad	Quelle / Eintragsbereich	Kunststoffeintrag [t/a]
Eintrag aus beabsichtigt in der Umwelt verwendeten („umweltoffen“	Reifen, KFZ (Abrieb)	143.260 (129.000- 158.000)
	Rohre	25.410 (4.620-46.200)
	Geotextilien	3.500 (2.500-4.500)

Eintragspfad	Quelle / Eintragsbereich	Kunststoffeintrag [t/a]
eingesetzten) Kunststoffprodukten und kunststoffhaltigen Produkten	Schuhe (Abrieb)	2.400 (1.600-3.200)
	Pflanztöpfe	2.285 (415-4.150)
	Klärschlamm	2.250 (1.500 – 3.000)
	Komposte	2.230 (1.090 – 3.340)
	Düngemittel	2.025 (1.970-2.075)
	Granulat für Kunstrasenplätze	1.930 (1.545 – 2.315)
	Rasengitter	1.790 (325 – 3.250)
	Fahrbahnmarkierungen	1.760 (1.130-2.390)
	Agrarfolien/Erntefolien	1.650 (300-3.000)
	Fahrradreifen	1.095 (820-1.370)
	Entwässerungsrinnen (Regenrinnen)	895 (165 – 1.625)
	Zigarettenfilter / -kippen	890 (165 – 1.620)
	landwirtschaftliche Netze, Schläuche, Vliese	880 (160 – 1.600)
	Sickerblöcke	825 (150 – 1.500)
	Erntegarne	825 (150 – 1.500)
	Bautenfarben	700 (350 – 1.049)
	Palisaden	650 (325-975)
	Fußplatten (Bakenfüße)	500 (250-759)
	Spielgeräte/Spielzeug	500 (250-75)
	Kosmetika	490 (475-500)
	Silagefolie	460 (230-690)
	Teichfolien	460 (83-830)
	Kabelummantelungen	395 (200-590)
	Verbissschutz	275 (50-500)
	Drainage	230 (40-415)
	Baufolien	200 (100—300)
Eintrag aus dem Littering von Kunststoffabfällen	Achtlos weggeworfene („gelitterte“) Kunststoffe, sowie inklusive Abfälle der illegalen Entsorgung, verlorengegangene Produkte etc.	1.500 (650-13.100)

Die Mengenströme des Kunststoffeintrags sind zudem gegliedert nach den Eintragspfaden in folgender Abbildung visualisiert. Hier erfolgt weiterhin eine Zuordnung zu den Eintragsorten.

Abbildung 1: Zusammenfassung der Abschätzung der Kunststoffeinträge



Quelle: Ökopol
Die Breite der Pfeile ist proportional zur entsprechenden Menge (t/a) dargestellt, wobei der schraffierte Pfeil „Umweltoffene Kunststoffanwendungen auf Siedlungsflächen" aufgrund seiner Größe nicht maßstabsgetreu abgebildet werden kann.

Zusammenfassend lässt sich anhand dieser Datenbasis festhalten:

- Die Einträge aus der Vielzahl der umweltoffenen Kunststoffanwendungen dominieren das Gesamtbild. Neben dem Verkehrsbereich, welcher überwiegend vom Reifenabrieb bestimmt wird, stellt insbesondere der Baubereich einen mengenrelevanten Eintragsbereich dar.
- Reifenabrieb stellt die mengenmäßig größte (einzelne) Quelle für Kunststoffeinträge dar. Die Unsicherheiten (bzw. Unterschiede in den angenommenen Abriebfaktoren) betragen hier weniger als 30 %. Es besteht unter Fachexperten eine breite Einigkeit bzgl. der Mengenrelevanz dieser Quelle.
- Neben dem Abrieb aus der bestimmungsgemäßen Nutzung von Reifen stellt insbesondere die nicht vollständige Entnahme von Kunststoffprodukten nach der Nutzung den relevanten Eintragsmechanismus dar, der langfristig zu hohen Einträgen führt.
- Das Littering von zumeist kleineren Kunststoffgegenständen wie insbesondere Verpackungen ist ebenfalls eine relevante Quelle für Kunststoffeinträge in die Umwelt. In Bezug auf die Gesamteinträge handelt es sich dabei allerdings lediglich um eine, unter vielen vergleichbar bedeutsamen Quellen. Durch Reinigungsmaßnahmen erfolgt hier in vielen Bereichen eine Reduzierung des Verbleibs (bzw. der dauerhaften Umwelteinträge). Veränderungen in der Art und Intensität solcher Reinigungsmaßnahmen schlagen sich im erarbeiteten Modell in einer Änderung des erfassten Abfallanteils bzw. des Reinigungsschlupfes nieder. Zentrale Unsicherheiten und Fragen bestehen bezüglich
  - der Wirksamkeit bestehender Reinigungsmaßnahmen: Hier fehlen für die unterschiedlichen Flächennutzungen und Reinigungsmaßnahem systematisch ermittelte Daten, die sowohl die Reinigungsmenge als auch den Reinigungsschlupf ausweisen und

die sich auf den jeweiligen Kunststoffanteil dieser Mengen beziehen lassen. Der Einfluss getroffener Annahmen zu Schlupf und Kunststoffanteil wurde hier insbesondere am Beispiel Straßen veranschaulicht. Parametervariationen können die Ergebnisse der Abschätzungen um bis zu einem Faktor 10 beeinflussen.

- der Unterscheidung zwischen Littering (achtlos weggeworfene oder liegenliegen gelassene Abfälle) und nicht-Littering (Umwelteinträge aufgrund von illegaler Entsorgung, Unfällen, Transportverluste etc.): Da sich diese Differenzierung an den in der Umwelt vorgefundenen Kunststoffprodukten faktisch kaum feststellen lässt, wird durch diese Unterscheidung eine zusätzliche Unschärfe in den Gesamtergebnissen erzeugt, der nach gutachterlicher Einschätzung kein entsprechender Mehrwert bei den Ergebnisaussagen entgegensteht.

Ableitung von Handlungsempfehlungen

Aus den durchgeführten Arbeiten und den erreichten Ergebnissen ergeben sich auf zwei Ebenen Handlungsempfehlungen.

Zum einen haben die durchgeführten Recherchen sowie die Analysen von bislang verfügbaren Informationen zu Umwelteinträgen von Kunststoffen gezeigt, dass diese in vielen Bereichen ungenügend sind, um eine valide Basis für die Abschätzung der Eintragsmengen zu bieten. Hier besteht dringender Handlungsbedarf, um den Wissensstand zum Status quo aber auch in Hinblick auf die Beobachtungen zukünftiger Entwicklungen zu verbessern.

Zum anderen zeigen bereits die durchgeführten ersten Abschätzungen zum Kunststoffeintrag (und -verbleib) in die Umwelt recht deutlich Bereiche der umweltoffenen Nutzung von Kunststoffprodukten, die mit Blick auf zukünftige Minderungsbestrebungen relevant für entsprechende Maßnahmendiskussionen sind.

Es sind dies die Handlungsbereiche:

- Einträge aus der Straßennutzung: Reifen, Fahrbahnmarkierungen, Schuhe
- Einträge aus Bauwirtschaft und Landschaftsbau: Geotextilien, Rohre, Bautenfarben, Kunstrasenplätze, Rasengitter
- Einträge aus Klärschlamm und Komposten
- Einträge aus der Agrarwirtschaft; Folien etc.

Ergänzend sind der Bereich der Abwasserbehandlung aufgrund seiner Querschnittsfunktion sowie der Bereich der gelitterten Zigarettenfilter aufgrund seiner medialen Aufmerksamkeit und der anstehenden rechtlichen Verpflichtungen (erweiterte Herstellerverantwortung) im Rahmen der Einweg-Kunststoff-Richtlinie von entsprechender Bedeutung.

Im Rahmen des Vorhabens wurden die vorstehend skizzierten Handlungsbereiche in Hinblick auf bereits bestehende Maßnahmen und Ansätze für mögliche zukünftige (Minderungs-)Maßnahmen untersucht.

Abwasserbehandlung

Je nach Art und Ort der Kunststoffanwendung erfolgt ein möglicher Eintrag von Kunststoffen in unterschiedliche Umweltmedien mit jeweils variierendem weiteren Verbleib und Verhalten der Kunststoffpartikel.

Besonders relevant – und ungeklärt – ist die Frage nach dem weiteren Verbleib in den Fällen, in denen davon ausgegangen werden kann, dass die Kunststoffteilchen ganz oder teilweise im Abwasser (Schmutzwasser oder Niederschlagswasser) mit nachfolgender Abwasserbehandlung landen. In diesen Fällen ist der Abwasserpfad ein relevantes Transportmedium für die Kunststoffeinträge und der Abwasserbehandlung kommt eine wichtige Rolle bei der Minderung der Einträge in die Umwelt zu.

Erkenntnisse darüber, in welchen Outputs von Kläranlagen Kunststoffpartikel in welchen Mengen zu finden sind und welche Einträge in die Umwelt hieraus resultieren, sind bislang nur lückenhaft vorhanden. Diesbezüglich laufen aktuell mehrere Forschungsvorhaben im BMBF-Förderschwerpunkt „Plastik in der Umwelt“, die hier zu einer Verbesserung des Wissenstandes beitragen können.

Die Ergebnisse dieser Forschungsvorhaben sind systematisch auszuwerten und bei der Fortschreibung der Gesamtmodellierung zu berücksichtigen.

Straßennutzung

Im Bereich der Straßennutzung wurden Reifenabrieb, Fahrbahnmarkierungen und Schuhe näher betrachtet. Im Bereich der Reifen kann insbesondere eine zukünftige Anpassung der EG-Verordnungen Nr. 1222/2009 oder 661/2009 eine Möglichkeit zur Reduktion des Kunststoffeintrags darstellen. Zudem sind aus dem aktuell laufenden BMBF-Forschungsvorhaben „RAU – Reifenabrieb in die Umwelt“ wertvolle Erkenntnisse über Eintrag und Vermeidungsmöglichkeiten von Reifenabrieb zu erwarten.

Bezüglich der Fahrbahnmarkierungen bestehen aus Sicht der Gutachter aktuell keine konkreten sinnvollen Handlungsansätze. Zwar ließe sich die Art der eingesetzten Markierungen grundsätzlich über das öffentliche Ausschreibungswesen regeln, aber da echte (preislich vergleichbare) Alternativen fehlen, bleibt dies ein theoretischer Ansatz.

Im Bereich der Schuhe kann ein Handlungsansatz in verbindlichen Vorgaben zur Abriebfestigkeit bestehen. Entsprechende Vorgaben finden sich bislang z. B. im Bereich der Sicherheitsschuhe sowie in freiwilligen Umweltzeichen (im Blauen Engel und EU-Ecolabel).

Bauwirtschaft und Landschaftsbau

Gerade im Bereich von Tief- und Straßenbau aber auch im Hochbau werden in stetig zunehmendem Maß Kunststoffprodukte direkt in den Boden eingebaut. Es handelt sich zum einen um Kunststofffolien oder –Gewebe, die als Dämm-, Dicht- oder Ausgleichsbahnen verwendet werden, zum anderen um eine breite Palette an Kunststoffformteilen wie z. B. Rohrleitungen, Abwasserrinnen, Kabelschächte u.ä. Auch Stützelemente für Geländestufen, Wegbefestigungen und anderes mehr wird mittlerweile zunehmend aus Kunststoffen gefertigt.

All diese Kunststofferzeugnisse sind für die langjährige Nutzung in Ihrem jeweiligen Einsatzbereich ausgelegt. In Hinblick auf Kunststoffeinträge in die Umwelt stellen sich dennoch durchgehend die drei zentralen Fragen:

a) In welchem Maß ist bei unterschiedlichen Einbaubedingungen aus der bestimmungsgemäßen Nutzung mit Emissionen von Kunststoffpartikeln oder Bestandteilen in die umgebende Umwelt zu rechnen?

b) In welchem Maß ist aufgrund von Beschädigungen aus der Nutzung, aber auch aus dem Einbau bzw. im Rahmen von Renovierungs-/Umbaumaßnahmen an den jeweiligen Bauwerken mit Kunststoffverlusten in die Umwelt zu rechnen?

c) Bei welchem Anteil der ursprünglich verbauten Kunststoffprodukte ist damit zu rechnen, dass diese nach dem Ende ihrer Nutzung dauerhaft in der Umwelt verbleiben, da sie entweder insgesamt im Boden verbleiben oder es während des Rückbaus des Bauwerkes zu Beschädigungen kommt, die dazu führen dass mehr oder minder große Teile nicht aus dem Boden entfernt werden?

Mit Blick auf die Gesamtmengen sind insbesondere die Fragen b) und c) von Relevanz. Für diese Bereiche liegen allerdings bislang keinerlei systematisch verwendbaren Basisinformationen vor.

In Bezug auf Frage b) besteht systematisch die Herausforderung, dass es gerade für die hier in Frage stehenden fest eingebauten Kunststoffprodukte im Normalfall keine routinemäßigen Wartungs- und Instandhaltungsroutinen o.ä. gibt, sodass Beschädigungen und damit Kunststoffeinträge, die nicht unmittelbar die Funktion des Gesamtbauwerkes in Frage stellen, üblicherweise nicht erkannt oder aber in Kauf genommen werden, ohne dass dies strukturiert erfasst wird.

Dies ist im Fall der Frage c) der Tatsache geschuldet, dass die vorgesehen Gesamtnutzungsdauer für einen Großteil der hier umweltoffen eingesetzten Kunststoffprodukte bislang (noch) nicht erreicht wurden und dass es selbst bei zwischenzeitlich erfolgtem Rückbau von Bauwerken mit entsprechenden Kunststoffkomponenten keinen Rückwärtsabgleich zwischen ursprünglich eingebauten und rückgebauten Kunststoffmengen gibt.

Aufgrund der hohen Mengenrelevanz dieses Eintragsbereiches erscheint es aus gutachterlicher Sicht unverzichtbar, im Bereich dieser Kunststoffprodukte konkrete Detailuntersuchungen zur derzeitigen Praxis der Bewirtschaftung und des Rückbaus der umweltoffen eingesetzten Kunststoffprodukte im Baubereich durchzuführen.

Klärschlamm und Kompost

Mögliche Handlungsansätze zur Verringerung der mit dem Klärschlamm ausgebrachten Kunststoffmengen sind eine Verringerung der in Kläranlagen eingetragenen Kunststoffmengen, eine Verringerung des Gehalts an Kunststoff im Klärschlamm sowie eine weitere Verringerung oder ein gänzliches Verbot der Klärschlammausbringung für landwirtschaftliche/landschaftsbauliche Zwecke. Ersteres wäre wünschenswert, würde aber Veränderungen in vielen anderen Bereichen erfordern. Eine Verringerung des Gehalts an Kunststoff im Klärschlamm wäre nur durch verbesserte Absiebung sinnvoll möglich. Um dies zu erreichen, könnte beispielsweise der gesetzliche Grenzwert für Klärschlamm, der landwirtschaftlich ausgebracht werden soll, verschärft und/oder auf Partikel unter 2 mm ausgedehnt werden. Da davon auszugehen ist, dass im Klärschlamm besonders viele sehr kleine Kunststoffpartikel enthalten sind (Reifenabrieb, Fasern etc.), ist fraglich, ob es technisch machbar ist, Kunststoffe in ausreichendem Maße zu entfernen. Dass eine weitere Verringerung oder ein gänzliches Verbot der Klärschlammausbringung in naher Zukunft rechtlich verbindlich beschlossen wird, ist eher unwahrscheinlich, da dies gerade erst für große Kläranlagen beschlossen wurde und jetzt umgesetzt werden muss. Darüber hinaus ist die Verbesserung der Datenlage ein wichtiger Handlungsansatz. Eine Reihe der laufenden Forschungsvorhaben im BMBF-Förderschwerpunkt „Plastik in der Umwelt“ widmen sich unter anderem diesem Thema.

Bei den Handlungsansätzen zur Verringerung des Kunststoffanteils im Kompost lassen sich zwei grundsätzliche Wege unterscheiden: zum einen die Reduzierung von Kunststoffen in den Inputs in die Kompostierungsanlagen (insb. Abfall aus Biotonne, Grüngut) und zum anderen das Reduzieren der Kunststoffgehalte in den Outputs (Produkt der Anlagen – Kompost) durch verbesserte Anlagentechnik, strengere Grenzwerte und/oder verschärften Vollzug. Auf der Input-Seite wäre es sinnvoll, auf Information der Verbraucherinnen und Verbraucher ausgerichtete Instrumente, wie die derzeit laufende „WirfürBio“-Kampagne auszubauen, wobei eine Evaluation der Effekte der Kampagne noch aussteht. Weitere mögliche Maßnahmen könnten eine verursachergerechte Gestaltung der Annahmepreise für Bioabfall sein sowie eine Anpassung der Normen DIN EN 13432 und DIN EN 14995, die Bedingungen für die Abbaubarkeit von Kunststoffen definiert, an die tatsächlichen Gegebenheiten in Kompostierungsanlagen.

Auf der Behandlungs- und Output-Seite bestünde die Möglichkeit, die gesetzlichen Grenzwerte zu verschärfen. Dafür hat sich im September 2018 auf Antrag einiger Länder der Bundesrat ausgesprochen. Die meisten Anlagen bleiben heute bereits deutlich unterhalb der Grenzwerte. Die Grenzwerte decken jedoch Partikel unter 2 mm nicht ab. Ob es technisch und wirtschaftlich machbar ist, bei der biologischen Behandlung Kunststoffe noch gründlicher (einschließlich noch kleinerer Partikel) zu entfernen, müsste im Detail mit Anlagenbetreibern und weiteren Expertinnen und Experten diskutiert werden. Des Weiteren könnten die Bioabfallverordnung und Düngemittelverkehrskontrolle in Bezug auf die Einhaltung der Fremdstoffgrenzwerte verstärkt werden. Diese obliegt den Bundesländern und wird stichprobenartig durchgeführt, die Situation ist jedoch von Land zu Land verschieden. Ob die Düngemittelverkehrskontrolle in Bezug auf Kunststoffgehalte in Komposten ausreichend ist, kann nach aktueller Informationslage nicht beurteilt werden.

Darüber hinaus ist eine Verbesserung der Datenlage zu Kunststoffgehalten im Kompost sinnvoll, da die meisten Erhebungen und Studien nur Kunststoffpartikel über 2 mm erfassen und somit der Kunststoffanteil an kleineren Partikeln unbekannt ist.

Agrarwirtschaft

Der Bereich der Agrarfolien umfasst Folien zur Ernteverfrühung sowie zur Futterkonservierung. Der Eintrag in die Umwelt erfolgt durch Verbleib im Boden ganzer Folien oder von kleineren Folienteilen, durch Verwehung sowie durch eine eventuelle nicht vollständige Entnahme nach der Nutzung. Zentrale Herausforderung ist die Gewährleistung einer weitgehenden Entnahme und Zuführung zu entsprechenden Verwertungssystemen. Mit der Initiative ERDE der RIGK GmbH besteht bereits ein solches System. Die Initiative ERDE (Erntekunststoffe Recycling Deutschland) ist ein Rücknahmesystem für Agrarfolien, initiiert von der Industrievereinigung Kunststoffverpackungen e. V. (IK). Finanziert wird das System von derzeit zehn teilnehmenden Herstellern von Agrarkunststoffen (RIGK 2018), um den Landwirten einen kostengünstigen Service für die Rücknahme der Folien zu bieten. Nutzer der Agrarfolien (Landwirte) können die gebrauchten Folien bei Sammelstellen abgeben oder abholen lassen.

Pflanztöpfe

Der Eintrag von Kunststoff durch Pflanztöpfe erfolgt durch Abtrennung (z. B. Abrieb) oder Absplittern kleiner Teilchen während der Nutzung oder vollständigen Verbleib in der Umwelt z. B. dadurch, dass die Töpfe im Außenbereich liegen gelassen und vom Wind verteilt werden. Der Eintrag von Kunststoff ließe sich ganz verhindern, wenn die Töpfe nicht aus Kunststoff, sondern aus unter den im Freiland gegebenen Bedingungen abbaubarem Material hergestellt wären. Derartige Töpfe aus biologisch abbaubaren und kompostierfähigen Materialien wie Stroh, Kork, Holzmehl und Maisstärke stehen auf dem Markt zur Verfügung.

Für im Handel für die private Nutzung angebotenen Pflanzen ist eine solche Lösung allerdings nur sehr begrenzt zielführend. Es wird derzeit nach geeigneten und bezahlbaren Alternativen gesucht. Eine weitere Möglichkeit, um den Eintrag zu verringern oder weniger wahrscheinlich zu machen, ist es, Verbraucherinnen und Verbrauchern Anreize zu bieten, die Töpfe intakt wieder einzusammeln und zurückzugeben (z. B. über Pfandsysteme).

Zigaretten

Im Bereich der Vermeidung des Litterings und Verbleibs von Zigarettenkippen in der Umwelt lassen sich diverse Handlungsansätze identifizieren, die sich wie folgt zusammenfassen lassen:

- eine gezielte Aufklärung über die negativen Umweltfolgen des Litterings,
- strukturierte Handlungshilfen für Kommunen,
- die Adressierung des Themas im Rahmen von übergeordneten „Anti-Littering-Kampagnen“,“,
- die Bereitstellung von „mobilen“ Aschenbechern (kostenlos oder gegen Entgelt) sowie
- die ordnungsrechtliche Ahndung des Litterings.

In Deutschland finden solche Aktivitäten bislang lediglich vereinzelt statt. Für eine mögliche Auswahl und (Weiter-)Entwicklung von wirksamen und gleichermaßen effizienten Handlungsempfehlungen für Deutschland wäre es aus Sicht der Gutachter sinnvoll zu prüfen, welche der identifizierten Handlungsansätze konkret zu einer Reduktion der gelitterten Menge von Zigarettenkippen geführt haben. Hierfür wäre zu prüfen, ob in ausgewählten Kommunen, die aktiv Maßnahmen gegen Littering umsetzen, Daten darüber erhoben werden, wie groß die Wirkung der umgesetzten Maßnahmen ist. Grundsätzlich wäre entlang des weiteren Legislativprozesses der EU-Kunststoffrichtlinie[2] zu prüfen, um welche Arten von „Sensibilisierungsmaßnahmen“ es sich bei dem Vorschlag der EU-Kommission konkret handeln könnte und wie das vorgeschlagene neue mögliche Instrumentarium der erweiterten Herstellerverantwortung konkret ausgestaltet werden könnte.

Systematische Weiterentwicklung der Gesamtmodellierung

Im Rahmen des durchgeführten ReFoPlan-Vorhabens wurde erstmalig ein Gesamtmodell für alle Bereiche des Kunststoffeintrages in die Umwelt in Deutschland erarbeitet. Angesichts der skizzierten Problematik der Datengrundlagen konnten für einige Bereiche bislang nur erste Abschätzungen mit entsprechend hohen Unsicherheiten vorgenommen werden. Dennoch erlaubt diese Modellierung eine erste rationale Ableitung der Gesamtrelevanz der Thematik der Einträge und des Verbleibs von Kunststoffen in die Umwelt.

Damit eröffnet sich nach Wahrnehmung der Autoren sowie der am Abschlussfachgespräch im Juni 2019 beteiligten Vertreter der Kunststoffbranche, der Umweltverwaltung und der Fachwissenschaft die Perspektive einer stärkeren Faktenbasierung der bislang z. T. recht kontroversen und emotional geführten Diskussionen zur Thematik.

Um dieser Funktion zukünftig gerecht werden zu können, bedarf es nach Einschätzung der benannten Akteure allerdings einer konsequenten Fortschreibung des Gesamtmodells, bei der bestehende Unsicherheiten und verbliebene Datenlücken gezielt minimiert werden.

Hierfür ist relevant, dass die in der erarbeiteten Modellierung angelegte strukturierte Darstellung aller Eintragsbereiche es jederzeit erlaubt, die derzeit verwendeten (Abschätz-) Werte durch aktualisierte und/oder besser unterlegte Detaildaten zu überschreiben. Damit wäre es ermöglicht, zukünftig in einem transparenten und ggf. auch arbeitsteiligen Prozess die Datenbasis zu verbessern und fortzuschreiben.

[2] Richtlinie (EU) 2019/904 des Europäischen Parlaments und des Rates vom 5. Juni 2019 über die Verringerung der Auswirkungen bestimmter Kunststoffprodukte auf die Umwelt.

Der im Vorhabenverlauf durchgeführte Abgleich mit anderen parallel erarbeiteten Teil-Modellen zu Umwelteinträgen von Kunststoffen und die mit den beteiligten Akteuren geführten Diskussionen zeigten allerdings auch, dass es wichtig ist im Kontext mit einer Fortschreibung und Weiterentwicklung eines Gesamt-Modells, die Zielstellung, d. h. die erwarteten Antworten, erneut zu überprüfen.

Grundlegend können mit einer Modellierung sowohl

- Vorsorgeorientierung
  durch die Schaffung einer systematischen Faktenlage als rationale Basis für gezieltes Handeln bei neu identifizierten Risiken und vorsorgende Minderungsstrategien als auch
- Risikomanagement/-minderung
  durch die (fokussierte) Verfolgung aus konkreten Risikoerwägungen abgeleiteter Beeinträchtigung der Umweltqualität in definierten Umweltkompartimenten

unterlegt werden. Es stellen sich aber Fragen in Bezug auf die Art der Aufbereitung der Informationen, also u. a.:

- Eintragsmenge in die Umwelt und/oder Verbleibsmenge in der Umwelt?
  => leitet zur Frage: Sind z. B. versiegelte (urbane) Flächen Teil der „Umwelt"?
- Akkumulierter Bestand und/oder jährlicher (Eintrags-/Verbleibs) Zuwachs?
  => leitet zur Frage: Betrachtungshorizont (Verbleib nach x Jahren …)?
- Menge an Makro und/oder Mikro-Kunstsoffen?
  => Ist verknüpft mit der Frage des Zeithorizontes und damit der Bildung „sekundärer" Mikro-Kunststoffe.
- Bilanzierung am Ort des Eintrages und/oder des Verbleibs?
  => Die aus Vorsorge- und Risikoerwägungen relevanten Fragen des (dauerhaften) Verbleibs machen die Integration von Transport- und Abbaumodellen notwendig.
- Bilanzierung der Grundpolymermengen und/oder auch der Mengen an Zusatzstoffen zur Additivierung/Funktionalisierung?
  => Erfordert weitergehende Kenntnisse/Informationen zu stofflicher Zusammensetzung verschiedener Produktgruppen.

Mit Blick auf diese Fragestellungen, die in Teilbereichen einer vermutlich durchaus längeren fachlichen Diskussion und Abstimmung bedürfen, schlagen die Autoren das folgende, gestufte weitere Vorgehen für die Weiterentwicklung der Gesamtmodellierung vor.

Schritt 1: Fortschreibung des bestehenden Gesamt-Modells als einheitliches Eintragsmodells auf der Basis von verwendeten Produktmengen.
Dabei sollten

- ergebnisbezogene Datenbezüge (also die derzeit verwendeten vorgefundenen Littering-Mengen) zugunsten eines einheitlichen Bezuges auf Verwendungsmengen aufgegeben werden und

- eine gezielte Einladung an die Marktakteure zur Mitwirkung an der Verbesserung der Datenbasis erfolgen. Im Fokus stehen dabei diejenigen Marktakteure, die (möglicherweise) relevante Produkte auf den Markt bringen.

Schritt 2: Entwicklung und Integration von Transport- und Abbaumodellen für in die Umwelt eingetragene Kunststoffe.
Dabei

- sind derartige Modelle systematisch an die verschiedenen Eintrags- und Verbleibsorte anzupassen.
- wird ein gezielter Transfer aktueller Forschungsarbeiten und -ergebnisse notwendig werden

Schritt 3: Transparente Durchführung von Risikobewertungen und Ableitung von Risikomanagementmaßnahmen für die identifizierten Verbleibsmengen.
Dies

- erfordert die Zusammenführung der Mengeninformationen mit aktuellen Erkenntnissen zur (Umwelt- und Gesundheitsbezogenen) Wirkung von (Mikro-)Kunststoffen in den verschiedenen Umweltkompartimenten.
- ermöglicht eine gezielte Überprüfung bereits (aus Vorsorgeerwägungen) ergriffener Maßnahmen zum Risikomanagement und ihrer Anpassung/Fortschreibung.

1 Aim and content of the project

For some years now, the emission and fate of plastics into the environment has been a much noticed and discussed topic both at the level of the public and in scientific specialist discussions, but increasingly also in political bodies. Particular attention is being paid to so-called "marine littering", i.e. the discharge of plastic waste into the oceans. In fact, other environmental media such as inland waters or soils and other natural areas such as meadows, forests and arable land, but also urban areas are affected by this problem.

For particular areas and environmental media, there are already findings on the quantities of plastics found here, based on targeted investigations (like monitoring, collections, analyses, etc.). However, up to now there has been no overall estimation of the emissions from plastics into the environment. Such an overall estimate would be very helpful to support rational emphasis in the scientific-political discussion on reduction strategies and approaches.

Against this background, the aim of this project was to obtain a first overview of the quantitative emission of plastics into the environment. In doing so, both the area of carelessly thrown away or left behind plastic waste ("littering") and the field of plastic products that are used in an environmentally sound way and from which emissions in the form of plastic particles into the environment can arise were considered. Various cleaning and dismantling measures are used to remove many of the plastic wastes from the environment. This project aimed specifically at estimating the mass of plastics that enter the environment via these different routes and ultimately remain there.

2 Layout and structure of the report

The report can be divided into four parts, which in turn are divided into several chapters: Introduction, analysis and modelling, evaluation and consolidation, as well as the derivation of recommendations for action. This structure of the report is summarised in the following table. In addition, the responsible processing is assigned to the participating institutions.

Table 2: Overview of the report structure

Report section	Chapter	Leading processing
Introduction	Chapter 1: Aim and content of the project Chapter 2: Layout and structure of the report Chapter 3: Methodical Approach	Ökopol
Analysis and modelling	Chapter 4: Plastic emissions through littering Chapter 5: Plastic emissions as a result of environmentally sound plastic applications	Intecus Consultic
Evaluation and comparison	Chapter 6: Comparison of studies Chapter 7: Summary of the findings	Ökopol
Derivation of recommended actions	Chapter 8: Closer examination and derivation of recommended actions for selected product groups	Ökopol

3 Methodical approach

On the basis of the annual amount of plastic waste and the amount of plastic products placed on the market that are intended for environmentally sound use, this study estimates the amount of plastic that remains in the environment even after cleaning and dismantling measures. The area under consideration is Germany. The approach in the project distinguishes between two basic emission pathways:

1. emission concerning the littering of plastic waste (chapter 4)
2. emissions from plastic products and plastic containing products intended to be used in the environment (chapter 5).

For both pathways, the quantity remaining in the environment is modelled on the basis of the annual input or quantities placed on the market each year. With regard to the littering of plastic waste, the main input sites were balanced by distinguishing between different types of land use.

Although the approach based on the quantity of plastic and plastic-containing products placed on the market in open environmental applications provides a picture of the inputs resulting from the annual quantity placed on the market, it does not provide a complete picture of the annual inputs into the environment: in the area of open environmental applications, the input often extends over longer periods (from over one year to several decades) and for a complete picture, the time series of historical placing on the market would also have to be taken into account, which is not foreseen in this project. Nevertheless, the approach provides an estimate of the annual entries: If the relevant products were to have constant quantities placed on the market over time, the quantity determined here (entries resulting from the quantity placed on the market in one year) would also correspond to the annual entry. Only if the quantity placed on the market fluctuates over time - especially for products with long periods of use or residence in the environment - is there a difference between the two quantities.

The modelling for the two basic emission pathways is described in detail separately in chapters 4 and 5.

In turn, the results of calculation of both emission paths are brought together (chapter 6) and structured according to the following emission sites:

- roads
- rivers and riverside strips
- settlement areas
- agricultural areas
- coastlines

For each of these sites/types of land use, there is thus a quantification of the annual input remaining in the environment. It should be noted, however, that the point of input does not have to be associated with a permanent residence of the registered plastics at this point. In the case of inputs from littering, typically a drift (or flushing) onto adjacent land or water bodies takes place. For some environmentally sound applications, the point of entry largely corresponds to the point of fate (e.g. plastic films or similar plastic products used in foundation engineering, which remain in the soil at the end of their use). Tire abrasion, for example, is a typical source of input with a clear focus on/along the roads, but various transports within the environment up to the place of final fate.

4 Plastic emissions through littering

4.1 Definitions of littering and possible typologies

Here, littering is understood as the careless throwing away or leaving of waste in public space at the place where it originates. In addition to carelessly thrown away and discarded waste, littering waste also includes waste that has accidentally been released into the environment (e.g. unnoticed falling out of bags, parts that have been entered as a result of accidents or lost cargo). It is generally not possible to analyse the origin of these wastes and they are therefore considered uniformly. On the other hand, the improper dumping of larger wastes, such as car tyres, bulky waste or refrigerators, is considered illegal disposal and not littering[3]. In addition to the size of the waste, illegal disposal and littering can also be distinguished by the motivation of the originators. In contrast to spontaneous or accidental littering, illegal disposal is carried out according to plan. The places where illegal waste is disposed of are visited specifically. They are usually based on the fact that little or no witnesses are present there. Littering, on the other hand, takes place regardless of location.

4.2 Modelling approach

The investigation of plastic inputs through littering aims to determine the amount of littered plastic waste that remains in the environment in the long term. Basically, there are two different approaches to model this:

- a modelling on the basis of fate quantities
- a modelling on the basis of input quantities

Modelling on the basis of fate would require that direct information on the input of plastic waste that has been littered and remains in the environment over a certain period of time is available as input data on a wide variety of land and land types. On this basis, a corresponding upscaling to the entire area of the Federal Republic of Germany could then be carried out. However, corresponding input data are not yet available.

The second modelling approach is based on the input of plastic litter into the environment at different locations and calculates "indirectly" the amount remaining in the environment. This approach is pursued in the context of this project and is described in more detail below. An explanation of the terms used in the model is given in section 4.2.1.

The model for determining the plastic litter remaining in the environment is basically a balance sheet model. The balance model refers to a defined period of time, in this case one year, and the geographical reference area is Germany. The input values (input and output) in the balance model correspond to total values over the defined period of time (one year), and the fate is also calculated as a total per period of time.

4.2.1 Glossary of terms

Table 3 lists the relevant variables of the calculation model for the estimation of the plastic input from litter and gives a brief explanation. Special reference should be made to Figure 2, Figure 3 and Figure 5, in which the relationships between the relevant calculation variables are illustrated.

[3] An overview of existing definitions of littering from the literature can be found in the appendix/chapter 10.1.

Table 3: Glossary of relevant modelling terms for the estimation of plastic emissions through littering

Term	Definition
Waste input	Amount of all waste deposited at the site or land use type under consideration; it should be noted that part of the waste is discharged through cleaning and collection with a time lag and another part remains in the environment as remaining plastic litter or slippage (see Figure 4).
Discharged plastic litter or plastic litter discharge	Quantity of all plastic litter waste discharged from the point(s) of input/type of land use under consideration.
Registered plastic litter or plastic litter input	Quantity of all plastic litter waste entered in/on the point(s) of input/type of land use under consideration.
Quantity of waste collected	Quantity of all waste collected at the considered input site/type of land use during cleaning/collection.
Plastic content of the waste entry/litter entry	Share of plastics in the total share of waste/litter input at the input site/type of land use considered.
Litter content of the plastic waste	Percentage of the total amount of all registered plastics (this includes e.g. illegal deposits) at the point(s) of input/type of land use under consideration
Litter input	Quantity of all waste entered in the input site/type of land use under consideration that has been littered.
Litter rate	Weight share of littered waste in the total share of basket waste at the input site/type of land use under consideration.
Non-litter input	Quantity of all waste registered at the input site/type of land use under consideration that is not classified as litter waste; examples include illegal deposits.
Quantity of waste in the wastebasket	Quantity of all waste generated at the point of input/type of land use under consideration when emptying wastebaskets.
(Socio-technical) cleaning slip	Quantity of all plastic litter waste not collected through cleaning/collection at the point(s) of input/type of land use under consideration.
Slip rate	Proportion of the *remaining plastic litter* in the registered plastic litter.
Remaining plastic litter, slip/slippage	Amount of all plastic litter waste remaining on the considered input site/type of land use; it is assumed that there is no future weight loss of the remaining plastic litter and that the previously predominant land use will continue indefinitely. The latter refers to the fact that a change of land use could also lead to a discharge of the plastic litter, e.g. by excavation of soil in which the plastic litter was previously present.
Quantity blown away	Amount of all plastic litter waste that has been introduced into and blown away/washed away (drifted/flushed) from the site or land use type under consideration but remains in the environment.

4.2.2 Determination of slip rate

Taking into account data availability and quality, ranges and baseline values were estimated for the *slip rate* in relation to the various entry points. The base values are assumed as mean values of the minimum and maximum limits of the range. The estimations of the ranges and base values are based on how often and how strongly drifts/flushing occur on the respective land use types, how short (or long) the cleaning intervals are and how high the cleaning slip is or whether cleaning is carried out at all. Due to a lack of data availability, the slip rates are not based on a (quantitative) evaluation or calculation, but largely on expert assessments by the consultants of the relevant influencing factors (exposure to drifting/flushing, cleaning intervals, cleaning slip) (see Table 4).

The estimations of the cleaning slip are based on the central assumption that mechanical cleaning is more thorough than manual cleaning, especially on beaches where beach cleaning machines are used, but also on areas that can be cleaned by sweepers (e.g. roads, paved walkways and squares). This assumption is based on information provided by the manufacturers of beach cleaning machines, in which a cleaning depth of 15 cm (H. Barber & Sons, Inc. n.y.) to 30 cm (Kässbohrer Geländefahrzeug AG 2007) is specified. In addition, there are beach cleaning machines that can also screen even the smallest pieces of waste such as cigarette butts from the beach sand (H. Barber & Sons, Inc. n.y.). On the other hand, manual cleaning, which is usually superficial and only includes visible waste parts (e.g. the sand-covered waste parts on beaches tend not to be collected), which is why manual cleaning is considered less thorough in many cases. With regard to land use types where sweepers are used, a more thorough cleaning is assumed only for paved surfaces, provided that the pavement is joint-free or the depth of the joints is small enough to allow waste to be removed.

Table 4: Slip rates of the individual land use types with corresponding description of the influencing factors (exposure to drifting/flushing, cleaning intervals, cleaning slippage)

Type of land use	Sub-division	Exposure to drifting/flushing	Cleaning interval	Cleaning slippage	Base value and range
Roadside	-	Medium; wind protection by trees possible; retention of larger waste possible by fences	Long; annual to monthly cleaning is typical; on the roads managed by the North Rhine-Westphalia state road construction company (Roads.NRW), cleaning is carried out at least once a year (Wilk 2017)	Medium; manual cleaning; covering of waste by grasses and plants typical	15% (5 – 25%)
Rest stop	-	Medium; wind protection by trees possible; retention of larger waste possible by fences	Medium; monthly to weekly cleaning typical	Low; mechanical and manual cleaning typical; larger waste is less concealed by low vegetation height	10% (5 – 15%)

Type of land use	Sub-division	Exposure to drifting/flushing	Cleaning interval	Cleaning slippage	Base value and range
Park	-	Low; due to the location within cities (wind protection of buildings) and wind protection by trees/plants on the site, hardly any drift is expected. If drifts do occur, there is a very high probability that waste will be collected on adjacent urban areas.	Short; daily to weekly cleaning typical; within a pilot project of Berlin City Cleaning (Berliner Stadtreinigung) (see chapter 10.4.3.1) the parks were cleaned as needed from once a week up to several times a day (BSR 2017)	Low; mechanical and manual cleaning; larger waste is less concealed due to low vegetation height	3% (1 – 5%)
Pedestrian zone	-	Very low; due to high surrounding buildings	Very short; daily cleaning typical, e.g. in the pedestrian zones studied by Ableidinger (2004)	Very low; through predominantly mechanical cleaning on paved surfaces	0,55% (0,1 – 1,0%)
Riverside	urban	Medium; wind protection from trees/plants and buildings possible from the edge strip side; flushing also possible	Medium; annual to monthly cleaning typical; the Ahna in Kassel is cleaned once a month (Breitbarth 2017)	Medium; manual cleaning typical; covering of waste on green areas by grasses and plants typical	60% (40 – 80%) (see chapter 10.6.5)
Riverside strip	Rural	High; from the land side wind protection by trees/plants possible; flushing also possible	Very long; side strips with annual or no cleaning typical	High; manual cleaning typical; covering of waste by grasses and plants typical; inaccessible places typical	80% (70 – 90%) (see chapter 10.6.5)
Coast	Seaside resorts	Very high; high wind speeds and flushing possible	Short; seasonal, a well-kept beach is a prerequisite for seaside resorts according to the health resort laws and regulations of the coastal federal states; see enquiries to operators and providers (chapter 10.7.3)	Low; mainly mechanical cleaning (see chapter 10.7.3)	25% (10 – 40%)

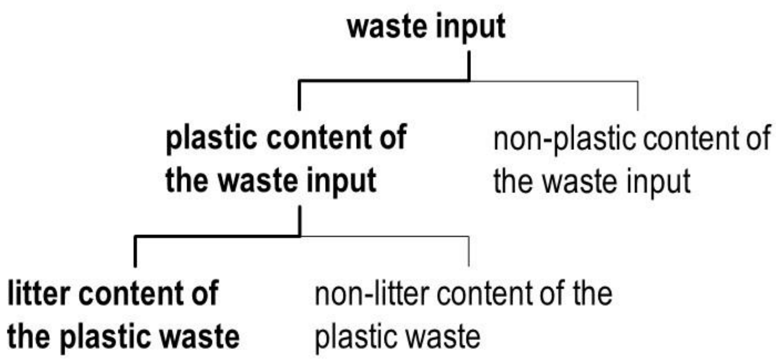
Type of land use	Sub-division	Exposure to drifting/flushing	Cleaning interval	Cleaning slippage	Base value and range
Coast	Other bathing sites	Very high; high wind speeds and flushing possible	Medium; seasonal, weekly to no cleaning typical; see enquiries to operators and carriers (chapter 10.7.3)	Medium; mainly mechanical cleaning (see chapter 10.7.3)	75% (60 – 90%)
Coast	Other coastal areas	Very high; high wind speeds and flushing possible	Very long; annual to no cleaning typical	Medium; mainly mechanical cleaning	95% (90 – 100%)
Coast	Urban coast-line	Very high; high wind speeds and flushing possible	Medium; seasonal, weekly to annual cleaning typical	Medium; mechanical and manual cleaning typical	50% (40 – 60%)
Inland bathing sites	-	Medium; from the land side wind protection by trees/plants possible; flushing also possible	Medium; seasonal, weekly to no cleaning typical	Medium; manual cleaning typical	60% (40 – 80%)

The descriptions of the three influencing factors (exposure to drifting/flushing, cleaning intervals, cleaning slip) are mainly based on the authors' assessments and, in some cases, on data surveys and literature sources. The influencing factors are not to be understood as quantitative factors of equal weight, on the basis of which the slip rates were calculated, but are rather intended to make the estimation of the slip rates more comprehensible. With regard to cleaning slip, it should be noted that mechanical cleaning is considered more thorough than manual cleaning.

4.2.3 Relationship between the plastic content of the waste input and the litter content of the plastic waste

The *plastic content of the waste input* and the *litter content of the plastic waste* are calculation quantities used to calculate the *slip* and the *remaining plastic litter* respectively (see Figure 5). Both are partial quantities of the total waste registered at a given input site or land use type. The *plastic content of the waste input* includes all plastic waste entered (see Figure 2). This includes littered plastic entries and non-littered entries (e.g. illegal dumping of plastic waste). The *litter content of the plastic waste* includes all littered plastic waste, which is the proportion of registered plastic waste that has entered the environment as a result of carelessness and careless handling. It should be noted that there is even more littered waste, but it is not made of plastic.

Figure 2: Schematic illustration of the relationship between the terms "waste input", "plastic content of the waste input" and "litter content of the plastic waste"

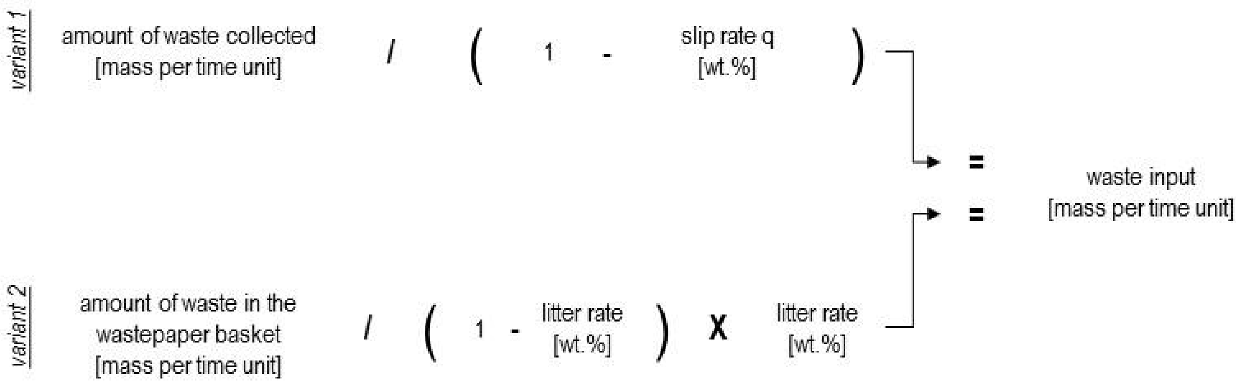


Source: Ökopol, the terms written in bold are important calculation parameters with regard to estimation.

4.2.4 Determination of the waste input

Central input variables for the designation of the waste input are results or evaluations of *collection and cleaning measures*. If data on collected waste quantities are available, the *slip rate* can be used to determine the *waste input* (see variant 1 in Figure 3). If no data on collected waste quantities are available, but data on *waste in the wastebasket*, the *waste input* can be calculated using variant 2 in Figure 3. If variant 2 (see Figure 3) is used as a basis, it should be noted that in the further calculation (see Figure 5) the *litter content of the plastic waste* is 100%, since the *waste input* was calculated using the *litter rate* and this refers exclusively to littered waste, while non-litter inputs are not considered (see glossary of terms in Table 3).

Figure 3: Variants of calculation for the waste input



Source: Ökopol, the *waste input* is a calculation variable for determining the slippage/remaining plastic litter (see Figure 5) and can be calculated using two variants.

The *waste input* so defined does not necessarily relate to the one-year period relevant for accounting purposes. The results may be available, for example, for one of several collection campaigns in the year and must then be extrapolated accordingly. This can be done on a linear basis (this corresponds to the assumption that littering, and thus the volume of waste, is constant over the year) or using adjustment factors (e.g. assuming that more waste is not properly disposed of in the summer months than in the winter months).

4.2.5 Composition of slippage

As described in Table 3, the total *slippage* is composed of the *cleaning slippage* and the *drift slippage* or the *quantities drifted/blown away*. Both values depend on the local conditions. *Quantities blown away* are understood comprehensively here, because they also include transport by water currents, e.g. on beaches and riverbanks. The *drift slip* indicates the proportion that is blown between cleanings. A high amount of *drift slip* means that a large proportion of the *waste input* escapes the cleaning process. For a type of land use that is rarely cleaned and is subject to a high amount of *drift*, this can lead to a high total *slip* or a high rate of *slip* despite a low *cleaning slip* (i.e. a very effective procedure during the cleaning itself).

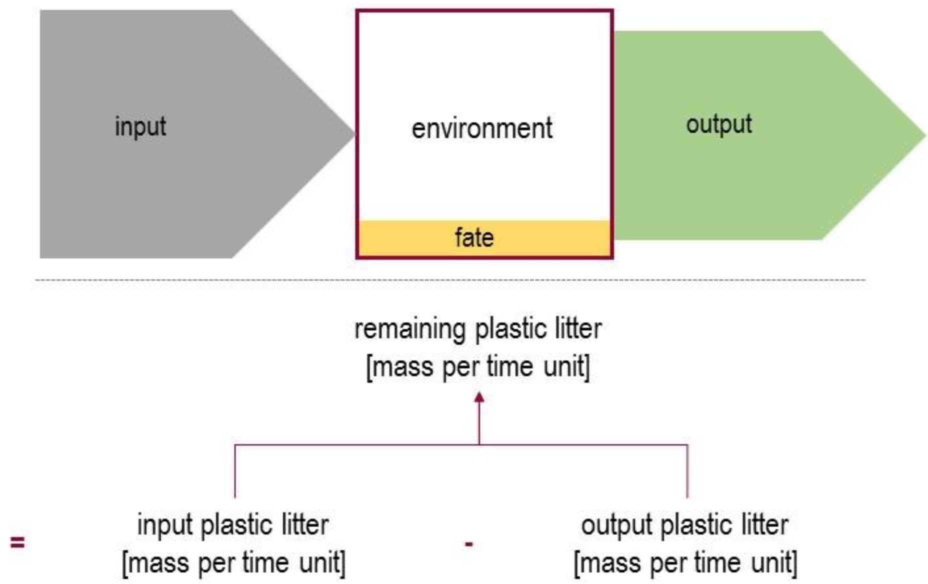
The *cleaning slip* is a socio-technical component that indicates the quality or the success rate of the cleaning carried out. It includes the proportion of waste that is present on an area at the time of the cleaning measure and is not collected. A *cleaning slip* of 0% means that the complete amount of waste present is collected during a cleaning operation. A *cleaning slip* of 50% would mean, for example, that only half of the existing waste is cleaned. The *cleaning slip*, like the *quantities blown away*, depends on local conditions. For the input model, it should be noted that the *quantity blown away* from a land use type A to a land use type B and remaining there is considered to be the fate for land use type A. On the other hand, the *quantity blown away* from land use type A to land use type B and discharged (by cleaning/collection) (*quantity blown away* without remaining in the environment) counts as discharge of land use type A. In reality, littering waste can rarely be reliably assigned to a precise input point. The model, however, refers to the location of the littering waste in order to delimit the individual land use types. If the model were to refer only to the location where the litter was deposited, land use types with high winds would be underestimated.

The size of the *slip* in relation to the *plastic litter input* can be represented as an overall *slip rate* or separately as cleaning slip and blowing rate. These relationships are illustrated in Figure 5.

4.2.6 Basic balance sheet model

The systematics on which the input model is based are presented in Figure 4.

Figure 4: Systematics of the input model

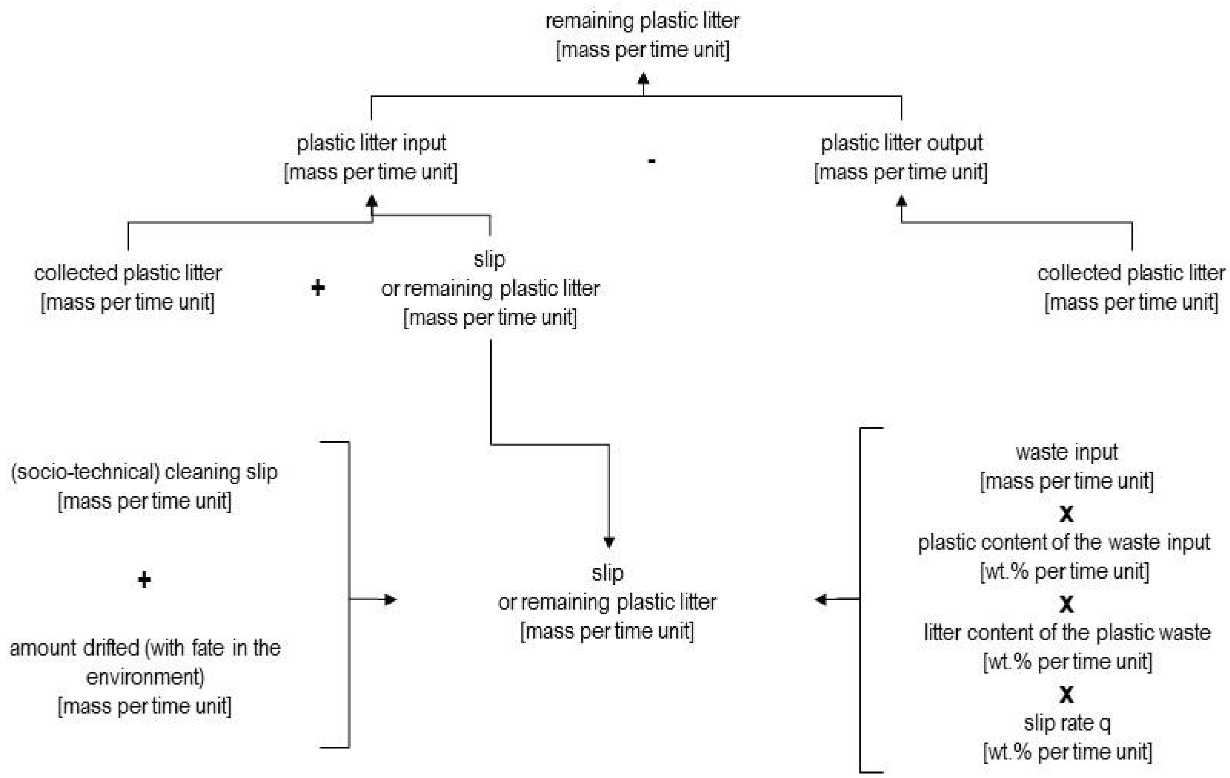


Souce: Ökopol

The fate per year (or time unit) results from the difference between the input per year (or time unit) and the output per year (or time unit). The entry is the quantity of plastic waste that has been littered over the period under consideration (here: one year). The output results from the removal of plastic waste by cleaning activities of all kinds. Accordingly, the input corresponds to the sum of the output and fate, that is, the quantity not cleaned or the quantity that is not cleaned, the so-called *slip*. The *slip* in turn is composed of the *cleaning slip* and the *quantity of blown away* (or otherwise transported in the environment) (see chapter 4.2.4).

The absolute *slip* or *remaining plastic litter* can be calculated as the product of *waste input*, *plastic content of waste input*, *litter content of plastic waste* and the *slip rate* (see Figure 5). This calculation method includes an estimation of the above factors, ideally based on reliable data. The *slip* or the *remaining plastic litter* was specified with a base value and a range, because the *slip* was calculated with the *slip rate*, which was also specified as a base value with a range. Figure 5 shows a summary of the individual relationships between the above mentioned calculation variables.

Figure 5: Relationships between input, output, cleaning and slippage



Souce: Ökopol

In the upper part of the figure, the systematics of the entry model from Figure 4 is shown again. In the lower part of the figure, the identification of the *slip* or the remaining plastic litter is explained. On the one hand, the remaining plastic litter can be calculated theoretically by adding the *cleaning slip* to the *quantity of blown away* off. However, the data basis for this is quite limited. For the practical modelling, another calculation method is therefore shown on the right side to calculate the remaining plastic litter (see chapter 4.2.4). The individual factors of this calculation method (waste input, plastic content of the waste input, litter content of the plastic waste, slip rate) are often not known either, but can be estimated on the basis of literature data and assumptions based on them. The calculation of the waste input is illustrated in Figure 3.

The input model is based on locations where anthropogenic inputs in the form of litter are more likely to occur. In fact, this can be both lines (e.g. roads, railway lines, river banks, paths) and areas (e.g. parks, pedestrian zones).

4.3 Types of areas considered

The input points/land use types considered in this report are:

- roadsides
- rest stops
- parks
- pedestrian zones
- riverside strips
- coast (North Sea and Baltic Coast)
- inland bathing sites

These entry points have been selected because they are fully or mainly accessible for the public. For sites that are not publicly accessible, it was assumed that those with access do not, or not to a relevant extent, litter.

4.4 Plastic litter remains: roadsides

In the following sections the estimation of the *remaining plastic litter* at roadsides is carried out. A more detailed description of the calculation method and the data sources can be found in chapter 10.2.

4.4.1 Description of the subject of consideration

The land use type roadsides is categorised into motorways, federal, state and district roads as well as other roads in the federal territory. Other roads include, for example, municipal roads and private roads. The roads were categorised according to the intensity of use, measured by the average daily traffic volume (DTV), which is different for the different road types. It was assumed that this results in different waste inputs: the higher the intensity of use, the higher the waste input. Table 5 gives an overview of the different road categories and their length.

Table 5: Roadside categories with respective lengths

Road type	Total length in Germany [km]
Motorways	12.996
Federal roads	38.069
State roads	86.970
District roads	91.939
Other roads	600.000

Source for length of motorways, federal, state and district roads: Destatis (2017a); source for length of other roads: BMVI (2016).

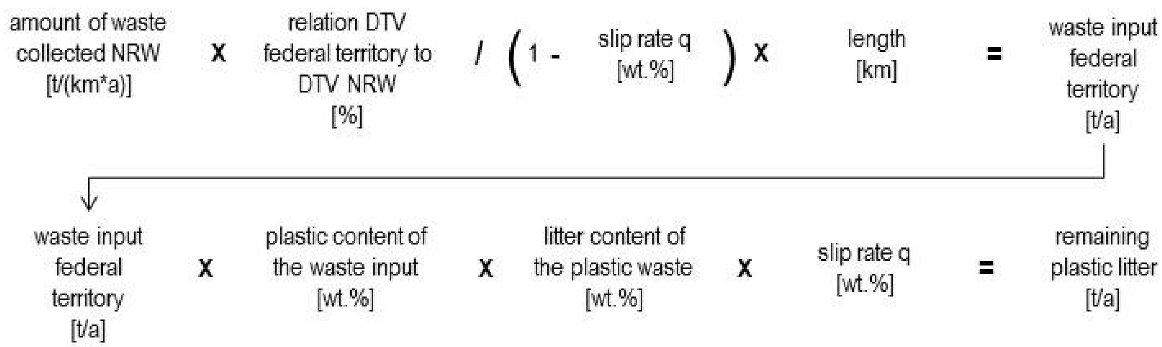
For the interpretation of the figures and calculations, it should be noted that one kilometre of road length corresponds to two kilometres of hard shoulder on which the waste can be entered. For motorways, the middle strip is also taken into account.

4.4.2 Specification of the methodological approach on the basis of the available data

Following the modelling approach described in chapter 4.2, the remaining plastic litter is determined on the basis of data from road and motorway maintenance authorities on collected waste volumes and additional information from Beyer and Winter (2016) on the plastic content of the waste input and assumptions on the slip rate (see chapter 4.2.2).

Data from road and motorway maintenance authorities are available for almost all of North-Rhine-Westphalia (NRW) (Wilk 2017). Under the assumption that waste input depends on the intensity of road use, these data are transferred to Germany using the DTV (see Figure 6).

Figure 6: Procedure for the estimation of the remaining plastic litter at edges of the respective road category



Souce: Ökopol, the procedure is slightly different from the procedure described in chapter 4.2.4, as the collected waste quantity for North-Rhine-Westphalia (NRW) for motorways, federal, state, district and other roads was first multiplied by the "relation DTV federal territory to DTV NRW", the "slip rate" and the respective "length" in order to calculate the waste input in Germany. DTV means average daily traffic volume and is considered a measure of potential litter.

4.4.3 Characterisation of the waste input

Roadside waste consists mainly of beverage and food packaging. In addition, there is waste from private households, bulky waste, building rubble and commercial waste (Roads.NRW, n.y.). It should be noted that voluminous and heavy wastes such as construction waste or bulky waste are mainly classified as illegally disposed of waste. Although these are not the subject of this study, they are included in the available data on collected waste quantities. This aspect will be considered in further calculations and derivations. Other possible relevant types of waste at roadsides are car parts that are lost (e.g. hubcaps) or entered through breakdowns and accidents (e.g. parts of burst tyres) and lost cargo. The latter types of waste are classified as litter waste (see chapter 4.1).

4.4.4 Description of central calculation variables

The following table gives an overview of the central parameters of the calculation of the remaining plastic litter resulting from the emissions at roadsides.

Table 6: Central calculation variables – roadsides

Calculated variable	Description
Waste input	Calculation is based on collective data from the North-Rhine-Westphalia State Road Construction Office (Roads.NRW), which is calculated using of the respective length (Destatis 2017a) and the average daily traffic volume (DTV) (BASt 2013, BASt 2017) was transferred to the territory of the Federal Republic of Germany.
Plastic content of waste input	Data from Beyer and Winter (2016).
Litter content of the plastic waste	Data from Beyer and Winter (2016).

Calculated variable	Description
Slip rate	The authors' expert assessment is based on the assumption of a medium exposure (with regard to drifting/flushing), long cleaning intervals and a medium cleaning slip (see chapter 4.2.2). Information on which the data on cleaning intervals is based is from Wilk (2017).

4.4.5 Results

For the sake of clarity, Table 7 quantifies the waste input and shows the results with regard to the estimation of the *plastic litter* deposited and remaining at roadsides depending on the roadside category.

Due to the significant amount of waste that is not classified as litter (e.g. illegal landfills), the importance of distinguishing between waste and litter should be emphasised. Without a corresponding distinction (or assumption of litter content = 100%), the determined quantity of remaining plastic litter would increase to up to 2,475 t/a, assuming otherwise the same assumptions for slip and plastic content (which, however, would represent a significant simplification)[4].

Table 7: Results on the estimation of plastic litter fate based on roadside litter

Category – roadsides	Waste input [t/a]	Litter input [t/a]	Plastic litter input [t/a]	Remaining plastic litter [t/a]
Motorways	8,776 (7,852-9,946)	5,266 (4,711-5,968)	1,158 (1,037-1,313)	174 (52-328)
Federal roads	7,779 (6,933-8,782)	4,649 (4,160-5,269)	1,023 (915-1,159)	153 (46-290)
State roads	7,581 (6,783-8,592)	4,549 (4,070-5,155)	1,001 (895-1,134)	153 (46-290)
District roads	5,009 (4,482-5,677)	3,005 (2,689-3,406)	661 (592-749)	99 (30-187)
Other roads	10,588 (9,474-12,000)	6,353 (5,684-7,200)	1,398 (1,251-1,584)	210 (63-396)
Total amount	**39,703 (35,524-44,997)**	**23,822 (21,314-26,998)**	**5,241 (4,689-5,940)**	**786 (234-1,485/ 2,475)**

The waste input was calculated on the basis of data from Roads.NRW, Destatis (2017a) and BASt (2013, 2017). The corresponding calculation method is illustrated in Figure 6. For the waste entries, ranges were given because the waste entry was calculated on the basis of the slip rate, which included a base value, a minimum and a maximum (see Figure 6). For the litter input, plastic litter input and the remaining plastic litter also ranges were given, because these calculation values were calculated on the basis of the waste input. Litter input was calculated on the basis of waste input and data from Beyer and Winter (2016). The plastic litter input was calculated on the basis of the litter input and data from Beyer und Winter (2016). The remaining plastic litter was calculated on the basis of the plastic litter input and estimates of the slip rates (see Table 4).

[4] A more detailed parameter variation can also be found in the chapter 6 (comparison of studies).

4.5 Plastic litter remains: rest stops

In the following chapters, the estimation of the *remaining plastic litter*, entered by the litter in rest facilities, is explained. A detailed description of the calculation method and the data sources can be found in chapter 10.3.

4.5.1 Description of the subject of consideration

Managed rest stops consist of a traffic infrastructure, which includes lanes, parking spaces and recreational areas, and one or more ancillary facilities (petrol station, service station, motel) (BMVI 2016b). Unmanaged rest stops consist only of a traffic infrastructure and possibly an additional toilet building (BMVI 2016b).

For the following analysis, this type of land use is categorised into managed motorway rest stops, managed rest stops on federal, state and district roads, unmanaged motorway rest stops and unmanaged rest stops on federal, state and district roads (see Table 8). The categorisation was based on the assumption that the service areas of the four categories are used differently. The reason for this was data from Roads.NRW, which contained differences in the average number of baskets for the above categories.

Table 8: Rest stop category with respective number of rest stops in Germany

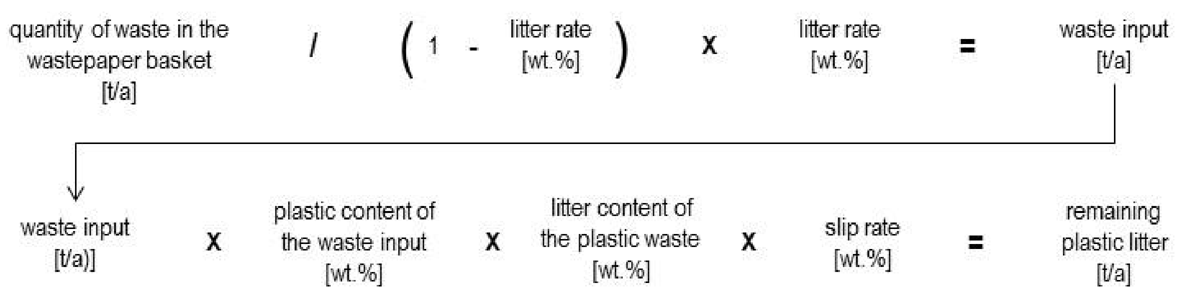
Category – rest stop	Amount in Germany
managed rest stops along motorways	434
managed rest stops on federal, state and district roads	159
unmanaged motorway rest stops	1,500
unmanaged rest stops on federal, state and district roads	389

Source for total number of managed and unmanaged motorway rest stops: BMVI (2016b). The number of managed and unmanaged rest stops on federal, state and district roads was extrapolated for the federal territory on the basis of data from Roads.NRW (see chapter 10.2).

4.5.2 Specification of the methodological approach on the basis of the available data

The estimation is based on the procedure described in chapter 4.2 (see Figure 7). The basic data were provided by Roads.NRW, which is why, analogous to the observation of the roadsides, an observation related to NRW is first carried out before extrapolating to the situation in Germany.

Figure 7: Procedure for the estimation of the remaining plastic litter that was deposited on German rest stops



Souce: Ökopol, the waste input was determined with variant 2 (see Figure 3). In this illustration, the individual mathematical operations from Figure 5 and Figure 3 are summarised in a slightly modified form. The litter content of the plastic waste here is 100% by weight, since the litter rate was used to determine the waste input (see chapter 4.2.4).

4.5.3 Characterisation of the waste input

Waste at rest stops can be divided into typical rest stop-wastes (beverage packaging, disposable crockery, leftover food) and waste that is not disposed of properly (other mixed waste in bags, household waste in bags, craftsmen's waste) (cf. investigations by Beyer and Winter (2016)). Other possible types of waste include cigarette packaging and cigarette butts, as well as printed matter read by passengers to pass the time during the journey.

The volume of waste may be higher at managed rest areas with take-away restaurants than at rest areas without take-away restaurants. In less frequented rest areas and/or rest areas with few users at certain times of the day, the volume of illegal dumping is estimated to be higher.

4.5.4 Description of central calculation variables

The following table gives an overview of the central calculation parameters for the calculation of the remaining plastic litter resulting from the entry at rest stops.

Table 9: Central calculation variables – rest stops

Calculated variable	Description
Waste input	Calculations are based on data on basket volumes in North-Rhine-Westphalia, collected by the North-Rhine-Westphalia State Road Construction Office (Roads.NRW), and estimates of the litter rate, based on studies and information from Breitbarth and Urban (2014), Heeb et al. (2005) and Wilk (2017). The transfer to the territory of the Federal Republic of Germany was based on data on the respective number of rest stops from BMVI (2016b) and the average daily traffic volume (DTV) (BASt 2013, BASt 2017).
Plastic content of waste input	Data from Beyer and Winter (2016).
Litter content of the plastic waste	Based on the methodological approach for estimating the waste input with variant 2 (see chapter 4.2.4).
Slip rate	The authors' expert assessment based on the assumption of a medium exposure (with regard to drifting/flushing), medium cleaning intervals and a low cleaning slippage (see chapter 4.2.2).

4.5.5 Results

For the sake of clarity, the *waste input* and the *remaining plastic litter* are quantified in Table 10 according to the category of rest stop.

Table 10: Results on the estimation of plastic litter fate based on litter in rest stops

Category – rest stops	Waste input or litter input [t/a]	Plastic litter input [t/a]	Remaining plastic litter [t/a]
managed rest stops along motorways	931	205	20.5 (10.2 - 30.7)

Category – rest stops	Waste input or litter input [t/a]	Plastic litter input [t/a]	Remaining plastic litter [t/a]
managed rest stops on federal, state and district roads	12	2.6	0.26 (0.13-0.38)
unmanaged motorway rest stops	1,367	301	30.1 (15.0-45.1)
unmanaged rest stops on federal, state and district roads	32	7.0	0.70 (0.35-1.06)
Total amount	**2,342**	**515**	**51.5 (25.8-77.3)**

The waste input was estimated with variant 2 (see Figure 3 in chapter 4.2.4), i.e. the waste input is equal to the litter input. Further explanations can be found in chapter 4.2.4. The calculation of waste and litter input was based on data from Roads.NRW, Breitbarth and Urban (2014), Heeb et al. (2005), Wilk (2017), BMVI (2016b) and BASt (2013, 2017). The calculation of the plastic litter input was based on the waste input or the litter input and data from Beyer and Winter (2016). No ranges were given for the waste input or litter input and the plastic litter input because the calculations of these quantities were not based on the slip rates. In contrast, ranges are given for the quantities of the remaining plastic litter because the calculations of the remaining plastic litter included slip rates, including the ranges.

4.6 Plastic litter remains: parks

In the following chapters, the estimation of the *remaining plastic litter* caused by litter in parks is explained. A detailed description of the calculation method and the data sources can be found in chapter 10.4.

4.6.1 Description of the subject of consideration

A park is an area that is kept free of buildings and can be interspersed with paths (Leser et al. 1998). The vegetation in parks ranges from herb layers to trees. The origin of this vegetation can be divided into four groups: original natural landscape, agricultural landscape, symbolic gardening and spontaneous urban-industrial growth (Sukopp and Wittig 1998).

The parks were categorised in order to preserve the park area. The categorisation of the parks was partly based on the type of city in which the respective parks were located. For towns/small cities (<20,000 inhabitants) no data were available regarding the green space on which the calculation of the park area was based. The parks of towns are therefore grouped together with all other parks outside cities in the category *other parks*. The parks were categorised in:

- parks in large major cities (> 500,000 inhabitants)
- parks in small major cities (100,000 – 500,000 inhabitants)
- parks in large cities (50,000 – 100,000 inhabitants)
- parks in medium cities (20,000 – 50,000 inhabitants)
- other parks.

No nationwide data on the area of the parking facilities were available. The next higher category within the classification of the Federal Statistical Office is green spaces, the areas of which were given for all district-free cities in Germany. On the basis of this data set, the green space areas were first calculated for each city type category. Subsequently, a certain proportion of the total green area was estimated for each category. These parking area proportions differed by category, since it was assumed that the proportion of parking area increases with increasing city size. The reason for this assumption is provided by Wöllper (2009), who found that with increasing urbanisation the share of public green spaces, which include parks, in the total area of cities increases. The estimates for the proportion of parking space are based on data from the Statistical Offices of the federal states of Bremen, Mecklenburg-Western Pomerania (MV), North Rhine-Westphalia, Rhineland-Palatinate and Thuringia (see Table 71). By multiplying the green space area by the respective proportion of park area, the individual park areas were obtained. For the sake of clarity, Table 11 lists the calculated areas of the individual categories with the corresponding park area proportions. For the subsequent estimation of the remaining plastic litter, categorisation was no longer necessary because it was assumed that the standardised calculation parameters of the individual categories (*collected waste quantity*, *slip rate*, *plastic content of waste input*, and *litter content of plastic waste*) do not differ for the different types of settlements. For future updates of the estimate, however, this categorisation is still useful, as it can be assumed that the standardised calculation parameters will then differ according to category, which is why this categorisation is also reflected in the results section.

Table 11: Park category with estimated areas

Category – parks	Green space [km²]	Share of park area in green space	Park area [km²]
Large major cities	359	30%	108
Small major cities	396	24%	95.1
Large cities	360	18%	64.8
Medium cities	273	12%	32.8
Other	1,527	6%	91.6
Total amount	-	-	**392**

A detailed description of the estimation of the area is given in chapter 10.4.2.

4.6.2 Specification of the methodological approach on the basis of the available data

The estimation was carried out according to the explanations in chapter 4.2. and the waste input was calculated according to variant 1 in Figure 3. The data basis for the estimation of the plastic litter fate in parks originates from a pilot project of the Berlin City Cleaning Service (Berliner Stadtreinigung (BSR)).

4.6.3 Characterisation of the waste input

Typical park waste disposed of by humans can be divided into litter waste, paper basket waste and bulky waste. Further park waste is generated by the care of the plants. Hertner and Großmann (2017) include leaves, green waste and the wild growth on paved surfaces.

4.6.4 Description of central calculation variables

Table 12 lists the central calculation parameters on which the estimation is based, together with a description.

Table 12: Central calculation variables – parks

Calculated variable	Description
Waste input	Calculations are based on data of collected waste quantities by the Berlin City Cleaning Service within a pilot project (Hertner and Großmann 2017; BSR 2017).
Plastic content of waste input	Data originate from a sorting analysis of Dresden's waste paper basket, which INTECUS GmbH carried out in 2017.
Litter content of the plastic waste	Data from the Berlin City Cleaning Service (BSR 2017).
Slip rate	The authors' expert assessment is based on the assumption of low exposure (with regard to drifting/flushing), short cleaning intervals and low cleaning slippage (see chapter 4.2.2).

4.6.5 Results

The results regarding the estimation of plastic litter fate in parks are listed in Table 13.

Table 13: Results on the estimation of plastic litter fate based on litter in parks

Category – parks	Litter input [t/a]	Plastic litter input [t/a]	Remaining plastic litter [t/a]
Large major cities	27,725	1,664	50 (16-85)
Small major cities	24,521	1,471	44 (14-75)
Large cities	16,706	1,002	30 (10-51)
Medium cities	8,443	507	15 (5,0-26)
Other parks	23,609	1,417	42 (14-72)
Total amount	**101,005**	**6,060**	**182 (59-309)**

The waste input was not reported because the initial data from Berliner Stadtreinigung related exclusively to litter within the meaning of this study and did not take into account other waste, such as illegal dumping within the meaning of this study. The calculation of the litter input was based on data from Hertner und Großmann (2017) and BSR (2017). The calculation of the plastic litter input was based on the litter input and analyses of the authors. The remaining plastic litter was calculated on the basis of the plastic litter input and the estimates of the slip rates (see Table 4). No ranges were given for litter input and plastic litter input because the calculations of these quantities were not based on the slip rates.

4.7 Plastic litter remains: pedestrian zones

This chapter summarises the estimation of the *remaining plastic litter* caused by litter in pedestrian zones. A detailed description of the calculation method and data sources is given in chapter 10.5.

4.7.1 Description of the subject of consideration

Pedestrian zones were understood to be traffic areas where pedestrians are given priority over other road users (Höfler 2004). These are often located in the centre of cities or towns. The pedestrian zones were divided into the following categories to define the area:

- Pedestrian zones in large major cities (>500,000 inhabitants)
- Pedestrian zones in small major cities (100,000 – 500,000 inhabitants)

- Pedestrian zones in large cities (50,000 – 100,000 inhabitants)
- Pedestrian zones in medium cities (20,000 – 50,000 inhabitants)
- Pedestrian zones in small cities (10,000 – 20,000 inhabitants).

The procedure for calculating the pedestrian zone area was similar to the procedure for calculating the park area. As with the parks, no nationwide data on the area of the pedestrian zones was available. The next highest category within the classification of the Federal Statistical Office is that of streets, paths and squares, the areas of which were available for all independent cities in Germany. Based on this, the areas of the streets, paths and squares were first calculated for each category. For each individual category, a certain proportion of pedestrian zones in the total proportion of streets, roads and squares was estimated, since it was assumed that the proportion of pedestrian zone area or the existence of a pedestrian zone in a city depends on the size of the city. The reason for this assumption was given by Monheim (2011), who describes that in Bavaria in 1985 only 50% of all medium cities and 20% of all small cities contained pedestrian zones, whereas in cities with a population of 50,000 or more, i.e. from large cities, the figure is 100%. Based on this statement it was assumed that the number of towns with pedestrian zones is very small, resulting in the neglect of pedestrian zones in towns of small size. For the pedestrian zone area share in large and small major cities and large cities, the pedestrian zone area share of the federal state of Bremen was used. Based on the statement of Monheim (2011), it was assumed for the pedestrian zone shares of medium cities and small cities that these are half and one fifth of the pedestrian zone shares of the other three categories (see Table 14). Table 14 includes, depending on the category, the calculated areas of streets, paths and squares, the pedestrian zone area shares and the pedestrian zone areas. For the subsequent estimation of the *remaining plastic litter*, categorisation was no longer necessary because the (standardised) calculation parameters of the individual categories were assumed to be the same (*plastic litter input*, *slip rate*). For future updates of the estimation, categorisation is nevertheless useful, as it can be assumed that the standardised calculation parameters will then differ according to category.

Table 14: Pedestrian zone categories with areas of the streets, paths and squares, the pedestrian zone area shares and the pedestrian zone area

Category – pedestrian zones	Area of the streets, paths and squares [km²]	Pedestrian zone area as a proportion of the area of streets, paths and squares	Pedestrian zone area [km²]
Large major cities	534	0.321%	1.71
Small major cities	809	0.321%	2.60
Large cities	713	0.321%	2.29
Medium cities	1,148	0.161%	1.84
Small cities	638	0.064%	0.41
Total amount	-	-	**8.86**

The detailed description for defining the areas is given in chapter 10.5.3.

4.7.2 Specification of the methodological approach on the basis of the available data

The estimation was based on the methodology described in chapter 4.2. Ableidinger (2004) contains data on the plastic litter input in pedestrian zones on which the estimation is based.

Using data on plastic litter input eliminated the need to calculate the *waste input* and then multiply it by the *plastic content* of the *waste input* and the *litter content of the plastic waste*.

4.7.3 Characterisation of the waste input

According to Heeb et al. (2005), the waste input in pedestrian zones consists of disposable beverage packaging, take-away packaging, newspapers and advertising, shopping bags and miscellaneous items. The latter includes e.g. textiles, hazardous waste and indefinable items.

4.7.4 Description of central calculation variables

The central calculation parameters for the estimation are listed in Table 15 with the corresponding description.

Table 15: Central calculation variables – pedestrian zones

Calculated variable	Description
Plastic waste input	Data based on investigations by Ableidinger (2004) and analyses by the authors
Slip rate	Expert assessment of the authors based on the assumption of a very low exposure (with regard to drifting/flushing), very short cleaning intervals and a very low cleaning slip (see chapter 4.2.2).

4.7.5 Results

The results regarding the *plastic litter input* and the amount of *plastic litter remaining* in pedestrian zones are listed in Table 16.

Table 16: Results on the estimation of plastic litter remains based on litter in pedestrian zones

Category – pedestrian zones	Plastic litter input [t/a]	Remaining plastic litter [t/a]
Large major cities	125	0.63 (0.13-1.25)
Small major cities	190	0.95 (0.19-1.90)
Large cities	167	0.84 (0.17-1.67)
Medium cities	135	0.67 (0.13-1.35)
Small cities	30	0.15 (0.03-0.30)
Total amount	**646**	**3.23 (0.65-6.46)**

The waste input and the litter input were not shown because the estimate was based on the plastic litter input. The plastic litter input was calculated on the basis of data from Ableidinger (2004) and analyses by the authors. The remaining plastic litter was calculated on the basis of the plastic litter input and the estimates of the slip rates (see Table 4).

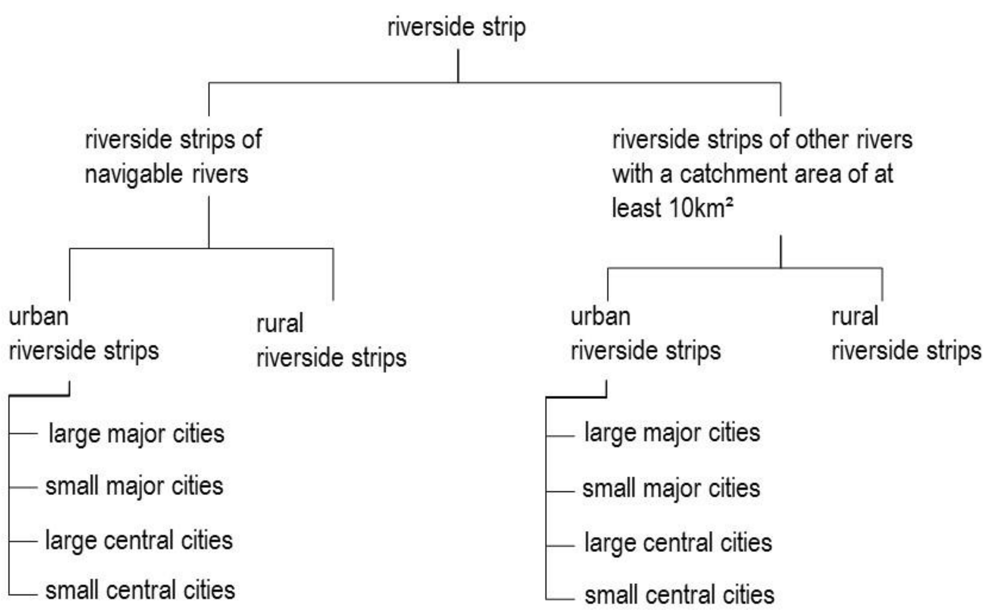
4.8 Plastic litter remains: riverside strip

The following chapters summarize the estimation of the *remaining plastic litter* caused by litter on riversides. A detailed description of the calculation method and data sources is given in chapter 10.6.

4.8.1 Description of the subject of consideration

The riversides have been divided into riversides of partly or fully navigable rivers, henceforth called navigable rivers, and other rivers with a catchment area of more than 10 km^2, subsequently referred to as other rivers, which are not navigable (see Figure 8). This subdivision has been made because it has been assumed that wider rivers, which include navigable rivers, have a higher potential for attracting inhabitants and tourists, and therefore contain a higher waste input than rivers of smaller width. The riversides of the navigable rivers and other rivers were further divided into urban and rural riversides, because it was assumed that the intensity of use and thus the waste input is higher in urban areas. The riversides of urban navigable rivers and other urban rivers are further divided into large major cities, small major cities, large cities and medium cities. This subdivision was important for the determination of the lengths of the riversides of navigable rivers and other rivers within cities, since rivers in larger cities are on average longer than in smaller cities. For the following estimation, the normalized calculation parameters are the same within the city categories (*waste input, slip rate, plastic content of waste input, litter content of plastic waste*). In future updates of the estimation, the categorization into different city types is nevertheless useful, since it can be assumed that the normalized quantities will then differ depending on the city type. Data on the number of small cities and towns in Germany that contain rivers were not available. These could, however, be included in future updates and given the data basis. As a separate category of small cities is currently not possible, they are considered together with the rural riversides in the current classification.

Figure 8: Categorisation of the riverside strips



Souce: Ökopol

When interpreting the figures and calculations, it should be noted that one kilometre of river length normally corresponds to two kilometres of riversides where the waste can be discharged. Based on this, the length of the riverside was assumed to be twice the length of the river (see Table 17). In reality, additional riversides through islands would have to be included. Furthermore, only the riversides of one side of the river would have to be considered for boundary rivers.

Table 17: Riverside categories with estimated river lengths

Riverside category	Estimated river length in Germany [km]	Estimated riverside length in Germany [km]
Navigable rivers in large major cities	420	840
Navigable rivers in small major cities	690	1,380
Navigable rivers in large cities	330	660
Navigable rivers in medium cities	356	712
Navigable rivers in rural areas	7,372	14,744
Other rivers in large major cities	6,073	12,146
Other rivers in small major cities	9,977	19,954
Other rivers in large cities	4,771	9,542
Other rivers in medium cities	5,151	10,302
Other rivers in rural areas	106,586	213,172

The detailed description for estimating the length is given in chapter 10.6.1.

4.8.2 Specification of the methodological approach on the basis of the available data

The estimation was carried out according to the procedure described in chapter 4.2. The basic data were provided by Breitbarth and Urban (2016), who established a quantitative material flow model for the river Ahna in Kassel. The Ahna belongs to the other rivers in urban areas (small city). Based on these data, the estimates for the other categories were made under certain assumptions.

4.8.3 Characterisation of the waste input

River wastes can be characterised as construction materials, beverage packaging, food packaging, other packaging, film/bags/sacks, items from sewage treatment plants, sports and leisure items, garden items and others. This classification originates from Breitbarth (2017), who studied waste at six rivers (Rhine, Elbe, Fulda, Saale, Haune and Ahna).

4.8.4 Description of central calculation variables

Table 18 lists the central calculation parameters on which the estimate is based, together with a description.

Table 18: Central calculation variables – riverside strips

Calculated variable	Description
Waste input	Data from Breitbarth and Urban (2016) and Breitbarth (2017)
Plastic content of waste input	Data from Breitbarth (2017)
Litter content of the plastic waste	Data from Breitbarth (2017)

Calculated variable	Description
Slip rate	The authors' expert assessment is based on the assumption of a medium exposure (with regard to drifts/flushes), medium cleaning intervals and a medium cleaning slip for urban riversides and a high exposure (with regard to drifting/flushing), very long cleaning intervals and a high cleaning slip for rural riversides (see chapter 4.2.2). Basic data for the riversides of other rivers in the urban area of a small city were provided by Breitbarth (2017).

4.8.5 Results

The results regarding waste input and the amount of plastic litter remaining in the environment, based on litter at riversides, are listed in Table 19.

Table 19: Results on the estimation of plastic litter fate based on litter at riversides

Category – river side	Waste input[t/a]	Litter input [t/a]	Plastic litter input[t/a]	Remaining plastic litter [t/a]
Navigable rivers in large major cities	67	43	15	9.1 (6.1-12)
Navigable rivers in small major cities	110	71	25	15 (9.9-20)
Navigable rivers in large cities	53	34	12	7.1 (4.8-9.5)
Navigable rivers in medium cities	57	36	13	7.7 (5.1-10)
Navigable rivers in rural areas	15	9,4	3,3	2.7 (2.3-3.0)
Other rivers in large major cities	486	311	109	66 (44-88)
Other rivers in small major cities	798	511	180	108 (72-144)
Other rivers in large cities	382	244	86	52 (34-69)
Other rivers in medium cities	412	264	93	56 (37-74)
Other rivers in rural areas	107	68	24	19 (17-22)
Total amount	**2,486**	**1,591**	**560**	**342 (232-451)**

The waste input was calculated on the basis of data by Breitbarth and Urban (2016) and Breitbarth (2017). The calculation of the litter input was based on the waste input and data from Breitbarth (2017). The calculation of the plastic litter input was based on the litter input and data from Breitbarth (2017). The remaining plastic litter was calculated on the basis of the plastic litter input and the estimates of the slip rates (see Table 4).

4.9 Plastic litter remains: coasts

In the following chapters the summary of the estimation of the *remaining plastic litter* starting from German coasts is explained. A detailed description of the calculation method and the data sources can be found in chapter 10.7.

4.9.1 Description of the subject of consideration

The coastal land use type is delimited as follows depending on the coastal federal state. In Lower Saxony (NI), it was referred to the mainland bordering the North Sea and the islands belonging to NI. In Schleswig-Holstein (SH), the Halligs were also considered in addition to the mainland coast and the islands. In Mecklenburg-Western Pomerania (MV) the outer coast and the inland coast were considered. In addition to the islands and peninsulas, the outer coast of MV includes the land border, which borders directly on the Baltic Sea. The Bodden and Haff coasts belong to the inland coast of MV.

The coast was categorized, since it was assumed that the litter input (or intensity of use) and the slip rate (or frequency and type of cleaning) vary in the respective categories. The individual categories are:

- Seaside resorts
- Other bathing sites
- Other coast
- Other inland coast of MV
- Urban coast.

There may be overlaps between the urban coast and the categories of seaside resorts, other bathing sites and other coast. Therefore, it is possible that another bathing site can be an urban coast at the same time. The four categories of seaside resorts, other bathing sites, other coast and other inland coast of MV do not overlap and altogether represent the length of the entire German coastline. The other inland coast of MV has been categorised individually because it was assumed that it is less frequently used than the outer coast of MV. The reason for this was the number of bathing sites in relation to the respective length (see chapter 10.7.1.3). The estimated coast lengths for each category are listed in Table 20.

Table 20: Coastal categories with estimated lengths

Category – coast	Length in Germany [km]
Seaside resorts	399
Other bathing sites	196
Other coast	1,308
Other inland coast of MV	1,541
Urban coast	74

The detailed description for estimating the length is given in chapter 10.7.2.

4.9.2 Specification of the methodological approach on the basis of the available data

The procedure for determining the remaining plastic litter from coasts differed slightly from the basic procedure (see chapter 4.2). First, the litter input (normalized to 100 m) was estimated for the individual coastal categories (see chapter 10.7.5). Based on this, the *litter input* was multiplied by the *plastic content of the litter* and the *slip rate* to obtain the respective *remaining plastic litter* (see Figure 9).

Figure 9: Procedure for estimating the remaining plastic litter from coasts

litter input [t/(100 m*a)]	X	plastic content of the litter [wt.%]	X	slip rate q [wt.%]	X	length [100 m]	=	remaining plastic litter [t/a]

Souce: Ökopol, the procedure for estimating the remaining plastic litter from coasts is slightly different from the basic procedure (see chapter 4.2), because the litter input was calculated first. The litter input was then multiplied by the plastic content of the litter, the slip rate and the length of the line to obtain the remaining plastic litter. The litter content of the plastic waste was not included in the calculation shown because the waste entry or the litter entry was made up of 100% litter.

4.9.3 Characterisation of the waste input

Coastal waste can be divided into waste discharged on land (land-based) and waste discharged at sea (sea-based). Sources of land-based waste are tourism/recreational activities and waste from discharged sewage (including combined sewer overflows due to heavy rainfall events) (OSPAR, 2007). Sources of sea-based waste are fisheries (including aquaculture), shipping and caboose (OSPAR, 2007). Schernewski et al. (2017) also cite offshore platforms as seaward sources. The individual shares of these groups in coastal waste and also the absolute quantities depend on the location. For example, the share of waste from tourism/recreational activities is lower on the North Sea coast than on the Baltic Sea coast, while the share of seaward waste is higher on the North Sea (Schernewski et al., 2017). Land based input is also strongly site-specific, i.e. higher inputs are to be expected in the vicinity of high tourism activities or the discharge of sewage (including combined sewer overflows as a result of heavy rainfall events). Furthermore, the distribution of waste objects in a small area is highly variable, so that the amount of waste (number of pieces) on adjacent 100-m coastal sections can increase by up to twice as much (Schernewski et al., 2017). In this study, beach litter is divided into litter, which includes waste from tourism/recreational activities, and non-litter, i.e. waste from discharged sewage, fishing, shipping, cabooses and offshore platforms.

4.9.4 Description of central calculation variables

Table 21 lists the central calculation parameters on which the estimate is based, together with a description.

Table 21: Central calculation variables – coast

Calculated variable	Description
Litter input	Basic data by Hengstmann et al. (2017) and the Dierhagen spa administration
Plastic content of the litter	Data by Hengstmann et al. (2017)
Slip rate	Expert opinion of the authors (see chapter 4.2.2); for seaside resorts and other bathing sites the assessment is based on interviews with institutions and operators (see chapter 10.7.3)

4.10 Plastic litter remains: inland bathing sites

This chapter describes the estimation of the *remaining plastic litter* at inland bathing sites.

4.10.1 Description of the subject of consideration

In Germany, there were 1,925 EU inland bathing sites in 2015 (EUA 2016). A definition of the EU bathing sites can be found in chapter 10.7.1.2, but there are other bathing sites in addition to the EU inland bathing sites. To record these, the data available for MV from KGeo LAIV (2017) was evaluated. In addition to the 152 EU inland bathing sites, 187 further inland bathing sites were recorded (KGeo LAIV 2017). This means that 45% of all inland bathing sites in MV are EU inland bathing sites. If this numerical ratio is transferred to the federal territory, the total number of inland bathing sites amounts to about 4,300. In order to calculate the total length of inland bathing sites, a specific inland bathing site length had to be assumed. In Schleswig-Holstein, the mean value of the inland bathing area length is 81 m and the median 50 m (GDI-SH LVerteo 2017). As the mean value deviates relatively strongly from the median, the length of inland bathing sites in Germany was estimated at 50 m on the basis of the median. With the number of inland bathing sites (4,300) and the specific length of 50 m, the total length is 215 km.

4.10.2 Results

The results regarding *waste input* and the amount of *plastic litter remaining*, based on coastal littering, are listed in Table 22.

Table 22: Results on the estimation of the plastic litter remains based on coastal litter

Category – coast	Length in Germany [km]	Litter input [t/a]	Plastic litter input [t/a]	Remaining plastic litter [t/a]
Seaside resorts	399	383	115	29 (11-46)
Other bathing sites	196	132	40	30 (24-36)
Other coast	1,308	153	46	43 (41-46)
Other inland coast of MV	1,541	6	1.7	1.6 (1.5-1.7)
Urban coast	74	26	8	3.9 (3.1-4.7)
Total amount	-	**699**	**210**	**107 (81-134)**

The calculations of the individual lengths are described in chapter 10.7.2. The calculation of the litter input was based on data from Hengstmann et al. (2017), Schernewski et al. (2017) and the Dierhagen spa administration. The calculation of the plastic litter entry was based on the litter entry and data from Hengstmann et al. (2017). The remaining plastic litter was calculated on the basis of the plastic litter entry and the estimates of the slip rates (see Table 4). The corresponding calculation method is illustrated in Figure 9.

4.10.3 Specification of the methodological approach on the basis of the available data

The estimation of plastic litter input and fate based on the litter from inland bathing sites corresponds to the estimation of other bathing sites in chapter 4.9 and 10.7.

4.10.4 Characterisation of the waste input

Waste input at inland bathing sites can be divided into land-based and sea-based waste, just like waste input at the coast (see chapter 4.9.3). Maritime waste is fishery waste (including aquaculture) and waste from shipping and cabooses. In comparison to the seaward waste inputs at the coast, waste from offshore platforms is excluded as inputs at inland bathing sites. Possible land-based entries are leftovers and packaging from the consumption of food on the move, cigarettes/filters, cigarette and tobacco packaging, children's toys (e.g. shovels) and bathing and beach utensils (e.g. empty sunscreen packaging, broken parasols, forgotten towels and swimwear).

4.10.5 Description of central calculation variables

It is assumed that the values of the individual calculation parameters (*litter input*, *plastic content of the litter*) used to determine the **remaining plastic litter** from inland bathing sites are equal to the values of the other bathing sites on the coast (see chapters 4.9 and 10.7). This assumption is based on the fact that the intensity of use and the cleaning intervals of other coastal bathing sites and inland bathing sites are estimated to be similar. The only parameter that differs from the estimation of other coastal bathing areas is the slip rate (see chapter 4.2.2).

Table 23: Central calculation variables – inland bathing site

Calculated variable	Description
Litter input	Basic data from Hengstmann et al. (2017)
Plastic content of the waste input	Data from Hengstmann et al. (2017)
Litter content of the plastic waste	Data from Schernewski et al. (2017)
Slip rate	The authors' expert assessment is based on the assumption of medium exposure (with regard to drifting/flushing), medium cleaning intervals and a medium cleaning slip (see chapter 4.2.2).

4.10.6 Results

The results regarding *waste input* and the amount of *plastic litter remaining*, based on litter from inland bathing sites, are listed in Table 24.

Table 24: Results on the estimation of plastic litter fate based on litter from inland bathing sites

Inland bathing sites	Length in Germany [km]	Litter input [t/a]	Plastic litter input [t/a]	Remaining plastic litter [t/a]
Total amount	215	145	43	26 (17-35)

The calculation of the length is described in chapter 4.10.1. The calculation of the litter input was based on data from Hengstmann et al. (2017) and Schernewski et al. (2017). The calculation of the plastic litter input was based on the litter input and data from Hengstmann et al. (2017). The remaining plastic litter was calculated on the basis of the plastic litter input and the estimates of the slip rates (see Table 4). The corresponding calculation method is illustrated in Figure 9.

4.11 Other types of land use

There are other types of land use that are subject to littering, such as natural areas used for tourism, forests or water surfaces (directly from riparian strips or bridges). However, there was no data basis for an estimate of the plastic waste discharged into the environment on these land use types. For a future estimation of the *remaining plastic litter* in the environment of Germany and given data basis these land use types should be considered.

4.11.1 Natural areas used for tourism

Natural areas used for tourism are, for example, hiking trails or cycle paths in the countryside. The share of litter waste in the waste input (litter and illegally disposed waste) on cycle and hiking paths is estimated to be very high. The reason for this is that the accessibility for cars, which are a possible means of transport for illegally disposed waste, is estimated to be very limited.

In comparison to the waste of the other land use types, it is assumed that the litter waste on hiking and cycling paths contains a higher proportion of plastic, as hikers and cyclists generally carry as little heavy material as possible, such as glass bottles, and therefore use plastic packaging as an alternative.

In the following, it is described how an estimation of the plastic litter remains on hiking trails could be carried out, if a sufficient data basis is available. A possible categorisation of the hiking trails could be done by classifying the trails according to their intensity of use. In this way, certain lengths of hiking trails could be obtained, which for example have a high, medium or low utilisation. By investigating the waste on hiking trails, the waste input, the plastic content of the waste input and the litter content of the plastic waste could be determined for the individual categories. The slip rate could be estimated by the number of cleanings and their intervals. Based on this, the plastic litter remains in the environment due to litter along hiking trails could be estimated. An estimation of the remaining plastic litter based on the littering of cycle paths could be done analogously.

4.11.2 Forests

The share of illegal landfills in the total share of waste disposed of by humans in forests is estimated to be high in comparison with natural areas used for tourism (see chapter 4.11.1), as access for cars is available at least in forests where timber is felled and driven away. Particularly along less frequented forest roads, which are located close to the public road network, a higher occurrence of illegal deposits can be expected. This is associated with a lower proportion of litter in the total amount of waste disposed of by humans compared to natural areas used for tourism (see chapter 4.11.1).

Forests could be categorised into forest roads and other forest. These two categories could be further subdivided according to their intensity of use (high, medium, low). Studies of man-made waste in forests could provide data for the individual calculation parameters (*waste input*, *plastic content of waste input*, *litter content of plastic waste*). The slip rate could be estimated by the number of cleanings and their intervals. If these data are available for the individual categories and thus a sufficient data basis is available, the plastic litter input can be estimated based on litter in forests.

4.12 Adaptability of the estimation

The study carried out represents an estimate of the plastic litter registered and remaining in one year. Periodically (freely) available input data would be necessary for an update of the modelling carried out. This means that the data used in the estimation would have to be collected several times under the same boundary conditions in the corresponding period. Based on the data used in this one-off estimation, this is often only possible to a limited extent, depending on the type of land use.

Limited adaptability is given for the land use types pedestrian zones, riverside strips, inland bathing sites and all categories of coast except seaside resorts, as these estimates are based on data from individual studies, expert interviews and results from surveys. As far as data from individual studies are concerned, an update is only possible under the same boundary conditions as for the original data generation. In the case of the land use types roadsides, rest stops, parks, and the category of seaside resorts (land use type: coast), updating is easier, since the data used are or could be collected under the same boundary conditions in the future. In order to update these land use types, it would then be necessary to request this data from the relevant authorities and update it in the estimate.

4.13 Summary of the results: Plastic litter remaining in Germany per year

In order to finally calculate the amount of the remaining plastic litter with a base value and a range, a balance sheet model was first established in which various calculation parameters were developed. This balance model was applied to publicly accessible entry points or land use types within which the litter is deposited. These land use types include roadsides, rest stops, parks, pedestrian zones, riversides, coasts (North Sea and Baltic Sea coasts) and inland bathing areas. The data for the individual variables of the balance model were then researched. In cases where the data were not available, the calculation variables were estimated on the basis of assumptions.

The estimation of the *remaining plastic litter* on the land use types under consideration amounts to 1,500 t/a (650 2,500 t/a) (see Table 25). The values vary considerably between the individual land use types, e.g. the *remaining plastic litter* at roadsides is 218 times the rema*ining plastic litter* of pedestrian zones. These fluctuations are caused in particular by the size or length of the respective land use type and the slip rate.

Table 25: Quantity of the remaining plastic litter of the considered land use types with total

Type of land use	Litter input [t/a]	Plastic litter input [t/a]	Remaining plastic litter [t/a]
Roadsides	23,822 (21,314-26,998)	5,241 (4,689-5,940)	786 (234-1,485)
Rest stops	2,342	515	52 (26-77)
Parks	101,005	6,060	182 (59-309)
Pedestrian zones	>646	646	3,2 (0,6-6,5)
Riversides	1,591	560	342 (232-451)
Coast	699	210	107 (81-134)
Inland bathing sites	145	43	26 (17-35)
Total amount	**>130,250**	**13,275**	**1,498 (651-2,497)**

The calculations of the individual values are explained in the respective chapters and in the appendix. The reported total sum of litter input includes all land use types except pedestrian zones. Data on the litter input in pedestrian zones were not available; instead, only the amount of plastic litter input could be used. Thus, the total sum of the litter input would be higher if the litter input in pedestrian zones was included. For the litter entry and the plastic litter entry of the road sides, ranges are given, because the calculation of these quantities was based on the slip rates and their ranges. In contrast to this, the litter and plastic litter entries of the other land use types are given without span widths, because due to a different data basis their calculation was not carried out using the slip rate and its span width. The calculations of the remaining plastic litter for all land use types are based on the assumption of slippage rates and their ranges, which is why the amount of remaining plastic litter was also given with ranges.

If other relevant land use types are included (cf. section 4.11), the sum will increase further, but the present estimate includes the most important land use types. Without the distinction made between litter waste and non-litter waste (or an assumption of litter content = 100%), the sum of plastic inputs would increase - with otherwise unchanged assumptions - to up to 3,750 t/a. However, this is only a first rough estimate, as a renewed examination of the sources and assumptions made would be necessary.

A more precise estimation (reduction of the ranges) would only be possible with a better data basis. The literature search showed that data on waste input are available for the number of pieces, but weight-related data were very often not available due to the high effort involved in generating the data (separating the waste, removing adhesions, drying). In addition, the data basis for determining area sizes was often not or only partially available. As a result, assumptions had to be made for many calculation variables, which is a weakness of the estimates and calculations presented.

5 Plastic emissions as a result of environmentally sound plastic applications

5.1 Basic methodological approach

In the following, the input of plastics into the environment resulting from the environmentally sound use of plastic products is estimated.

In principle, this is based on the type and quantity of plastic products used in the environment in Germany. However, the environmental impact is not the use of the products themselves, but only the quantities of plastic that remain in the environment after the end of the use of the products. These are, on the one hand, quantities of plastics which are released into the environment by these products during the environmentally compatible use of the products – mostly unintentionally, but often to a certain extent expected or unavoidable (e.g. as a result of ageing processes, wear, abrasion or damage). On the other hand, it concerns the proportion of plastic products which are not or not completely removed from the natural environment after the end of their use (i.e. which are not covered by deconstruction measures, for example).

In order to enable comparability and consistency with the results of chapter 4 (littering of plastics), a balance model is also used here, which conceptually records the net input of plastics from product use into the environment. In principle, this net input is the difference between the quantities of plastic products placed on the market that are intended for environmentally sound use minus the quantities of plastics removed from the environment after use.

While available data can be used – at least in principle – for the (plastic) products for environmentally sound use placed on the market in Germany every year, there is a virtually complete lack of corresponding quantified information on the annual withdrawal of such products from the environment.

For this reason, the balance framework was drawn up in such a way that for the quantities of plastic products currently placed on the market per year, the future, anticipated environmental impacts during and after use are determined and related to the balance period of placing on the market.

Claims about the form in which the plastics introduced into the environment are present, i.e. claims about their size structure or their possible state of degradation, and are not the subject of these assessments.

5.1.1 Derivation of a structured "product list" as a central element of modelling

Corresponding to this basic methodological approach, a "listing" of all products that are used in the environment and from which plastics can result in environmental impacts during and after use is required. In order to compile this "product list", the following procedure was applied:

5.1.1.1 Definition of product categories of use in the environment

In order to identify and delimit relevant product groups that are used (at least predominantly) in the environment, basic categories of use for products in the environment were first identified. These are the following categories:

- Construction sector
- Vehicles/traffic

- Agriculture and gardening
- Sports, games, recreation and events
- Consumer products

5.1.1.2 Identification of product groups within the product categories

With regard to these fields of application, a systematic screening of product and material groups of production and trade statistics and of association statistics was carried out in order to identify product groups which (mainly) consist of plastics and are used in the environment to a relevant extent.

A total of 62 product groups have been identified in this process so far, which can be assigned to the five product categories as follows:

- Construction sector –19 product groups
- Vehicles/traffic –11 product groups
- Agriculture and gardening –19 product groups
- Sports, games, recreation and events – 4 product groups
- Consumer products – 9 product groups

5.1.2 Description of the product groups in terms of products, polymer type and typical additives

The 62 identified product groups of the "product list" are described in more detail in the manner outlined below.

5.1.2.1 Description of typical products and mainly used polymer types

In the course of further discussion and coordination of the product group system used, a short product description of typical products is given in order to make clear which products are included in the different product groups. In addition, the types of polymer predominantly used for these products or within the product group were researched.

5.1.2.2 Identification of (hazardous) ingredients

Besides a purely quantitative estimation of the input quantities of the plastics in the project framework, a discussion of the input of possibly problematic ingredients (e.g. from additives and other functionalities) is to be carried out. Therefore, it is also explained for the individual product groups whether (against the background of the base polymers used and the conditions of use) it can be assumed that additives from one or more of the following functional groups are contained to a relevant degree[5]:

- Flame retardant
- Stabilisers

[5] The relevance was not defined here on the basis of existing quantity or concentration thresholds, but on the basis of our own expertise, feedback from experts or on the basis of Internet research, e.g. at producers.

- Plasticisers
- Antistatics
- Dye
- Filler
- Lubricant

A more detailed consideration of possible material risks can only be carried out on the basis of this first orienting allocation in an appropriate manner if the investigations focus on individual products within the larger product groups.

With reference to specific products, internal industry sources such as the Additives List of the European Plastics Recyclers and, in cooperation with producers, corresponding product information and safety data sheets can then be evaluated with regard to the hazardous characteristics of the additives and compounds added.

5.1.3 Characterisation of environmental inputs

5.1.3.1 Creation of environmental input categories

As already mentioned above, two fundamentally different types of input of plastics into the environment can be distinguished with regard to product use:

- emissions during the period of use
- inputs or remains in the environment after end of use

The time at which the environmental impact occurs varies according to the product. In the case of tyres, it obviously occurs over the entire service life, whereas in the case of cigarette butts it occurs almost 100% after use.

During the utilisation phase, a distinction can then be made between, on the one hand, inputs from leaching or erosion/weathering processes and, on the other hand, inputs from (greater) mechanical loads and/or damage.

During the research to quantify the input quantities for the different product groups, the following challenges became apparent:

- Quantified studies, e.g. on the concentration of plastics in the (rain-) water runoff from weathered surfaces, are only available in very isolated cases and only for specific products in specific conditions of use. Furthermore, such analyses are practically always lacking a reference to the respective total mass of the product used in an environmentally sound manner (e.g. rain gutter, roof coverings, etc.). This means that the available individual analyses cannot be used for the methodological step of input-output analysis.
- With regard to mechanically induced losses of use and the environmental fate after the use phase, quantified secondary studies are practically non-existent.

Surveys of stakeholders who in practice manage (e.g. base plates) or use (e.g noise protection walls) concrete product stocks (from a product group) are thus in many cases the only source of actual information or estimates. Examples here are, among others, employees of a road maintenance company who have practical experience and, in some cases, specific data on the degree of use-related damage and the resulting need for replacement of base plates or similar. The same applies, for example, to the use of browsing protection in a forestry operation.

However, even in such cases, there is naturally no real quantitative division of the damaged products into the mass components that can be disposed of in an orderly manner and the parts that were released into the environment during/due to the damage (not retrievable). Here, then, only expert assessment can be used, whereby it must be taken into account that the experience of different experts or users can vary greatly (e.g. one forest ranger takes the browsing protection as far as possible from conservation and can thus at least approximately estimate the material loss during the use phase, while the other leaves it rather in the forest, as the collection costs would be too high and therefore no statement can be made about its fate in the environment during the use phase).

These uncertainties are even more serious in relation to the proportion of products (of a product group) that remain in the environment at the end of their useful life, e.g. certain construction products such as pipes. Here too, a demolition company can probably give a comparatively good estimate of the percentage of the various assemblies/products that will remain in the environment after demolition. However, the question of what percentage of the plastic products of a product group that are used in the environment but for which specific dismantling measures are carried out is usually not known to the demolition contractor.

This is aggravated by the fact that many of the products used in the environment to a relevant extent today, particularly in the area of foundation and site construction, have not yet reached their intended useful lives, as their quantitative use did not begin until the 1970s or 1980s, for example. Naturally, no practical experience is yet available.

In this context, it was decided to estimate the quantity of environmental impacts on the basis of an allocation of the various product groups to quantified environmental impact categories.

The "ideal-typical" input categories listed below were created for this purpose.

Table 26: Environmental input categories and applied fate factors

Environmental input categories	Product examples	Medium fate factor base value	Min. fate factor minimum value	Max. fate factor maximum value
Very minor	Facades, windows, garden furniture etc.	0.0001	0.00005	0.00015
Extremely low	Noise protection walls, architectural paints	0.001	0.0005	0.0015
Medium	Marking paint	0.01	0.005	0.015
medium to high	Agricultural films	0.055	0.01	0.1
High	Only partially dismantled product groups such as geotextiles	0.7	0.5	0.9
Particularly high	EPS flakes for soil loosening; coated depot fertilizer	0.975	0.95	1

The fate factor measures the proportion of the quantity placed on the market that is released into the environment after the product has been placed on the market (usually until the product is removed from the environment). The fate factors were determined as described below on the basis of individual information and expert estimates.

On the basis of the available individual information and expert estimates, the magnitude of the environmental fate factor was then allocated to these entry categories, with a minimum and maximum value for this ratio being created in addition to a base value. The fate factor is defined as the proportion of the quantity of a product group placed on the market that is likely to remain permanently in the environment. The range of minimum and maximum values is intended to make it clear that an exact estimate of the fate factor on the basis of the available information is not possible or only possible to a very limited extent in many product groups.

Each product group was assigned one of these entry categories on the basis of the available information, expert assessments and by analogy. For individual product groups, the fate factors listed in the “ideal-typical” input categories listed below were created for this purpose.

Table 26 were not assigned if there was primary or secondary information that made other fate factors likely (e.g. for marking inks). For these product groups, the respective "individual" fate factors were then indicated.

Only in some selected product groups – such as tyres or road markings – were other calculation approaches used to estimate environmental impacts.

5.1.3.2 Time horizons for environmental inputs

Even if the "balance sheet model" used as a basis "brings forward" the future environmental impacts to the time of first use of the respective products, it is nevertheless helpful with regard to the subsequent discussion of approaches to reduction and possible development of measures to be taken if the typical useful lives of the various product groups are known. These give rise both to an input period for use-related inputs and the possible start of post-use inputs/remaining in the environment.

Due to the heterogeneity of the products within the product groups and the diversity of their specific uses, only orders of magnitude of useful lives can be applied here as well.

The individual product groups were therefore allocated to the following useful life classes:

- < 1 year (e.g. plant pots or fertilizer)
- 1 < 10 years (buoys/fenders or cable sheaths)
- 10 < 30 years (pipes, pond liners)
- > 30 years (palisades, sewage and water pipes)

5.1.3.3 Quantifying the amounts used and the resulting environmental impacts

For the quantity placed on the market as the relevant quantity for estimating the input according to the methodology chosen for most product categories, public production and trade statistics and industry publications were used wherever possible. However, since these statistics often do not provide sufficient differentiation of the product groups, in many cases internal consultative studies were also used for evaluation and quantity estimation.

In some product categories, such as tyres or artificial turf fields, own calculations were made in order to be able to derive environmental impacts in a meaningful way. In the case of tyres, for example, the kilometres driven by cars and trucks in Germany were used to calculate the environmental impact of tyre wear on the basis of wear losses known from the literature. In other words – not in all cases the amount discharged refers to production figures. This has been noted at the appropriate places.

Wherever possible, the year **2015** was used as the **reference year** for the quantities used.

The respective **input quantities** per product group were then determined or estimated by multiplying the quantity placed on the market by the three reference values (min, base, max) for the retention factors of the respective input category created.

5.1.3.4 Prioritisation

As it was not possible to collect and verify all relevant information for all 62 product groups within the given framework (e.g. by talking to market participants or other know-how holders), a prioritisation of the product groups for closer examination was carried out in a further methodical step. The prioritisation was carried out in coordination with the German Environment Agency, taking into account the quantity relevance.

The main objectives of this prioritisation are,

- to designate those product groups which are responsible for the vast majority of the unintentional introduction of plastics and
- to define initial approaches for these groups that are suitable for minimising unintentional entry (see chapter 8).

In this stage the following product groups were selected for priority consideration:

- tyres
- pipes

- compost
- agricultural films
- geotextiles
- floor coverings for sports/playgrounds
- plant pots
- sewage sludge
- architectural paints
- fertilizers
- lawn grid
- road markings
- shoes
- cigarettes

5.2 Characterisation and volume estimation for the identified product groups

The following chapters first present the product groups grouped together in the five product categories and then document the volume estimates for the respective product groups individually and for the category as a whole.

When characterising the product groups, the data basis for the quantity placed on the market is outlined, as are the input category and the underlying fate factors in their minimum, maximum and assumed basic values.

More detailed information on the individual product groups can be found in the appendix.

5.2.1 "Construction sector" – characterisation of the product groups in the product category

The construction product category comprises the following 19 product groups, which are shown in the table below.

Table 27: Description of the product groups of the product category "construction sector"

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Construction films	Estimate based on internally available data (Consultic Study) and expert discussions	Remain in the area of the construction site. Input by separation of small particles after/during use. After use: extraction.	0.005 / 0.01 / 0.015
Geotextiles	same	Remains largely in the environment after the	0.5 / 0.7 / 0.9

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
		period of use, no general dismantling.	
Facade elements	same	Remain in the area of the construction site. Input occurs through separation/chipping (e.g. weathering) of small particles after/during use. After use: extraction.	0.00005 / 0.0001 / 0.00015
Storage tents	same	Input occurs during use (abrasion).	0.00005 / 0.0001 / 0.00015
Palisades	same	Remain in the area of the construction site. Input occurs through separation/chipping (e.g. weathering) of small particles after/during use. After use: extraction.	0.005 / 0.01 / 0.015
Lawn grid	same	Input occurs through separation/chipping (e.g. weathering) of small particles after/during use. After use: partial extraction.	0.01 / 0.055 / 0.1
Drainage channels (rain gutters)	same	Input occurs through separation/chipping (e.g. weathering) of small particles after/during use. After use: extraction, if used in the soil, possible fate.	0.01 / 0.055 / 0.1
Cable sheathing	same	Input occurs through separation/chipping (e.g. weathering) of small particles after/during use.	0.005 / 0.01 / 0.015
Pipes	Estimate based on internally available data (Consultic Study) and on a study by the German Water and Sewage Association	Input occurs through separation/chipping (e.g. weathering) of small particles after/during use. Input occurs by remaining in the soil after use.	0.01 / 0.055 / 0.1

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Formed parts	Estimate based on internally available data (Consultic Study) and expert discussions	Input occurs through separation/chipping (e.g. weathering) of small particles after / during use.	0.0005 / 0.001 / 0.0015
IBC (Intermediate Bulk Containers) storage tanks above ground	2015 quantity figures from IPA (Industrial Packaging Association) available for Germany	Input occurs through separation/chipping (e.g. weathering) of small particles after/during use. After use: extraction	0.0005 / 0.001 / 0.0015
Roof coverings	Estimate based on internally available data (Consultic Study) and expert discussions	Input occurs through separation/chipping (e.g. weathering) of small particles after use.	0.00005 / 0.0001 / 0.00015
External insulation	same	Input occurs through separation/chipping (e.g. weathering) of small particles after use.	0.00005 / 0.0001 / 0.00015
Cable channels	same	Input occurs through separation/chipping (e.g. weathering) of small particles after use.	0.0005 / 0.001 / 0.0015
PCC (polymer cement concrete)	same	Input occurs through separation/chipping (e.g. weathering) of small particles after use.	0.0005 / 0.001 / 0.0015
Plastic windows	same	Input occurs through separation/chipping (e.g. weathering) of small particles after use.	0.00005 / 0.0001 / 0.00015
Seepage blocks	same	Input occurs through separation/chipping (e.g. weathering) of small particles after use. Input occurs through incomplete extraction after use.	0.01 / 0.055 / 0.1

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Noise protection walls	Data from noise protection statistics 2015, discussions with manufacturers	Input occurs to a lesser extent during dismantling, which usually takes place after a very long period of time, in problematic cases even after a few years. Minor damage is caused through game browsing.	0.0005 / 0.001 / 0.0015
Architectural paints	Own research as well as information from the Association of the German Paint and Printing Ink Industry on plastic contents	Input is usually caused by weathering during use	0.0025 / 0.005 / 0.0075

The product groups were modelled according to the described procedure.

5.2.2 "Construction sector" – estimation of input quantities for the product groups in the product category

The quantities placed on the market per product group determined for the year 2015 and taking into account the factor values determining the environmental impact from the product group characterisation described above, the following volume estimates for the product category "construction sector" result with regard to the input of plastics into the environment. Depending on the fate factor, the fate quantity expected to be introduced varies between about 8,875 t/a and 60,425 t/a, with pipes being by far the most relevant product group (fate quantity between 4,600 and 46,000 t/a). The second most important product group is geotextiles, followed by architectural paints. According to the estimates made, these three product groups are responsible for over 85% of the expected fate quantity.

Table 28: Quantity estimation of the environmental impact from the product groups in the product category "construction sector"

No.	Product group	Quantity placed on the market [t/a]	Remaining quantity min. [t/a]	Remaining quantity basis [t/a]	Remaining quantity max. [t/a]
1-01	Construction films	20,000	100	200	300
1-02	Geotextiles	5,000	2,500	3,500	4,500
1-03	Facade elements	28,802	1.4	2.9	4.3
1-04	Storage tents	2,000	0.1	0.2	0.3
1-05	Palisades	65,000	325	650	975
1-06	Lawn grid	32,500	325	1,788	3,250

No.	Product group	Quantity placed on the market [t/a]	Remaining quantity min. [t/a]	Remaining quantity basis [t/a]	Remaining quantity max. [t/a]
1-07	Drainage channels (rain gutters)	16,250	163	894	1,625
1-08	Cable sheathing	39,250	196	393	589
1-09	Pipes	462,000	4,620	25,410	46,200
1-10	Formed parts	105,000	53	105	158
1-11	IBC (Intermediate Bulk Containers) storage tanks above ground	30,400	15	30	46
1-12	Roof coverings	40,000	2.0	4.0	6.0
1-13	External insulation	546,000	27	55	82
1-14	Cable channels	20,000	10	20	30
1-15	PCC (polymer cement concrete)	5,000	2.5	5.0	7.5
1-16	Plastic windows	682,500	34	68	102
1-17	Seepage blocks	15,000	150	825	1,500
1-18	Noise protection walls	750	0.4	0.8	1.1
1-19	Architectural paints	139,915	350	700	1,049
(-)	**Total amount**	**2,255,367**	**8,874**	**34,649**	**60,425**

5.2.3 "Vehicles/traffic" – characterisation of the product groups in the product category

The product category vehicles/traffic consists of the following 11 product groups.

Table 29: Description of the product groups in the product category "vehicles/traffic"

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Tyres	Separate calculation based, among other things, on the number of kilometres driven in Germany per vehicle type, tyre wear per vehicle type, the proportion of out-of-town trips per vehicle type – different data sources	Input is made during the entire time-of-use	- / - / -
Barriers	Estimation based on internally available data (Consultic Study)	Input occurs through separation/chipping (e.g. weathering) of small particles during use.	0.0005 / 0.001 / 0.0015

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Road markings	Data from Ökopol Study, detailed information from Evonik; talks with motorway maintenance authorities	Input occurs during use through abrasion (truck and car tyres) and through separation/chipping (e.g. weathering) of small particles during use.	0.18 / 0.28 / 0.38
Guide elements	Estimate based on internally available data (Consultic Study)	Input occurs through separation/chipping (e.g. weathering) of small particles during use.	0.0005 / 0.001 / 0.0015
Beacons	Estimate based on internally available data (Consultic Study)	Input occurs through separation/chipping (e.g. weathering) of small particles during use.	0.0005 / 0.001 / 0.0015
Base plates	Estimate based on internally available data (Consultic Study) and expert discussions	Input occurs through separation/chipping (e.g. weathering) of small particles during use.	0.005 / 0.01 / 0.015
Vehicle parts	Estimation on the basis of registered vehicles 2015	Input occurs by parts falling off during use (e.g. covers) or in the event of accidents.	0.0005 / 0.001 / 0.0015
Waste bins	Estimation based on manufacturer's data on the production quantity in Germany of tonnes in various sizes	Input occurs through separation/chipping (e.g. abrasion) of small particles during use.	0.0005 / 0.001 / 0.0015
Ship colour	Base quantity from Destatis data and figures of the Association of the German Paint and Printing Ink Industry	Input is made during the entire period of use by peeling off.	0.0005 / 0.001 / 0.0015
Bicycle tyres	Separate calculation based on number of bicycle coats, weight, abrasion etc.	Input occurs during use due to abrasion.	- / - / -
Shoes	Estimated value based, i. a., on discussions with shoe sole manufacturers and research institutes	Input is made during the entire period of use.	- / - / -

In the case of car, truck, and bicycle tyres, it was not the quantity placed on the market that was taken into account to calculate the fugitive quantities, but the abrasion per kilometre driven in Germany (differentiated by vehicle type in each case). For shoes, too, a separate calculation was made using an assumed annual sole abrasion (based on expert discussions) and an average number of shoes placed on the market per year.

5.2.4 "Vehicles/traffic" – estimation of the input quantities for the product groups in the product category

For the quantity placed on the market in the product category vehicles/traffic in 2015, the quantity placed on the market can be estimated at between 132,785 t (min.) and 165,440 t (max.). This category is dominated by tyres, which account for over 97% of the fate quantity. It should be noted that tyre abrasion has been fully taken into account in the present estimate, even if this does not involve typical plastic entries. The rubber and petroleum content of tyres is around 60%, but this too should be distinguished from the "typical" plastic inputs otherwise considered.

In addition, the analysis of tyre abrasion took into account how much of the abrasion occurs on roads connected to the sewerage system, as only a small proportion of the abrasion on these roads remains unintentionally in the environment. This estimation was based on the 2014 driving performance survey of the German Highway Research Institute.

After tyres, footwear is the second most relevant product group with a residual weight of between 1,600 and 3,200 tonnes, followed by road markings (between 1,130 and almost 2,400 tonnes).

Table 30: Quantitative estimation of the environmental impact from the product groups in the product category "vehicles/traffic"

No.	Product group	Quantity placed on the market [t/a]	Remaining quantity min. [t/a]	Remaining quantity basis [t/a]	Remaining quantity max. [t/a]
2-01	Tyres	Different calculation	128,934	143,261	157,587
2-02	Barriers	20,000	10	20	30
2-03	Road markings	6,290	1,132	1,761	2,390
2-04	Guide elements	10,000	5.0	10.0	15.0
2-05	Beacons	10,000	5.0	10.0	15.0
2-06	Base plates	50,000	250	500	750
2-07	Vehicle parts	1,000	0.5	1.0	1.5
2-08	Waste bins	33,130	17	33	50
2-09	Ship colour	21,312	11	21	32
2-10	Bicycle tyres	Different calculation	821	1,095	1,369
2-11	Shoes	Different calculation	1,600	2,400	3,200
	Total amount	**(151,732)**	**132,786**	**149,112**	**165,439**

The total quantity placed on the market includes only those product groups for which a quantity placed on the market is indicated.

5.2.5 "Agriculture and horticultural sector" – characterisation of the product groups in the product category

The product category Agriculture and Horticulture comprises 19 product groups. For all these product groups, the quantity placed on the market and the fate were calculated or derived by default according to the described procedure.

Table 31: Description of the product groups in the product category "agriculture and horticulture“

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Pond liners	Approximated value	Pond liner remains in the ground during use, input into the environment occurs after use. After use: mainly extraction.	0.01 / 0.055 / 0.1
Agricultural/harvesting film	Data from Consultic Study; comparison with numbers by RIGK	Input occurs by remaining in the soil during/after use (drifts).	0.01 / 0.055 / 0.1
Silage film	Data from Consultic Study; comparison with numbers by RIGK	Input occurs through separation/chipping (e.g. abrasion) of small particles during use.	0.005 / 0.01 / 0.015
Baler twines	Estimate based on internally available data (Consultic Study)	Input occurs by remaining in the soil during/after use (drifts).	0.01 / 0.055 / 0.1
Drainage	Estimate based on internally available data (Consultic Study)	Input occurs through partial retention in the soil after use due to incomplete extraction.	0.01 / 0.055 / 0.1
Plant pots	Estimate based on internally available data (Consultic Study)	Input occurs by remains in the soil after use, drifts, and other improper disposal.	0.01 / 0.055 / 0.1
Agricultural nets	Estimate based on internally available data (Consultic Study)	Input occurs by remaining in the soil during/after use, drifts, and other improper disposal.	0.01 / 0.055 / 0.1
Fertilizer	Estimate based on internally available data (Consultic Study)	Input occurs by remaining in the soil after/during use.	0.95 / 0.975 / 1
Greenhouses	Estimate based on internally available data (Consultic Study)	Input occurs through separation/chipping (e.g. abrasion) of small particles during use or dismantling.	0.0005 / 0.001 / 0.0015

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Fences	Estimate based on internally available data (Consultic Study)	Input occurs through separation/chipping (e.g. weathering) after/during use or when small particles are decomposed.	0.0005 / 0.001 / 0.0015
Gates	Estimate based on internally available data (Consultic Study)	Input occurs through separation/chipping (e.g. weathering) of small particles after/during use or dismantling.	0.0005 / 0.001 / 0.0015
Other landscaping elements	Estimate based on internally available data (Consultic Study)	Input occurs through separation/chipping (e.g. weathering) of small particles after/during use or during dismantling.	0.0005 / 0.001 / 0.0015
Fishing industry nets	Estimate based on internally available data (Consultic Study)	Input occurs through loss of material during use.	0.005 / 0.01 / 0.015
Buoys/fenders	Estimate based on internally available data (Consultic Study)	Input occurs through loss of material during use.	0.0005 / 0.001 / 0.0015
Browsing protection	Estimated value, i. a. on the basis of expert discussions	Input occurs through loss of material. After use: mainly removal.	0.01 / 0.055 / 0.1
Sewage sludge	Destatis data and technical discussions with associations and others	Input occurs during use, usually on agricultural land	- / 1 / -
Digestate	Statistical data of the German Environment Agency and analyses of the Quality Association for Compost	Input usually during use on agricultural land	- / 1 / -
Composts	Statistical data of the German Environment Agency and analyses of the Quality Association for Compost	Input is usually made during use on parking spaces, in horticulture and in vegetable or fruit cultivation	- / 1 / -
Biocarrier	Estimate based on internally available data (Consultic Study) and expert discussions	Input occurs by being washed out of the sewage treatment plants during use.	0.005 / 0.01 / 0.015

5.2.6 "Agriculture and horticultural sector" – estimation of the input quantities for the product groups in the product category

For the product category "agriculture and horticulture" the calculated fate quantities for the year 2015 vary between about 6,200 t/a (min.) and 21,500 t/a (max.). It is noticeable that the fate quantities are distributed over many different product groups and that there are no individual groups which are very dominant in terms of fate as in other product categories. Composts are the most dominant, followed by – depending on the fate factor used – either fertilizers or agricultural/harvesting films as well as plant pots and sewage sludge.

Table 32: Quantitative estimation of the environmental input from the product groups in the product category "agriculture and horticulture"

No.	Product group	Quantity placed on the market [t/a]	Remaining quantity min. [t/a]	Remaining quantity basis [t/a]	Remaining quantity max. [t/a]
3-01	Pond liners	8,300	83	457	830
3-02	Agricultural/harvesting film	30,000	300	1,650	3,000
3-03	Silage film	46,000	230	460	690
3-04	Baler twines	15,000	150	825	1,500
3-05	Drainage	4,150	42	228	415
3-06	Plant pots	41,500	415	2,283	4,150
3-07	Agricultural nets, tubes, fleeces	16,000	160	880	1,600
3-08	Fertiliser	2,075	1,971	2,023	2,075
3-09	Greenhouses	1	0.0	0.0	0.0
3-10	Fences	100	0.1	0.1	0.2
3-11	Gates	100	0.1	0.1	0.2
3-12	Other landscaping elements	2,000	1.0	2.0	3.0
3-13	Fishing industry nets	10,000	50	100	150
3-14	Buoys/fenders	5,000	2.5	5.0	7.5
3-15	Browsing protection	5,000	50	275	500
3-16	Sewage sludge	Different calculation	1,500	2,250	3,000
3-17	Digestate	Different calculation	149	166	183
3-18	Composts	Different calculation	1,088	2,229	3,369
3-19	Biocarrier	2,000	10	20	30

No.	Product group	Quantity placed on the market [t/a]	Remaining quantity min. [t/a]	Remaining quantity basis [t/a]	Remaining quantity max. [t/a]
	Total amount	**(190,226)**	**6,202**	**13,853**	**21,502**

The total quantity placed on the market includes only those product groups for which a quantity placed on the market is indicated.

5.2.7 "Sports, games, recreation and events" – characterisation of the product groups in the product category

Four product groups are combined in this product category.

Table 33: Description of the product groups in the product category "sports, games, recreation and events“

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Granulate for artificial turf pitches	Separate calculation based on estimated granulate replacement per square metre of the stock of artificial turf pitches in Germany and granulate loss on newly built fields	Input occurs through loss of material.	0.4 / 0.5 / 0.6
Play equipment/toys	Approximated value	Input occurs through separation/chipping (e.g. weathering) of small particles during use or through loss/forgetting.	0.005 / 0.01 / 0.015
Garden decoration items	Own rough calculation Consultic	Input occurs through separation/chipping (e.g. weathering) of small particles during use.	0.0005 / 0.001 / 0.0015
Fishing line	Destatis production volume, not adjusted for imports and exports	Input occurs through loss of material.	0.005 / 0.01 / 0.015

5.2.8 "Sports, games, recreation and events" – estimation of the input quantities for the product groups in the product category

In the product category "sports, games, recreation and events", a remaining quantity of around 1,820 t (min.) and 3,140 t (max.) can be assumed. This category is dominated in terms of fate by the granulate for sports and playgrounds made of artificial turf, which accounts for 80 to 85% of the total fate.

Table 34: Quantity estimation of the environmental impact from the product groups in the product category "sports, games, recreation and events"

No.	Product group	Quantity placed on the market [t/a]	Remaining quantity min. [t/a]	Remaining quantity basis [t/a]	Remaining quantity max. [t/a]
4-01	Granulate for artificial turf pitches	3,857	1,543	1,929	2,314
4-02	Play equipment/toys	50,000	250	500	750
4-03	Garden decoration items	22,296	11	22	33
4-04	Fishing line	2,890	14	29	43
(-)	**Total amount**	**79,043**	**1,818**	**2,480**	**3,141**

5.2.9 "Consumer products" – characterisation of the product groups in the product category

Together, 9 product groups form this product category. It should be noted that the cigarette filters were calculated on the basis of the filter weight and an assumption regarding the proportion of improperly disposed cigarette butts.

Table 35: Description of the product groups in the product category "consumer products"

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Garden/terrace furniture	Approximated value	Input occurs through separation/chipping (e.g. weathering) of small particles during use.	0.00005 / 0.0001 / 0.00015
Balloons	Own rough calculation Consultic	Input takes place after use.	0.005 / 0.01 / 0.015
Fireworks (rocket caps)	Own rough calculation Consultic	Input takes place after use.	0.0005 / 0.001 / 0.0015
Cigarette filters/butts	Cigarette sales in 2015; calculation of the filter weight, acceptance of improperly disposed of cigarettes	Input takes place after use.	0.01 / 0.055 / 0.1

Product group	Data basis - quantity placed on the market	Input category	Fate factor min./basis/max.
Lighters	Own rough calculation Consultic	Input takes place after use.	0.005 / 0.01 / 0.015
Cosmetics	Estimations based on the study "Sources for micro plastics with relevance for marine protection in Germany" by the German Environment Agency	Input takes place during use.	0.95 / 0.975 / 1
Clothing fibres	Estimate based on the Consultic Study From Land to Sea - Model for the collection of land-based plastic waste 2016	Input is made during the entire period of use.	- / - / -
Decorative elements made of plastic (e.g. for weddings)	Own rough calculation Consultic	Input is made during the entire period of use.	0.01 / 0.055 / 0.1
Other paints and varnishes (excluding architectural and ship paints)	Data from Ökopol report on paints and varnishes as well as estimates of the proportion of plastics based on internet research and expert discussions	Input is made during the entire period of use by spalling off.	0.0005 / 0.001 / 0.0015

5.2.10 "Consumer products" – estimation of input quantities for the product groups in the product category

For the product category "consumer products", the following volume estimations result with regard to the input of plastics into the environment. The total fate quantity fluctuates between 860 and about 2,540 t/a, with the product groups "other paints and varnishes" and "cosmetics" being very dominant in the minimum variant and "cigarette filters" in the other two variants, with a joint share of over 85%.[6]

[6] The cigarette filters were considered in detail in the report in chapter 8 on the basis of a bottom-up approach. The input quantities worked out are not to be understood in addition to the quantities from chapter 8.

Table 36: Quantitative estimation of the environmental impact from the product groups in the product category "consumer products"

No.	Product group	Quantity placed on the market [t/a]	Remaining quantity min. [t/a]	Remaining quantity basis [t/a]	Remaining quantity max. [t/a]
5-01	Garden/terrace furniture	5,000	0.3	0.5	0.8
5-02	Balloons	2,000	10	20	30
5-03	Fireworks (rocket caps)	49	0.0	0.0	0.1
5-04	Cigarette filters/butts	16,200	162	891	1,620
5-05	Lighters	820	4.1	8.2	12.3
5-06	Cosmetics	500	475	488	500
5-07	Clothing fibres	175	150	175	200
5-08	Decorative elements made of plastic (e.g. for weddings)	5.6	0.1	0.3	0.6
5-09	Other paints and varnishes (excluding architectural and ship paints)	116,238	58	116	174
(-)	**Total amount**	**140,988**	**860**	**1,699**	**2,538**

5.3 Overview of the input quantities in all five product categories examined

In summary, the fate of the five product categories examined can be estimated as follows. Depending on the assumed fate factors, a minimum fate of 150,540 t/a and a maximum fate of 253,045 t/a can be assumed.

It becomes clear that the category "vehicles/traffic" represents by far the largest share of the entries, followed by the construction sector. The two product categories of sports, games, recreation, events and consumer products play a rather subordinate role with regard to the expected environmental impacts.

Table 37: Quantitative estimation of the environmental impact from all five product categories studied

No.	Product group	Quantity placed on the market [t/a]	Remaining quantity min. [t/a]	Remaining quantity basis [t/a]	Remaining quantity max. [t/a]
1	Construction sector	2.255.367	8.874	34.649	60.425
2	Vehicles/traffic	151,732	132,786	149,112	165,439
3	Agricultural and horticultural sector	190,226	6,202	13,853	21,502

No.	Product group	Quantity placed on the market [t/a]	Remaining quantity min. [t/a]	Remaining quantity basis [t/a]	Remaining quantity max. [t/a]
4	Sports, games, recreation and events	79,043	1,818	2,480	3,141
5	Consumer products	140,988	860	1,699	2,538
(-)	**Total amount**	**2,817,355**	**150,539**	**201,793**	**253,045**

With regard to the stated quantity placed on the market, it should be noted that individual products for which the calculation of the fate was carried out using a different methodology (see explanations in the individual subsections) are not included in the stated quantities (this applies to vehicle tyres, bicycle tyres and shoes as well as sewage sludge, fermentation residues and composts).

6 Comparison of studies

Apart from the UFOPLAN project "Plastics in the Environment", which is the subject of this report and which is being processed by Ökopol (hereafter referred to as the Ökopol Study), other studies are currently also dealing with a quantification of the input of plastics into the environment. Specifically, the following should be mentioned here:

- Bertling, Jürgen; Hamann, Leandra; Bertling, Ralf (2018): Kunststoffe in der Umwelt. Mikro- und Makroplastik. Ursachen, Mengen, Umweltschicksale, Wirkungen, Lösungsansätze, Empfehlungen. Unter Mitarbeit von Tatiana Bladier, Rodion Kopitzky, Daniel Maga, Nils Thonemann und Torsten Weber. Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT (Hg.), Oberhausen (hereafter: Umsicht Study) and
- Conversio (2018): Vom Land ins Meer - Modell zur Erfassung landbasierter Kunststoffabfälle. Unter Mitarbeit von Christoph Lindner und Thomas Jäger. Hg. v. Conversio und BKV. Frankfurt. (hereafter: Conversio Study)

Although the three studies or projects differ in some points, there are major similarities - in each case, plastic inputs from different applications or activities are quantified. All studies basically aim at identifying and quantifying relevant sources of plastic discharges. All three studies deal with the difficult data situation in different ways and differ in various aspects of the methodological approach as well as in their objectives and scope of investigation.

In order to correctly interpret the respective statements and results of the studies, it is important to understand the essential differences.

Against this background, a comparison of the three studies is presented below. This comparison is based on an evaluation of the respective published reports and documentations[7] on the one hand, and on the other hand on a workshop that was held in September 2018 at Ökopol in Hamburg with the participation of the respective authors from Fraunhofer Umsicht (Umsicht Study) and Conversio.

6.1 Comparison of methodology, aim and scope

The three studies differ in various methodological aspects as well as in their objectives and scope of investigation. A very important difference between the Ökopol and Umsicht Study on the one hand and the Conversio Study on the other hand is that the Conversio Study focuses on discharges into the sea, while the other two studies consider discharges into the environment as a whole (i.e. into all environmental media). In addition, there are a number of other relevant differences. Table 38 summarizes key similarities and differences.

Table 38: Summary of methodology, aim and scope

Aspect	Ökopol Study	Conversio Study	Umsicht Study
Item	Residues from plastic uses in the environment	Emissions from land to sea model to cover land based plastics	Isolated plastics in the environment (micro and macro plastics)

[7] With regard to the published reports and documentation, it should be noted that the calculation approaches and assumptions made and the data used are not disclosed here to an extent that would allow full traceability.

Aspect	Ökopol Study	Conversio Study	Umsicht Study
Geographical reference	Germany	North Sea, Baltic Sea, Black Sea, based on inputs in Germany,	Germany
Temporal dimension	Reference year: year of production/year placed on the market; back-referencing of the inputs to this year	Input in current year	Reference year: year of production/year placed on the market;
Type of input	No differentiation of plastics by size: abrasion is quantified in the same way as for entire products	Micro (< 5mm) and macro plastics (> 5mm)	Micro plastics (type A/B) and macro plastics type A: specifically produced type B: occurs during use
Subject of consideration	litter and 62 product groups, selected on the basis of expert knowledge	8 product areas	49 product groups based on expert assessments (survey)
Modelling approach	Littering (from packaging etc.): bottom-up based on collective data; plastic applications: top-down based on production data (and quantity placed on the market data) at the level of individual product groups	Top-Down based on waste quantities	Top-down based on production data (and quantity placed on the market data) at the level of individual product groups
Cause of input	intended, accepted, careless	intended, accepted, careless	intended, accepted, careless

Thus, for a comparative analysis of the three studies, the following aspects in particular must be considered:

- Differences with regard to the product groups/application areas considered: The selection of the product groups or application areas and activities included in the three studies is based on expert assessments of their relevance and the availability of data. There are differences between the three studies (although there are major overlaps between the Umsicht and the Ökopol Study).
- Different understanding of plastic inputs: although all three studies deal with plastic inputs, they differ in what is included and what is not. For example, the Conversio Study does not include product applications that do not or have not become waste. The Umsicht Study includes abrasion from applications and the input of macro-plastics due to littering. In addition, the Ökopol Study also considers the (possible) fate of complete products in the environment after use.

► Differences in the modelling approach and - related to this - in the data basis used:

1. Top-Down vs. Bottom-Up: With regard to plastic inputs as a result of litter (from plastic packaging), the Ökopol Study uses a bottom-up approach based on data from street cleaning (and other cleaning activities). The other studies follow a top-down approach, in the Conversio Study based on the total amount of packaging waste, in the Umsicht Study based on data from waste statistics (amount of street sweepings). Both the top-down and the bottom-up approach require different assumptions.
2. In the Ökopol and the Umsicht Study, products are also considered; the data basis in each case is the quantity of waste placed on the market. In the Conversio Study, a much more aggregated approach is followed; the starting point is data on waste quantities.
3. Consideration of time horizons: The Conversio Study quantifies the inputs in a calendar year. The Ökopol Study and the Umsicht Study use the year of placing (of products) on the market as reference year. However, there are greater differences especially for the Ökopol Study, as it considers the (final) fate of products after use, which means a correspondingly longer relevant period.

In addition to these aspects, a different use of the term littering may also cause confusion for the readers of the three studies: In the Ökopol Study, littering is used closely in the sense of the relevant literature (see, for example, Breitbarth and Urban 2014, Meer et al. 2007, Heeb et al. 2005) and is understood as the careless throwing away or leaving of waste in public space at the place where it is generated. In contrast, the improper dumping of larger wastes, such as car tyres, bulky waste or refrigerators, is considered illegal disposal rather than littering and is not explicitly part of the consideration. In the Conversio Study, all (here relevant) inputs are included under marine litter, which also includes, for example, inputs of plastic fibres or micro-plastics from composts. In the Umsicht Study, all macro-plastics entries are included under litter, as far as can be understood from the study.

6.2 Comparison at the level of overall results: largest sources and totals

There is a fundamental difference between the Ökopol and Umsicht Study on the one hand and the Conversio Study on the other. While the former refer to individual product groups, the Conversio Study takes a more aggregated approach. The Conversio Study distinguishes six sub-categories of micro-plastics (fibres, consumer products, household others, compost/digestion residues, production and processing waste, industrial/commercial others) and three sub-categories of macro-plastics (packaging, agricultural, others) for which quantities are reported:

Table 39: Order of the plastic sources according to quantity relevance according to Conversio Study

Type of source	Input into the sea in 2014 [t]	Detailed description
Packaging (macro plastics)	741	Sales, transport and outer packaging (e.g. household, agricultural, construction and industrial), including bottles and films
Macro plastics other	434	Inputs from waste (household goods, other areas)
Macro plastics fibres	93	Textile washing fibres

Type of source	Input into the sea in 2014 [t]	Detailed description
Agriculture (macro plastics)	50	Waste from the agricultural sector, mainly film, canisters, watering systems
Consumer products (micro plastics)	46	Especially cosmetics
Household other (micro plastics)	27	e.g. cleaning agent
Production and processing waste (micro plastics)	8	Plastic granulates from production and processing, micro-plastics in industrial waste water
Industry/commercial other	3	Waste from the automotive, construction, electronics and other sectors
Compost/digestate	3	Plastics contained in bio waste/green materials from households and businesses, fermentation products from the fermentation of bio waste, kitchen waste etc.

The Ökopol and Umsicht Study, on the other hand, looks at littering by land use type (Ökopol Study) and the input of macro-plastics in urban and rural areas (Umsicht Study) on the one hand, and inputs from the use of plastic products on the other hand, for each of which a selection has been made on the basis of expert assessments.

Table 40: Largest sources of plastic discharges into the environment according to Ökopol and Umsicht Study, sorted by amount of discharge

Source No.	Ökopol Study	Input [t/a]	Umsicht Study	Input [t/a]
1	Tyres, motor vehicle (abrasion)	143,261 (129,000- 158,000)	Tyres, motor vehicle (abrasion)	90,338
2	Pipes	25,410 (4,620-46,200)	Macro plastics (littering of waste)	34,000
3	Geotextiles	3,500 (2,500-4,500)	Abrasion bitumen in asphalt*	18,810
4	Shoes (abrasion)	2,400 (1,600-3,200)	Pellet losses	15,015
5	Planting pots	2,283 (415-4,150)	Compost	13,943
6	Sewage sludge	2,250 (1,500 – 3,000)	Release on disposal of waste, excluding compost*	11,039
7	Composts	2,229 (1,088 – 3,369)	Windblown sports and playgrounds	10,874
8	Fertilisers	2,023 (1,971-2,075)	Abrasion shoe soles	8,993

Source No.	Ökopol Study	Input [t/a]	Umsicht Study	Input [t/a]
9	Granulate for artificial pitches	1,929 (1,543 – 2,314)	Abrasion plastic packaging*	8,176
10	Grass paver	1,788 (325 – 3,250)	Abrasion road markings	7,508
11	Road markings	1,761 (1,132-2,390)	Abrasion on the construction site during demolition work*	7,425
12	Agricultural foils	1,650 (300-3,000)	Fibre abrasion during textile washing	6,336
13	Littering (of plastic packaging)	1,497 (651-2,497)	Abrasion of paints and varnishes	5,363
14	Bicycle tyres	1,095 (821-1,369)	Abrasion of plastics used in agriculture	3,713
15	Drainage channel (rain channel)	894 (163 – 1,625)	Flocculants in urban water management*	3,589
16	Cigarette filters (butts)	891 (162 – 1,620)	Abrasion brooms and road sweepers*	3,160
17	Agricultural nets, tubes, fleeces	880 (160 – 1,600)	Abrasion of building facades	3,053
18	Seepage blocks	825 (150 – 1,500)	Abrasion industrial wear protection, conveyor belts	2,475
19	Baler twines	825 (150 – 1,500)	Processing of plastics on the construction site*	2,096
20	Construction paints	700 (350 – 1,049)	Wet cleaning of containers	1,898
21	Palisades	650 (325-975)	Contents micro plastic in cosmetics	1,568
22	Base plates	500 (250-759)	Abrasion of tyres, skateboards, etc.	1,477
23	Toys / play equipment	500 (250-75)	Abrasion belt*	1,361
24	Cosmetics	488 (475-500)	Abrasion of tyres, bicycles	1,287
25	Silage films	460 (230-690)	Abrasion pipelines	990
26	Pond liners	457 (83-830)	Abrasion of decorative material, glitter, confetti etc.	479

Source No.	Ökopol Study	Input [t/a]	Umsicht Study	Input [t/a]
27	Cable coatings	393 (196-589)	Ingredient of washing, care and cleaning products in private households*	380
28	Browsing protection	275 (50-500)	Abrasion of fishing equipment	371
29	Drainage	228 (42-415)	Abrasion of gears, slide bearings, slide rails*	206
30	Construction foil	200 (100—300)	Abrasion of lawn trimmers/blade brushes*	124

Comments:
The data of the Ökopol Study refer to the baseline values of the study, additionally the ranges are given in brackets.
The data for the Umsicht Study come from Bertling et al. (2018)
* The products marked with * in the fourth column indicate products or operations that have no direct equivalent in the Ökopol Study and may represent possible gaps. A more detailed consideration is given in section 6.3.9.

6.3 Comparison at the level of individual selected product groups and areas

In the following, a comparison of the input volumes reported in the Ökopol and Umsicht studies is made at the level of individual selected products or product groups. The differences in approach mentioned above must be taken into account. Due to the different approach, the Conversio Study can only be taken into account in this comparison when considering the littering of plastic packaging.

6.3.1 Tyres

The reported input of tyre wear in the Ökopol Study is slightly higher than the figures of the Umsicht Study. It should be noted that the Ökopol Study quantified the total tyre abrasion, which includes natural and synthetic rubber (40-60%), fillers (carbon black, SiO2: 20-35%), mineral oil (15-20%) and other substances (see Kocher 2010, Dave 2013, Degussa 2007).

Studies that have identified abrasion factors for tyres do not show major differences (Hillenbrand et al. 2005, Giese et al. 2018, Wigger et al. 2018, Wang et al. 2016, Essel et al. 2015, Kole et al. 2017; Zimmermann et al. 2018). The indicated abrasion factors fluctuate by less than 30%. Against this background, no discrepancy between the figures of the Ökopol Study and the Umsicht Study can be identified. A study by the Federal Highway Research Institute (Kocher 2010) indicates an abrasion rate of 111,420 t/a, which is also in the same order of magnitude.

Table 41: Comparison of the input quantities - tyre wear

Product group	Ökopol Study [t/a]	Umsicht Study [t/a]
Tyres	128,934 – 157,587	90,338
Bicycle tyres	821 – 1,369	1,287
Tyres skateboards etc.	excluded	1,477

6.3.2 Composts, sewage sludge, digestates

With regard to composts, there is a relevant difference in the underlying assumptions on the plastic content of compost. The use of the legal limit value of 0.5% of the dry matter in the Umsicht Study leads to relatively high figures. Analyses by the Federal Quality Assurance Association for Compost indicate a significantly lower proportion of plastics (0.038% average proportion of plastics in compost). With regard to the data of the Federal Quality Assurance Association for Compost, it should be noted that these relate to only about 70% of all composting plants and do not allow any statement on the remaining 30%. Therefore, the Ökopol Study gives a range between an assumed minimum plastic content of 0.038% for the total compost (this would be the case if the Federal Quality Assurance Association for Compost data were applicable to 100% of the compost) and a content of 0.038% for 70% of the compost and an assumed plastic content of 0.3%[8] for the remaining 30%.

Table 42: Comparison of the input quantities - compost, sewage sludge, digestate

Product group	Ökopol study [t/a]	Umsicht Study [t/a]
Composts	1,088 – 3,369	13,943
Sewage sludge	1,500 – 3,000	excluded
Digestate	149 - 183	excluded

6.3.3 Pipes

With regard to the plastic input from the use of plastic pipes, there are significant differences between the figures of the Ökopol Study and the Umsicht Study. This is due to the fact that in the Ökopol Study the (final) fate of the pipes after use is included in the balance sheet (assuming that 1-10% of the pipes remain in the environment after use). In the Umsicht Study, only the abrasion of the pipes during use is taken into account.

Table 43: Comparison of the input quantities – pipes

Product group	Ökopol study [t/a]	Umsicht Study [t/a]
Pipes	4,620 – 46,200	990

6.3.4 Plastic packaging/litter

With regard to the plastic entries as a result of the use of plastic packaging, all three studies partly differ significantly with regard to the chosen procedure.

In the Ökopol Study, a quantification of plastic discharges as a result of littering according to the above-mentioned definition (the careless throwing away or leaving of waste in public spaces at the place of origin) is carried out, which does not exclusively but primarily include packaging waste made of plastics. The modelling is based on different land use types (roads, rest stops, parks, pedestrian zones, riversides, coastal strips, inland bathing sites) using a bottom-up approach based on cleaning quantities (quantity of waste cleaned) and slip assumptions (i.e. quantities not collected in cleaning).

The Umsicht Study makes no distinction between litter and "non-litter waste" in the sense of the understanding of litter in the Ökopol Study. It quantifies the input of macro-plastics based on

[8] This value is based on a study using EU-wide data and assuming a total plastic content in moist composts of 0.12%, resulting in a share of 0.3% in dry matter (Sundt et al. 2014, p. 47).

urban and nonurban waste. The calculation is based on a hybrid approach: For out-of-town areas, data from road and motorway maintenance authorities are used (bottom-up approach). In urban areas, waste statistics for cleaned quantities of road sweepings are used. In addition to macro-plastics, the circumspection study also quantifies the abrasion of plastic packaging (as an additional entry of micro-plastics).

In the Conversio Study, the littering of plastic packaging is calculated using a top-down approach. In relation to the total amount of plastic packaging waste, it is assumed that 0.3% is not collected and remains in the environment.

In all three studies, different input quantities are found as shown in Table 44.

Table 44: Comparison of the input quantities - plastic packaging

Product group/input path	Ökopol Study [t/a]	Umsicht Study [t/a]	Conversio Study [t/a]
Plastic packaging/litter	647 – 2,499	different categorisation	9,293*
input of macro-plastics (infrastructure waste, waste on traffic and green spaces)	different categorisation	34,000	different categorisation
Plastic packaging/abrasion	excluded	8,176	excluded

*Input volume of the Conversio Study, calculated on the basis of an input rate of 0.3% and a plastic packaging waste volume of 3,097,700 [t/a] (Schüler 2018).
In this study (Ökopol Study), not only plastic packaging was included in the area of plastic entries through littering, although - as far as can be seen from the underlying data - it nevertheless accounts for the largest share in terms of volume.

With regard to the abrasion of plastic packaging, it should be noted that this is only included in the Umsicht Study. Littered plastic waste is part of the consideration in all three studies. In the Conversio Study, the quantification is carried out using a highly aggregated approach based on the total amount of plastic (packaging) waste produced.

Plastic inputs along roads

With regard to the balancing of the input of macro-plastics in the Umsicht Study and the quantification of the inputs due to litter in the Ökopol Study, a central difference is that "non-littering waste" in the Ökopol Study is not included in the stated total of inputs, whereas in the Umsicht Study no corresponding delimitation is made. This aspect is particularly evident in the area of roads, for which both studies used the same data basis (data from roads in North Rhine-Westphalia)[9]. The methodological difference described is reflected in the Ökopol Study in the assumptions on the "litter share" (share of litter waste in total waste). Here, the Ökopol Study assumed that 60% of the waste originates from littering; 40% (e.g. illegal dumping) is accordingly not part of the total amount stated.

[9] With regard to the comparability of the data basis, it should nevertheless be noted that the Ökopol Study extrapolated from North Rhine-Westphalia to Germany. In the Umsicht Study, the extrapolation was made in a different way, which is why there is no "one-to-one comparability" here either.

Further differences exist in the underlying assumptions on slippage, i.e. the quantity not covered by collection and treatment measures. While the Umsicht Study assumes an unrecorded share of 50%, the Ökopol Study assumes 5% to 25%. The assumed slip is a crucial calculation parameter, as it is used to determine the waste input and the cleaning data. The third relevant assumption concerns the plastic content of the waste. In the Ökopol Study a share of 22% was assumed here. In the Umsicht Study, a higher proportion of 35%[10] was assumed.

Table 45 illustrates the potential influence of these varying assumptions. Without a distinction between litter waste and "non-litter waste" assuming a slip of 50% and an assumed plastics content of 35%, the inputs in the Ökopol model increase to up to about 11,800 [t/a].

Table 45: Collected waste volume and resulting plastic input in Germany to roadsides in Germany based on street cleaning data from North Rhine-Westphalia - comparison based on varying assumptions

Calculated variable	Sum – scenario 1	Sum – scenario 2
Waste input [t/a]	39,703 (35,524 – 67,496)	39,703 (35,524 – 67,496)
Litter input [t/a]	23,822 (21,314 – 40,497)	39,703 (35,524 – 67,496)
Plastic litter input [t/a]	5,241 (4,689 – 8,909)	13,896 (12,433 – 23,623)
Remaining plastic litter [t/a]	**786 (234 – 4,455)**	**2,084 (622 – 11,812)**

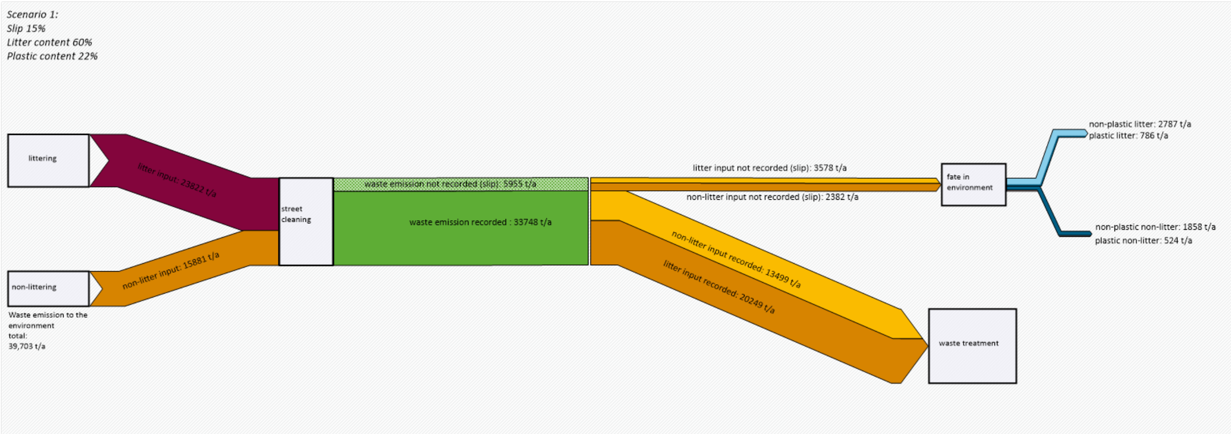
Scenario 1: Slip 5; 15; 50%; litter content 60%; plastic content 22%

Scenario 2: waste input = litter input, i.e. assumed litter content: 100%; plastic content: 35%; slip as in scenario 1

The differences resulting from the various assumptions become particularly clear in the graphical comparison made in Figure 10 to Figure 12. The amount of waste collected by street cleaning measures is constant. Depending on the slip assumptions made, the calculated total amount of waste and the amount not collected varies considerably. Depending on the assumptions made regarding the litter content of the waste, the volume flows of litter and "non-litter" vary accordingly. In the last step, the plastic input varies depending on the assumption regarding the plastic content in the waste.

[10] In Bertling et al. (2018) no plastic content is specified. The value of 35 % was calculated on the basis of the available data and it cannot be excluded that due to unavailable information (e.g. further assumptions made) the actual assumed plastic content may deviate from this.

Figure 10: Waste streams and plastic emissions at roadsides: Scenario 1a with average slip of 15%



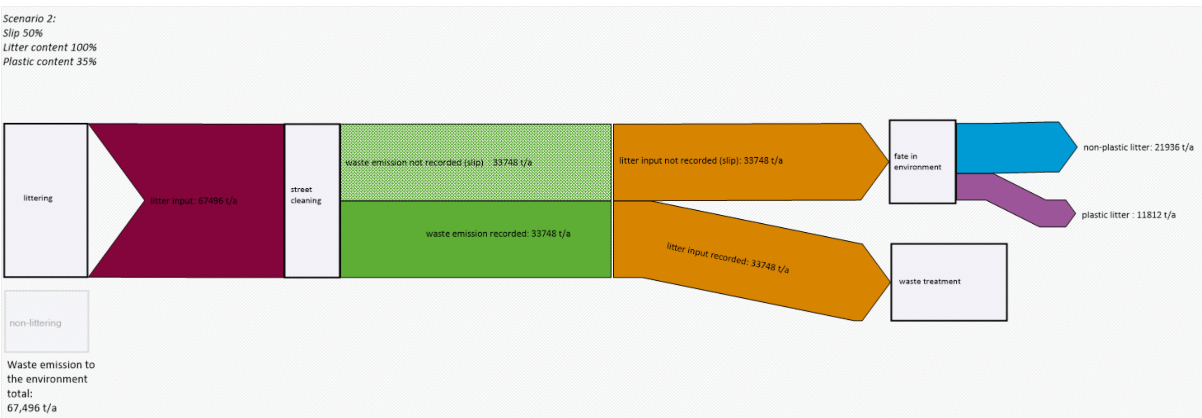
Souce: Ökopol, Scenario 1a: Slip: 15%; litter content: 60%; plastic content: 22%

Figure 11: Waste streams and plastic emissions at roadsides: Scenario 1b with high slip of 50%

Scenario 1b: Slip: 50%; litter content 60%; plastic content: 22%

Souce: Ökopol, Scenario 1b: Slip: 50%; litter content 60%; plastic content: 22%

Figure 12: Waste streams and plastic emissions at roadsides: Scenario 2 with high slip of 50%



Souce: Ökopol, Scenario 2: Slip: 50%; litter content: 100%; plastic content: 35%

Depending on the definition of the area under consideration (with balancing of "non-litter waste") and assumptions on the efficiency of street cleaning (5-25% slip vs. 50% slip), the differences between the studies – in terms of input via streets – are thus reduced significantly.

For other land use types, the Ökopol Study also estimated the relevant amount of litter waste in accordance with the objective. If instead the total waste inputs were taken as a basis, the differences in the reported quantities would be further reduced.

With regard to the consideration within the city, the two studies differ significantly. The Umsicht Study is based on data on road sweepings, whereas the Ökopol Study is based on cleaning data on pedestrian zones and green spaces, which must be evaluated methodically very differently. Road sweepings are only a small part of the areas considered in the Ökopol Study, but originate mainly from the road traffic area. It consists mainly of leaves and chippings, depending on the season. The proportion of plastics is rather low and the origin of the plastics cannot be clarified. Here, drift is likely to play a significant role. In this respect, the Ökopol Study did not consider road sweepings to be a useful measure of litter in public spaces. In 2016, 738,000 tonnes of road sweepings were produced nationwide. With an assumed slip rate of 20%, the proportion of plastic in road sweepings would have to be 11% to reach 16,000 tonnes of plastic, which according to an estimate by Intecus is very high.

6.3.5 Shoe soles/footwear

The input quantities from the abrasion of shoe soles differ by a factor of 3 to 4 between the Ökopol Study and the Umsicht Study, and a different methodological approach was chosen here as well. In the Umsicht Study, the calculation was based, among other things, on the total number of shoes sold per year in Germany (tagesschau.de 2018). In the Ökopol Study it was assumed that not the number of shoes sold but the number of shoe wearers was the relevant reference figure. The calculation model of the Umsicht Study results in a per capita shoe sole abrasion of 109 g/a, compared to a per capita abrasion of 20-40 g/a in the Ökopol Study.

It should be noted that, in addition to the literature research carried out, an expert consultation done as part of the Ökopol Study has made it clear that no representative surveys on the actual extent of shoe sole abrasion are known. Therefore, there is currently no approach to evaluate the differences between the studies in more detail.

Table 46: Comparison of the input quantities - shoe abrasion

Product group	Ökopol Study [t/a]	Umsicht Study [t/a]
Shoes/footwear	1,600 – 3,200	8,993

6.3.6 Road markings

With regard to the input as a result of the use of road marking paints, there are at first glance relevant differences between the Ökopol Study and the Umsicht Study. However, in this case, the discussion with the authors of the Umsicht Study has shown that the reported amount includes not only plastics but also additives and other components, which explains the difference to a large extent. Furthermore, a different data basis was used, but this is likely to be of minor importance in this context.

Table 47: Comparison of the input quantities - road markings

Product group	Ökopol Study [t/a]	Umsicht Study [t/a]
Road markings	1,132 – 2,390	7,508

6.3.7 Building sector

In the building sector there are differences in the selection of the products or product groups considered. The Ökopol Study looks at a number of individual products here (architectural paints, exterior insulation, facade elements, drainage gutters (rain gutters), roof covers, plastic windows). In the Umsicht Study, on the other hand, the abrasion of building facades is considered a more aggregated product group. Comparing the sums, the two studies are not too far apart. However, consultation with the authors of the Umsicht Study has also shown that primarily the abrasion of paints is relevant for the input quantity in the Umsicht model, which is listed as a single product group in the Ökopol Study. The data situation regarding the quantities of building paints used (placed on the market) is considered equally difficult by the authors of both studies, which is why there are corresponding uncertainties here.

Table 48: Comparison of the input quantities - building area

Product group	Ökopol Study [t/a]	Umsicht Study [t/a]
Abrasion building facades	excluded	3,053
Architectural paints	350 – 1,049	excluded
External insulation	27 - 82	excluded
Facade elements	1.4 – 4.3	excluded
Drainage gutters (rain gutters)	163 – 1,625	excluded
Roof coverings	2.0 – 4.0	excluded
Plastic windows	34 - 102	excluded
Sum	**577 – 2,866**	**3,053**

6.3.8 Agricultural sector

In the agricultural sector, similar to the building sector, the product groups under consideration have a different structure. While the Ökopol Study looks at various individual products, the Umsicht Study takes an aggregated view of the abrasion of plastics used in agriculture. However, the comparison of the totals shows a good agreement of the figures.

Table 49: Comparison of input quantities - agricultural sector

Product group	Ökopol Study [t/a]	Umsicht Study [t/a]
Abrasion of plastics used in agriculture	excluded	3,713
Pond liners	83 - 830	excluded
Agricultural film	300 – 3,000	excluded
Silage film	230 - 690	excluded
Baler twines	150 – 1,500	excluded
Fishing industry nets	50 - 150	excluded
Sum	**813 – 6,170**	**3,713**

6.3.9 Operations not considered in the Ökopol Study

The Umsicht Study covers a number of applications or activities that were not considered in the Ökopol Study. This is primarily due to the focus of the Ökopol Study on products that are used in an environmentally sound way.

6.3.9.1 Emissions during waste disposal

These represent the second largest source group in the Umsicht Study, comprising the individual sources compost, shredding of construction waste, metal shredding, plastics recycling and landfills. Apart from composts, the other sources have not been considered individually in the Ökopol Study. Due to their quantitative relevance, the inclusion of plastics recycling and the shredding of construction waste would have to be examined. With regard to the latter point in particular, however, it is possible that the corresponding inputs in the model are already covered by the consideration of individual product groups (geotextiles, external insulation, facade elements, drainage channels, etc.).

6.3.9.2 Abrasion on the construction site during demolition

In the Umsicht Study, abrasion on construction sites during demolition work represents a relevant activity that results in plastic discharges into the environment. A corresponding consideration in the Ökopol Study has not been made, but could possibly represent a sensible future expansion. In particular, it should be examined to what extent double counting is possible with regard to construction products already covered by the Ökopol model (geotextiles, external insulation, facade elements, drainage channels etc.) – cf. also the comments on releases during waste disposal in chapter 6.3.9.1.

6.3.9.3 Processing of plastics on the construction site

With regard to the processing of plastics on the construction site, the same can be stated as with regard to the emissions during waste disposal and the abrasion on the construction site during demolition work. An inclusion for a future extension of the Ökopol model may be useful, possible double counting should be examined.

6.3.9.4 Abrasion of bitumen from asphalt

The abrasion of bitumen in asphalt - especially by motorised traffic - represents the third largest source group in the Umsicht Study. Due to its quantitative relevance, consideration for the Ökopol Study would be a conceivable future extension. First of all, however, it would have to be clarified to what extent bitumen abrasion is to be considered in principle with regard to plastic inputs, or which components should be part of such consideration.

Due to the environmental relevance of road wear, (air) emissions from road wear are also reported in German emissions reporting under the CLRTAP[11] and NEC Directives[12]. This includes the heavy metals cadmium, lead, mercury, arsenic, chromium, copper, nickel, selenium and zinc as well as dust and particle emissions.

6.3.9.5 Pellet losses

Pellet losses were not considered in the Ökopol Study. This is due to the focus of the Ökopol Study on "environmentally friendly applications", which does not include pellet processing and transport. In the Umsicht Study, on the other hand, pellet losses with an annual input of more

[11] UNECE (United Nations Economic Commission for Europe) Convention on Long Range Transboundary Air Pollution.

[12] Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, revising Directive 2003/35/EC and replacing Directive 2001/81/EC

than 15,000 t are listed as one of the largest sources in terms of volume. This quantity was calculated on the basis of processing quantities and assumed loss factors.

6.4 Conclusion

All three studies considered quantify plastic discharges into the environment (Conversio Study: seas only) from different sources. The data situation is a central challenge in each case, which is taken into account with different methodological approaches and different selected data bases.

Due to existing differences between the three studies in terms of aim, scope of investigation and methodological approach, a comparison at the level of the sums of the total plastic discharges determined in each case is not meaningful. Nevertheless, the following conclusions can be drawn with regard to the identified relevant (main) sources and in direct comparison of individual product applications (based on the Ökopol and Umsicht Study):

- Tyre abrasion is the largest (single) source of plastic inputs in terms of volume.
- Littering of plastic packaging is a relevant source of plastic discharges into the environment, but in terms of total discharges it is only one of many sources of plastic discharges into the environment. Cleaning measures can reduce the input - in the models this is reflected in a change in the waste content or slip. With regard to this factor (slip), there are also large uncertainties in the models.
- The abrasion of plastic packaging was not considered in this study (outside the scope of the study), but in the study by Fraunhofer Umsicht (Bertling et al. 2018), where high quantities are estimated for this input area. It would be useful to consider including these in the further development of the model and quantity structure resulting from this project.
- Further quantitatively relevant areas are in particular:
  - Product applications and operations in the construction sector,
  - Product applications and operations in the agricultural sector and
  - Product applications and operations in the field of personal consumption and recreational activities.

In order to combine the findings of all three studies, meaningful steps would be

- the establishment of a uniform categorisation with regard to products covered (harmonisation of product types),
- the creation and transfer into a uniform categorisation of the plastic inputs, with regard to
  - micro-macro (micro-plastic definition and other size differentiation)
  - polymer types and handling of additives etc.
  - persistence of the plastic inputs
- as well as the development of a uniform data framework/database.

7 Summary of the findings

To obtain an estimate of the quantitative input of plastics into the environment, the area of carelessly thrown away or left behind plastic waste ("littering") (chapter 4) and the area of fate from the environmentally sound use of plastic products (chapter 5) were investigated. In the following the results of the two separate models for the two input paths are combined and considered together. In particular, the following points should be noted:

Handling and improvement of the data situation

The data situation for both input paths is incomplete; this was also confirmed by the study evaluation. The ranges given should therefore be regarded as initial estimates. Future refinements of the calculations with new data can help to reduce the existing uncertainties. Central points that would contribute to an improved estimation can be mentioned here in particular:

- Improvement of knowledge on slip, i.e. the proportion of waste not covered by cleaning measures, by area type;
- Improvement of data on the fate of products after use – especially in the construction sector (pipes, geotextiles, etc.) and in the horticultural and agricultural sectors (films, plant pots, etc.)
- Improvement of the data situation on the abrasion behaviour of particularly volume-relevant products (tyres, shoes, paints, pipes, etc.)

Definition of the scope of investigation – "littering" and "non-littering" waste

The analyses carried out for the area of carelessly thrown away or left behind plastic waste ("littering") (chapter 4) have made it clear that the distinction made between "litter" and "non-litter" waste (illegal deposits, etc.) is hardly meaningful on the basis of the available data. For the necessary distinction, additional assumptions had to be made (on the "litter content" of the waste), which represents an additional (uncertain) calculation parameter. The differentiation made on the basis of the specifications for the study is therefore not meaningful in the opinion of the experts. Moreover, for an overall estimate of the plastic input, the total quantity is the relevant reference value anyway.

In this study, the consideration of "non-littering" waste was only supplementary and approximate, but the influence of the delimitation made could be made visible on this basis.

Understanding the calculated quantities

The amount of plastic that remains in the environment as a result of carelessly throwing away or leaving behind of plastic waste is the amount of plastic that has been littered in one year. With regard to the input and the beginning of (permanent) fate in the environment, it can be assumed with sufficient accuracy that these occur in immediate succession, i.e. in the same period.

The situation is different with regard to the fate of plastics in the environment, which results from the environmentally friendly use of plastic products. Here, the fate results on the one hand (as far as relevant for the respective product use) from annual inputs of a part of the original product quantity (e.g. as a result of abrasion, weathering or damage) and on the other hand from the fate of a part of the originally used product quantity in the environment after the end of the use phase (as far as there is no complete removal from the environment). As some products have a useful life of several decades, there is in reality a significant time lag between the initial use of the product (to which reference is made in the annual total) and its environmental fate. In the modelling approach used here, this future environmental fate (with a few exceptions, which are indicated in the text in the relevant sections of chapter 4) is brought forward to the period of the original use of the plastic product (quantity placed on the market in the relevant period).

Results: Plastic inputs into the environment

The estimation of the remaining plastic litter (carelessly thrown away or left behind), based on the land use types considered, is around 1,500 t/a (650-2,500 t/a). Roadsides, parks and riversides are the places of input with the highest potential input and resulting plastic fate. Including "non-littering" waste (e.g. illegal disposal), the quantity (with otherwise unchanged assumptions on slip and plastic content) increases to up to 3,750 t/a, although this is only a first rough estimate, as a renewed examination of the sources and assumptions made would be necessary. The study comparison has made the influence of the assumptions made on slip and plastic content even clearer. An adjustment of the assumptions made in chapter 4, which was carried out using the example of the roads using the assumptions of the Umsicht Study as an example (cf. chapter 6.3.4),increases the calculated total amount to around 13,100 t/a (at 11,800 t/a in the area of the roads, cf. chapter 6.3.4). Compared to the original base scenario (1,500 t/a), corresponding adjustments of the assumptions thus result in changes in the calculated quantity by a factor of almost 10. To take this into account, the following summary adjusts the range with regard to the input range of carelessly discarded plastics, including waste from illegal disposal, etc., accordingly.

The estimation of the remaining quantity of plastics from environmentally friendly applications has resulted in a quantity of around 200,000 t/a (150,540 t/a to 253,045 t/a), with the product group "vehicles/traffic" making the largest contribution, which is due to the large quantity of tyre abrasion (129,000 to 158,000 t/a). Most entries (across all area types) besides tyre wear result from

- pipes that are not dismantled to a relevant extent after use but remain in the environment (4,620-46,200 t/a),
- geotextiles (2,500-4,500 t/a), grass paver (325 - 3,250 t/a) and seepage blocks (150 - 1,500 t/a), which are not dismantled,
- shoes (1,600-3,200 t/a) and bicycle tyres (820-1,370 t/a) which are partially worn (rubbed off) during use,
- agricultural films (300-3,000 t/a), planting pots (415-4,150 t/a), agricultural nets, etc. (160 - 1,600 t/a) and baler twines (150 - 1,500 t/a), which are not completely removed or correctly disposed of after use,
- composts (1,090-3,370 t/a) and sewage sludge[13] (1,500 - 3,000 t/a), which are deliberately introduced into the environment,
- granulates for artificial turf pitches (1,545 - 2,315 t/a), which are partially removed during use,
- road markings (1,130-2,390 t/a) that are partially removed (rubbed off) during use,

[13] Double counting with other entries (from cosmetics, colours, ...) cannot be excluded.

- fertilisers (1,970-2,075 t/a), which are applied in a controlled manner,
- micro plastics in cosmetics (475 - 500 t/a), which are mainly filtered out in the course of sewage treatment and introduced into the sewage sludge,
- drainage channels (rain gutters), which are used in large quantities and to a small extent removed over their useful life (165 - 1,625 t/a),
- architectural paints used in large quantities that are gradually being removed over many years of use (350 - 1,050 t/a),
- cigarette butts that are not disposed of correctly (160 - 1,620 t/a).

The following table summarises the 30 most relevant sources:

Table 50: Summary of the 30 most relevant sources for plastic inputs

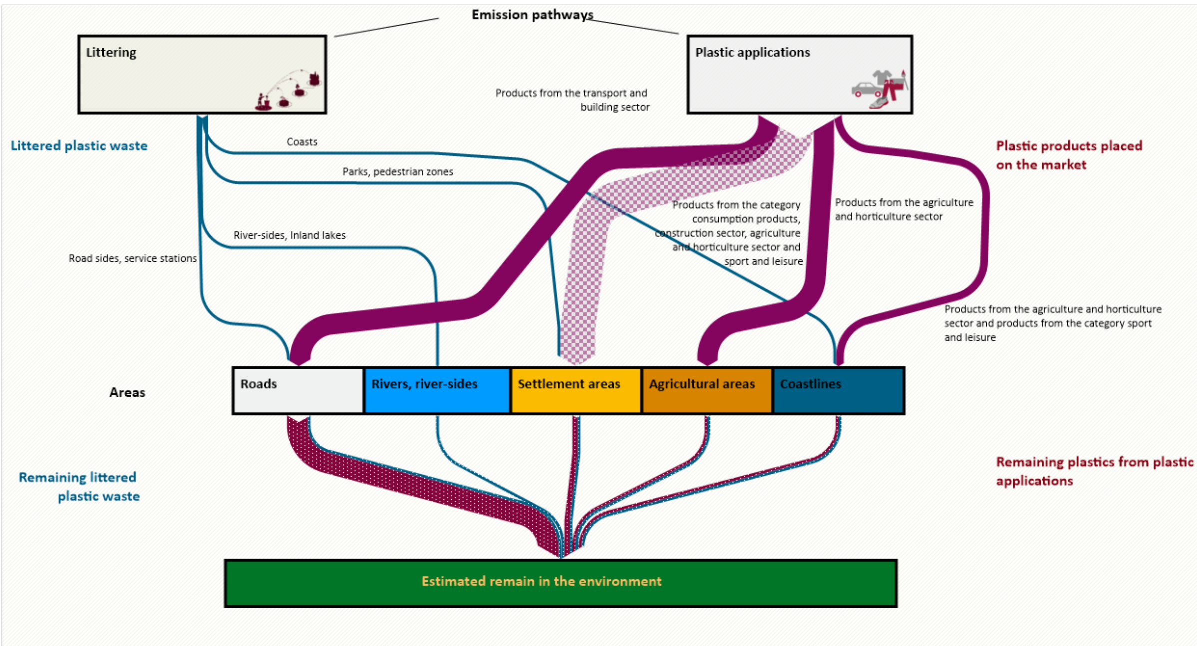
Source for plastic input	Input [t/a]
Tyres, motor vehicle (abrasion	143,261 (129,000- 158,000)
Pipes	25,410 (4,620-46,200),
Geotextiles	3,500 (2,500-4,500)
Shoes (abrasion)	2,400 (1,600-3,200)
Planting pots	2,285 (415-4,150)
Sewage sludge	2,250 (1,500 – 3,000)
Composts	2,230 (1,090 – 3,340)
Fertiliser	2,025 (1,970-2,075)
Granulate for artificial pitches	1,930 (1,545 – 2,315)
Grass paver	1,790 (325 – 3,250)
Road markings	1,760 (1,130-2,390)
Agricultural foils	1,650 (300-3,000)
Carelessly thrown away plastics, including waste from illegal disposal, lost products etc.	1,500 (650-13,100)
Bicycle tyres	1,095 (820-1,370)
Drainage channel (rain channel)	895 (165 – 1,625)
Cigarette filters (butts)	890 (160 – 1,620)
Agricultural nets, tubes, fleeces	880 (160 – 1,600)
Seepage blocks	825 (150 – 1,500)
Baler twines	825 (150 – 1,500)
Construction paints	700 (350 – 1,050)

Source for plastic input	Input [t/a]
Palisades	650 (325-975)
Base plates	500 (250-759)
Toys / play equipment	500 (250-75)
Cosmetics	490 (475-500)
Silage films	460 (230-690)
Pond liners	460 (83-830)
Cable coatings	395 (200-590)
Browsing protection	275 (50-500)
Drainage	230 (40-415)
Construction foil	200 (100—300)

In terms of quantity, the comparison of the two fundamentally different input paths is dominated by inputs from the environmentally sound applications of plastic products. In total, the two input paths, i.e. littering and open uses, result in estimated inputs of 151,190 t to 266,545 t/a that remain permanently in the environment.

The calculation results of the two input paths are visualized in Figure 13, structured according to input locations (see section 3). Further (possible) transports in the environment are not considered in this project, so that no further differentiation can be made with regard to the places and media of "permanent" fate in the environment.

Figure 13: Summary of the estimation of plastic emissions



Souce: Ökopol, the width of the arrows is proportional to the corresponding quantity (t), although the shaded arrow "Environmentally friendly plastic applications on settlement areas" cannot be shown to scale due to its size.
Regarding the quantities of plastic products placed on the market, it should be noted that data on quantities placed on the market were not available or used for individual products, as described in the relevant sections of chapter 5. Therefore, the quantities shown do not reflect the total quantity placed on the market that is relevant for the fate.

In terms of input locations, the largest quantity is obtained for the input location "roads". This is followed by the entries for settlement areas and agricultural areas. Settlement areas are the entry point with the largest quantities of environmentally friendly plastic applications and the largest quantities of littered waste in absolute terms.

Conclusions

- The entries from the multitude of environmentally sound plastic applications dominate the overall picture. In addition to the transport sector, which is dominated by tyre abrasion, the construction sector in particular represents a particularly quantitatively relevant input area.
- Tyre abrasion is the largest (individual) source of plastic input in terms of volume. Uncertainties (or differences in the assumed abrasion factors) are less than 30%. There is fundamental agreement regarding the quantitative relevance of this source.
- In addition to abrasion, the incomplete extraction of products after use is a particularly significant input mechanism that leads to high inputs in the long term.
- The littering of plastics is a relevant source of plastic inputs into the environment, but is nevertheless only one of many sources in relation to total inputs. A reduction of the inputs can be achieved by cleaning measures – in the models this is reflected in a change in the waste content or the slip. A distinction between littering (carelessly thrown away or left behind) and non-littering (illegal disposal, accidents, losses, etc.) is not recommended. Central uncertainties and questions exist regarding
  - slippage or unrecorded quantities: Here, expert assessments are made in all available studies. A verification based on available data is hardly possible.
  - The influence of the assumptions made on slip and plastic content was illustrated here, particularly using the example of roads. Parameter variations can influence the results by up to a factor of 10.
  - Abrasion of packaging (within the scope of intended use): Here, the Umsicht Study estimates high quantities that make future testing appear reasonable.
- An improvement of the database is strongly needed. This applies in particular to slippage, data on the fate of products after use and the abrasion behaviour of products of particular volume relevance.

Further development

Within the framework of the Departmental Research Plan (ReFoPlan) project, an overall model for all areas of plastic input into the environment in Germany was developed for the first time. Given the problems of the data basis outlined above, only initial estimates with correspondingly high uncertainties could be made for some areas. Nevertheless, this model allows a first rational derivation of the overall relevance concerning the input and fate of plastics in the environment.

According to the authors, however, this opens up the prospect of a stronger factual basis for the sometimes quite controversial and emotional discussions on the topic for the representatives of the plastics industry, environmental administration and the scientific community involved in the final expert discussion in June 2019.

To be able to fulfil this function in future, the designated actors believe that a consistent update of the overall model is necessary, in which existing uncertainties and remaining data gaps are minimised in a focused manner.

It is relevant that the structured representation of all input areas created in the developed model allows the currently used (estimated) values to be overwritten by updated and/or better substantiated detailed data at any time. This would make it possible to improve and update the data basis in a transparent and also work-sharing process in the future.

However, the comparison with other partial models on environmental impacts of plastics developed in parallel and the discussions held with the actors involved also showed that, in the context of updating and further developing an overall model, it is important to re-examine the objective, i.e. the expected answers.

Basically, modelling can be used to underpin both

- precautionary orientation by creating a systematic factual situation as a rational basis for targeted action in the case of newly identified risks and precautionary reduction strategies,
- and risk management/reduction by the (focused) pursuit of impairment of environmental quality in defined environmental sections derived from concrete risk considerations.

But questions arise regarding the way the information is prepared, i.e. among other things:

- Quantity discharged into the environment and/or fate in the environment

  => leads to the question: are e.g. sealed (urban) areas part of the "environment

- Accumulated stock and/or annual (input/remaining) increase

  => leads to the question: observation horizon (fate after x years ...)

- Quantity of macro and/or micro plastic materials

  => is linked to the question of the time horizon and thus the formation of "secondary" micro-plastics

- Accounting at the place of input and/or remaining?

  => the questions of (permanent) fate relevant for precautionary and risk considerations make the integration of transport and mining models necessary.

- Balancing of the basic polymer quantities and/or the quantities of additives/functionalising substances

  => requires further knowledge/information on material composition of different product groups

With regard to these questions, which in some areas will probably require a longer discussion and coordination, the authors propose the following step-by-step procedure for the further development of the overall modelling.

Step 1: updating the existing overall model as a uniform input model on the basis of product quantities used
This should include

- results-related data references (i.e. the currently used found litter quantities) are abandoned in favour of a uniform reference to use quantities
- a pointed invitation to the market players to participate in the improvement of the database will be issued. The focus here is on those market players who (possibly) bring relevant products into use

Step 2: development and integration of transport and degradation models for plastics introduced into the environment

Thereby,

- such models should be systematically adapted to the different input and fate locations
- a targeted transfer of current research work and results will be necessary

Step 3: transparent implementation of risk assessments and derivation of risk management measures for the identified fate quantities

This

- requires the combination of the quantity information with current knowledge on the (environmental and health-related) effects of (micro) plastics in the various environmental sections

enables a targeted review of measures already taken (for precautionary reasons) for risk management and for their adjustment/extrapolation.

8 Closer examination and derivation of recommendations for action on selected product groups

On the basis of the models for the estimation of the plastic input, a closer look at selected product groups is now carried out. Including an examination of possible courses of action or identification of questions to be clarified. The list of products to be examined in more detail was derived by the experts and agreed with the German Environment Agency. The following table gives an overview of the list, structured by areas of action. The central selection criterion here is the quantitative relevance of the estimated plastic fate in the environment. In addition, consideration was given to the areas of application in which potentially actionable constellations of actors can be found with whom proposals for effective reduction measures can be coordinated.

Table 51: Possible product groups for the development of recommended actions

Field of action	Product group/input area	Input into the environment [t/a]	Relevance criterion
Road usage	Tyres	129,000 – 158,000	Very high quantity relevance, if necessary, pollutant levels and environmental input as (fine) dust in case of accepted release
	Road markings	1,130-2,390	High quantitative relevance and environmental release as fine dust
	Shoes (abrasion)	1,600 – 3,200	High quantitative relevance
Construction industry and landscaping	Pipes	4,620 – 46,200	Very high quantitative relevance, partly lack of dismantling as a cause of input
	Construction paints	350 – 1,050	Medium to high quantitative relevance; possible pollutant content due to numerous functionalisation/additives (contamination of urban soils in particular). Input mostly as dust or in the form of small particles
	Geotextiles	2,500 – 4,500	High quantitative relevance, lack of systematic dismantling (or intended fate)
	Granulate for artificial pitches	1,545 – 2,315	High quantitative relevance
	Grass paver	325 – 3,250	High quantitative relevance and (intended?) quantitative fate
Sewage sludge/ compost	Composts	1,090 – 3,370	High quantitative relevance and accepted application (with possible input into food chain)

Field of action	Product group/input area	Input into the environment [t/a]	Relevance criterion
	Sewage sludge	1,500 – 3,000	High quantitative relevance and intended application (with possible input into food chain)
Agriculture	Planting pots	415 – 4,150	High quantitative relevance and high recycled content (possibly pollutant carryover)
	Agricultural foils	300 – 3,000	High quantitative relevance
Special section	Cigarettes	162 – 1,620	"easily avoidable inputs into the environment"; relevant in the public debate

Methodologically, the development of the recommendations for action is initially based on a closer examination, including relevant publications, before a consultation of experts has taken place on this basis, where considered necessary and useful.

Before the individual fields of action and product groups are dealt with, a more general consideration of the fate of plastics discharged into the sewage system is made, which is a relevant cross-sectional question for various product groups.

8.1 Cross-sectional issues: Fate of plastics and possible inputs through sewage

Depending on the type and location of the plastic application, plastics may be introduced into different environmental media with varying further fate and behaviour of the plastic particles.

The question of further fate is particularly relevant - and unresolved - in cases where it can be assumed that the plastic particles end up wholly or partially in sewage (waste water or precipitation water) with subsequent sewage treatment. In these cases, the sewage pathway is a relevant transport medium for the plastic inputs and the sewage treatment plays an important role in reducing the inputs into the environment.

This can be the case for inputs from

- tyre wear (including bicycle tyres),
- abrasion of construction paint and other plastic parts on buildings,
- shoe abrasion,
- fibres or
- cosmetics.

The plastic abrasion from applications such as tyres, construction paints, parts of buildings etc. is - partly - transported via rainwater into the municipal sewage systems or the municipal water management[14]. Plastic fibres, plastics from cosmetics etc. are transported via domestic sewage.

[14] Approximately 0.1 % of the precipitation falling in Germany is treated in the urban water management system, which is why it can be assumed that the relevant transport and input of plastics is caused by precipitation runoff (Bertling et al. 2018).

Within urban water management, a distinction must be made between mixing and separation systems. In mixed systems, sewage and precipitation water is fed to the sewage treatment plant, whereas in separation systems the precipitation water is fed directly to the water bodies. Both systems are found in Germany in roughly equal proportions. In Germany, about five billion cubic meters of domestic wastewater are treated in municipal wastewater treatment plants every year. In addition, there are about two billion cubic metres of precipitation water and the same amount of extraneous water (estimate of the German Environment Agency; Busse et al. 2019)). Wastewater flows in Germany, volume and type of treatment are summarized in Table 52.

Table 52: Sewage flows in Germany

Sewage flow	Type of treatment	Volume in million m³
Waste water (domestic/commercial)	treated in sewage plants	5080
External water		2240
Precipitation water		2570
Total volume of sewage		9890
Deductions from the mixed sewer system	not treated in sewage treatment plants, partly mechanical treatment	1310
Discharge of precipitation water	not treated in sewage treatment plants, partly mechanical treatment or natural processes	3960

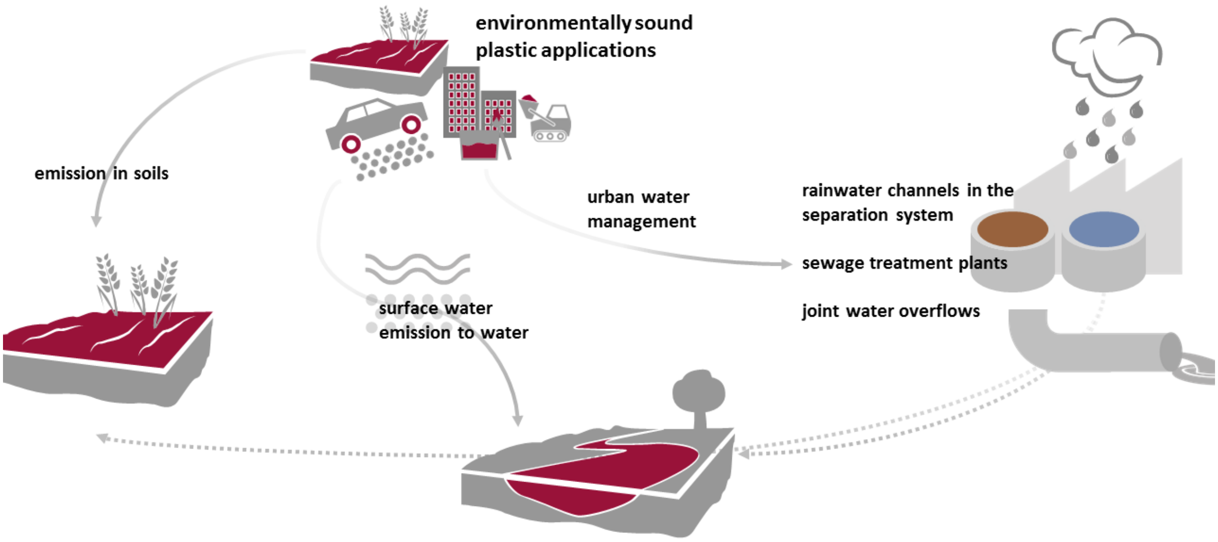
Source: German Environment Agency / position paper "Plastics in the Environment"

In this context, a distinction has to be made in the field of urban water management as fundamental paths of input for plastics into the environment:

- rainwater channels in the separation system/ rainwater discharges: Discharge of precipitation water from the separation sewer system mainly without effective purification into water bodies.
- combined sewer overflows: Discharge of combined sewer overflows from sewage treatment plants into surface waters during heavy rainfall to prevent damage to infrastructure (sewers, pumps, sewage treatment plants).
- purified effluents from wastewater treatment plants: treated wastewater from sewage treatment plants is discharged into water bodies or used for irrigation.
- Other sewage treatment plant outflows, in particular sewage sludge and grit: Plastics in waste water flowing into sewage treatment plants are divided into three other waste water

treatment plant outflows: screenings, grit and sewage sludge (see Figure 15). However, there are gaps in the knowledge of which outputs from wastewater treatment plants contain plastic particles and in what quantities, and what inputs into the environment result from this, e.g. via the spreading of sewage sludge on agricultural soils[15]. Screenings are usually incinerated, which is why plastic discharges can be excluded.

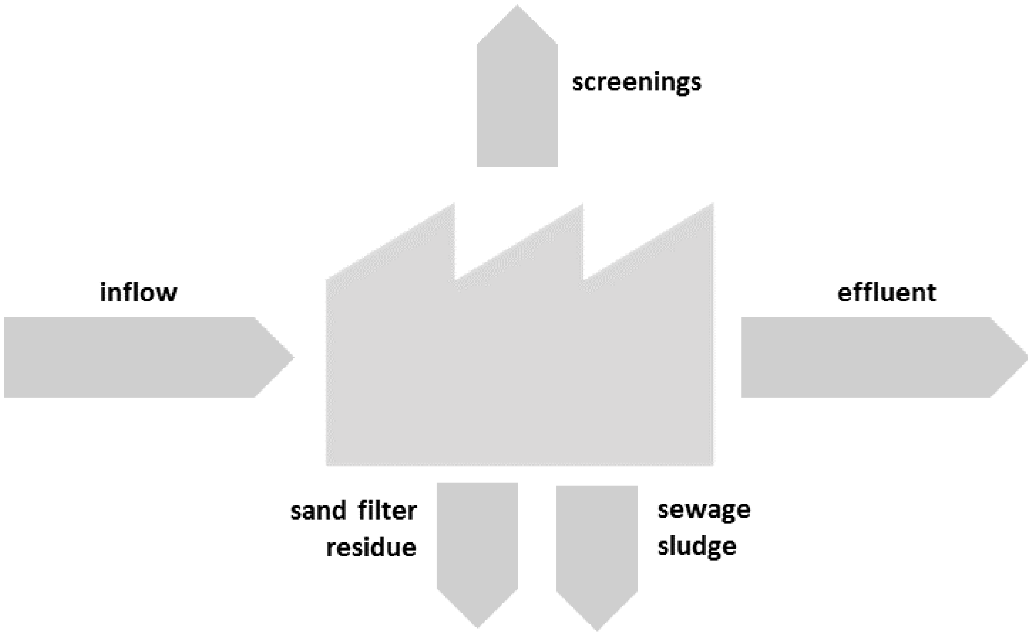
Figure 14: Schematic representation of fate mechanisms of plastic emissions



Souce: Ökopol

[15] In this context, it should be mentioned that, due to an alteration to the Sewage Sludge Ordinance adopted in 2017, sewage sludge from large sewage treatment plants may no longer be spread on agricultural land from 2029 or 2032, respectively, which will reduce the quantities of plastic introduced into the environment via the sewage sludge (cf. section 8.5.2 in detail).

Figure 15: Schematic representation of basic inputs and outputs of sewage treatment plants



Source: Ökopol, based on (Bertling et al. 2018)

With regard to the determination and prevention of plastic discharges into the environment, the following fundamental central questions can therefore be identified:

- Which proportions of plastic inputs enter a sewage treatment plant and which do not?
- In what quantities are plastics in the inflow?
- In what quantities are plastics distributed among the outputs?
- How can plastics in wastewater treatment be (specifically) removed or components be fed into the incineration process?

With regard to these central questions, various research projects are currently underway at the German Environment Agency in order to improve the data situation and be able to make statements based on it. In addition, the Federal Ministry of Education and Research's (BMBF) funding priority "Plastics in the Environment" addresses various questions relevant in this context in a series of research projects (see project selection in box).

One goal in each case is to achieve uniform monitoring on the basis of a uniform method, which is the prerequisite for a valid and comparable data situation.

Selection of projects in the funding priority "Plastics in the environment“ by The Federal Ministry of Education and Research (BMBF)

Project "MicBin: Micro plastics in inland waters – investigation and modelling of the input and fate in the Danube basin as a basis for action planning" coordinated by the Helmholtz Centre for Environmental Research

The aim of the project is to balance the input of macro-, meso- and micro plastics for a larger catchment area of an inland water body for the first time, using the example of the German

Danube catchment area with measuring campaigns on two of the larger Danube tributaries. Both sewage treatment plant discharges and potential discharge paths, which have been less considered so far, are investigated and determined. These include agricultural land, airborne inputs and comminution and transport processes of macro- and micro-plastics in the environment. The aim of the joint project is to quantify inputs, transport routes, distribution and fate of micro plastics. The project thus provides information on the quantities of micro plastics that are (or can be) introduced into waterbodies via sewage treatment plant effluents. A further analysis of airborne and agricultural inputs can provide valuable information about these input paths, which are not subject to wastewater treatment.

Project "Plastrate – solution strategies to reduce the input of urban plastics into limnetic systems" coordinated by the University of the Federal Armed Forces Munich

The aim of the project is the development of solution strategies for the sustainable limitation of the spread of plastic residues in the aquatic environment. For this purpose a quantification and estimation of possible technical measures for micro plastic retention in the urban water management is carried out. In addition, analyses of sewage sludge, fermentation residues and compost as possible micro plastic sinks are carried out to determine the respective contamination with plastics. In a further work package, a multi-criteria evaluation approach for the environmental compatibility of limnic systems of plastic types is to be developed, on the basis of which a quality seal for plastics is to be developed. For this purpose stakeholder dialogues are.

Project "REPLAWA – reduction of the discharge of plastics into the aquatic environment via wastewater" (German: REPLAWA – Reduktion des Eintrags von Plastik über das Abwasser in die aquatische Umwelt)

The project deals with possible approaches to protect the resource water from plastic discharges in connection with wastewater discharge and wastewater treatment. The input paths into the watercourse through wastewater treatment plants, storm water inlets and combined sewer overflows as well as sinks in wastewater treatment and sewage sludge are determined and quantitatively assessed. Various methods for reducing and eliminating the input of plastics during wastewater treatment are tested and evaluated in practice. Based on the results of the investigations and evaluations of international regulatory approaches, strategies for the reduction of plastics input and for sensitising decision makers and plant operators as well as for the reduction of input via wastewater are derived.

8.2 Action area road use

In the area of action "road use", three product groups, tyres, shoes and road markings, are examined in more detail. In terms of quantity, tyres are dominant here (cf. Table 51), while road markings and shoes also lead to inputs above 1,000 t/a.

8.2.1 Tyres

The calculation for tyres was based on the annual kilometres driven in Germany, with a distinction being made between different types of vehicle. The input is made by the abrasion of the tyres during use. The emission factors (or abrasion factors) applied are taken from a study by the German Environment Agency (Hillenbrand et al. 2005). In addition, assumptions were made for the proportion of inner-city kilometres driven, based on data from the Federal Highway Research Institute (Bäumer et al. 2017).

The figures determined here do not differ significantly from the data of other authors. There is broad agreement between various studies regarding the extent to which tyre wear occurs (Hillenbrand et al. 2005; Giese et al. 2018; Wigger et al. 2018; Wang et al. 2016; Essel et al. 2015; Kole et al. 2017; Zimmermann et al. 2018), the reported or deducible fate factors usually fluctuate by less than 30%.

Regarding the composition of tyre wear, the literature also presents a rather homogeneous picture:

Table 53: Tyre abrasion composition according to various studies

Material	Dave (2013); Wik and Dave (2009)	Kocher (2010)	Krömer et al. (1999)	Degussa (2007) quoted in Kocher (2010)	Okel and Rueby (2016)
Synthetic or natural rubber	40-60%	39%	42%	53.6%	Not specified
Carbon Black / SiO2	20-35%	34%	34%	34%	22-40%
Mineral oil	15-20%	Not specified	17.1%	4.3%	Not specified
Sulphur	1%	Not specified	Not specified	2.1%	1-4%
Zinc oxides	1.5%	1.1%	0.5%	1.3%	1%
Stearic acid	1%	Not specified	Not specified	0.9%	Not specified
Sulphenamides or thiazoles	0.5%	Not specified	Not specified	2.7%	Not specified
Other / not specified	1.2%	24.5%	6.4%	1.1%	55-76%

The proportion of synthetic rubbers is particularly relevant here in relation to the issue of plastic discharges into the environment. However, the other constituents are also environmentally relevant, which is why it seems more appropriate to consider the entire tire abrasion as a whole than to look at the quantities of the individual constituents individually.

The specific composition of tires results from a multitude of requirements for the respective application, whereby aspects such as safety (braking behaviour, road grip), driving characteristics (including noise development and rolling resistance) and durability or service life (mileage) play a particularly important role. Abrasion behaviour, in turn, results from these properties, but is not a primary target variable in tyre development, even though it is closely related to mileage.

There are no regulations or standards that limit tyre wear to date. Even in the EU tyre label, abrasion is not a criterion so far. The report from the European Commission to the European Parliament and the European Council assessing the need to review Regulation (EC) No 1222/2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters (EU Commission 2017) states:

"The abrasion, like the mileage, depends largely on external factors (i.e. tyre pressure, road surface, load, driving style, etc.). The tyre labelling system should not necessarily be used to regulate TRWP [Tire Road Wear Particles] emissions. However, this issue could be further explored in a future

revision of the regulation. However, this should take into account the increasing concerns about air pollution and micro plastics in the oceans and the consequences for the environment and human health. ...] It may also be relevant to mention that this issue could also be examined in the context of the Tyre Approval Regulation [Regulation (EC) No 661/2009] for tyres.“

This makes it clear that consideration in EC Regulations No. 1222/2009 or 661/2009 could represent a future possibility to reduce the input of plastics into the environment.

In addition to this regulatory approach, two further approaches can be identified with regard to the reduction of tyre abrasion inputs into the environment:

- Reduction of tyre wear by reducing the volume of traffic and/or limiting the permissible driving speed (prevention of formation)
- Reducing the input of tyre wear into the environment by preventing the input after it has occurred

The reduction of traffic volume is the subject of various public programmes. In the Sustainable Development Goals, sustainable mobility is a sub-aspect of Goal 11 "Sustainable Cities and Towns" ("safe, affordable and sustainable urban and rural mobility"). The Federal Ministry of Education and Research's (BMBF's) "Future City" competition awards prizes for such concepts[16]. The Federal Government's sustainability strategy at least states the intention to reduce "final energy consumption in goods and passenger transport [...] by 15 to 20 percent by 2030" and to improve "the rapid accessibility of centres by public transport". The Reconstruction Loan Corporation (Kreditanstalt für Wiederaufbau, KfW), for example, provides local authorities with development loans for the implementation of measures for the sustainable design of urban transport policy[17]. The Federal Ministry of Transport, Building and Urban Affairs (BMVBS) has collected a number of best practice examples in a publication (BMVBS and BBR 2007). The main pillars for reducing the volume of traffic in these examples are:

- ensuring short distances to the supply infrastructure
- prohibition zones for cars (partly with the exception of residents), road re-use, traffic calming
- reduction of parking facilities
- expansion of public transport services
- extension of the cycle path network
- creation of bicycle parking spaces
- bike (short term) rental possibilities, "City Bikes“

These possibilities are known in principle but will not be discussed further at this point.

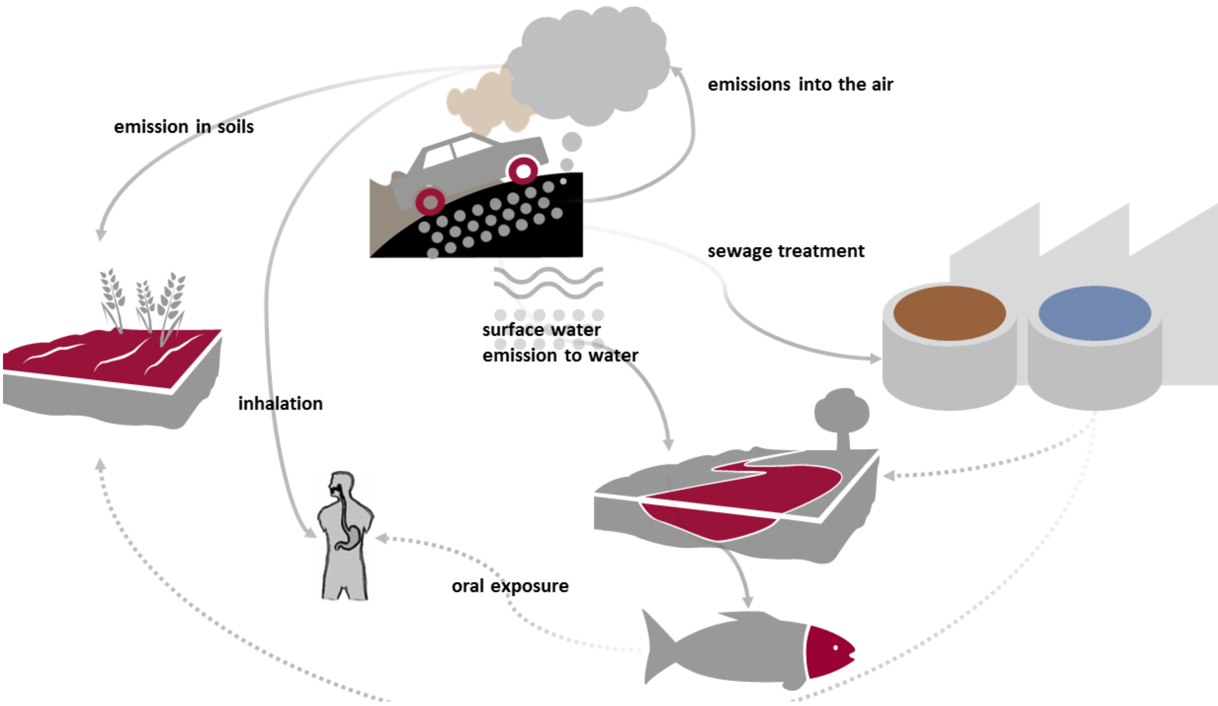
The reduction of the input of tyre abrasion into the environment by reducing the input after its formation addresses the question of the fate of the abrasion. The abrasion from the tyres is either swirled into the air while driving or remains directly on the road, e.g. in wet road/rain.

[16] see https://www.wettbewerb-zukunftsstadt.de/der-wettbewerb/kurzbeschreibung.html

[17] see e.g. https://www.kfw.de/PDF/KfW-Research/Economic-Research/Publikationsarchiv/Mittelstands-und-Strukturpolitik/Umweltschutz-und-Energie/Per-43-Nachhaltige-Verkehrskonzepte.pdf

With the (rain) water or by deposition, the tyre abrasion is distributed in soils (see e.g. Hillenbrand et al. 2005) and water bodies (see e.g. Sundt et al. 2014; Wik and Dave 2009). A model of the distribution of tyre wear in the environment is shown in Figure 16.

Figure 16: Possible distribution of tyre abrasion and reduction of tyre abrasion in the environment



Source: Ökopol, based on Zimmermann et al. (2018)

Possible actions could include improved street cleaning[18], which removes a relevant proportion of tyre abrasion and prevents further discharge into the environment, and optimised wastewater treatment, which prevents tyre abrasion from entering the environment via rainwater runoff or sewage sludge.

How street cleaning could be optimised in order to achieve a better cleaning of tyre abrasion and which technical measures can be used to minimise the input is currently being researched in the Federal Ministry of Education and Research (BMBF)-funded study project "tyre abrasion in the environment"[19] (specifically, a wet sludge trap is mentioned as a sink for tyre abrasion). More detailed findings were not yet available at the time. The project should, however, be closely monitored with regard to possible courses of action.

Further research projects as described in section 8.1 also deal with possible approaches to avoid the input of plastics from sewage treatment plants and wastewater.

8.2.2 Road markings

The calculation for the road markings is based on information from another Ökopol project, information from Evonik and information from motorway maintenance authorities and the German Study Association for Road Markings.

[18] It should be noted here that the brushes in conventional mechanical street cleaning are a potential source of contamination (abrasion of the plastic brushes).

[19] see https://bmbf-plastik.de/verbundprojekt/rau

The quality of the data on quantities placed on the market, useful lives, and plastic content on which the modelling is based is rated as very good. Only the assumptions regarding abrasion over the useful lives and the input into the environment are based on expert estimates and are subject to uncertainties which are reflected in the range of the modelling results.

A less aggregated consideration on the basis of the data collected provides more concrete findings or estimates as to which types of marking paints per tonne of marking paints placed on the market lead to annual plastic inputs and to what extent. On this basis, a rough sorting of the types of paint can be made:

- comparatively high inputs
  - (1) water based paints
  - (2) solvent based paints
- medium inputs
  - (3) thermoplastic systems – thin film
- comparatively low inputs
  - (4) thermoplastic systems – thick film
  - (5) cold plastic systems – thin film
  - (6) cold plastic systems – thick film
  - (7) films.

In reverse order, this sorting also approximately reflects the costs of the different systems: while the short-lived systems, water and solvent-based paints, are cheaper, films, for example, are significantly more expensive and therefore only make economic sense on heavily trafficked roads.

In addition to the cost of the various systems, however, a number of possible properties of road marking paints play a role in their selection, including various safety-relevant properties. The following table provides a (non-exhaustive) overview of such properties.

Table 54: Examples of relevant properties of road marking paints

Feature	Explanation
Costs	Basically, the short-living inks (water and solvent based) have lower costs than the more durable systems. Depending on the required properties, the concrete system costs result.
Basic abrasion resistance	A high abrasion resistance is necessary for roads with heavy traffic, while high abrasion resistance is usually not required on roads with less traffic. Water and solvent based paints have lower abrasion resistance and are often used on secondary roads, while cold and thermoplastic systems have higher abrasion resistance.
Drainage behaviour	Special structures in road markings can help to drain water from the road. Mostly cold plastic systems with corresponding structures.
Snowplough resistance	This feature is especially required in regions with a higher probability of snow. Certain (long-lasting) paints are particularly resistant to abrasion by snow ploughs and are specifically used here. Mostly cold plastic systems.

Feature	Explanation
Alarm function (noise generation when leaving the lane)	By special structuring, high visual, audible and perceptible properties of the road marking can be created. Mostly cold, but also thermoplastic systems.
Night visibility	Night visibility is usually achieved by introducing glass pearls into the material, which reflect light. The service life is not limited here by the abrasion of the marking paint, but by the glass pearls. In the course of the repair work, a thin layer of paint and glass pearls is usually applied. Mostly cold plastic systems, although thermoplastic systems also have good visibility.

Source: Ökopol on the basis of expert discussions

Against this background, the selection of road marking paints is a balancing act between costs and desired properties. The possible use of plastics has no direct relevance here. However, it can be stated that more expensive systems are associated with lower potential entries.

In the opinion of the experts, there is no concrete, meaningful approach here. In principle, the use could be regulated by public tendering, but since real (price-comparable) alternatives are missing, this remains a theoretical approach.

8.2.3 Shoes

As regards footwear abrasion, it should be noted in principle that there are no studies which have systematically investigated footwear abrasion in practice. Therefore, an exchange with experts was initiated for the analysis in the project, whereby the Test and Research Institute Pirmasens (Prüf- und Forschungsinstitut Pirmasens e.V.) should be mentioned in particular. In addition, shoe sole manufacturers, among others, were contacted.

The assumptions made in the analysis described in section 5.2.3 of this report of an annual abrasion of 10 to 20 g[20] (a sole weighs between 50 and 300 g) are based on these discussions, which at the same time emphasised that shoe wear is very variable and depends on a number of factors (foot deformations, type of use - much/ little road; mainly carpet, office, use in the garden, ... - profiling, ...).

The main materials used for shoe soles are ethylene-vinyl acetate copolymer (EVA, Phylon), polyurethane, rubber and thermoplastic polyurethane (TPU, slightly stronger; more likely to be used in safety footwear). Other materials such as leather play practically no role in the overall picture.

With regard to the different materials, no fundamental statements can be made in terms of different abrasion tendencies. Within the individual material types, the specific additives are relevant for abrasion behaviour. As an approximation: the softer the material, the more flexible the shoe (can be a quality feature), the more abrasion. Nevertheless, no fundamental statement can be made about a correlation between high and low price and abrasion behaviour: In most cases, the sole is not the price differentiating criterion. This is rather the upper materials.

[20] The idea was that one pair of shoes should be worn all year round. With around 160 million pairs of shoes, it can therefore be assumed that between 1,600 and 3,200 tonnes remain.

There are legal requirements for abrasion behaviour in the field of personal protective equipment (PPE)[21]. Here, the following requirements according to DIN EN ISO 20345ff[22] apply to the abrasion resistance for shoes that are considered to be PPE:

- density (of the sole material) ρ > 0.9 g/cm3: ≤ 150 mm^3
- density (of the sole material) ρ ≤ 0.9 g/cm3: ≤ 250 mm^3.

Therefore, material with a higher density must show less wear.

The abrasion resistance of shoes (upper material, lining and cover soles) is determined, for example, by DIN EN 13520 or ISO 17704[23]. The Taber abrasion test (e.g. DIN 53754 Testing of plastics[24]) is also used for shoe soles. In addition, other industrial standards of the Testing and Research Institute (PFI) are in use for testing the wear of sole materials.

The Blue Angel for shoes also contains specifications for the maximum abrasion of various types of shoes, which are borrowed from the EU Ecolabel for footwear. These specifications are summarized in the following table:

Table 55: Blue Angel specifications for the abrasion resistance of shoes

Shoe type	Abrasion resistance for ρ ≥ 0,9 g/cm3	Abrasion resistance for ρ < 0,9 g/cm3
General sports footwear	≤ 200 mm^3	≤ 150 mg
Children's shoes	≤ 200 mm^3	≤ 150 mg
Casual shoes	≤ 250 mm^3	≤ 170 mg
Men's street shoes	≤ 350 mm^3	≤ 200 mg
Winter boots	≤ 200 mm^3	≤ 150 mg
Women's street shoes	≤ 400 mm^3	≤ 250 mg
Fashion shoes	No guidelines	No guidelines
Toddler's shoe	No guidelines	No guidelines
House slipper	≤ 450 mm^3	≤ 300 mg

Appendix N to the award basis RAL UZ 155 (RAL 2018)

With regard to a possible transfer of corresponding requirements into legal specifications, the experts believe there is a need for further examination and discussion.

Alternative materials do not yet represent a solid alternative. In certain segments, for example, leather outsoles are used. However, even these are usually problematic from an environmental point of view (water pollution, water consumption, use of chemicals). Leather outsoles are only used in the high-priced segment as an "equivalent replacement" for plastic soles, but are much

[21] Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on personal protective equipment and repealing Council Directive 89/686/EEC

[22] The abrasion resistance is determined according to DIN on a rotating cylinder drum covered with sandpaper. The test specimen is moved at a defined speed until it has covered a distance of 40m on the sandpaper at the end. Afterwards the volume (mm^3) is determined which was rubbed off.

[23] DIN EN 13520 (2005-03). Footwear - Test methods for uppers, linings and insoles - Abrasion resistance; and ISO 17704 (2004-10). Footwear - Test methods for uppers, linings and cover soles - Abrasion resistance, issued 2004-10.

[24] DIN 53754 (1977-06). Testing of plastics; determination of abrasion by the friction wheel method, issued 1977-06.

more cost-intensive. Leather soles are also generally less (long) durable, among other things because they do not have a profile (therefore higher wear behaviour). In the high-price segment a new sole is usual once a year.

8.3 Construction industry and landscaping

8.3.1 Geotextiles

Geotextiles are flat or three-dimensional textiles that are used primarily in civil engineering, waterways and traffic route construction. They are made of polypropylene (PP), polyamide (PA), polyethersulfone (PES), among others. The quantity estimates for geotextiles are based on consultative studies and supplementary expert discussions. The input is done by remaining in the environment after the period of use, in most cases no deconstruction is carried out (current assumption: 50-90% of the installed quantities remain in the environment). The input horizon is 10-30 years, but also > 30 years in some cases.

Central questions on these basic assumptions and in relation to possible reduction approaches for the remaining quantities include:

- When does the function and thus the use of a geotextile in the soil end "objectively"?
- In which applications is there a systematic removal of textile webs from the environment?
- In which applications would extraction be possible only through unreasonable impact on the environment?
- To what extent is the presence of geotextiles in the soil systematically recorded and documented in a long-term "retrievable" manner for building construction, civil engineering and horticultural or landscaping measures?
- Under which conditions can landowners be expected to be obliged to deconstruct their land, and how can this obligation be operationalised?

In view of the assumed volume significance of this product group, it seems reasonable from the expert's point of view to address these and other possible questions within the framework of further research projects.

8.3.2 Pipes

Relevant here are pipelines in supply networks, primarily supply and sewage pipes made of PVC, PE and PP. The current volume estimates for pipes are based on Consultic studies and a study by the German Water and Wastewater Association.

The input is made by remaining in the environment after the period of use. This means that it is assumed that in some cases complete dismantling will not take place. (Current assumption: 1%-10% of the pipes used remain in the environment). The input horizon is beyond 30 years.

Central questions regarding these basic assumptions and with regard to possible reduction approaches for the remaining quantities include:

- When does the useful life of a pipeline in the ground "objectively" end?
- How can it be ensured that pipes are removed from the environment (the ground) at the end of their useful life?

- When does the presence of an unused pipeline in the ground result in an obligation to dismantle it?
- How is the necessary knowledge (location, type of installation, ...) made available?
- What are the usual procedures?
- How can it be ensured that these are recycled or disposed of in an orderly manner?
- Where are existing gaps in the dismantling and disposal of pipes seen?
- Is the contamination of building rubble and other construction waste (excavated soil, road construction, construction site waste) with plastics (e.g. from pipes) seen as a relevant problem?
- Are there cases where it makes more sense from an ecological point of view to leave it after use?
  - Which starting points are seen to reduce such contamination?

8.3.3 Construction paints

The volume estimation for construction paints is based on information provided by the Association of the German Paint and Printing Ink Industry in the context of emission reporting. The input into the environment during use is usually caused by weathering (current assumption 0.25%-0.75% input via use). A reduction in plastic emissions can be achieved by using paints with a lower plastic content, although there is little room for manoeuvre so far with regard to the products available on the market. A reduction could also be achieved by using paints with a higher weather resistance and a longer service life, although in the opinion of the experts a detailed feasibility study would have to be carried out here, also taking into account the interactions with other relevant (environmental) parameters.

8.3.4 Artificial turf pitches

The relevant plastic input from artificial turf pitches comes from the used granulate, which can enter the environment via various paths via carry-over (adherence to clothing, shoes, etc.) and drifts.

According to a study by the Scientific Service of the German Bundestag, some of the granulate used comes from recycled car tyres and may contain polycyclic aromatic hydrocarbons (PAHs), which is why this is particularly relevant in terms of pollutants (Deutscher Bundestag 2010).

Possible alternatives for plastic granulate include cork granulate or sand-rubber granulate mixtures[25], which are increasingly used. In the case of rubber granulates from recycled rubber, however, concerns were expressed in the context of a restriction application under REACH regarding the PAH content and the health hazards when the granulates are used in sports fields and similar applications[26]. A possible new solution may also be hydride systems consisting of natural grass and a proportion of synthetic fibres.

[25] See https://www.sportstaettenrechner.de/wissen/kunstrasen/belagstypen-und-anwendungsbereiche/

[26] See Annex XV restriction request (NL, 2018), https://echa.europa.eu/documents/10162/9777e99a-56fb-92da-7f0e-56fcf848cf18

For sports fields that are used exclusively for certain sports such as hockey and American football, it is also possible to dispense with granulate infill of the artificial turf pitch altogether (German Bundestag 2017).

8.3.5 Grass paver

Grass paving serves as a structural reinforcement of trafficable and at the same time greened traffic areas, such as garden and footpaths, driveways or even parking areas. Mainly plastics such as PE-LD, PE-HD are used. Grass paving grids have the advantage that the surface can be driven on without sealing the surface.

The quantity estimate is based on internally available data from Consultic and discussions with experts. There are no production statistics available.

The input is made by separation/chipping (e.g. weathering) of small particles during use or by incomplete removal after use. Input locations are settlement areas as well as sports fields and leisure facilities. Partial removal after use (assumed fate 1% - 10%).

Remaining questions are:

- Is there an (orderly) dismantling/removal of grass pavers from the environment?
- Is dismantling feasible? What are possible obstacles/problems?

8.4 Agriculture

8.4.1 Agricultural foils

The range of agricultural films includes films for early harvesting (mulch films, asparagus films, greenhouse films) and for feed preservation (round bale films, mobile silage films, tubular films). The films consist mainly of PE. They are released into the environment by remaining in the soil of entire films or smaller film parts, by blowing them away by wind and by possible incomplete removal after use (here, a fate factor of 1-10% was assumed in the modelling).

Against this background, the central challenge is therefore to ensure that the material is largely removed and fed into appropriate recycling systems.

With the initiative ERDE of RIGK GmbH such a system already exists. The initiative ERDE (Harvest Plastics Recycling Germany/Erntekunststoffe Recycling Deutschland) is a take-back system for agricultural films, initiated by the Industrial Association for Plastic Packaging (Industrievereinigung Kunststoffverpackungen e.V. (IK)). The system is currently financed by ten participating manufacturers of agricultural plastics (RIGK 2018) in order to offer farmers a cost-effective service for the return of the films. Users of the agricultural films (farmers) can hand in the used films at collection points or have them collected.

RIGK GmbH in Wiesbaden acts as the system operator of ERDE, which offers various services in the field of commercial packaging, such as the collection and recovery of pesticide packaging from the agricultural sector or industrial packaging of hazardous products. ERDE organises the acceptance of agricultural films throughout Germany via a collection network of currently around 350 collection points and via additional mobile collections directly from the farmer. The collection points are cooperative and private trade as well as agricultural engineering companies and waste disposal companies. The price for collection and acceptance is determined by the collection points themselves (RIGK 09/2018).

A distinction is made in collection between PE-LD (category 1) and PE-LLD (category 2). As the films consist of over 90% of these PE categories and material combinations are rare, they represent relatively homogeneous mono-categories which are in principle well suited for recycling, although there are limitations due to the high dirt adhesion typical of agricultural films. In 2017, 6,500 t of films were collected in this way, according to the company's own information, or just under 10% of the agricultural films placed on the market annually (70,000 t). For the year 2020, EARTH has set itself the goal of collecting and recycling 50% of all agricultural films placed on the market (RIGK 2017a).

The recovery of the films currently takes place in 8 recycling plants in Europe, which first clean and shred the films and then melt them down into regranulate material, which can be used in new plastic products such as waste bags, construction films and stretch films or which is reprocessed into agricultural film (RIGK 2017a). The main obstacle to recycling is the high degree of contamination of agricultural films, which makes pre-cleaning by the end consumer necessary. As an motivation for clean collection, the final consumer receives a return bonus for stretch films, which he can redeem with his next purchase (IK 2014).

8.4.2 Planting pots

The input of plastic through plant pots is done by separating (e.g. abrasion) or splintering off small particles during use or by leaving them completely in the environment, e.g. by leaving the pots outside and letting the wind spread them. Another way to reduce or make less likely the input is to provide incentives for consumers to collect and return the pots intact.

The strategy of promoting alternative materials is pursued, for example, by the Blue Angel for compostable plant pots and mouldings (DE-UZ 17). In its current version, the Blue Angel has the following requirements:

- ▶ The products must consist of 100% biodegradable (compostable) substances such as straw, cork, wood flour, corn starch.
- ▶ The following substances must not be contained in the products: synthetic plastics, plasticizers, materials containing PVC.
- ▶ The products must be fit for the intended purpose.
- ▶ Plant pots must not be treated with biocidal substances, e.g. in pesticides and preservatives.

A total of 14 products have been awarded the Blue Angel for compostable plant pots and mouldings, seven of which are plant pots from various manufacturers. In addition, a number of coconut tablets for growing plants (pot and substrate in one) and similar products have also been awarded.

The criteria for awarding plant pots have existed for a very long time (since about 1982), but they have changed over time: in the beginning, the emphasis was on the fact that the products had to be made of secondary raw materials. This requirement was completely removed a long time ago, so that now the main focus is on compostability. A background study with a life cycle assessment of this eco-label is not available. If the pots are made of plant raw materials grown specifically for this purpose, this could be a disadvantage in terms of the life cycle assessment. A clear recommendation to promote plant pots made of compostable material in principle (i.e. without excluding certain materials) can therefore not be given.

It is also important that pots made of degradable materials are functionally comparable to non-degradable plastic plant pots. Problems often arise when the pots are used, for example, in the plant trade, because they soften too easily or if they stand around for a few days, moss will grow. In addition, they are often not suitable for handling by machines because they cannot be detached from each other easily enough. Furthermore, pots made of natural materials are clearly too expensive for commercial use, e.g. in garden centres, as there is only a very small profit margin on herbs and young plants.

According to an expert discussion with a representative of a producer cooperative, pots based on sunflower seeds are functionally well suited, but they are particularly expensive. The cooperative is currently having flower pots developed from tomato plant fibres (after harvesting the plants, i.e. from waste products). However, it remains to be seen whether these are functionally and economically suitable.

A second approach could be the introduction of deposit systems for plant pots by plant dealers (especially garden centres). Individual garden centres and market gardening companies operate such deposit systems, and systems for both corporate customers and consumers are practised. A number of expert discussions were held with the operators of the deposit systems, on which the following descriptions of different systems are based:

- A small market gardening company has been operating a deposit system for pots for at least 20 years, in which smaller and larger plants (e.g. tomatoes) are sold. The pots used are recognisable and quite stable and durable, as they have been in use for several years. As the company has about 80-90% regular customers, the return rate is quite high and only about 10% of the pots per year are not returned. The amount of the deposit is 50 cents for large pots and 20 cents for smaller ones. The reactions of the customers are almost exclusively positive. Rather seldom is it asked to remove the plant from the pot when selling, as returning the pot is too time-consuming for the customer. So far there have been no hygienic problems due to reuse.
- A company that sells solid plastic pots mainly to planters (companies that supply plants in pots to their customers and are also responsible for their maintenance) has for some time been operating a take-back system with a deposit for plant pots that no longer meet the customers' expectations in terms of appearance. Since the company recycles the pots itself, they are used as raw material in the production of new pots. The return rate is approx. 40%, although it should be noted that the pots are also sold internationally and transport is quite costly as they cannot be stacked inside each other. The deposit is 1 € per pot.
- According to a large, international company which does not offer to end customers but only to large customers, it operated a deposit system for plant pots for a time; however, due to the size of the company, this was logistically too complex and expensive. In addition, the pots had to be thoroughly cleaned to remove possible pathogens and to eliminate hygiene problems. For large transport containers, however, the deposit system still existed.

The voluntary deposit systems found all use stable, comparatively durable plant pots. However, it would be conceivable to introduce a statutory deposit system for thin-walled, inexpensive plastic pots in a similar way to the deposit on disposable plastic bottles for beverages.

8.5 Sewage sludge and compost

Compost and sewage sludge used in agriculture contain a small proportion of plastics which are not removed by the existing separation and screening processes in the plants. Due to the large quantities of compost and sewage sludge that are currently being spread, a fairly large amount of plastic is released into the environment in this way. For both input paths, this study expects a good 2,200 t of plastic per year in each case.

8.5.1 Composts

8.5.1.1 Starting point

Compost is organic waste after decomposition in specially constructed plants, which are used for fertilisation and soil improvement in agriculture, horticulture, park management and private gardens. They originate from biological treatment plants whose raw materials are various waste streams (see Table 56). Most suitable for composting are separately collected biowaste (from the organic waste bin) and garden and park waste from households and municipal green spaces. Food waste and waste from food processing, for example, are more likely to undergo fermentation due to their high energy content[27].

Table 56: Input flows to biological treatment plants 2016 (Destatis data)

Type of waste	Input amount (1.000 t)
Waste and sludge from agriculture and food processing	2,662.6
liquid manure, slurry, stable manure	1,003.3
Waste from wood processing	112.6
food waste from canteens and restaurants	610.7
Organic waste bin	4,357.5
Garden and park waste	4,801.1
Wastes from waste and sewage treatment plants (mainly sewage sludge from municipal sewage treatment plants)	1,460.1
Other	603.4
Sum	**15,611.3**

With the bio waste and green waste going into composting (and digestion), many larger and smaller plastic parts, as well as other foreign matter, end up in composting plants. These are mainly waste collection bags made of conventional or "degradable" plastic. However, all other types of plastic products (plastic buckets, toys, bottles, bathroom articles) and composite materials (Tetra-Paks, coffee capsules) are also included in the bio waste. In green waste you can find many plastic flower pots, but also whole garden tools.

Composting plants (as well as bio waste digestion plants) have several treatment stages in which foreign matter is separated as far as possible. In the beginning, large pieces of foreign matter are

[27] This also applies to the recently much-discussed, no longer saleable, packaged food waste, which is not unpacked but often enters the process completely (i.e. packaged goods including packaging). According to an expert discussion, treatment using the best possible technology and careful quality assurance does not result in significant plastic contents in the finished fermentation residues. The packaging is typically divided into four parts with two cuts. The comparatively large parts of the packaging that are created in this process can be removed without difficulty. In cases where shredding is carried out, plastic may be released into the environment despite filter stages.

removed, but some larger pieces of plastic are shredded during the treatment due to the mechanical stress. The finished compost therefore contains small proportions of shredded foils (including so-called degradable plastics) and plastic fragments. A complete separation of small plastic parts is not possible.

For compost to be used as fertiliser, a legal limit of max. 0.5% of dry matter in total for foreign matter larger than 2 mm applies. Of this, a maximum of 0.1% may be foil plastics and a maximum of 0.4% other foreign matter (incl. hard plastics). Smaller particles are not included in the limit value. For quality-assured substrates there is an additional limit value for the total area of plastic films, as their weight is so low that the weight-related limit value is not sufficient. Previously (since 2007) this was 25 cm2/L substrate, since July 2018 a limit value of 15 cm2/L applies. Quality assured composts achieve an average plastic content of 0.038% of dry matter (data of the Federal Quality Compost Association for 2016, based on over 2000 analyses). However, particles below 2 mm are not considered here either.

Nevertheless, there have recently been media reports about visible plastic parts on the fields, which are introduced by compost and other fertilizers (Schröder 2018). It is unclear how often there are enforcement deficits here, i.e. no inspection of the composts and fertilizers took place and the existing limit value is exceeded, or whether such visible contamination can also be present if the existing limit value is observed.

8.5.1.2 Approaches for action

There are basically two approaches for reducing the proportion of plastics in compost:

- reduce plastics in the inputs to composting plants (waste from organic waste bins, green waste)
- reduce the plastic content in the outputs (product of the plants – compost) through improved plant technology, stricter limit values and/or stricter enforcement.

Furthermore, an improvement of the data situation is useful, as most surveys and studies only cover plastic particles above 2 mm and thus the plastic content of smaller particles is unknown.

According to the German Environment Agency, the most important factor influencing the foreign matter content in the finished compost is the content of these substances in the separately collected bio waste. In the literature, values of between 0.9 and 12% are cited (German Environment Agency 2017). This is where a whole series of existing measures come into play, which could, however, be significantly expanded. The "WirfürBio"[28] (We for Bio) campaign has recently been launched with the aim of informing consumers that plastics (including degradable plastics) do not belong in the organic waste bin. Several municipalities, especially in northern Germany, have joined this campaign and are implementing a varying number of measures with varying intensity. The measures taken so far include purely informative approaches and, in some cases, sanctions, among others:

- posters
- door trailers (which are also distributed in buses)

[28] see https://www.wirfuerbio.de/. Another current campaign, the "Aktion Biotonne" (action organic waste bin), is also partly devoted to this topic, but is primarily aimed at increasing the quantities of separately collected organic waste (https://www.aktion-biotonne-deutschland.de/).

- media-effective kick-off event with minister of the environment
- Letter to households with a bin sticker ("separate yourself from your plastic bag here and now"; illustrations of what is and is not allowed in the organic waste bin)
- the possibility of uploading a photo with the sticker on the bin on Facebook with a chance to win
- In the area of 1-2 family homes: distribution of ton trailers with corresponding information if a lot of plastic is contained in the bio waste; if the ton is not collected for the second time, this is a sanction

An evaluation of the effects of the campaign has not yet taken place, but is planned. According to one participating municipality, it can at least be stated that there have been no relevant negative reactions to the measures implemented (including, in this case, the occasional non-collection of tonnes). One possible reaction from households would be to collect less bio-waste separately, which would be an undesirable effect of the campaign.

Another possible measure could be a polluter-pays policy[29] on the part of the operators of the installations; this would concern operators who accept bio-waste from third parties (Public waste management company). However, if the operator of the composting plant is the public waste disposal company itself which collects the bio waste bins, this possibility is not applicable. It would probably be too costly and time-consuming to control this by charging households directly, and in many cases the collection of the bio waste bin is free of charge anyway.

There is already a broad debate on "degradable" plastic bags, which will not be discussed in detail here. One possibility here would be to adapt the standard DIN EN 13432 to the actual conditions in composting plants. This topic is currently being addressed within the framework of the European Plastics Strategy. On the treatment and output side, there would be the possibility to tighten the legal limits. In September 2018, the Bundesrat voted in favour of this at the request of several federal states (reduction "as far as practically possible"; Bundesrat 2018). Most plants are already well below the limits today, as data from the quality assurance authorities show[30]. However, the experts have no data on the remaining 30% of installations that are not members of the voluntary quality assurance scheme. Also, as mentioned, the limit values do not cover particles below 2 mm. Here, information on the quantities of very small plastic particles in compost is missing. However, work is currently underway on appropriate analytical methods (cf. German Environment Agency 2017)[31]. According to information from an expert discussion (with a plant operator), the technical possibilities for removing plastics during biological treatment are almost exhausted.

In addition, the control of fertiliser traffic could be strengthened with regard to compliance with the limits on contaminants[32]. This is the responsibility of the federal states and is carried out on a random basis, but the situation differs from country to country. According to expert discussions, the limit values for compost are occasionally exceeded and then a return is ordered.

[29] In this case, "polluter pays" means that the treatment price also depends on the foreign material content of the organic waste.

[30] An evaluation of the average content of foreign substances in composts and fermentation products was made available.

[31] Cf. also the project "plastics in soils - occurrence, sources, effects" (2017-2020) running at the German Environment Agency.

[32] The Bio waste Regulation is limited to the scope of application of the use of bio waste as fertiliser on land used for agriculture, forestry or horticulture. The fertilizer law, on the other hand, generally regulates the marketing of fertilisers (including soil additives, culture substrates, plant additives) and is not limited to specific areas of application. Since bio waste (here compost and digestates) is usually fertiliser within the meaning of the Fertiliser Regulation, both the provisions of waste law and the provisions of fertiliser law must be observed (BGK 2014).

Controls are sometimes carried out, especially when abuses are suspected. Plastic particles applied with agricultural fertilizers can be visually conspicuous even if the limit values are complied with, as they may be washed off by rain in the field while the fertilizer is being decomposed. In particular, possible infringements can no longer be detected if a fertilizer has already been applied, as sampling can then no longer take place. Whether the fertilizer traffic control with regard to plastic contents in composts is sufficient cannot be assessed on the basis of the current information available.

8.5.2 Sewage sludge

8.5.2.1 Starting point

Plastic, which gets into sewage treatment plants via the wastewater, can only be removed from the water via the screenings (large parts), the sand (from grit chambers, i.e. rather heavy particles) or the sewage sludge. According to studies, a large proportion (50-95%) of the smaller plastic particles from wastewater treatment plant inflows are removed from the wastewater via the sewage sludge (cf. Sundt et al. 2014). It is therefore a good idea for the sewage sludge to absorb as high a proportion of the plastic particles as possible, otherwise they will be discharged into the surface water via the receiving water.

For sewage sludge that is to be used as fertiliser, a legal limit value of max. 0.5% of the dry matter for impurities >2 mm applies (of which max. 0.1% is foil plastics and max. 0.4% other impurities incl. hard plastics). However, smaller particles are not included in the limit value, which is likely to play a special role in the case of sewage sludge (compared with other fertilisers such as compost), as it can be assumed that it contains a particularly large number of very small particles (tyre wear, fibres, etc.).

According to the little information available, a check of compliance with the limit values for plastics by the fertiliser traffic control authorities has so far not taken place at all in some federal states. It is assumed that larger plastic particles over 2 mm do not or hardly ever get into the sewage sludge (Schröder 2018 as well as an expert discussion). Occasionally the limit value is expected to be exceeded, for example in the case of the plastics discharged by the Schleswig sewage treatment plant. In which food waste shredded with packaging was also fermented in the digestion tower and whose sewage sludge was accidentally partly spread on agricultural land (Schröder 2018).

In Germany, almost two thirds of sewage sludge is disposed of by thermal means, destroying the plastics, but one third is so far mainly released into the environment in agriculture and also in landscaping measures (annually about 0.6 million t dry matter). Since October 2017 an alteration of the Sewage Sludge Ordinance has been in force, according to which from 2029 no sewage sludge from sewage treatment plants with a population equivalent (p.e.)[33] of > 100,000 may be used for agricultural purposes and from 2032 for plants with a population equivalent (p.e.) of > 50,000. For plants with < 50,000 p.e. the prohibition of spreading does not apply. The share of waste water treated by plants with < 50,000 p.e. is about 40.8% (data from 2013). The amount of sewage sludge spread and thus the plastic input is therefore likely to decrease in the future, but not by just under 60% as one might expect, but by a smaller proportion, since large plants already recycle more thermally. In cities such as Hamburg and Berlin, for example, sewage sludge is already completely combusted today (Roskosch/Heidecke 2018).

[33] The population equivalent is the sum of the number of inhabitants living in the catchment area of a WWTP plus the hypothetical number of inhabitants who would produce a similar load of pollution as the operations located in the catchment area of the WWTP.

Assuming that the plastic input would be reduced by 50%, the input quantities estimated in this study would decrease from a maximum of 3,000 t per year to 1,500 t, which would still be a comparatively large quantity.

8.5.2.2 Approaches for action

Theoretically possible courses of action to reduce the amount of plastic that is spread with the sewage sludge are

- a reduction in the quantities of plastics discharged into waste water treatment plants from a wide range of plastics applications (as considered in section 5),
- a reduction in the content of plastic in sewage sludge and,
- further reduction or a total ban on the spreading of sewage sludge for agricultural/landscaping purposes.

The former would be desirable, but would require changes in many other areas. In this respect, reference is made to the recommendations for action in other sections of this chapter (e.g. on tyre wear, section 8.2).

A reduction of the plastic content in the sewage sludge would be technically very difficult to implement and only possible by screening, which has not taken place so far. Since the plastic particles contained in the sewage sludge are usually very small, it is questionable in any case what proportion of them could be removed at all. In enforcement, however, it should be checked more intensively that the existing limit values for sewage sludge to be used in agriculture are adhered to in order to avoid incidents such as the Schleswig sewage treatment plant.

That a further reduction or a complete prohibition of the sewage sludge spreading is decided in the near future legally binding, is rather improbable, since this was decided straight only for large sewage treatment plants and must be converted now. In the long term, it would be conceivable to ban the spreading of sewage sludge altogether and instead to recycle it thermally using phosphorus recovery processes.

Furthermore, improving the data situation is an important approach. A number of the ongoing research projects in the Federal Ministry of Education and Research's (BMBF) funding programme "plastics in the environment" are devoted to this topic, among others (cf. section 8.1).

8.6 Special section: cigarettes

In Germany, isolated actions and measures to prevent cigarette butt litter have so far been initiated by a few governmental and non-governmental actors. The approaches identified include:

- information from environmental associations
- initiatives by local authorities
- regulatory measures of the federal states and local authorities and the EU
- initiatives by private or non-profit organisers
- initiatives by cigarette manufacturers

In addition, in some media the environmental pollution caused by cigarette butts is addressed by appropriate coverage, such as:

- "Cigarettes as environmental pollution - A lot of poison in the cigarette butt" (sueddeutsche.de, 19.4.2011)
- "Nicotine pollutes waters" (deutschlandfunk.de, 2.6.2014),
- "Up to 7000 chemicals - cigarette butts poison the soil" (n-tv.de, 31.5.2017) or
- "How cigarette butts poison the environment" (welt.de, 31.5.2017).

The results of the research on existing approaches to action are presented below.

8.6.1 Information from environmental organisations

According to current knowledge, Greenpeace is the only environmental association that has addressed the consequences of cigarette butt litter as an environmentally relevant issue (in the form of an article in the association's own magazine) (Stukenberg, 2011). So far, no specific activities in the field of consumer information and communication on the environmental impacts of littered cigarette butts have taken place in Germany, neither by state, civil society nor private actors.

8.6.2 Initiatives by local authorities

In January 2018, the SPD and Green parliamentary groups in Hamburg asked the city's parliament to pass a resolution requesting the senate to initiate action and information measures to reduce the environmental impact of cigarette butts and to sensitize smokers (see SPD Parliamentary Group Hamburg, 17 January 2018). Accordingly, the senate should

- "within the framework of conferences of federal ministers for environmentally sound solutions for the disposal of cigarette butts, i.e. to find solutions to prevent the pollution caused by cigarette butts and to stop their disposal in public places,
- to educate in Hamburg about the dangers of carelessly thrown away cigarette butts, and to report to the citizens by the end of 2018" (ibid.).[34]

Some other municipalities have tried to counteract the littering of cigarette butts through concrete activities by distributing free pocket ashtrays or by giving them away once. Berlin City Cleaning Service (BSR) offers the "BSR Pocket Ashtray" for sale in its online shop under the heading "practical things to take with you", alongside reusable "bread towels" and beverage bottles (BSR 2018). In contrast, in Frankfurt/M., Würzburg and Saarbrücken, the pocket ashtrays were distributed to citizens free of charge. The actions were each part of a broader campaign against littering and to promote cleanliness in the city area. In Frankfurt, the pocket ashtrays were distributed in June 2018 by voluntary helpers, so-called "cleanliness ambassadors" as part of the "#cleanffm" campaign. The campaign is part of an action programme for the cleanliness of squares and green spaces adopted in 2017, which has so far included the installation of 187 additional waste bins marked with the "#cleanffm" logo. The campaign is aimed in particular at younger people and, in addition to an independent website, also has various social media sites that provide information about so-called "clean facts", among other things[35]. In 2009, the city of Würzburg distributed one-time pocket ashtrays as part of the

[34] Despite written and telephone enquiries, the evaluators did not receive any information on the outcome of the vote.

[35] Such as: "#9 Did you know that one cigarette butt pollutes up to 40 liters of groundwater? And that even one liter of contaminated water can cost a fish its life?" (cleanffm 2018).

"Action Clean City - Strategy and Campaign against Littering" ("Aktion Saubere Stadt - Strategie und Kampagne gegen Littering") (City of Würzburg 2009)[36]. In Saarbrücken, the distribution of the pocket ashtrays was carried out by employees of the Central Municipal Waste Management Company and took place as part of the "Clean is Better" campaign, a joint campaign of the city, citizens' initiatives and the Central Municipal Waste Management Company (Saarbrücker Zeitung, 27.7.2017). However, no information is yet available on the possible short or long-term effects of these campaigns on the amount of cigarette butts entering the city.

On the Baltic Sea coast in Mecklenburg-Western Pomerania, 3,000 pocket ashtrays ("beach ashers") are distributed annually free of charge to locals and tourists and are handed out by the beach managers. The purpose of this measure is to make it easier for smokers to dispose of cigarette butts properly in order to reduce the amount of cigarette butts entering the soil and water, thereby contributing to marine and coastal protection and strengthening or maintaining the quality of the holiday region (Der Warnemünder, 20 July 2015). The beach ashes are financed by the Rostock Warnemünde Tourist Office. The original initiators of the measure were "AIDA - Friends of the Seas" association ("AIDA Freunde der Meere e.V.") in cooperation with the Rostock & Warnemünde Tourist Board and the Mecklenburg Spa Association (cf. Der Warnemünde, July 8, 2014).

According to the tourist office, the "beach ashers" are accepted and established especially among local bathers. However, the effect of the measure has not yet been assessed. On the one hand, a corresponding "proof of effect" has not yet been required for the approval of funding, and on the other hand, such an analysis is accompanied by considerable methodological difficulties.

In addition to the mobile "beach ashers", ten "Baltic Sea ashers" are permanently installed on the beach, which are intended to contribute to raising the awareness of smokers and to playfully draw attention to the issue of littering from cigarette butts. Nine of the "Baltic Sea ashers" were financed by the Rostock Warnemünde Tourism Centre and one was financed by the Warnemünde Youth Hostel. The "Baltic Sea ashers" are operated in cooperation with EUCC – „The Coastal Union Germany" (association). In addition, there are smoke-free beach sections in Warnemünde and Markgrafenheide since 2011.

Accompanying initiatives have been the annual "Blue Flag"[37] award events - an international award in the field of sustainable tourism based on criteria such as water quality, environmental education for tourists and residents, safety at the beach and exemplary environmental management - and the flyer "Order and Cleanliness in the Holiday Region"[38] published by the Environmental Office of the Hanseatic City of Rostock. In addition, a pilot project is currently being planned in which an increased number of staff will be tested to punish administrative offences on the beaches.

8.6.3 Regulatory actions

In the fines catalogues of the federal states[39], "leaving, pouring away and throwing away the contents of an ashtray" is an offence. In Baden-Württemberg, Bavaria, Berlin, Brandenburg,

[36] The strategy paper of the City of Würzburg includes several both general and specific measures against littering, which are summarized under the "bundle of measures - clearing up - punishing", see "City of Würzburg 2009."

[37] cf. online: http://www.blaue-flagge.de/

[38] cf. online: https://www.rostock.de/files/rostock/img/urlaub/rostock-warnemuende/ostseestraende/umweltmanagement-am-strand/broschuere-ordnung-sauberkeit-warnemuende-2018.pdf

[39] cf. online: https://umwelt.bussgeldkatalog.org/muell/

Hesse or North Rhine-Westphalia, for example, the fine for this is 10 to 25 € maximum. In other federal states the maximum amount is higher (Hamburg: €70, Saarland: €100).

In some municipalities, even throwing away a single cigarette is an administrative offence (e.g. Frankfurt or Würzburg), whereas in other municipalities it is not (e.g. Jena). No information is available to date on the effectiveness of this instrument in reducing the amount of cigarette butts that are littered. Furthermore, there is hardly any quantified information on the extent and intensity of municipal enforcement. In Lübeck, for example, 45 smokers would have had to pay a corresponding fine over a period of two years (see shz.de, 9 February 2011), but the population of regulatory violations is not known. Some sources indicate, however, that the effort involved in providing evidence and enforcement tends to stand in the way of the actual imposition of fines. In this context, van Meer et al (2007, p. 10) point out that the imposition of fines is only effective if they are enforced with great consistency.

8.6.4 Initiatives by organisers

Some organisers of major events taking place over several days in the open air and on extensive, natural terrain (such as "Suddenly by the Sea", "The Sound of the Sea", "Auerworld Festival") distribute free pocket ashtrays to their guests. These are often marked with the logo of the event. Those organisers who provide free pocket ashtrays point out the careful handling of cigarette butts on their websites in advance of the events.

8.6.5 Initiatives by cigarette manufacturers

According to the current state of knowledge of the experts, there are practically no manufacturer's own activities to reduce litter. One exception concerns British American Tobacco (Industrie) GmbH (BAT GmbH). BAT GmbH claims to provide pocket ashtrays free of charge (BAT, n.d.). Between 2009 and 2011 the company distributed 1,000,000 pocket ashtrays (BAT, 15.2.2012). In a press release the company points out that the use of the pocket ashtrays would "protect the environment" and keep the "streets clean" (BAT, 15.2.2012).

8.6.6 Actions by other European countries

8.6.6.1 England: Guide to reducing litter from cigarette butts for local authorities

In the UK, the Department for Environment, Food and Rural Affairs (Defra) published the guide "Preventing Cigarette Litter in England - Guidelines for Local Authorities" in 2007. The aim of the guide is to help local authorities to reduce cigarette butt litter through concrete activities of their own (cf. Defra 2007, p. 1). The proposed measures and recommendations include the installation and labelling of suitable ashtrays, the disposal of littered cigarettes, concrete educational measures or the establishment of cooperation with local organisations.

8.6.6.2 Switzerland: Awareness campaigns and "no-littering label“

In Switzerland, various local authorities, such as the environmental advisory service in Lucerne, provide specific information on the consequences of cigarette littering[40]. In Fribourg, Switzerland, a campaign ("STOP MÉGOTS") against littering from cigarette butts was implemented in 2017 (City of Fribourg, n.d.). Elements of the campaign were action days, the set up of a "giant cigarette", posters, video spots in cinemas and on buses, the distribution of 3,000 pocket ashtrays and the education of restaurants and property management companies. The aims of the campaign were to reduce environmental and water pollution and to lower urban

[40] Cf. online: http://umweltberatung-luzern.ch/themen/littering/zigarettenstummel

costs for cleaning public areas (cf. SRF, 11.5.2017). The initiator of the campaign was the City of Freiburg as part of its "Clean City Freiburg" strategy.

Another approach from Switzerland is the "no-littering label" (IGSU, 29.5.2018). Since 2017, this label can be applied for by public institutions (cities, municipalities and schools) that implement certain measures against littering. There are no costs for the label holders. The label is awarded by the Interest Group for a Clean Environment, a private sector initiative[41] in which the cigarette industry is also represented.

8.6.6.3 Portugal: "Station-based" beach ashtrays

On several beaches in Portugal, beach ashtrays ("cinzeiros de praia") are available on loan to bathers. These are small plastic funnels that can be borrowed at the beach entrances and returned after use (see Figure 17). As a "pocket ashtray" and for "non-local" use, this version of the Beach ashtrays are unsuitable, as it is not a closed container and can only be placed in sand. In contrast to the examples presented under 8.6.2, this model does not become the property of the user, but is intended to be used exclusively for the duration of the stay on the beach and can then be used by another beach guest. The beach ashtrays are partly co-financed by companies as advertising media (e.g. by Vodafone). No information is available on the impact of this measure.

Figure 17: "Station-based" beach ashtrays in Portugal

Source: João Menéres (18.9.2015), URL: https://grifoplanante.blogspot.com/2015/09/cinzeiros-na-praia.html

8.6.7 Approaches for action at EU level

A draft "Directive on the reduction of the impact of certain plastic materials and articles on the environment" COM(2018) 340 has been on the table since 2018, which also covers cigarette butts. The Directive addresses the littering of cigarette butts through the following measures[42]:

- an extended producer responsibility for cigarette manufacturers

[41] Sponsors of the organisation include the Swiss Cigarette Association, McDonald's Switzerland 2018, the PRS PET-Recycling Association and Migros.

[42] Proposal for a Directive of the European Parliament and of the Council on reducing the impact of certain plastic products on the environment COM(2018) 340 final

- awareness raising actions on the consequences of litter

Under current legislation, cigarette manufacturers are not yet responsible for the collection or proper disposal of cigarette butts. However, the current draft directive of the EU Commission provides for extended producer responsibility for "tobacco products with filters as well as filters marketed for use in combination with tobacco products" - i.e. a contribution to the costs of collection, transport and treatment, including the costs of "cleaning up operations" (cf. Article 8 (2) COM(2018) 340). In addition to extended producer responsibility, the implementation of awareness raising measures on the consequences of cigarette butt litter is another measure. Article 10(a) and (b) states in this respect:

"Member States shall take measures to inform consumers of disposable plastic articles of the following:

(a) the available reuse systems and waste management options for those articles [...] and best practices for sound waste management as referred to in article 13 of directive 2008/98/EC;

(b) the impact on the environment, and in particular on the marine environment, of careless discarding and other inappropriate disposals of these articles and of fishing gear containing plastics."

The concrete implementation and enforcement of these measures is the responsibility of the individual member states.

8.6.8 Conclusion

The initiatives and measures identified can be summarised in the following approaches:

- systematic education about the negative environmental consequences of litter
- structured guidance for municipalities[43]
- the addressing of the issue within the framework of higher-level "anti-litter campaigns"
- the availability of "mobile" ashtrays (free of charge or against payment) and
- the regulatory sanction of littering
- an extended producer responsibility for manufacturers of cigarettes and cigarette filters
- awareness raising imperatives

In Germany, such activities have so far only taken place sporadically. The active players include almost exclusively the municipalities and/or municipal waste management companies. The two main motives for the activities seem to be, on the one hand, the reduction of costs for cleaning public squares, streets and areas, and, on the other hand, the maintenance or restoration of a clean cityscape to ensure the quality of the location. In the area of the communication used, it becomes clear that this varies from region to region. While inland campaigns are covered with slogans in which the subject of communication is the contribution of the inhabitants to a "clean and beautiful city", in coastal areas the focus is on the contribution to "protecting the sea" or "the fish".

[43] According to the current state of knowledge of the experts, such a system only exists in England up to now.

At the same time, it became clear through the conducted research that no activities have been initiated by the industry (with one exception) that are directed against the littering of cigarette butts - neither in the area of consumer information or voluntary product labelling, nor in the area of practical approaches. It also became clear that the environmental pollution caused by cigarette butts does not seem to be an issue for environmental associations.

On the basis of this initial research into possible courses of action, it was thus possible to describe the basic features of existing approaches, but no statements can be made on their short or medium-term effect, i.e. whether and by which courses of action the amount of cigarette butts that have been littered could actually be reduced. At the same time, the EU plastics directive could, in the medium term, provide the member states with an instrument to develop and implement concrete measures to reduce the littering of cigarette butts within the framework of national implementation.

8.6.9 Recommended actions

For a possible selection and (further) development of effective and equally efficient recommendations for action, it would be useful, in the view of the experts, to examine which of the identified approaches to action have led to a concrete reduction in the amount of cigarette butts that have been littered. To this end, it would be necessary to examine whether data on the extent of the effect of the implemented measures is collected in selected municipalities that actively implement measures against littering. The effectiveness of the approach of increasing the use of pocket ashtrays might, however, be better assessed by means of a survey of organisers of major events who repeatedly hold such events in order to enable a comparison of the amount of littered cigarettes before and after the distribution of pocket ashtrays.

Simultaneously, selective discussions could be held with environmental organisations in order to communicate in a targeted manner the amount of inputs identified in the context of the project carried out and to find out to what extent the issue is under current consideration or work programmes and whether relevant activities such as studies, campaigns or position papers are planned.

In principle, it should be examined along the lines of the EU disposable plastic directive what types of "awareness-raising measures" the COM proposal might specifically involve and how the proposed new possible instruments of extended producer responsibility might be designed in concrete terms. These considerations should take place with the involvement of relevant and affected stakeholders, such as local authorities. In this context, it should also be examined whether voluntary measures are being planned by industry, for example in the area of consumer communication.

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10 Appendix A: Detailed description of procedure for chapter 4

10.1 Definitions of litter and possible types

There is no uniform definition of the term littering in the literature. Therefore, it seems to make sense to list definitions of other publications in addition to the definition in this paper (see chapter 4.1) in order to show the differences and similarities. In addition, the types of litterers, their motives and types of action are described below.

Sample collection of definitions of litter and litter "types"

Definitions

• Throwing away or leaving waste in public spaces (Breitbarth and Urban 2014).

• Littering is the general term for carelessly throwing away waste in public spaces and in the open air (Institute for Technology and Sustainable Product Management at the Vienna University of Economics and Business Administration, cited in Heeb et al. 2005).

• Carelessly discarding waste at the place where it is produced without using the waste bins or baskets provided for this purpose (Littering study of the Programme for Man, Society and the Environment of the University of Basel, cited in Heeb et al. 2005).

• Marine litter is a persistent, produced or treated solid material that is discarded, disposed of or left in the marine or coastal environment. Marine litter consists of objects made or used by humans that have been intentionally dumped into seas, rivers or beaches. Indirectly, these objects can also enter the seas via rivers, sewage, precipitation or wind. These objects may also have been lost accidentally, e.g. objects lost at sea during bad weather (fishing nets, ship's cargo), or may have been intentionally left on the beach or shore by man. (UNEP 2005)

• The term "littering" covers in the broadest sense the incorrect disposal of waste in public spaces (Meer et al. 2007).

• Those forms of trash that either originate by people throwing away or leaving behind artifacts they consider functionless in places not officially intended or designated for such a purpose, or that end up in such places by indirect action or inaction of people (Wever et al. 2006).

Types of "litterers" according to (Breitbarth and Urban 2014)

1. people who do not care about the litter problem or who lack awareness of the harmful effects of their actions.

2. people suffering from peer pressure who move in groups where littering is considered "cool".

3. the leaders of such groups, who want to strengthen their status by littering and vandalism.

4. comfortable people who are aware of the problem and use missing litter bins as an excuse.

5. people whose actions lead to the littering of objects without this action having a direct relation to littering in the first place.

Also: "animal litter": various species of birds, rats, cats, dogs, raccoons etc.

Litter motives according to (Meer, Elke van der et al. 2007)

- Rejection of responsibility: the violation of the norm is neutralized by shifting the responsibility for action to others or to the given circumstances ("others also throw their rubbish on the street.", "it is already dirty here.", "if it were cleaned more often, it would be clean too.")

- Denial of injustice: an action is considered illegitimate, but not immoral (trivialisation of behaviour: "it is only small objects that do not attract attention", "it is cleaned anyway").

- Condemnation of the damned: attention is shifted from one's own misconduct to motives of the control and sanction apparatus (neutralization of one's own co-responsibility: "fines are actually collected to fill the state treasury").

- Metaphor of the "general ledger": reference to otherwise practiced environmental protection ("otherwise I always use the waste bins").

- Appeal to ignorance: pretending not to have known that the misconduct is harmful to the environment or causes costs.

- Powerlessness of the individual: pointing out that one's own behaviour carries no weight and that change is only worthwhile if everyone participates ("whether or not I drop my litter makes no difference in the cleanliness of the city").

- Defense of necessity: reference to the lack of behavioural alternatives ("no litter bin, no ashtray there").

- After me the deluge: avoiding thoughts about the consequences in the future ("I don't care.").

- Convenience: the own comfort is seen as a priority ("I won't run around with my garbage forever if I can get rid of it immediately.").

Litter types according to (Wever et al. 2006)

- "wedging" (litter is pressed into gaps between seats or other places),

- "fragrant flinging" (used objects are thrown into the air),

- "inching" (waste is littered and the polluter is slowly leaving),

- "foul shooting" (trash is thrown towards the trash, misses the target and polluter continues),

- "undertaking" (waste is buried, often in the sand of beaches),

- "clean sweeping" (in a place where others have already littered, own litter is added),

- "90%ing" (most of the waste is disposed of in waste baskets, only a small amount is left behind, often this is small size waste),

- "herd behaviour" (habit of orienting oneself towards others by walking past empty wastebaskets and leaving one's rubbish next to full wastebaskets)

10.2 Plastic litter remains: roadsides

In the following chapters, the estimation of the *remaining plastic litter* at roadsides is explained in more detail. This type of land use is subdivided into motorways, federal, state and district roads as well as other roads in the federal territory.

First of all, based on the data of the State Road Construction Office North Rhine-Westphalia (Wilk 2017), the *amount of waste collected* for the mentioned road categories in North Rhine-Westphalia (NRW) is determined or estimated (see Figure 6). For each road category, the ratio of the average daily traffic volume, which is used as an indicator for potential litter and waste input, and the *slip rate* is used to calculate the *waste input* for the federal territory (kg/(km*a)) (see Figure 6). By multiplication with the nationwide *route length*, the *waste input* in the entire federal territory [t/a] is scaled up for each road category. The respective *remaining plastic litter* is then calculated by multiplying the *waste input* of the federal territory by the *plastic content of the waste input*, the *litter content* of the *plastic waste* and the *slip rate* (see Figure 6). The quantities of *remaining plastic litter* of each road category calculated in this way are then added up to obtain the total sum of the *remaining plastic litter*.

In Bavaria and Saxony there are no state roads, but there are state roads which correspond to the state roads and are therefore included in the sum of the state roads in the federal territory. In Saarland there are no district roads, but there are state roads II. Order, which correspond to the district roads and are therefore included in the sum of the district roads in the federal territory.

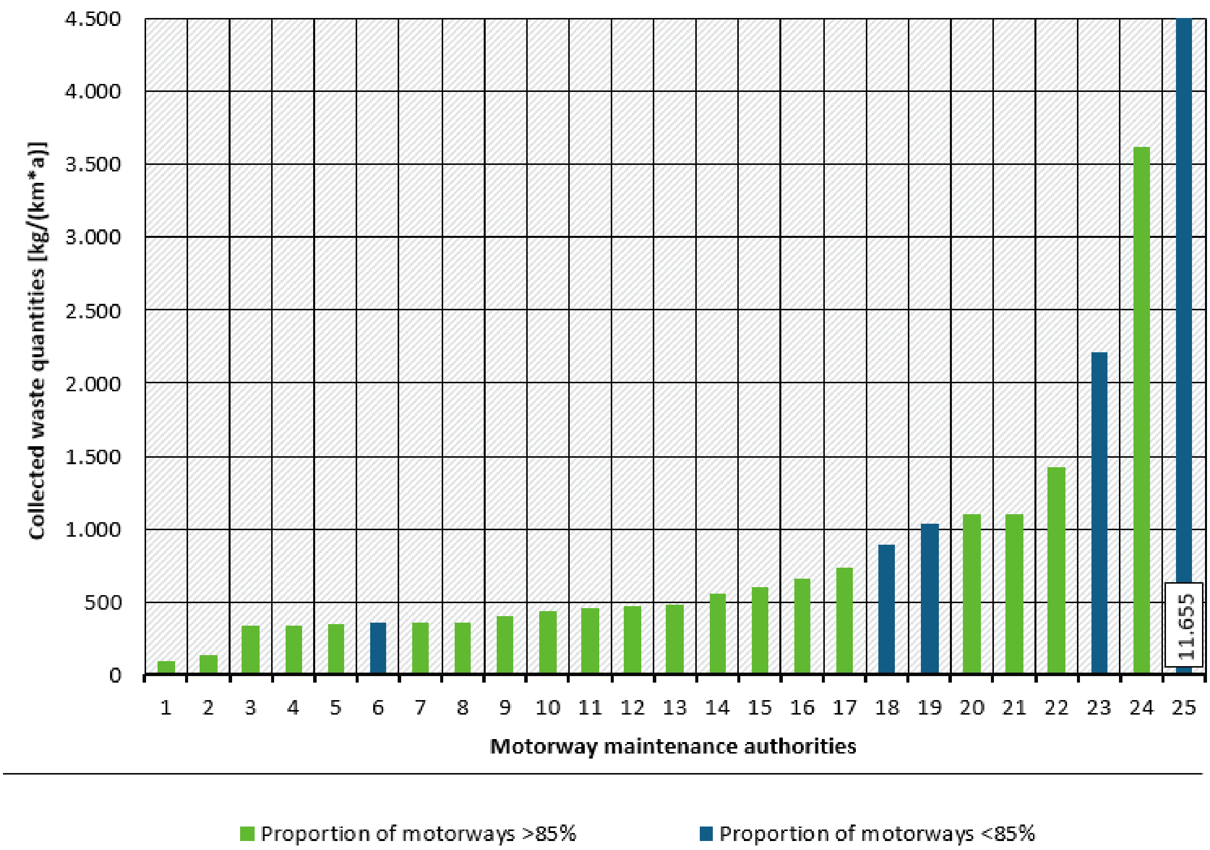
10.2.1 Determination of the collected waste amount for North Rhine-Westphalia

With regard to the *collected amount of waste*, data from the North Rhine-Westphalian Road Construction Company (Roads.NRW) is assumed, which will later be transferred to the federal territory. The available data set from Roads.NRW refers to the year 2011 and includes reports from all 29 motorway (AM – German: Autobahnmeisterei) and 55 road maintenance authorities (SM – German: Straßenmeisterei) in NRW. The roadsides maintained by the AM and SM are cleaned at least once a year (Wilk 2017). It should be noted that the AM and SM are not obliged to collect quantity data (Wilk 2017). In the data set used in such cases there is a quantity of 0 t. Therefore, only data from AM and SM that indicated *collected waste quantities* of more than 0 t were considered. Further calculations were based on the mean value of the *collected amount of waste* determined for the respective road type (AM/SM).

10.2.1.1 Motorways in North Rhine-Westphalia

In addition to the requirement that only data from AM are used that recorded more than 0 t collected amount of waste, it had to be taken into account for the consideration of motorways that the data provided by AM do not exclusively refer to motorways, but in some cases also include federal, state and district roads. The approach taken for the analysis of motorways was to consider only those AM whose share of motorways was higher than 85% of the total share of roads covered, which is 20 out of 29 AM. These 20 AM together cover a distance of 1,596 km of motorway, which is 72% of the total motorway distance in NRW. For each AM it is known to which route length the data refer. The collected waste quantities [kg/a] of the AM were divided by the respective route length [km] to calculate the collected waste quantities [kg/(km*a)] of the AM. The data distribution of the collected waste quantities for AM is shown in Figure 18. For the further calculations, the mean value (703 kg/(km*a)) was used for the collected waste quantity NRW. In addition, Figure 18 also shows the five AM whose share of motorways is below 85% (blue bars). Together with the other 20 AM they cover a distance of 1,909 km, which is 86% of the total motorway distance in NRW. It is not known what the reason for the very high value of AM number 25 (11,655 kg/(km*a) is.

Figure 18: Distribution of the collected waste quantities for the 25 motorway maintenance authorities (AM)



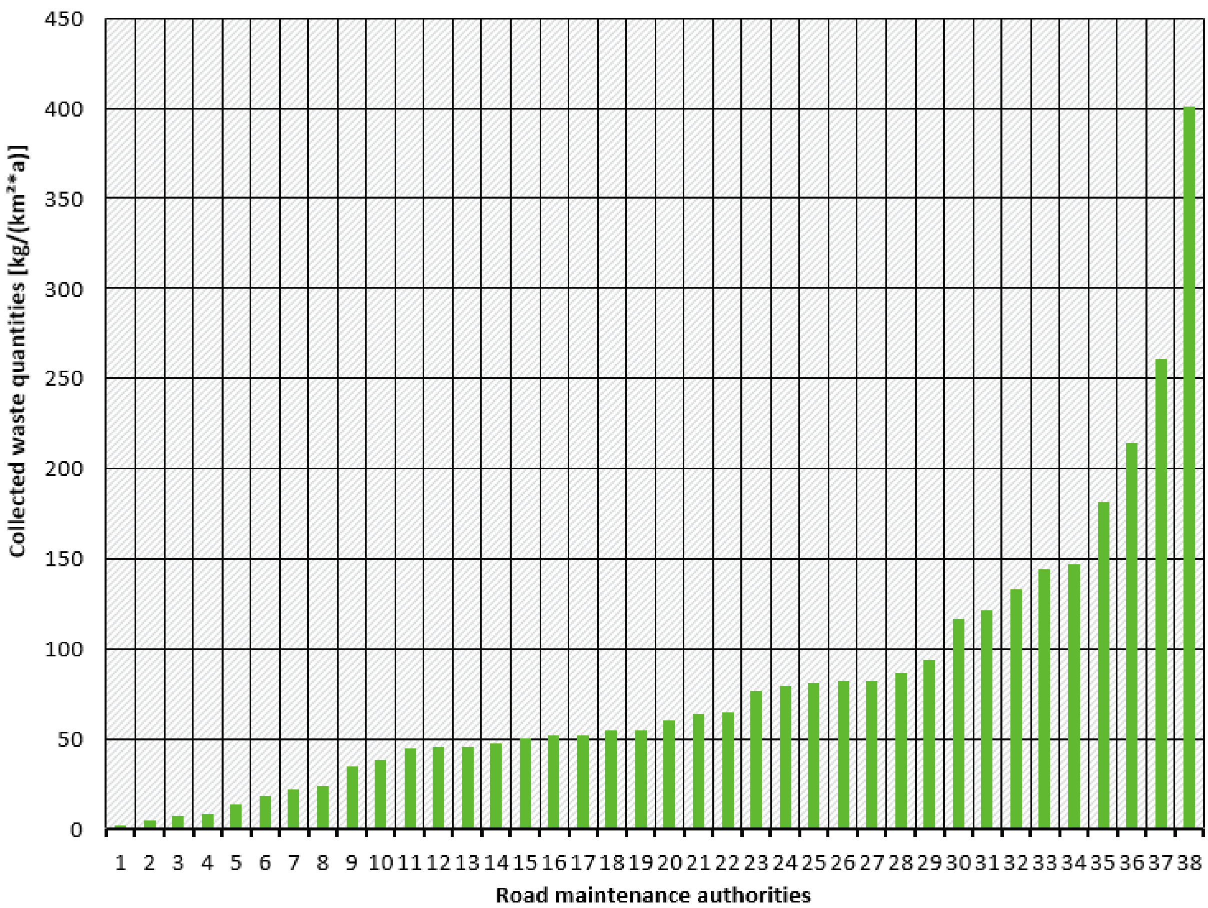
Souce: Ökopol

This includes the 20 motorway maintenance authorities (AM; blue bars), which reported more than 0 t of collected waste volumes in 2011 in the data of Roads.NRW and whose share of motorways in the respective managed route length was more than 85%. For the sake of completeness, the collected waste quantities of the five AM, for which the share of motorways in the total route to be managed was less than 85%, are shown as blue bars. The bar number 25 ends at 11,655 kg/(km*a) and is not shown in full in the diagram.

10.2.1.2 Federal, state and district roads of Roads.NRW

Due to the condition to use only data from SM that recorded more than 0 t *collected amount of waste*, data from 38 of the 55 SM were further considered. The SM whose data were used as a basis, together managed 3,252 km of federal roads (corresponding to 73% of all federal roads in NRW), 8,251 km of state roads (corresponding to 59% of all state roads in NRW) and 947 km of district roads (corresponding to 10% of all district roads in NRW). The calculations of the *collected amount of waste* for the SM were carried out in the same way as for the AM (see chapter 10.2.1.1). The distribution of the *collected amount of waste* for the SM is shown in Figure 19. The mean value of the *collected amount of waste* by the SM is 82 kg/(km*a).

Figure 19: Distribution of the collected waste quantities for the 38 road maintenance authorities (SM)



Souce: Ökopol, only those road maintenance authorities are taken into account that reported more than 0 t collected waste quantities in 2011 in the data of Roads.NRW.

The average *amount of waste collected* (82 kg/(km*a)) is summarised for federal, state and district roads, as the SM of Roads.NRW did not divide their data into the above-mentioned road categories.

10.2.1.3 Federal, state and district roads in North Rhine-Westphalia

The following section explains how, on the basis of the combined *collected amount of waste* (82 kg/(km*a)) of the 38 SM and a combined average daily traffic volume (DTV) on the roads of the 38 SM (DTV_{BLK}), individual *collected amounts of waste* are determined for federal, state and district roads in NRW. It is assumed that the DTV and the *collected amounts of waste* are proportional to each other. The DTV_{BLK} is calculated using the following formula:

$$DTV_{BLK} = DTV_B * \frac{L_B}{L_B + L_L + L_K} + DTV_L * \frac{L_L}{L_B + L_L + L_K} + DTV_K * \frac{L_K}{L_B + L_L + L_K}$$

DTV_{BLK} summarised DTV of federal, state and district roads

DTV_B DTV of federal roads in NRW (10.528 vehicle/24h, see Table 57)

DTV_L DTV of state roads in NRW (5.347 vehicle/24h, see Table 57)

DTV_K DTV of district roads in NRW (2.394 vehicle/24 h, see Table 57)

L_B Route length of the federal roads of the 38 SM by Roads.NRW (3.252 km)

L_L Route length of the state roads of the 38 SM by Roads.NRW (8.251 km)

L_K Route length of the district roads of the 38 SM by Roads.NRW (947 km)

Table 57: Length of the roads covered by the 38 road maintenance authorities considered

Term	Data used by Roads.NRW	North Rhine-Westphalia total
Length of motorway (km)	1,596	2,223 (2017) (Destatis 2017a)
Length of federal road (km)	3,252	4,452 (2017) (Destatis 2017a)
Length of state road (km)	8,251	13,085 (2017) (Destatis 2017a)
Length of district road (km)	947	9,776 (2017) (Destatis 2017a)
DTV motorway (vehicle/24h)	-	61,377 (2015) (BASt 2017)
DTV federal road (vehicle/24h)	-	10,542 (2010) (BASt 2013)
DTV state road (vehicle/24h)	-	5,347 (2010) (BASt 2013)
DTV district road (vehicle/24h)	-	2,394 (2010) (BASt 2013)
DTV_{BLK} (vehicle/24h)	6,479	-

In addition, the route lengths and average daily traffic volumes (DTV) of motorways, federal, state and district roads for North Rhine-Westphalia are listed. The year to which the data refer is indicated in the brackets after the respective data. The DTV_{BLK} is a calculated DTV of the federal, state and district roads of the 38 road maintenance authorities whose roads were taken into account.

The DTV_{BLK} on the roads for which data was available according to Roads.NRW is thus 6,479 vehicles/24 h. The total *amount of waste collected* for federal, state and district roads in NRW can now be calculated using the following formula. The basis for the calculation of the *collected amount of waste* for federal, state and district roads in NRW is the assumption that the DTV for the respective road category in NRW is the same as the DTV for the respective road category of the 38 SM of Roads.NRW.

$$GA_x = GA_{BLK} * \frac{DTV_x}{DTV_{BLK,NRW}}$$

GA_x amount of waste collected on federal, state or district roads in NRW [kg/km*a]

GA_{BLK} collected amount of waste on federal, state and district roads, calculated on the basis of the data of the 38 SM by Roads.NRW (82 kg/(km*a))

DTV_x average daily traffic volume on federal, state or district roads in NRW (see Table 57) [vehicle/24h]

$DTV_{BLK,NRW}$ combined DTV of the federal, state and district roads of the 38 SM by Roads.NRW (calculated with above formula from chapter 10.2.1.3) [vehicle/24h]

So ergeben sich für Bundes-, Landes- und Kreisstraßen in Nordrhein-Westfalen *gesammelte Abfallmengen* von 195 kg/(km*a), 99 kg/(km*a) und 44 kg/(km*a).

10.2.2 Determination of the collected amount of waste in Germany

The *amount of waste collected* in Germany was determined by multiplying the *amount of waste collected* in NRW by the ratio between the DTV of the Federal territory (see Table 58) and the DTV of North Rhine-Westphalia (see Table 57).

Table 58: Average daily traffic volume (DTV) of motorways, federal, state and district roads in Germany and their relationship to the respective DTV in North Rhine-Westphalia (DTV NRW)

Road category	DTV Federal territory [vehicle/24h]	DTV NRW [vehicle/24h]	Relationship between DTV Federal territory and DTV NRW
Motorway	50,149 (2015) (BASt 2017)	61,377 (2015) (BASt 2017)	82%
Federal road	9,323 (2010) (BASt 2013)	10,542 (2010) (BASt 2013)	89%
State road	4,000 (own estimation)	5,347 (2010) (BASt 2013)	75%
District road	2,500 (own estimation)	2,394 (2010) (BASt 2013)	104%

The brackets after the respective data, indicate the years to which the data refer.

For motorways, federal, state and district roads, this results in ratios between the DTV of the federal territory and the DTV of NRW of 82%, 89%, 75% and 104% (see Table 58).

There are no data on the DTV of the state and district roads for the entire federal territory, which is why they were estimated. The basis of this estimate were the DTVs of the federal states listed in Table 59.

Table 59: DTV of the state and district roads from selected federal states

Federal states	DTV state roads (vehicle/24h)	DTV district roads (vehicle/24h)
Baden-Württemberg	5255 (2015) (RPT, 2016)	2655 (2015) (RPT, 2016)
Bavaria	3850 (2010) (BASt, 2013)	1787 (2010) (BASt, 2013)
Hesse	3208 (2010) (BASt, 2013)	-
Mecklenburg-Western Pomerania	2627 (2010) (BASt, 2013)	-
North Rhine-Westphalia	5347 (2010) (BASt, 2013)	2394 (2010) (BASt, 2013)
Saarland	5298 (2010) (BASt, 2013)	3529 (2010) (BASt, 2013)
Saxony	3112 (2010) (BASt, 2013)	-
Saxony-Anhalt	2462 (2010) (BASt, 2013)	-
Federal territory	4000 (own estimation)	2500 (own estimation)

The brackets after the respective data, indicate the years to which the data refer. All data refer to the year 2010, except for the data from Baden-Württemberg, which refer to the year 2015.

Multiplying the respective *collected amount of waste* of NRW (see chapter 10.2.1.3) by the respective ratios between the DTV of the federal territory and the DTV of NRW (see Table 58) results in *collected waste amounts* of 574 kg/(km*a), 173 kg/(km*a), 74 kg/(km*a) and 46 kg/(km*a) for motorways, federal, state and district roads in the federal territory.

10.2.3 Determination of the plastic content of the waste input, the litter content of the plastic waste and the slip rate

The slip rate base value of the roadsides was estimated to be 15% by weight and the range 5-25% by weight (see chapter 4.2.2). The estimation of the *plastic content of the waste input* (see Figure 6) was based on the results of Beyer and Winter (2016). Beyer and Winter (2016) analysed *collected amount of waste* from Luxembourg roadsides. A comparable analysis for roads in Germany is not available. Therefore, the analyses from Luxembourg are transferred here to the roads in Germany.

The analysis by Beyer and Winter (2016) included a total of 307 kg of waste from roadsides with a total length of 50.2 km. 42.7 km of the 50.2 km were part of four national roads (Routes nationales) and the remaining 7.8 km belonged to one secondary road (Chemins repris). The *collected waste quantity* of 6 kg/km seems to be so small compared to the *collected waste quantity* in Germany (federal roads: 93 kg/(km*a), state roads: 47 kg/(km*a), district roads: 21 kg/(km*a)) because it does not cover the whole year. Beyer and Winter (2016) state that the cleaning interval of the sample routes is sometimes only 7 days. The plastic content of the road waste examined was 22% by weight. Assuming that the plastic content of the collected waste examined by Beyer and Winter (2016) is equal to the *plastic content of the waste input* in Germany, this value was adopted for the *plastic content of the waste input*.

In further studies by Beyer and Winter (2016), the packaging proportion of roadside waste was also analysed, which amounts to 54 to 66% by weight. It is assumed that the packaging was exclusively littered. Illegal waste deposits, such as bulky waste, were not mentioned in Beyer and Winter (2016). Based on the analysed packaging share of Beyer and Winter (2016), a *litter content* of 60% *of plastic waste* is assumed for all roads.

10.2.4 Determination of the remaining plastic litter

The calculation of the *remaining plastic litter* is explained below for motorways, federal, state, district and other roads (see Figure 6, lower formula).

10.2.4.1 Motorways, federal, state and district roads

The *waste input* in the federal territory was calculated on the basis of the *amount of waste collected* in the federal territory, the *slip rate* and the respective route length (see Table 60). Based on this, the *plastic litter remaining* in the environment was calculated by multiplying the *waste input* by the *plastic content of the waste input*, the *litter content of the plastic waste* and the *slip rate* (see Table 60). The quantities of *plastic litter remaining* for each road category are also listed in Table 60 (motorways: 174 t/a (52-328 t/a); federal roads: 153 t/a (46-290 t/a); state roads: 150 t/a (45-284 t/a); district roads: 99 t/a (30-187 t/a)).

10.2.4.2 Other roads

This is followed by an analysis of other roads in Germany (e.g. municipal roads and private roads), which the Federal Ministry of Transport and Digital Infrastructure (BMVI) estimates at 600,000 km (BMVI 2016). The *amount of waste collected* on the other roads is assumed to be lower than on the district roads and estimated at 15 kg/(km*a). As with the other road categories, the slip rate is estimated at a base value of 15% by weight and a range of 5-25% by weight. This results in a *waste input* of 10,588 t/a (9,474-12,000 t/a). With the help of the lower formula in Figure 6, the *remaining plastic litter* on other roads now amounts to 210 t/a (range: 63,396 t/a) (see Table 60).

10.2.4.3 Overall view

For the sake of clarity, Table 60 lists the main calculation parameters and results regarding the estimation of the *remaining plastic litter* that is littered at roadsides. On the basis of the quantities of the individual road categories, a total of 786 t/a (range: 234-1,485 t/a) of plastics result that are littered on German roads, are partially blown away and/or are not collected by cleaning measures and thus remain in the environment.

Table 60: Factors and results of the estimation of plastic litter input and fate per year at roadsides in Germany

No.	Calculated variable	Calculation	MW	FR	SR	DR	oR	Total amount
[1]	Collected amount of waste NRW [kg/(km*a)]		703	195	99	44	-	-
[2]	Relationship DTV NRW to DTV federal territory		82%	89%	75%	104%	-	-
[3]	Collected amount of waste Germany [kg/(km*a)]	= [1] * [2]	574	173	74	46	15	-
[4]	Slip rate base value [wt.%]		15%	15%	15%	15%	15%	-
[5]	Slip rate range [wt.%]		5-25%	5-25%	5-25%	5-25%	5-25%	-
[6]	Route length [km]		12,996	38,069	86,970	91,939	600,000	-
[7]	Waste input federal territory base value [t/a]	= [3] / (1 – [4]) * [6]	8,776	7,749	7,581	5,009	10,588	-
[8]	Waste input federal territory range [t/a]	= [3] / (1 – [5]) * [6]	7,852-9,946	6,933-8,782	6,783-8,592	4,482-5,677	9,474-12,000	-
[9]	Plastic content of waste input [wt.%]		22%	22%	22%	22%	22%	-
[10]	Litter content of plastic waste [wt.%]		60%	60%	60%	60%	60%	-
[11]	Remaining plastic litter base value [t/a]	= [7] * [4] * [9] * [10]	174	153	150	99	210	786
[12]	Remaining plastic litter range [t/a]	= [8] * [5] * [9] * [10]	52-328	46-290	45-284	30-187	63-396	234-1,485

The abbreviations used stand for the following street categories: MW - motorway, FR - federal roads, SR - state roads, DR - district roads, oR - other roads. According to this estimation, the weight of the remaining plastic litter along the roadsides is 786 t/a (234-1,485 t/a). The data on the length of the MW, FR, SR, and DR roads are taken from Destatis (2017a). The information on the line length of oR comes from BMVI (2016).

10.3 Plastic litter remains: rest stops

Based on the summarized explanations in chapter 4.5, this chapter explains in detail the estimation of the *remaining plastic litter*, entered by the litter on rest stops.

First of all, based on the data from Roads.NRW, the amount of waste in the *basket* is determined for the four rest stop categories in NRW. An extrapolation to the federal territory was then made using the respective number of rest stops of the category in the federal territory and the ratio between the DTV in the federal territory and the DTV in NRW. Using the *litter rate*, the estimation of which is explained in chapter 10.3.3, the *waste input* could thus be calculated (see Figure 7). The *remaining plastic litter* was then calculated by multiplying it by the factors *plastic content of the waste input*, *litter content of the plastic waste* and the *slip rate* (see Figure 7).

10.3.1 Determination of the amount of waste in the basket for North Rhine-Westphalia

The raw data for the estimation were provided by Roads.NRW. According to this, there are 100 maintained rest stops in NRW in 2017 (80 on motorways, four on federal roads, 15 on state roads and one on district roads) and 264 unmanaged rest stops (215 on motorways, 17 on federal roads, 31 on state roads and one on district roads). In the following, both the 20 maintained and the 49 non-maintained rest stops on federal, state and district roads are summarised (see Table 61, Table 58, Table 62). Since data on the waste collected by the individual rest stops in 2011 was also available, the emptying weight could be calculated with the respective number of baskets and the emptying frequency (mean value: 15.56 kg; median: 15.60 kg). In the subsequent calculations, the average emptying weight was used (rounded value in Table 61, Table 58, Table 62). The amount of *basket waste* collected *per year* in NRW is the product of the factors *number of the respective rest stops* (managed or unmanaged), *average number of empties per rest stop and year* and *average emptying weight*. For managed and unmanaged rest stops on motorways in NRW, this results in *basket* volumes of 3,992 t and 4,557 t *per year* (see Table 61, Table 58, Table 62). For the other road categories, the figure is 33 t for managed rest stops and 92 t for unmanaged rest stops (see Table 61, Table 58, Table 62).

Table 61: Number of rest stops managed in North Rhine-Westphalia, average emptying weight, number of empties per rest stop and the amount of waste paper per year for motorways on the one hand and for federal, state and district roads on the other

No.	Calculated variable	Calculation	motorways	Federal, state, and district roads
[1]	Number of managed rest stops		80	20
[2]	Average number of waste baskets per managed rest stop		31	2
[3]	Average number of emptyings per managed rest stop and year		3,207	107
[4]	Average emptying weight [kg]		16	16
[5]	Amount of basket waste per year [t]	= [1] * [3] * [4]	3,992	33

All values are rounded to the ones digit. The "average number of empties per managed rest stop and year" on motorways is more than twelve times higher than on federal, state and district roads, because the "number of managed rest stops" and the "average number of waste paper baskets per managed rest stop" are higher on motorways. The waste baskets at motorway rest stops are not emptied more frequently per year than those at rest stops on federal, state and district roads. In a comparison of the individual road categories, the frequency of emptying is similar and fluctuates between once or twice a week. The "amount of basket waste per year" is the product of "number of managed rest stops", "average number of emptyings per managed rest stop and year" and "average emptying weight".

Table 62: Number of unmanaged rest stops in North Rhine-Westphalia, average emptying weight, number of emptyings per rest stop and the amount of waste paper per year for motorways on the one hand and for federal, state and district roads on the other

No.	Calculated variable	Calculation	motorways	Federal, state, and district roads
[1]	Number of unmanaged rest stops		215	49
[2]	Average number of waste baskets per unmanaged rest stop		13	2
[3]	Average number of emptyings per unmanaged rest stop and year		1,362	119
[4]	Average emptying weight [kg]		16	16
[5]	Amount of basket waste per year [t]	= [1] * [3] * [4]	4,557	92

All values are rounded to the ones digit. The "average number of emptyings per unmanaged rest stop and year" on motorways is more than eleven times higher than on federal, state and district roads, because the "number of unmanaged rest stops" and the "average number of waste paper baskets per unmanaged rest stop" are higher on motorways. The "waste paper basket quantity per year" is the product of "number of unmanaged rest stops", "average number of emptyings per unmanaged rest stop and year" and "average emptying weight".

10.3.2 Determination of the amount of waste in the basket in Germany

In this chapter, the extrapolation to the entire federal territory is explained, based on the *amount of waste in the basket per year* in NRW. At the end of 2014, there were 434 managed and around 1,500 unmanaged motorway rest stops in Germany (BMVI 2016b). According to the BMVI, the size of a motorway rest stop and thus the number of baskets depends mainly on the volume of traffic and the location in the motorway network. The location in the motorway network was neglected in the extrapolation, whereas the traffic volume was included in the extrapolation with the calculation factor DTV. It can be assumed that the larger the DTV, the larger the rest stop.

The *amount of waste in the basket per year* in Germany were calculated using the following formula:

$$PAM_{Bund} = PAM_{NRW} * \frac{N_{Bund}}{N_{NRW}} * \frac{DTV_{Bund}}{DTV_{NRW}}$$

PAM_{Bund} Amount of waste paper per year in the federal territory (Bund)
PAM_{NRW} Amount of waste paper per year in NRW
N_{Bund} Number of rest stops in the federal territory (Bund)
N_{NRW} Number of rest stops in NRW
DTV_{Bund} DTV of the respective road category in the federal territory (Bund)
DTV_{NRW} DTV of the respective road category in NRW

The data required for the calculation are listed in Table 64 for managed rest stops and Table 65 for unmanaged rest stops. Since the rest stops on federal, state and district roads were combined, the DTV of federal, state and district roads was also combined for the further procedure. As in chapter 10.2.1.3, the combined DTV for federal, state and district roads was calculated using the following formula:

$$DTV_{BLK} = DTV_B * \frac{L_B}{L_B + L_L + L_K} + DTV_L * \frac{L_L}{L_B + L_L + L_K} + DTV_K * \frac{L_K}{L_B + L_L + L_K}$$

DTV_{BLK} combined DTV of federal, state and district roads (BLK)
DTV_B DTV of federal roads
DTV_L DTV of state roads
DTV_K DTV of district roads
L_B Length of federal roads
L_L Length of state roads
L_K Length of district roads
Data can be found in Table 63.

Table 63: DTV of the motorways and the federal, state and district roads in NRW and in the federal territory

Calculated variable	North Rhine-Westphalia	Federal territory
Length of motorway [km]	2,223 (2017) (Destatis 2017a)	12,996 (2017) (Destatis 2017a)
Length of federal roads [km]	4,452 (2017) (Destatis 2017a)	38,069 (2017) (Destatis 2017a)
Length of state roads [km]	13,085 (2017) (Destatis 2017a)	86,970 (2017) (Destatis 2017a)
Length of district roads [km]	9,776 (2017) (Destatis 2017a)	91,939 (2017) (Destatis 2017a)
DTV of motorways [vehicle/24 h]	61,377 (2015) (BASt 2017)	50,149 (2015) (BASt 2017)
DTV of federal roads [vehicle/24 h]	10,542 (2010) (BASt 2013)	9,323 (2010) (BASt 2013)
DTV of state roads [vehicle/24 h]	5,347 (2010) (BASt 2013)	4,000 (own estimation)
DTV of district roads [vehicle/24 h]	2,394 (2010) (BASt 2013)	2,500 (own estimation)
Combined DTV on federal, state and district roads [vehicle/24 h]	5,137 (calculated value)	4,304 (calculated value)

The brackets after the respective data, indicate the years to which the data refer. The DTV of the state and district roads in the federal territory were estimated on the basis of the data in Table 59.

Data regarding the number of managed and unmanaged rest stops on federal, state and district roads were not available and were therefore calculated using the following formula:

$$N_{Bund} = N_{NRW} * \frac{L_{Bund}}{L_{NRW}}$$

L_{Bund} Length of federal, state and district roads in the federal territory

L_{NRW} Length of federal, state and district roads in NRW

Table 64: Number of managed rest stops and the quantities of waste they generate on motorways and on federal, state and district roads for North Rhine-Westphalia and for the federal territory

Calculated variable	North Rhine-Westphalia	Federal territory
Number of managed rest stops on motorways	80 (2017) (Roads.NRW 2017)	434 (2014) (BMVI 2016b)
Amount of basket waste from the managed motorway rest stops [t]	3,992 (calculated value)	17,697 (calculated value)
Number of managed rest stops on federal, state and district roads	20 (2017) (Roads.NRW 2017)	159 (calculated value)
Amount of basket waste from the managed rest stops on federal, state and district roads [t]	33 (calculated value)	221 (calculated value)

The brackets after the respective data, indicate the years to which the data refer.

Table 65: Number of unmanaged rest stops and the quantities of waste they generate on motorways and on federal, state and district roads for North Rhine-Westphalia and for the federal territory

Calculated variable	North Rhine-Westphalia	Federal territory
Number of unmanaged rest stops on motorways	215 (2014) (BMVI, 2016b)	1111,500 (2014) (BMVI, 2016b)
Amount of basket waste from the unmanaged motorway rest stops [t]	4,557 (calculated value)	25,974 (calculated value)
Number of unmanaged rest stops on federal, state and district roads	49 (calculated value)	389 (calculated value)
Amount of basket waste from the unmanaged rest stops on federal, state and district roads [t]	92 (calculated value)	608 (calculated value)

The brackets after the respective data, indicate the years to which the data refer.

According to this, the amount of waste paper from managed rest stops on motorways in Germany is 17,697 t/a and on federal, state and district roads 221 t/a. The quantity of waste paper from unmanaged rest stops on motorways in Germany is 25,974 t/a and on federal, state and district roads 608 t/a. A total of 44,500 t/a of waste is thus properly disposed of in waste baskets at German rest stops.

10.3.3 Determination of the litter rate

The *litter rate* was estimated at 5% by weight. This means that 95% by weight of the waste produced ended up in the waste baskets (*amount of basket waste per year*), but 5% by weight did not. The basis for this estimate is provided by Breitbarth and Urban (2014), who found in the Kassel urban area that 12 pcs.% of the waste produced did not end up in the basket. Heeb et al. (2005), on the other hand, investigated the littering behaviour at 16 highly frequented places in five Swiss cities and found that 30 pcs.% of the waste produced was littered, while 70 pcs.% was properly disposed of. The percentage of the estimated *litter rate* (5 wt.%) is lower than that of the Breitbarth and Urban (2014) (12 pcs.%) and Heeb et al (2005) (30 pcs.%) studies because it can be assumed that the littered waste is smaller than the basket waste. Assuming the same bulk density, this also results in a lower weight-related proportion. Another reason for the lower ratio is that the staff who empty the waste baskets in NRW are also obliged to collect waste that lies within a radius of several metres around the wastebasket (Wilk 2017). This means that waste within the radius is counted towards the *amount of waste in the basket per year* or the 95% by weight. This waste would have been classified as a *waste input* in the above-mentioned studies. With an *amount of waste in the basket per year* of 44,500 t and a litter rate of 5% by weight, the waste input is 2,342 t (see Table 66).

10.3.4 Determination of the plastic content, litter content and slip rate

The *plastic content of the waste input* is estimated at 22% by weight. It is assumed to be equal to the plastic content of the roadside waste. This is because the waste producers are the same (driver, passengers) and the waste is similar in both cases because it is generated during the journey.

The *litter content of the plastic waste* is 100% because the waste input was calculated with variant 2 (see chapter 4.2.4). The slip rate base value of the rest stops was estimated at 3% by weight and the range at 1-5% by weight (see chapter 4.2.2).

10.3.5 Determination of the remaining plastic litter

The amount of *remaining plastic litter* caused by litter on rest stops is the product of *waste input*, *plastic content of waste input*, *litter content of plastic waste* and *slip rate* (see Figure 5 and Figure 7). Using the values from chapter 10.3.3 and 10.3.4, the *remaining plastic litter* is 52 t/a (26 - 77 t/a) (see Table 66).

Table 66: Calculation variables and result of the estimation of the remaining plastic litter caused by litter at German rest stops

No.	Calculated variable	Calculation	Value
[1]	Amount of waste in the basket [t/a]		44,500
[2]	Litter rate [wt.%]		5%
[3]	Waste input [t/a]	= [1] / (1 - [2]) *[2]	2,342
[4]	Slip rate base value [wt.%]		10%
[5]	Slip rate range [wt.%]		5-15%
[6]	Plastic content of the waste input [wt.%]		22%
[7]	Litter content of the plastic waste [wt.%]		100%
[8]	Remaining plastic litter base value [t/a]	= [3] * [4] * [6] * [7]	52
[9]	Remaining plastic litter range [t/a]	= [3] * [5] * [6] * [7]	26-77

10.4 Plastic litter remains: parks

Building on the summary in chapter 4.6, this chapter explains in detail the estimation of the *remaining plastic litter* caused by litter in parks.

Parks (usage type key: 421) are listed in the statistics of the Federal Statistical Office as a subcategory of green spaces (usage type key: 420), which are defined as undeveloped areas that are predominantly used for recreation (Destatis 2016). In addition to parks, there are eight other subcategories of green spaces (422 playground, football ground; 423 zoological garden; 424 game reserves; 425 botanical garden; 426 allotment garden; 427 weekend place; 428 garden; 429 green space, not further subdivided). Apart from the cemeteries (940; subcategory of areas of other uses), these are not included in the estimate, since a rather lower relevance is assumed with regard to the *remaining plastic litter*.

10.4.1 Categorisation of parks

The categorisation of the parks is described in chapter 4.6.1 and was based on the system of the Federal Office for Building and Regional Planning (BBR 2017). The definitions of the individual city types were based on the number of inhabitants (see Table 67). The categorisation of green spaces, which was necessary to determine the area of parks, was carried out analogously.

Table 67: City types with definition according to number of inhabitants, number, ground area and population in Germany

Category	Definition by number of inhabitants	Amount	Ground area, in total [km²]	Population
Large major cities	>500,000	14	4,870	13,659,710
Small major cities	100,000-500,000	65	8,790	12,296,524
Large cities	50,000-100,000	108	9,947	7,350,782
Medium cities	20,000-50,000	468	39,003	14,356,861

Source: Destatis (2016). The ground area is defined here as the total area of the city.

10.4.2 Park area in Germany

Park areas were not available to the Federal Statistical Office because not all state statistical offices collect data at this depth. This chapter explains how the parks in the individual categories were determined. First, the respective green space was calculated for each category. Then the park proportion of the green areas was estimated on the basis of data from some of the federal states and multiplied by the respective green area to obtain the respective park area.

10.4.2.1 Green space of the individual categories

Data on the green space area of all German cities were not available, but it was possible to evaluate the green space areas of the district-free cities (Destatis 2017b). Table 68 lists the number, ground area and green area of all the autonomous cities according to city type category.

Table 68: Number and ground area of district-free cities in Germany divided according to the respective city types

Category	Number	Ground area in total [km²]	Green space in total [km²]
Large major cities	14	4,870	359
Small major cities	56	7,883	342
Large cities	25	2,569	83
Medium cities	15	1,011	18

Source: Destatis 2017b

The district-free city with the smallest population is Zweibrücken with 34,260 inhabitants (Destatis 2017b).

Since the number of large district-free major cities in Table 68 corresponds to the number of large major cities in Table 67, the green space area of all large major cities in Germany is 359 km^2. In order to obtain the green space area of the non-urban small major cities and large cities, the average green space areas were first calculated for both types of cities (6.1 km^2 and 3.3 km^2 respectively) on the basis of the data in Table 68. For the calculation of the green space areas of the medium cities that are not independent of the district, the procedure was different. The average green space area of the district-free medium cities is 1.2 km^2 (Destatis 2017b), but almost no cities with a population of less than 35,000 have been included in this calculation. Zweibrücken (34,260 inhabitants) is the only one of the 15 medium cities with a population of less than 35,000 inhabitants. It is assumed that medium cities with populations between 20,000 and 35,000 also have smaller green space areas than medium cities with populations between 35,000 and 50,000. For this reason, half of the average green space area of medium cities was assumed (0.6 km^2; see Table 69).

Table 69: **Average green space area of district-free cities and all cities in Germany divided according to the respective city types except large major cities**

Category	Average green space area of the district-free cities [km²]	Average green space area of all cities (estimation) [km²]
Small major cities	6.1	6.1
Large cities	3.3	3.3
Medium cities	1.2	0.6

Source for average green space area: Destatis 2017b

By multiplying the number of all cities of the respective city type (see Table 67) and the respective estimate of the average green space area of all cities (see Table 68), the respective total green space area is obtained (see Table 70). For the sake of completeness, Table 70 also shows the green area of the large cities and other green areas. The area of other green spaces is the difference between the total green space in Germany (2,915 km² - Destatis 2017b) and the sum of the green space of large and medium-sized cities (1,296 km²) (see Table 70).

Table 70: **Park category with associated green space area**

Category	Green space area [km²]
Large major cities	359
Small major cities	396
Large cities	360
Medium cities	273
Other	1,527

10.4.2.2 Park area of the individual categories

The calculation of the park area based on the green space area was carried out by first estimating the share of park areas in the green space area for the individual categories. Wöllper (2009) found that the proportion of green space areas increases with increasing urbanisation. It should be noted that this applies primarily to publicly accessible green space areas, such as parks, and not to publicly inaccessible green spaces, such as allotment gardens. It is therefore fundamentally assumed for cities that the proportion of parks in green spaces also increases as the population increases. This assumption is reinforced by the data in Table 71. In terms of trend, the proportion of parks in green space areas in the federal states increases with increasing population density.

In order to determine the share of parks in the green space, all 14 statistical offices of the federal states (the federal states of Berlin and Brandenburg as well as Hamburg and Schleswig-Holstein each cooperate in one statistical office) were asked. The estimates of the proportion of green space accounted for by parks were based on data from five federal states, which provided usable data (see Table 71).

Table 71: Absolute green space area, absolute park area, park area shares of green space area and population density of five selected federal states

Federal state	Green space area [km²]	Park area [km²]	Park area share of green space area	Population density [inhabitant/km²]
Bremen	29.3 (2015) (Destatis 2017b)	7.58 (2016) (Geo.Bremen 2017)	26%	1,599 (2015) (Destatis 2017c)
Mecklenburg-Western Pomerania	299 (2015) (Destatis 2017b)	24.2 (2015) (Statistical Office of Mecklenburg-Western Pomerania 2017b)	8.1%	69 (2015) (Destatis 2017c)
North Rhine-Westphalia	491 (2015) (Destatis 2017b)	135 (2015) (IT.NRW 2017)	27%	524 (2015) (Destatis 2017c)
Rhineland-Palatinate	265 (2015) (Destatis 2017b)	36.3 (2015) (Rhineland-Palatinate State Statistical Office 2017)	14%	204 (2015) (Destatis 2017c)
Thuringia	40.9 (2015) (Destatis 2017b)	5.22 (2016) (LVermGeo Thüringen, 2017)	13%	134 (2015) (Destatis 2017c)

For the share of park areas in the large major cities, the figures for the federal states of Bremen and NRW were used. The reason for this is that, on the one hand, the Federal State of Bremen consists exclusively of the two independent cities of Bremen (large major city) and Bremerhaven (small major city) and, on the other hand, NRW comprises a total of 37% of all large cities in Germany. Thus, a high degree of urbanisation can be assumed in both federal states, which comes closest to the large major cities of all the figures in Table 71. However, since the figures for Bremen and NRW in Table 71 also include cities and regions that are not part of large major cities, the proportion of parks in the green space areas for large major cities was set slightly higher at 30% (see Table 71). The share of parks in the green area of MV comes closest to that of the category other parks because, due to the small number of small major cities (number: 1; 1.5% of all small major cities in Germany), large cities (number: 4; 3.7% of all large cities in Germany) and medium cities (number: 4; 0.85% of all medium cities in Germany), very low urbanisation is assumed in relation to an area of 6.5% of Germany (Destatis 2016). The share of parks in the green space areas of the category other parks was estimated at 6%, slightly below the value of MV (8.1%; see Table 71). As described, Mecklenburg-Western Pomerania includes some large and medium cities (see Table 72). Based on the estimated park area shares of green space areas in the category large major city (30%) and the category other green spaces (6%), it was assumed that for each category the park area shares of green spaces decrease by 6% to the next higher category (see Table 72). The park area in Table 72 was calculated by multiplying the estimated park area proportions of green space areas (see Table 72) by the green space proportions (see Table 70).

Table 72: Category of park area with an estimated proportion of green space in the park the resulting calculated park area

Category	Estimated proportion of green space in parks	Park area [km²]
Large major cities	30%	108
Small major cities	24%	95.1
Large cities	18%	64.8

Category	Estimated proportion of green space in parks	Park area [km²]
Medium cities	12%	32.8
Other green spaces	6%	91.6

10.4.3 Determination of the collected amount of waste

Data for determining the *amount of waste collected* was available for the twelve pilot objects of the Berlin City Cleaning Service (BSR), which is why they were initially calculated. Based on this, the *collected amounts of waste* of the individual park categories were estimated.

There were 14 responses to the survey of the green space offices, with five green space offices, all of which were among the *large major cities* (number of inhabitants: >500,000), providing data. These five data sets differed within the data units (volume or weight data), were partly based on estimates and considered different types of waste (exclusively w*aste paper waste quantities* or *waste paper waste quantities* and *collected waste quantities* together). None of the five data sets contained information that related exclusively to the *collected waste quantities*. The data records could only have been standardized if assumptions had been made about litter rates. However, this would have increased the uncertainty of the results, as some of the data were estimated anyway. Therefore, the following section refers to the *collected waste quantities* of the pilot project park cleaning of BSR, which included data on weighted collected waste quantities.

10.4.3.1 Determining the amount of waste collected by the pilot project park cleaning

The calculation of the *amount of waste collected* for the individual park categories is based on data from the BSR's park cleaning pilot project. Hertner and Großmann (2017) reported on the one-year experience of the BSR pilot project: from 01.06.2016, BSR took over the collection and disposal of all park waste listed in chapter 4.6.1 except green waste in twelve Berlin green spaces. The aim of this pilot project was to support the green space offices, which were responsible for the collection and disposal of all park waste in the twelve green spaces before the pilot project began (Hertner and Großmann 2017).

Table 73 lists the *quantities of waste collected* (hand cleansing waste) for the individual pilot objects. These are exclusively wastes left behind by users on the pilot object areas and collected manually by BSR employees. The period in which the waste was collected was one year (01/06/2016 to 31/05/2017). The twelve pilot objects were cleaned according to requirements from once a week to several times a day (BSR 2017). Using the area (BSR 2017; see Table 73) and the bulk density, the weight-related *collected waste quantity* per hectare could be determined. A bulk density of 83 kg/m^3 was calculated. This bulk density was the result of a sorting analysis of waste from the Dresden basket, which was carried out by INTECUS GmbH in August and September 2017. It is assumed that the bulk density of the investigated waste paper basket waste is equal to the bulk density of the *collected waste quantity*.

Table 73: Areas and collected amounts of waste of the pilot objects of the project park cleaning of the Berlin city cleaning (BSR 2017)

Pilot objects	Area [m²]	Collected amount of waste [m³/a]	Collected amount of waste [t/(km²*a)]
Area in front of the Berlin television tower	46,809	145	257
Gorlitz Park	116,719	434	309
Greenwich Promenade	50,452	190	312
Grünzug Britz between Johannisthaler Chaussee and Lipschitzallee	49,398	93	156

Pilot objects	Area [m²]	Collected amount of waste [m³/a]	Collected amount of waste [t/(km²*a)]
Luisenhain with waterside promenade	15,820	42	222
Münsinger Park	48,463	124	212
Nelly-Sachs-Park	14,010	103	609
Park at Buschkrug	69,332	113	135
Park at Weißen See	123,797	451	302
Paul-Ernst-Park	165,031	216	108
Spreebogenpark	67,811	184	225
City park Lichtenberg	69,830	209	248

The data on the *amount of waste collected* [m³/ha] are rounded to the units. The data on the *collected waste quantity* [t/(km²*a)] are rounded to the second decimal place.

The reasons for the different *amounts of waste collected* [t/(km²*a)] in the individual pilot objects are different types of use and areas and also different locations within the city (Hertner and Großmann 2017). These factors determine the number of users and also the individual usage time. The higher the number of users and the longer the individual usage time, the higher is probably the *amount of waste collected*. Furthermore, different environmental awareness among users can result in different *amounts of waste collected*.

Based on the data of the twelve pilot objects (average value: 258 t/(km²*a)), the *collected waste amount* from parks in the individual park categories is estimated at 250 t/(km²*a).

10.4.4 Determination of the plastic content, litter content and slip rate

It was assumed that the *plastic content of the waste input* in parks is equal to that of the waste paper basket waste, which INTECUS GmbH determined for Dresden waste paper basket waste in 2017. The analysis resulted in a plastics content of 6.0 wt.%. In addition to pure plastic waste, one fifth of the composites were also considered to be plastic. The 6.0 wt.% share of plastics relates exclusively to waste generated on the road. This figure does not include residual waste, such as waste generated in private households and disposed of in public waste baskets. Since data on *collected waste quantities* were available for the pilot project park cleaning, which related exclusively to littered waste, the *litter content of plastic waste* is 100% in this case. Bulky waste quantities were balanced separately within the pilot project. The slip rate base value of the parks was estimated at 3% by weight and the range at 1-5 wt.% (see chapter 4.2.2).

10.4.5 Determination of the remaining plastic litter

The *remaining plastic litter* of the individual categories was determined by first calculating the waste input in each case by means of the estimated *collected amount of waste*, the *slip rate* (base value: 3 wt.%; range: 1-5 wt.%) and the park area (see Table 72). By multiplying the *waste input* by the *plastic content of the waste input* (6 wt.%), the *litter content of the plastic waste* (100 wt.%) and the *slip rate*, the *remaining plastic litter* was calculated in each case. Table 74 lists the quantities of *plastic litter remaining* for each category. In total, the *remaining plastic litter* is 182 t/a (59-309 t/a) based on littered waste from parks.

Table 74: Calculation variables and result of the estimation of the remaining plastic litter caused by litter in German parks

No.	Calculated variable	Calculation	lmC	smC	lC	mC	oP	Total amount
[1]	Amount of waste collected [t/(km²*a)]		250	250	250	250	250	-
[2]	Slip rate base value [wt.%]		3%	3%	3%	3%	3%	-
[3]	Slip rate range [wt.%]		1-5%	1-5%	1-5%	1-5%	1-5%	-
[4]	Park area [km²]		108	95.1	64.8	32.8	91.6	-
[5]	Waste input base value [t/a]	= [1] / (1 - [2]) * [4]	27,725	24,521	16,706	8,443	23,609	-
[6]	Waste input range [wt.%]	= [1] / (1 - [3]) * [4]	27,165-28,309	24,026-25,038	16,369-17,058	8,273-8,621	23,132-24,106	-
[7]	Plastic content of the waste input [wt.%]		6%	6%	6%	6%	6%	-
[8]	Litter content of the waste input [wt.%]		100%	100%	100%	100%	100%	-
[9]	Remaining plastic litter base value [t/a]	= [5] * [2] *[7] * [8]	50	44	30	15	42	182
[10]	Remaining plastic litter range [t/a]	= [6] * [3] * [7] * [8]	16-85	14-75	10-51	5.0-26	14-72	59-309

The abbreviations in the first line of the table represent the individual park categories: lmC – large major cities; smC - small major cities; lC - large cities; mC - medium cities; oP - other parks

10.5 Plastic litter remains: pedestrian zones

Building on the summary in chapter 4.7, this chapter explains in detail the estimation of the *remaining plastic litter* caused by litter in pedestrian zones.

10.5.1 Detailed information on waste input characterisation

A study by the Programme for Human, Social and Environmental Affairs (TU) of the University of Basel ("Basel Study") divided littered waste generated at 16 highly frequented sites in five Swiss cities into five groups (disposable beverage packaging, take-away packaging, newspapers and advertising, carrier bags, miscellaneous) (Heeb et al. 2004). Heeb et al. (2005) compared the results of the Basel study with those of Ableidinger (2004) ("Vienna study"), which analysed the littered waste at 20 sites in five European cities (Barcelona, Brussels, Frankfurt, Prague, Vienna). In both studies the share of "flying catering" packaging, i.e. the sum of take-away packaging and disposable beverage packaging, accounted for about 50 pcs.% of the total share of waste (see Table 75). The share of newspapers and advertising in the Basel study is four times higher than in the Vienna study, which is due to high values for the cities of Basel and Zurich. In Basel, a large number of flyers were distributed at one of the four survey locations shortly before the survey began, and these flyers were then littered by a sufficient number of passers by after they were received. Which means that the Basel average for the newspaper and advertising category is very high compared with the other cities. The Zurich average is also high in the category of newspapers and advertising, which is due to increased shares of newspapers and advertising in two out of three survey locations. The share of shopping bags is in the single-digit percentage range in each case. The miscellaneous category includes textiles, hazardous substances and indefinable items. Some of the waste materials found were not included in the comparative study, including cigarettes, broken glass, vegetables and chewing gum.

Table 75: Quantity-based percentage distribution of types of waste in the Basel and Vienna study (Heeb et al., 2005)

Types of waste	Basel study	Vienna Studie
Take-away-packaging	34.6 pcs.%	46.1 pcs.%
Newspapers and advertising	23.8 pcs.%	5.6 pcs.%
Disposable beverage packaging	16.9 pcs.%	6.0 pcs.%
Shopping bags	4.9 pcs.%	7.4 pcs.%
Miscellaneous	19.8 pcs.%	34.9 pcs.%

10.5.2 Categorisation of pedestrian zones

The categorisation of pedestrian zones (see chapter 4.7.1) was based on the categorisation of parks (see chapter 4.6.1). In comparison to the categorisation of the parks, small cities are additionally categorised. Furthermore, there is no equivalent for the other parks. Accordingly, the following categories were distinguished:

Pedestrian zones in large major cities (>500,000 inhabitants)

Pedestrian zones in small major cities (100,000 – 500,000 inhabitants)

Pedestrian zones in large cities (50,000 – 100,000 inhabitants)

Pedestrian zones in medium cities (20,000 – 50,000 inhabitants)

Pedestrian zones in small cities (10,000 – 20,000 inhabitants).

Towns have been omitted, as it is assumed that pedestrian zones are only present in very few towns. This assumption is based on a study conducted by the State Association of the Bavarian Retail Trade (Landesverband des bayrischen Einzelhandels e.V. (LBE)). It describes that in Bavaria all cities with more than 50,000 inhabitants have pedestrian zones (LBE 2004). In contrast, only 35% of the cities with a population of between 10,000 and 50,000 inhabitants have pedestrian zones. It can be assumed that within these cities the existence of pedestrian zones will decrease as the number of inhabitants decreases. For example, in 1985 in Bavaria about half of all medium cities contained pedestrian zones, but only about a fifth of all small cities (Monheim 2011). Furthermore, according to LBE (2004), a condition for a functioning pedestrian zone is a certain city size of more than 10,000 inhabitants.

10.5.3 Pedestrian zone areas in Germany

Data on pedestrian zone areas (usage type key: 513) were not available to the Federal Statistical Office, which is why they were estimated in a similar way to park areas (see chapter 4.6). First of all, the area of roads (510), paths (520) and squares (530) was determined for each category, which are given as a sum in the publications of the Federal Statistical Office for the entire area. Then the area share of the pedestrian zones was estimated on the basis of data from the Federal State of Bremen and multiplied by the area of the roads, paths and squares to obtain the respective pedestrian zone area

10.5.3.1 Area of roads, paths and squares in each category

The areas of roads, paths and squares in the district-free cities are divided into the individual categories in Table 76. The data for this are taken from Destatis (2017b).

Table 76: Number, ground area and surface area of roads, paths and squares of the district-free cities in Germany divided according to the respective city types

Category	Amount	Ground area in total [km²]	Total area of roads, paths, squares [km²]
Large major cities	14	4,870	534
Small major cities	56	7,883	697
Large cities	25	2,569	165
Medium cities	15	1,011	73.6

Source: Destatis 2017b

The district-free city with the smallest population is Zweibrücken with 34,260 inhabitants (Destatis 2017b).

Since the number of large major cities without districts (see Table 76) is equal to the number of all large major cities (see Table 67), the area of roads, paths and squares in all large major cities in Germany is 534 km^2. In order to obtain the area of roads, paths and squares in small major cities and large cities, the average area of roads, paths and squares was first calculated for both types of cities on the basis of the data in Table 76 (12 km^2 and 6.6 km^2 respectively; see Table 77).

For the calculation of the area of roads, paths and squares in medium cities, a different approach was used. For the reasons mentioned in chapter 10.4.2.1 the average area of roads, paths and squares of the district-free medium cities was halved in order to obtain the average area of roads, paths and squares of all medium cities (2.5 km^2; see Table 77).

There are no small cities in Germany that are at the same time district-free cities. Since only data for district-free cities were available for the area of roads, paths and squares, this area had to be estimated for small cities. For this purpose, the data for medium cities was used (2.5 km^2 per medium city). The estimate for the area of roads, paths and squares in small cities was then given as half the value for medium cities (1.25 km^2; see Table 77).

Table 77: Average area of roads, paths and squares in the district-free cities and all cities in Germany, divided according to the respective city types except large major cities

Category	Average area of roads, paths and squares of district-free cities [km²]	Average area of roads, paths and squares in all cities [km²]
Small major cities	12	12 (estimation)
Large cities	6.6	6.6 (estimation)
Medium cities	4.9	2.5 (estimation)
Small cities	-	1.25 (estimation)

Source of the average area of roads, paths and squares of district-free cities: Destatis 2017b. Within the category of small major cities and large cities, the values for the district-free cities (middle column) and the values for all cities (right column) are equal and rounded. Within the category of medium cities, the value for the district-free cities (middle column) is twice the value for all cities (right column), both values are rounded. In Germany, there are no district-free cities that are also small cities, so the area of small cities is estimated to be half the area of medium cities, rounded off.

By multiplying the number of all cities in the respective category (large major cities: 14; small major cities: 65; large cities: 108; medium cities: 468; small cities: 520 - Destatis 2016) and the respective estimate of the average area of roads, paths and squares of all cities (see Table 77), the respective total areas of roads, paths and squares are obtained (see Table 78). For the sake of completeness Table 78 also shows the areas of roads, paths and squares in all large major cities.

Table 78: City category with corresponding area of roads, paths and squares

Category	Area of roads, paths and squares [km²]
Large major cities	534
Small major cities	809
Large cities	713
Medium cities	1,148
Small cities	650

10.5.3.2 Pedestrian zone area of each category

The estimates of the pedestrian zone shares of the areas of roads, paths and squares were made on the basis of data from Geo.Bremen (2017). In 2016 the area of pedestrian zones in the federal state of Bremen was 0.127 km^2 (Geo. Bremen 2017), which, measured in terms of the area of streets, paths and squares (39.53 km^2 in 2015 - Destatis 2017b), gives a share of 0.321%. On this basis, a share of 0.321% was also assumed for large and small major cities, and large cities (see Table 79). Lower values were used for medium cities and small cities, because Monheim (2011) describes that in Bavaria in 1985 only 50% of all medium cities and 20% of all small cities had pedestrian zones, whereas for cities with a population of 50,000 or more, i.e. large cities, the figure is 100%. For this reason, the proportion of pedestrian zones in medium cities was estimated to be half (0.161%) and in small cities one-fifth (0.064%) of the proportion of pedestrian zones by the Federal State of Bremen. This results in a total pedestrian zone area of 8.86 km^2 (see Table 79).

Table 79: Pedestrian zone category with estimated pedestrian zone share of the area of roads, paths and squares and pedestrian zone area based on this

Category	Estimated share of pedestrian zones in the area of roads, paths and squares	Pedestrian zone area [km²]
Large major cities	0.321%	1.71
Small major cities	0.321%	2.60
Large cities	0.321%	2.29
Medium cities	0.161%	1.84
Small cities	0.064%	0.41
Total amount	-	8.86

10.5.4 Determination of plastic litter input and slip rate

The Vienna study includes numbers of plastic pieces, which were counted in public places in the five European cities. These are touristically highly frequented places with a dedication as pedestrian zones (Ableidinger 2004). The squares where the investigations took place are as follows: Av. de la Catedral (Barcelona; 5,032 m^2), Grand' Place (Brussels; 3,408 m^2), Römerberg (Frankfurt; 4,841 m^2), Staromestske namesti (Prague; 9,211 m^2) and Stephansplatz (Vienna; 6,711 m^2). These data form the basis for estimating the plastic litter input caused by litter in German pedestrian zones. It should be noted here that the investigations were carried out in 2003. Since 2003 the *litter input* in these pedestrian zones may have changed. More recent data were not available. Table 80 shows the plastic pieces of the five places from Ableidinger (2004). The waste was counted once a day on four consecutive days (twice in the morning, twice in the afternoon) (Ableidinger 2004). Between the counts the observation fields were cleaned at least once (Ableidinger 2004). The plastic quantities listed in Table 80 refer to one day.

Table 80: Plastic quantities on squares (pedestrian zone) in five European cities (Ableidinger 2004)

Types of plastic	Barcelona	Brussels	Frankfurt	Prague	Vienna
PET beverage bottles [piece/(ha*d)]	<15: 0.0 >15: 5.5	<15: 1.8 >15: 0.7	<15: 0.0 >15: 1.0	<15: 0.0 >15: 4.9	<15: 0.0 >15: 0.3
Plastic beverage cups [piece/(ha*d)]	<15: 0.0 >15: 2.1	<15: 7.3 >15: 1.5	<15: 0.0 >15: 0.0	<15: 0.0 >15: 1.9	<15: 0.0 >15: 0.0
Plastic packaging: Non-beverages [piece/(ha*d)]	<15: 77.5 >15: 11.8	<15: 296.2 >15: 30.6	<15: 95.5 >15: 10.8	<15: 134.9 >15: 8.1	<15: 52.0 >15: 1.6
Composites [piece/(ha*d)]	<15: 118.8 >15: 11.8	<15: 299.1 >15:1.5	<15: 77.0 >15: 0.0	<15: 142.2 >15: 6.0	<15: 47.4 >15: 0.3
Plastic – other [piece/(ha*d)]	<15: 169.0 >15: 18.5	<15: 1.852.1 >15: 59.1	<15: 743.7 >15: 10.3	<15: 135.4 >15: 20.9	<15: 70.2 >15: 4.9
Total amount [piece/(ha*d)]	**415.1**	**2,550.0**	**938.4**	**454.3**	**176.7**

In order to convert the piece number data into weight data, specific weights of the individual plastic litter components from Ableidinger (2004) were required (see Table 81). These were determined during a basket sorting analysis, which was carried out by INTECUS GmbH in Dresden in 2017.

Table 81: Specific weights of the plastic components PET beverage bottles, plastic beverage cups, plastic packaging: Non-drinks, composites and plastic – other

Types of plastic	Specific weight [g]
PET beverage bottles	28 (n=121)
Plastic beverage cups	11 (n=280)
plastic packaging: Non-drinks	<15 mm: 1.0 (n=70) >15 mm: 3.6 (n=50)
Composites	<15 mm: 7.2 (n=117) >15 mm: 11.3 (n=69)
Plastic – other	<15 mm: 3.3 (n=93) >15 mm: 8.5 (n=164)

Data are from a wastebasket sorting analysis conducted by INTECUS GmbH in August and September 2017. In addition to the weight, the number of waste pieces is given in brackets.

With the quantities from Table 80 and the specific weights from Table 81, weight-related data could now be determined for the plastic litter components from Ableidinger (2004) (see Table 82). The data for the specific weights of PET beverage bottles and plastic beverage cups were not subdivided into <15 mm and >15 mm (see Table 81). To obtain weight-related data for the PET beverage bottles and plastic beverage cups from the five European cities (see Table 82), the fractions <15 mm and >15 mm from Table 80 were added and then multiplied by the specific weights from Table 81.

Table 82: Weights of the plastic litter components in squares (pedestrian zones) in the five European cities by Ableidinger (2004)

Types of plastic	Barcelona	Brussels	Frankfurt	Prague	Vienna
PET beverage bottles [g/(ha*d)]	154	70	28	137	8
Plastic beverage cups [g/(ha*d)]	23	97	0	21	0
Plastic packaging: Non-beverages					
[g/(ha*d)]	120	406	134	164	58
Composites					

In order to estimate the proportion of plastics in the group of composites, information from the Trade Association for Carton Packaging of Liquid Foodstuffs (Fachverband Kartonverpackungen für flüssige Nahrungsmittel e.V. (FKN)) was used. This indicates a plastic content of 20% by weight for a Tetra-Pak (FKN 2018). On the basis of this information, the plastic content of the composites was estimated at 20 wt.%. This results in plastic litter inputs in the five European cities mentioned above, which are listed in Table 83. Frankfurt, as a major German city, has an average value of 2,815 g/(ha*d), which is close to the average value of the five European cities (2,644 g/(ha*d)).

Table 83: Plastic litter weights on squares (pedestrian zones) in five European cities

Calculated value	Barcelona	Brussels	Frankfurt	Prague
Plastic litter input [g/(ha*d)]	1,210	7,622	2,815	1,165

One criterion for the choice of places in Ableidinger (2004) was that they were heavily frequented by tourists, which is why a higher *litter input* is to be expected there than on average pedestrian zones in German cities. The *litter input* in pedestrian zones of German cities was therefore estimated to be 2,000 g/(ha*d), resulting in 73 t/(km^2*a). The slip rate base value of the pedestrian zones was estimated at 0.55 wt.% and the range at 0.1-1 wt.% (see chapter 4.2.2).

10.5.5 Determination of the remaining plastic litter

To calculate the amount of *remaining plastic litter*, the plastic litter input was multiplied by the *slip rate* and the pedestrian area (see Table 84). For the sake of completeness, Table 84 lists the individual calculation values from the entire chapter on pedestrian zones. The *remaining plastic litter* based on litter in pedestrian zones amounts to 3.6 t/a (0.65-6.5 t/a).

Table 84: Calculated values and result of the estimation of the remaining plastic litter caused by litter in German pedestrian zones

No.	Calculated value	Calculation	lmC	smC	lC	mC	sC	Total amount
[1]	Plastic litter input [g/(ha*d)]		2,000	2,000	2,000	2,000	2,000	-
[2]	Plastic litter input [t/(km²*a)]		73	73	73	73	73	-
[3]	Slip rate base value [wt.%]		0.55%	0.55%	0.55%	0.55%	0.55%	-
[4]	Slip rate range [wt.%]		0.1-1%	0.1-1%	0.1-1%	0.1-1%	0.1-1%	-
[5]	Pedestrian zone area [km²]		1.71	2.60	2.29	1.84	0.41	-
[6]	Remaining plastic litter base value [t/a]	= [2] * [3] * [5]	0.69	1.0	0.92	0.74	0.16	3.6
[7]	Remaining plastic litter range [t/a]	= [2] * [4] * [5]	0.13-1.3	0.19-1.9	0.17-1.7	0.13-1.3	0.030-0.3	0.65-6.5

The abbreviations in the first line of the table represent the individual pedestrian zone categories: lmC - large major cities; smC - small major cities; lC - large cities; mC - medium cities; sC - small cities.

10.6 Plastic litter remains: riverside strip

In this chapter, the estimation of the *remaining plastic litter* is explained in detail, based on the explanations in chapter 4.8.

10.6.1 Determination of the river length

The total length of rivers with a catchment area of over 10 km^2 in Germany is 141,726 km (BfN 2004). The navigable rivers in Germany have a total length of 9,168 km (Destatis 2005). The length of the other rivers is the difference between the two values (132,558 km).

The average length per navigable river for each city type was estimated on the basis of the data in Table 85. The average length per navigable river in large major cities was estimated at 30 km based on data from Berlin, Frankfurt am Main and Dresden (see Table 85). The average length per navigable river in small major cities was estimated to be 15 km, half the length of large cities, based on the data of Mainz and Würzburg (see Table 85). No literature data on river length were available for large and medium cities, so the lengths of these city types were estimated to be half the length of the next largest city type, which is 7.5 km for large cities and 3.75 km for medium cities.

Table 85: Lengths of navigable rivers in selected large and small major cities

City	Type of city	River	Length [km]	Source
Berlin	Large major city	Spree, Dahme, Havel	89.0	Senate Department for Environment, Transport and Climate Protection (2018)
Frankfurt/ Main	Large major city	Main	27.0	City of Frankfurt/Main (2018)
Dresden	Large major city	Elbe	30.5	State capital Dresden (2015)
Mainz	Small major city	Rhein	15.5	State capital Mainz (2018)
Würzburg	Small major city	Main	15.6	City Würzburg (2013)

The definition of city types by population is given in Table 67. The length is rounded to the first decimal place.

Table 86 lists the number of cities of the respective city type situated on navigable rivers and puts them in relation to the respective total number of cities in Germany. As there are three navigable rivers in Berlin and two each in Hamburg and Bremen, together with the other seven major cities, the total length of rivers in major cities is 420 km, which is 5% of all navigable rivers. In Germany there are 40 small major cities through which navigable rivers flow (see Table 86). Six of these contain two navigable rivers each within the urban area. This gives a total length of navigable rivers in small major cities of 690 km, which is 8% of all navigable rivers. There are 44 large cities in Germany, through each of which only one navigable river flows. This corresponds to 330 km, which is 4% of all navigable rivers. There are also 93 medium cities in Germany through which navigable rivers flow. Two of them are crossed by two navigable rivers each. This gives a length of 356 km, which is 4% of all navigable rivers. The length of navigable rivers in rural areas (7,372 km) is the difference between the sum of all urban navigable rivers (1,796 km) and the total length of navigable rivers in Germany (9,168 km).

Table 86: Number of cities situated on navigable rivers with total number of cities divided into the respective city type

Type of city	Total number in Germany	Number of navigable rivers as a proportion of total number of cities
Large major cities	14	10 (71%)
Small major cities	65	40 (62%)
Large cities	108	44 (41%)
Medium cities	468	98 (20%)

The definition of city types by population is given in Table 67. The brackets show the respective shares of cities situated on navigable rivers in the total number of each city type in Germany.

To obtain the river length shares of the respective city types in the total length of the other rivers, the individual river length shares of the respective city types in the total length of the navigable rivers (navigable rivers in large major cities: 5%; navigable rivers in small major cities: 8%; navigable rivers in large cities: 4%; navigable rivers in medium cities: 4%) were multiplied by the total length of the other rivers. The results of these calculations are listed in Table 87, among others. The length of the other rivers in rural areas was determined analogous to the length of the navigable rivers. Based on this, the length of riversides was assumed to be twice the length of the river (see Table 87). In reality, additional riversides through islands would have to be included. Furthermore, in the case of boundary rivers only the riversides of one side of the river would have to be considered.

Table 87: River lengths, shares of total length and length of riversides of navigable rivers or other rivers with a catchment area of more than 10 km²

Table header	Table header	Table header
Navigable rivers in large major cities	420 (5%)	840
Navigable rivers in small major cities	690 (8%)	1,380
Navigable rivers in large cities	330 (4%)	660
Navigable rivers in medium cities	356 (4%)	712
Navigable rivers in rural areas	7,372 (80%)	14,744
Other rivers in large major cities	6,073 (5%)	12,146
Other rivers in small major cities	9,977 (5%)	19,954
Other rivers in large cities	4,771 (5%)	9,542
Other rivers in medium cities	5,151 (4%)	10,302
Other rivers in rural areas	106,586 (80%)	213,172

Values are rounded to the first digit before the decimal point.

10.6.2 Determination of the waste input

Breitbarth and Urban (2016) have developed a quantitative material flow model for the river Ahna, in which the riverside was also taken into account. In this model, the litter input on the riverside was given as 1.76 t/a. Breitbarth and Urban (2016) define litter as waste that is thrown away or left in public spaces, including building materials. The definition of litter from Breitbarth and Urban (2016) is therefore not consistent with the definition in this study. The value of 1.76 t/a is therefore considered to be *waste input*.

The river Ahna is about 21 km long, accordingly the length of the riverbank is 42 km, and flows from the source first through the district of Kassel until it reaches the urban area of the small city of Kassel after about 3 km. After another 18 km the Ahna flows into the Fulda within the city of Kassel. Based on 1.76 t/a, a river edge strip of 42 km results in a distance-related *waste input* of 42 kg/(km*a). Breitbarth (2017) adds to this figure (1.76 t/a) that this waste is composed of litter, building site waste and drifts from waste collection containers. In contrast to Breitbarth's definition of litter (2017), in this study the drifting of waste containers is also counted as litter, as it is not possible to clearly identify the waste that has been blown away from waste containers.

The Ahna is classified under the category of other rivers. The waste input from riversides of other rivers in urban areas, which includes all city categories, is given as 40 kg/(km*a), rounded up or down, based on the result calculated for the Ahna (see Table 88). The waste input from the riversides of navigable rivers in urban areas, which includes all city categories, was estimated to be double (80 kg/(km*a)), because it was assumed that a wider river, which may include navigable rivers, is a greater attraction for inhabitants and tourists than rivers of smaller width. This is associated with a higher litter input. Waste input in rural areas is estimated to be very low and is reported as 1 kg/(km*a) for riversides of navigable rivers and 0.5 kg/(km*a) for riversides of other rivers.

Table 88: Waste input to various riverbank categories

Category of riverside strips	Estimated waste input [kg/(km*a)]
Navigable rivers in large major cities	80
Navigable rivers in small major cities	80
Navigable rivers in large cities	80
Navigable rivers in medium cities	80
Navigable rivers in rural areas	1
Other rivers in large major cities	40
Other rivers in small major cities	40
Other rivers in large cities	40
Other rivers in medium cities	40
Other rivers in rural areas	0.5

10.6.3 Determination of the plastic content

Breitbarth (2017) examined not only riverside strip waste from the Ahna river but also riverside strip waste from the Fulda river in the Kassel district and in the city of Kassel, and determined the mass-related composition by material type for these (see Table 89). In total, waste was collected from nine sections with a total length of 5.5 km. Six of the nine sections are located in inaccessible or less frequented places (fields, forests, island), so it was assumed that the waste there contained only washed up material that had been deposited in previous river sections. The other three sections are part of a park where littering takes place. These three sections in particular are to be assigned to the land use type park. However, this circumstance is irrelevant when determining the proportion of plastic, because only the waste from the riverbank of the park was sampled.

In addition to the material type plastic, other plastics are expected to be used in the material type of composites. The proportion of composites was 26% by weight (Breitbarth 2017). Information on the proportion of plastics in these composites was not available in Breitbarth (2017), which is why it was estimated to be 20 wt.% based on the data of the Trade Association for Carton Packaging of Liquid Foodstuffs (Fachverband Kartonverpackungen für flüssige Nahrungsmittel e.V. (FKN)) (2017) (see chapter 0). Together with the 30 wt.% of the material type plastic, the plastic content of the composites (5.2 wt.% of the total share of all collected waste) results in a plastic content of the collected waste of rounded 35 wt.%. Assuming that the waste collected by Breitbarth (2017) is representative of the waste of all riversides, the *plastic content of the waste input* for further estimation is 35 wt.% (unrounded: 35.2 wt.%).

Table 89: Mass related composition according to material type of riverside waste from the Fulda

Material type	Proportion [wt.%]
Plastic	30%
Composites	26%
Glass	22%
Miscellaneous	15%
Metal	6%
Paper/cardboard	1%

Source: Breitbarth (2017)

10.6.4 Determination of the litter content

In addition to the type of material, Breitbarth (2017) has also sorted the waste from the Fulda riverbank by product class (see Table 90). It was assumed that the litter waste includes all product classes with the exception of building materials, which are classified as illegal deposits. This results in a litter content of 64% by weight of the plastic waste. It is assumed that this litter content is equal to the *litter content of the plastic waste*.

Table 90: Mass related composition of riverside waste of the Fulda according to product classes

Product classes	Proportion [wt.%]
Construction materials	36%
Beverage packaging	24%

Product classes	Proportion [wt.%]
Other packaging	6%
Garden items	4%
Sports and leisure equipment	3%
Films/bags/sacks	3%
Food Packaging	2%
Objects from sewage systems	0%
Other	22%

Source: Breitbarth (2017)

10.6.5 Determination of slip rate

In this chapter, the information in Table 4 is described in more detail. The estimation of the slip rate is mainly based on the quantitative material flow model of the Ahna of Breitbarth and Urban (2016). In the balance area of the material flow model, 1.76 t/a are input and 1.06 t/a are output, resulting in a *slip rate* of 40 wt.%. However, this slip rate only applies if all discharged waste, i.e. waste that has been flushed away, is collected and disposed of elsewhere. Breitbarth (2017) goes on to explain that almost exclusively the riverbank was cleaned and that cleaning was carried out every four weeks. Furthermore, Breitbarth (2017) considers systematic cleaning to be untypical. It was also assumed that during heavy rainfall events with high wind speeds all waste is transported from the riversides to the Ahna. Therefore, the *slip rate* of 40% by weight was assumed to be the minimum range for riversides in urban areas. The base value was estimated to be 60 wt.% and the maximum to 80 wt.%. The slip rate for riversides in rural areas was estimated to be slightly higher (base value: 80 wt.%; range: 70-90 wt.%), because it was assumed that cleaning is less frequent and therefore the cleaning intervals are longer.

10.6.6 Determination of the remaining plastic litter

Table 91 lists all the calculation parameters and the result of the estimation of the *remaining plastic litter* of the respective riverside categories of navigable rivers. Table 92 lists all the variables and the result of the estimation of the *remaining plastic litter* of the respective riverside categories of the other rivers. The total amount of *remaining plastic litter* on the riversides of the navigable rivers and other rivers is 342 t/a (232-451 t/a).

Table 91: Factors and results of the assessment of plastic litter input and fate based on litter on riversides of navigable rivers

No.	Calculated variable	Calculation	lmC	smC	lC	mC	rA	Total amount
[1]	Waste input [kg/(km*a)]		80	80	80	80	1	-
[2]	River length [km]		840	1,380	660	712	14,744	-
[3]	Plastic content of the waste input [wt.%]		35%	35%	35%	35%	35%	-
[4]	Litter content of the plastic waste [wt.%]		64%	64%	64%	64%	64%	-

No.	Calculated variable	Calculation	lmC	smC	lC	mC	rA	Total amount
[5]	Slip rate base value [wt.%]		60%	60%	60%	60%	80%	-
[6]	Slip rate range [wt.%]		40-80%	40-80%	40-80%	40-80%	70-90%	-
[7]	Remaining plastic litter base value [t/a]	= [1] * [2] * [3] * [4] * [5]	9.1	15	7.1	7.7	2.7	42
[8]	Remaining plastic litter range [t/a]	= [1] * [2] * [3] * [4] * [6]	6.1-12	9.9-20	4.8-9.5	5.1-10	2.3-3.0	28-55

The abbreviations in the first row of the table represent the individual riverbank categories: lmC - large major cities; smC - small major cities; lC - large cities; mC - medium cities; rA - rural areas.

Table 92: Factors and results of estimation of plastic litter input and fate based on litter on riversides of other rivers with a catchment area over 10 km²

No.	Calculated variable	Calculation	lmC	smC	lC	mC	rA	Total amount
[1]	Waste input [kg/(km*a)]		40	40	40	40	0.5	-
[2]	Length [km]		12,146	19,954	9,542	10,302	213,172	-
[3]	Plastic content of the waste input [wt.%]		35%	35%	35%	35%	35%	-
[4]	Litter content of the plastic waste [wt.%]		64%	64%	64%	64%	64%	-
[5]	Slip rate base value [wt.%]		60%	60%	60%	60%	80%	-
[6]	Slip rate range [wt.%]		40-80%	40-80%	40-80%	40-80%	70-90%	-
[7]	Remaining plastic litter base value [t/a]	= [1] * [2] * [3] * [4] * [5]	66	108	52	56	19	300
[8]	Remaining plastic litter range [t/a]	= [1] * [2] * [3] * [4] * [6]	44-88	72-144	34-69	37-74	17-22	204-396

The abbreviations in the first row of the table represent the individual riverbank categories: lmC - large major cities; smC - small major cities; lC - large cities; mC - medium cities; rA - rural areas.

10.7 Plastic litter remains: coasts

Based on the summarised explanations in chapter 4.9, this chapter explains in detail the estimation of the *remaining plastic litter* based on litter on the German coast.

10.7.1 Further information on the classification of the coast

The classification of the coast is described in chapter 4.9.1. With regard to intensity of use and cleaning intervals, the coast was divided into the categories seaside resorts, other bathing sites and other coast. It was assumed that the intensity of use and the cleaning intervals decrease or increase from the category seaside resorts via other bathing sites to other coasts. Coastal areas that also belong to urban areas are expected to have a higher intensity of use and shorter cleaning intervals, which is why urban coastal areas should be distinguished from non-urban coastal areas. Non-urban coastal areas, like urban coastal areas, may overlap with the categories seaside resorts, other bathing areas and other coast.

Litter caused by ports is included in the urban coast category. Although the litter from near-coastal boat traffic is not disposed of directly on the coastline but is primarily washed up, it is also included in this estimate.

10.7.1.1 Urban coast

The category of urban coast should take into account the higher intensity of use compared to the non-urban coast. Table 93 lists the small major cities, large and medium cities, as well as small cities and towns according to the coastal federal state. Stralsund and Greifswald are not located on the outer coast of Mecklenburg-Western Pomerania, but were nevertheless included in the consideration, since a not negligible input of plastic litter is to be expected from these two large cities.

Table 93: Small major cities, large cities, medium cities, small cities and towns on the coast listed by coastal federal state

Coastal federal state	Small major cities at the coast	Large cities at the coast	Medium cities at the coast	Small cities	Towns
Lower Saxony	-(0)	Wilhelmshaven (1)	Cuxhaven, Geestland (city), Nordenham, Norden, Nordeney, Varel, Wittmund (7)	-(0)	Borkum, Esens, Otterndorf (3)
Schleswig-Holstein	Kiel, Lübeck (2)	Flensburg (1)	Husum, Eckernförde (2)	Fehmarn (1)	Glücksburg (Baltic Sea), Heiligenhafen, Kappeln, Meldorf, Neustadt in Holstein, Oldenburg in Holstein, Wyk on Föhr (7)
Mecklenburg-Western Pomerania	Rostock (1)	Stralsund, Greifswald (2)	Wismar (1)	Bad Doberan, Ribnitz-Damgarten, Wolgast (3)	Barth, Dassow, Garz/Rügen, Klütz, Kühlungsborn, Lassan, Putbus, Rerik, Sassnitz, Ueckermünde, Usedom (City) (10)

The number in brackets indicates the number of cities of the respective city type in the respective coastal state.

10.7.1.2 Seaside resorts, other bathing sites and other coastal areas

In Mecklenburg-Western Pomerania, the law on health resorts regulates which requirements a resort must meet in order to be officially called a seaside resort or a sea health resort. In Schleswig-Holstein and in Lower Saxony it is the respective spa ordinances. In all three legal texts, a well-maintained bathing beach is a prerequisite for the award of the title "seaside resort or sea health resort" ("Seebad/Seeheilbad") (KurortG 2000, KurortVO NI 2005, KurortVO SH 2009). Seaside resorts and seaside health resorts are collectively referred to as seaside resorts in the following. All seaside resorts include one or more bathing sites. The length of the seaside resorts is equal to the length of the bathing sites within the seaside resorts.

A bathing site is according to the EU Bathing Water Directive (2006):

- any stretch of surface water where the responsible authority expects a large number of bathers, and
- for which it has not issued a permanent bathing prohibition, or
- do not advise against bathing in the long term.

For EU bathing sites according to this definition, regular tests of water quality are required, among other things. EU bathing sites are registered with the respective health authorities. Bathing sites were considered particularly important with regard to litter input. However, in addition to EU bathing sites, it is likely that there are other unofficial bathing sites. In order to include the unofficial bathing sites in the categories of seaside resorts and other bathing sites, the total length of EU bathing sites in these two categories was increased by 25%. For the different coastal federal states this means in detail:

- 80% of the *bathing sites* in Mecklenburg-Western Pomerania (MV) are EU bathing sites that are displayed as bathing sites on the coast in the geodata viewer of the Coordination Centre for Geoinformation in the State Office for Internal Administration (KGeo LAIV, 2017).
- 80% of the *bathing sites* in Schleswig-Holstein (SH) are all EU bathing sites that are also listed as *coastal waters* or *transitional waters* in the Schleswig-Holstein State Portal (2017).
- 80% of the *bathing sites* in Lower Saxony (NI) are bathing sites that are listed in the category coastal and transitional waters in the overall list of EU bathing sites of the Lower Saxony Health Authority (NLGA, 2017).

The other bathing sites are all bathing sites that are outside of seaside resorts. The other coast includes all coastal sections which are not bathing sites.

10.7.1.3 Other inland coast of Mecklenburg-Western Pomerania (MV)

The inland coast of MV (377 km) is more than four times as long as the outer coast (1,568 km). The intensity of use of the inland coast is lower than that of the outer coast (LALFF 2016). This is shown by the ratio of the EU number of bathing sites between the two types of coasts. Based on a length of 100 km, the length of bathing sites on the inland coast is 1.35 km and 42.2 km on the outer coast (KGeo LAIV 2017). It was assumed that this ratio also reflects the ratio of the intensity of use and thus the *litter input* between other coasts, which includes the outer coast of MV, and other inland coasts of MV. Therefore, the *litter input* on the other inland coast of MV is 3.2% of the *litter input* of the other coast.

The bathing sites and seaside resorts located on the inland coast are treated in the same way as bathing sites and seaside resorts on the outer coast. In a comparison of the two types of coastline, fewer users per bathing area can be expected at inland bathing sites, but these bathing sites are also shorter (median EU bathing site length on the inland coast: 300 m; median EU bathing site length on the outer coast: 1,200 m) (KGeo LAIV 2017).

10.7.2 Determination of the individual coast lengths

The coastline length of NI is 629 km (LGLN 2017). The North Sea coast length of SH is 468 km including halligs and islands (Statistik Nord 2008). The Baltic Sea coast length of SH is 402 km including Fehmarn and without Schlei (Statistik Nord 2008). The outer coast length of MV is 377 km and the inner coast length is 1,568 km (LALFF 2016). This results in a total coast length of 3,444 km.

10.7.2.1 Seaside resorts

The EU bathing site length of the seaside resorts in NI was not available. However, with the average EU bathing site length of North Sea resorts in SH (2.94 km; Landesportal Schleswig-Holstein 2017) and the number of seaside resorts in NI (17; Lower Saxony Ministry of Economics, Labour and Transport 2017), where EU bathing sites are listed (NLGA 2017), the length of EU bathing sites in seaside resorts could be estimated (50 km). The total length of EU bathing sites in seaside resorts of SH is 146 km (State Portal Schleswig-Holstein 2017). The EU bathing site length in MV is 123 km (outer coast: 118 km; inner coast: 5 km) (KGeo LAIV 2017). This results in a total EU bathing area length in seaside resorts of 319 km. As already described in chapter 10.7.1.2, EU bathing sites do not include all bathing sites, which is why it was assumed that EU bathing sites include 80% of all bathing sites. This results in a bathing site length in seaside resorts of 399 km.

10.7.2.2 Other bathing sites

In NI there are three EU bathing sites outside of seaside resorts (NLGA 2017; Lower Saxony Ministry of Economics, Labour and Transport 2017). A corresponding length was not available, so the average EU bathing site length from the North Sea coast in SH (1.72 km; Landesportal Schleswig-Holstein 2017) was multiplied by the number of EU bathing sites outside seaside resorts (3; Lower Saxony Ministry of Economics, Labour and Transport 2017) (5.16 km). The length of EU bathing sites outside seaside resorts in SH is 101 km (Landesportal Schleswig-Holstein 2017). The length of EU bathing sites outside seaside resorts in MV is 50 km (outer coast: 34 km; inland coast: 16 km) (KGeo LAIV 2017). This results in a total length of the EU bathing sites outside seaside resorts of 157 km (80%). Including the unofficial bathing sites, the total length is 196 km (100%).

10.7.2.3 Other coast

By subtracting the length of bathing sites (seaside resorts: 392 km; outside of seaside resorts: 176 km) from the total coast length without inland coast of MV (1,876 km), the length of the other coast (1,308 km) is deducted.

10.7.2.4 Other inland coast of MV

The length of sea resorts and other bathing sites on the inland coast of MV is 27 km (KGeo LAIV 2017). The difference between the inland coast length of MV (1,568 km) and the length of bathing sites (27 km) results in the length of the other inland coast of MV (1,541 km).

10.7.2.5 Urban coast

The length of the urban coastal sections of small major cities, large cities, medium cities, small cities and towns was assumed to be 8.0 km, 4.0 km and 2.0 km 1.0 km and 0.5 km respectively. With the number of individual city types (see Table 93), this results in a length of 24.0 km for small major cities, 16.0 km for large cities, 20.0 km for medium cities, 4.0 km for small cities and 10.0 km for towns. Thus the urban coast is 74 km long in total.

10.7.3 Enquiries to providers and operators of bathing sites

The intensity of use and cleaning intervals were determined as essential criteria for the plastic litter input and fate. Originally, the overnight stay figures in the individual coastal communities were regarded as a measure of the intensity of use, but these would have to be put in relation to the coastal line of the community. The coastlines belonging to the communities are rarely given in the literature. Furthermore, the catchment area of the coastal visitors cannot be exactly defined. Tourists could therefore use the coast and stay overnight in communities that do not belong to the coast. For future updates of the estimates it would be useful to check whether a better data basis with regard to this problem exists or can be created, in order to then classify the coast on the basis of the number of overnight stays in the individual communities and the associated coastline. The accessibility of the coastal section is another criterion to be considered for the plastic litter input and retention on the coast. The data basis for the criterion accessibility was also not available, but must be taken into account in future updates.

In order to make conclusions about the *slip rate* (see chapter 0) and the *litter input* (see chapter 10.7.5) and, based on this, to estimate the amount of *remaining plastic litter*, the executing agency and the operator were asked to provide information about collected waste quantities, cleaning intervals and types. For data collection, the operators or providers of 284 EU bathing sites (NI: 40; SH: 148; MV: 96) on the German North Sea and Baltic Sea were asked. 24 operators or providers of a total of 40 EU bathing sites responded. Regarding the manually collected waste quantities, one operator provided monthly waste weights for the year 2016 (see chapter 10.7.5.1). Manually collected waste is defined as waste that was collected manually from the surface of the coastal section. Recycle bin waste is excluded in this definition. In addition, there were also several feedbacks, although these contained data on collected waste quantities. However, these were often estimated or included waste quantities from manual cleaning as well as waste quantities from mechanical cleaning, which contained a higher sand content, a higher water content and also biogenic material (e.g. shells, seaweed). Some figures were also given in volume units. Some conversion factors would have been necessary in order to standardise these different details on a uniform data basis. However, this would have led to less precise results, which is why these data were not included.

In addition to the isolated data on collected waste quantities, data on cleaning intervals were provided by 10% of all the requested institutions and operators of EU bathing sites (see Table 94). As expected, the cleaning intervals are rather shorter for seaside resorts and rather longer for other bathing sites. In addition to the cleaning intervals, data on the type of cleaning were also provided (see Table 96). All promoters and operators of the other bathing sites that provided data on cleaning methods stated that they only clean manually. In the seaside resorts, on the other hand, in addition to manual cleaning, about 50% of the cleaning is also carried out mechanically. A seaside resort even cleans exclusively by machine.

Table 94: Cleaning intervals in enquired seaside resorts and among owners and operators of other bathing sites

Cleaning interval	Number of seaside resorts (n=18)	Number of owners and providers of other bathing sites (n=11)
Short (at least once a day in the high season)	11	0
Medium (at least several times a week in the high season)	5	2
Long (at least once a week in the high season)	0	2
Irregular/on demand/no cleaning	2	7

The definitions of the cleaning intervals are not transferable to the estimates of the other land use types regarding the cleaning intervals in Table 4, as the definition in Table 94 refers to the main season.

Table 95: Types of cleaning of enquired seaside resorts and of owners and providers of other bathing sites

Type of cleaning	Number of seaside resorts (n=17)	Number of owners and providers of other bathing sites (n=6)
Manually and automatically	8	0
Manually	8	6
Automatically	1	0

10.7.4 Determination of the slip rate

Based on the information on cleaning intervals and types of cleaning in chapter 10.7.3 and the explanations in chapter 4.2.2, estimates were made regarding the slip rate (see Table 4). The basic values of the slip rate for seaside resorts, other bathing sites and other coastal areas are 25%, 75% and 95% by weight, and the corresponding ranges are 10-40%, 60-90% and 90-100% by weight. For the urban coasts, a base value (50 wt.%) and a range (40-60 wt.%) were assumed, which are between those of the seaside resorts and other bathing sites.

10.7.5 Determination of the litter input

In the following, the litter input for the individual categories is estimated.

10.7.5.1 Seaside resorts

The basic data for the annual *litter input* of the *seaside resorts* were provided by the Dierhagen Spa Administration (2017), which manages a bathing area length of 7.5 km. Specifically, data on waste collection weights were provided for the individual months in 2016 (see column "collection weights" in Table 96). It should be noted that the waste of the months in which no collection quantities are recorded was collected in the month in which a collection quantity is subsequently recorded. It is therefore possible that some of the waste from one month was not collected until the following month and was therefore counted for the following month. For this reason, the waste collected within one month was estimated for each month in Table 96 (column: "waste collected in the wastebasket and waste collected on the beach"). It has been assumed that the collection weights are made up of equal proportions of the previous months without collection and the month in which the waste was collected for the first time. According to this assumption, the collection weight of waste collected in April (1.88 t), for example, is made up of a total of four months (January to April), whose waste weights (basket waste and waste collected on the beach) each amounted to 0.47 t. The share of the waste collected on the beach, which consisted of litter and non-litter waste, in the total amount of collected waste was estimated by the Dierhagen Spa Administration to be about 20 weight percent (Dierhagen Spa Administration 2017). This estimate results in the monthly weights of the waste volume collected on the beach (see column "quantity of waste collected on the beach" in Table 96), which results in a waste volume collected on the beach of 10.79 t/a for the year 2016 (see Table 96). Related to a distance of 7.5 km, this results in 144 kg/(100 m*a) of *waste collected* on the beach.

Table 96: Waste collection weights from the Dierhagen Spa Administration (2017) and, based on this, estimated monthly waste disposal

Month	Collection weights [t]	Waste collected in the wastebasket and waste collected on the beach [t]	Quantity of waste collected on the beach [t]
January	-	0.47	0.09
February	-	0.47	0.09
March	-	0.47	0.09
April	1.88	0.47	0.09
May	1.44	1.44	0.29
June	6.72	6.72	1.34
July	6.42	6.42	1.28
August	21.64	21.64	4.33
September	7.82	7.82	1.56
October	-	3.77	0.75
November	7.54	3.77	0.75
December	-	0.47	0.09
Total	**53**	**54**	**11**

The collection weight data only represent the waste weights at the time of collection. For months without data, this does not mean that no waste was collected, but that the quantity of waste collected was not worth collecting. For this reason, the 1.88 t in April (column: collection weights) was divided over the first four months (column: waste collected in the wastebasket and waste collected on the beach). The collection weight in November was averaged for October and November (column: waste collected in the wastebasket and waste collected on the beach). For December it was assumed that the waste collected was the same as in the other two winter months. The additional information for December (column: waste collected in the wastebasket and waste collected on the beach) also gives the larger sum in the column "waste collected in the wastebasket and waste collected on the beach ". 20% of the sum of "waste collected in the wastebasket and waste collected on the beach" is "Quantity of waste collected on the beach". The amount of waste collected on the beach includes litter and non-litter waste.

With a *slip rate* of 25% by weight (see base value in Table 4), the *collected amount of waste* is 75% by weight of the annual waste input, in this case 144 kg/(100 m*a). The annual waste input is thus 192 kg/(100 m*a). To calculate the annual *litter input*, the annual *waste input* must be multiplied by the litter content. The determination of the *litter content* is described in more detail below.

Schernewski et al. (2017) state that 50 pcs.% of the waste they investigate comes from tourism/recreational activities, 25 pcs.% from discharged wastewater, 10 pcs.% from shipping, 8 pcs.% from offshore platforms and 7 pcs.% from fisheries. The waste from tourism/recreational activities is subsequently defined as litter. Waste from discharged waste water, shipping, offshore platforms and fishing is hereinafter referred to as non-litter. Schernewski et al. (2017) note, however, that the above-mentioned figures only refer to the proportion of waste to which an origin could be assigned. 42 pcs.% of all waste could not be assigned (Schernewski et al., 2017). In the following, it is assumed that the composition of the waste that can be determined by origin is the same as that of the waste that cannot be determined by origin. Furthermore, it is assumed that the litter content of 50 pcs.% per unit (share of tourism/recreational activities from Schernewski et al. (2017)) is equal to the weight-related *litter content* (50 wt.%). Thus the annual litter input is 96 kg/(100 m*a). It is assumed that this value is representative for all seaside resorts on the German coast.

10.7.5.2 Other bathing sites

In Hengstmann et al. (2017), empirical studies were carried out for four coastal sections (one in Dranske, two in Varnkevitz, one in Vitt) on the island of Rügen with regard to the weight of waste. Although only one of the four coastal sections belongs to an EU bathing site, it can be assumed that all four fall into the category of *other bathing sites*, because the predominant beach use of these four coastal sections is "swimming/sunbathing" or the tourist use is high (Hengstmann et. al 2017). The selection of the coastal sections was based on the OSPAR guideline (Oslo-Paris Convention), which states for reference beaches that ideally they should not be cleaned by other actors (OSPAR, 2010). The waste from the four beaches was collected once each in mid-July 2015 (Hengstmann, 2017). The collected waste weights were 0.59 kg/100 m, 1.62 kg/100 m, 3.80 kg/100 m and 5.75 kg/100 m. For further calculations the average value (2.94 kg/100 m) was used. It is important to note that the estimate of the *remaining plastic litter* of the *other bathing sites* is based on these four values only. Further weight-related information from other studies was not available.

The cleaning slip, i.e. the waste that was not collected in the investigations by Hengstmann et al. (2017), was estimated at 5 wt.%. The reason for this estimate is that Schernewski et al. (2017) collected an average of another 10 pcs.% of the total amount of waste (from cleaning and control) during the inspection of five beach sections already collected. It is assumed that the pieces collected during the inspection were on average smaller than those from the previous cleaning. With a smaller size, a lower weight is also assumed, which is why the overall cleaning slip is estimated at 5% by weight. This results in a waste quantity of 3.09 kg/100 m at the time of cleaning.

Remaining on the coast is estimated to be very low compared to other land use types. It can be assumed, for example, that with one cleaning a year, the majority of the litter waste that has been disposed of on the coast has already been blown or washed away. Therefore, a balance model was needed to determine *the litter input* for the whole year based on the waste quantities (3.09 kg/100 m) available at the time of collection. This balance model is described below.

A balance model is assumed in which the balance area is a coastal section that is representative of a coastal section in the category "other coast". If the model is considered excluding clean-up operations, the waste inputs are as high as the waste outputs. The location of the waste between input and output is defined as a depot and contains a maximum number of waste components. Immediately after a cleaning, if the storage facility does not contain any waste, the outflows are zero and increase steadily until they are equal to the inputs. In the following, it is estimated how long it takes from the time of a cleaning until the deposit contains the maximum number of waste parts again.

Schernewski et al. (2017) compared monthly and quarterly cleanings at a beach in Kägsdorf (MV) and concluded that a cleaning that took place a month ago has no effect on the number of waste parts of a current cleaning. Similar results are provided by Smith and Markic (2013), who compared waste items from cleaners with different cleaning intervals at an Australian beach. Cleanings which were preceded by non-cleaning intervals of approximately one month resulted in similarly high numbers of units as cleanings which were preceded by non-cleaning intervals of more than one month (see Table 97). In addition, these are similar to the results of the piece count of the first cleaning at the beginning of Smith and Markic's investigations (2013). They counted about 800 pieces of waste at daily cleaning intervals on the beach section they investigated (see Table 97). At cleaning intervals of 28 days and longer they counted about 4,000 waste items (n=6; average: 3,829; see Table 97). At the first cleaning without previous cleaning 4,044 waste parts were counted. On the basis of these data it can be assumed that on the beach section analysed by Smith and Markic (2013) without cleaning, about 800 waste items are brought in and taken out per day and about 4,000 waste items are in deposit.

Under the assumption that the Australian beach of Smith and Markic (2013) behaves similarly to the balance area of the balance model under consideration with regard to its waste input and output rates, it can be concluded that it takes at least one month after cleaning until the waste output (by drifting or rinsing, not by cleaning) has returned to the level of waste input (by humans). This means that for a section of coast where no cleaning takes place, there are twelve periods (=months) per year in which the waste is theoretically exchanged.

Table 97: Cleaning intervals, number of repetitions, average recorded waste pieces with their minima and maxima from Smith and Markic (2013)

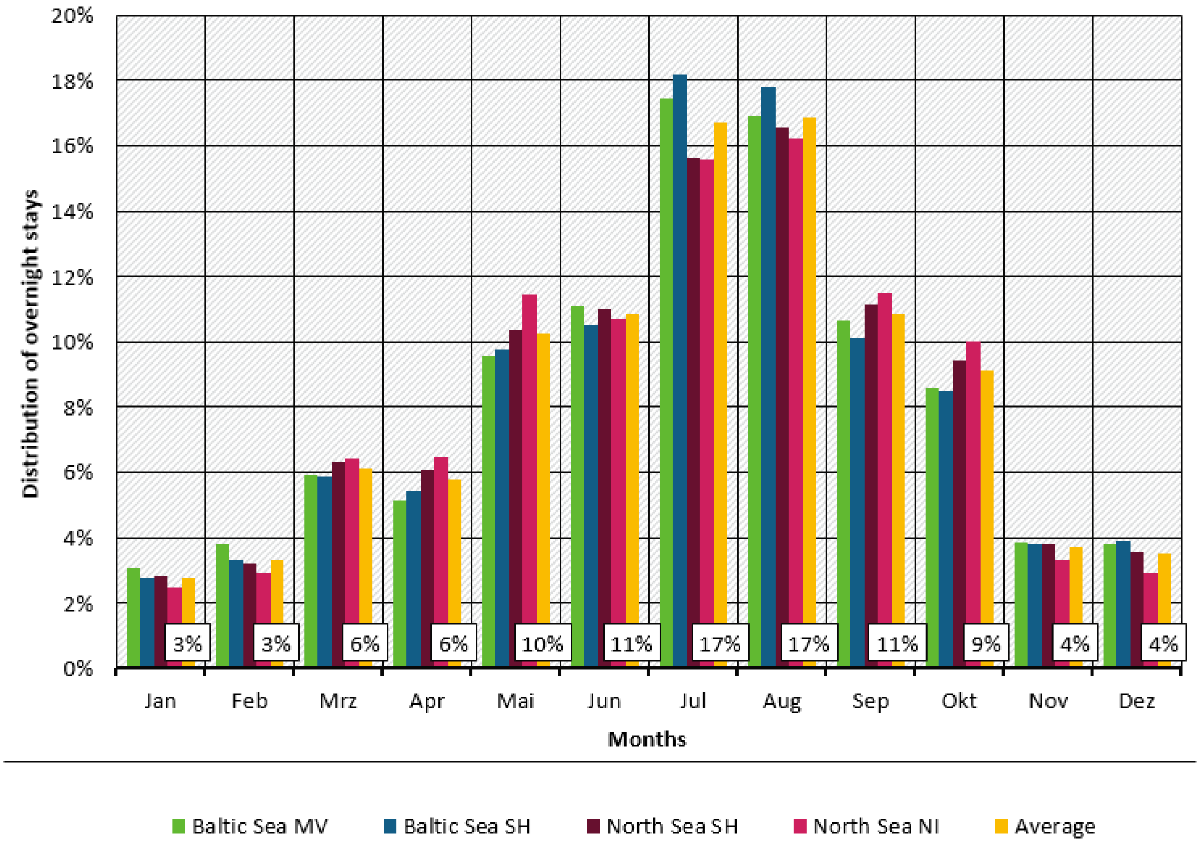
Cleaning interval [d]	Number of repetitions	Average [waste pieces]	minima [waste pieces]	maxima [waste pieces]
1	7	772	540	928
4	1	1211	1211	1211
14	6	1506	825	2944
21	1	3762	3762	3762
28	2	4565	2080	7049
63	1	4571	4571	4571
84	1	1795	1795	1795
126	1	2360	2360	2360
165	1	5118	5118	5118

Now the amount of waste found during a cleaning is not the waste input of one month, because the waste entered can also be discharged again. Based on the assumption that 800 waste parts are entered into the balance area of the balance model under consideration per day, about 24,000 waste parts are entered per month (30 days), which means six times the quantity of the storage facility. If the described balance model is applied to the beaches investigated by Hengstmann et al. (2016), the *waste input* in the month prior to cleaning (mid-June to mid-July

2015) is six times as high as the waste quantity available at the time of cleaning (mid-July 2015) (3.09 kg/100 m), which results in 18.57 kg/100 m.

The second part of the *waste input* calculation consisted in determining the conversion factors for the other eleven months based on the *waste input* between mid-June and mid-July (18.57 kg/100 m). This temporal variation was necessary because, for example, littering waste is very likely to be higher in summer than in winter. It was assumed that overnight stays in coastal tourist accommodation establishments are proportional to the litter waste. Figure 20 shows the monthly distribution of overnight stays for the North Sea and the Baltic Sea for the year 2016, broken down by federal state. It also shows average values on which the conversion factors are based. It is assumed that between mid-June and mid-July, i.e. the period in which the estimated *waste input* was 18.57 kg/100 m, 14% of all overnight stays of the year took place (average value from June (11%) and July (17%)). Thus a *litter input* of 9.28 kg/100 m corresponds to 14% of all nights spent during the year. Based on this, Table 98 lists the individual monthly *litter inputs*. The total weight of *litter* per year at the *other bathing sites* is thus 67 kg/(100 m*a).

Figure 20: Distribution of overnight stays in the North Sea and Baltic Sea with an additional subdivision into the respective neighbouring federal states and the mean value of these four areas



The data for the Baltic Sea area of Mecklenburg-Western Pomerania (MV) are taken from the monthly Statistical Reports of the Statistical Office of Mecklenburg-Western Pomerania (2017a). The data for the area Baltic Sea Schleswig-Holstein (SH) and North Sea SH come from the monthly Statistical Reports of Statistics North (2017). The data for the area North Sea Lower Saxony (NI) are taken from the regional database of the State Office for Statistics of Lower Saxony (LSN, 2017). The areas considered in the respective publications refer to non-uniform areas, e.g. in SH all municipalities bordering on the coast are covered, while the statistical areas in MV are divided into non-administrative areas. This circumstance most likely has no effect on the distribution of overnight stays, but should be mentioned as background information. Mean values are given as percentages at the base of the mean value bars. The sum of the mean values is not 100% because the mean values are rounded. If not rounded, the mean values add up to 100%.

Table 98: Distribution of overnight stays (mean value) of the four coastal areas and the respective litter input

Month	Distribution of overnight stays on the coast (mean value)	Litter input (kg/100 m)
January	3%	1.9
February	3%	2.2
March	6%	4.1
April	6%	3.9
May	10%	6.9
June	11%	7.3
July	17%	11.3
August	17%	11.4
September	11%	7.3
October	9%	6.2
November	4%	2.5
December	4%	2.4
Total	**100%**	**67**

The mean values for the distribution of overnight stays are taken from Figure 20, based on the fact that 14% of overnight stays correspond to 9.28 kg/100 m litter per month. The 14% is the mean value of the overnight stays from June and July, and the 9.28 kg/100 m per month is the litter entry calculated on the basis of the investigations by Hengstmann et al (2017). The sum of the mean values is not 100% because the mean values are rounded. If the mean values are not rounded, the sum of the mean values is 100%.

10.7.5.3 Urban coast, other coast and inland coast of Mecklenburg-Western Pomerania

It was assumed that the *litter input* for other and urban coasts is lower than that of seaside resorts and other bathing areas, as the number of users and thus the measure of potential littering on coastal sections of seaside resorts was estimated to be higher. *Litter input* from the urban coast was estimated to be about half of the *litter input* from other bathing sites (35 kg/(100 m*a)), as the number of users of other bathing sites was estimated to be higher compared to urban coasts.

In the Baltic Sea region, countings were carried out on urban and rural coastal sections between 2011 and 2013 (MARLIN 2015). The waste quantities on urban coastal sections (average: 236.6 waste parts/100 m) were about three times as high as on the rural coast (average: 75.5 waste parts/100 m). Rural coast is understood here as a synonym for the category other coast. Therefore, the litter input on other coasts is estimated to be one third (11.7 kg/(100 m*a)) of the litter input from urban coasts (35 kg/(100 m*a)).

Chapter 10.7.1.3 explained why the *litter input* on the other inland coast of MV was estimated to be 3.2% of the *litter input* from the other coast. In absolute numbers, the *litter input* on the other inland coast of MV is therefore 0.4 kg/(100 m*a).

10.7.6 Determination of the plastic content of the litter

For the determination of the *remaining plastic litter* on the coast, the *plastic content of the litter* was given as 30% by weight. This figure is based on the investigations carried out by Hengstmann et al (2016), in which a plastic content of 30.55 wt.% was analysed. It was assumed that the *plastic content of the waste input* is equal to that of the *litter input*.

10.7.7 Determination of the remaining plastic litter

Table 99 lists the individual factors of the assessment for the sake of completeness, together with the quantities of *plastic litter remaining* by category.

Table 99: Factors and results of the assessment of plastic litter input and fate based on coastal litter

No.	Calculated variable	Calculation	Seaside resorts	Other bathing sites	Other coast	Other inland coast of MV	Urban coast	Total amount
[1]	Quantity of waste collected [kg/(100 m*a)]		144	-	-	-	-	-
[2]	Slip rate base value [wt.%]		25%	75%	95%	95%	50%	-
[3]	Slip rate range [wt.%]		10-40%	60-90%	90-100%	90-100%	40-60%	-
[4]	Litter input base value [kg/(100 m*a]		96	67	12	0.4	35	-
[5]	Length of coast [km]		399	196	1,308	1,541	74	-
[6]	Plastic content of the litter [wt.%]		30%	30%	30%	30%	30%	-
[7]	Remaining plastic litter base value [t/a]	= [4] * [5] * [6] * [2]	29	30	43	1.6	3.9	107
[8]	Remaining plastic litter range [t/a]	= [4] * [5] * [6] * [3]	11-46	24-36	41-46	1.5-1.7	3.1-4.7	81-133

For the slip rate, the average value is also shown next to the range. For the litter input of the seaside resorts, a range and an average value are also given, because the data of the seaside resorts are based on actually collected waste quantities. Based on the collected waste quantities of seaside resorts, the litter input changes with varying slip rate. The litter input for the other inland coast of MV is 3.2% of the litter input at the other coast (see chapter 10.7.1.3). In order to obtain the amount of remaining plastic litter of all categories, the base values of the remaining plastic litter from Table 99 were added, which together result in 107 t/a. The corresponding range is 81-133 t/a.

10.8 Sub topic: cigarette butts

In the following digression, the input of cigarette butts is considered separately. While in the other examinations of the plastic litter input no separate consideration of individual products or product groups is given, cigarette butts are again separately analysed due to their dominance among the littered waste.

For the following estimation of cigarette butt input and fate, an average dry weight of a cigarette butt of 0.2 g is assumed. In general, regarding the slip rate, it should be noted that due to their small size and in case of manual cleaning, which is not specifically designed for the collection of small pieces, cigarette butts can often only be collected at high time and cost. This is an obstacle to a high cleaning performance and causes a high slip rate. In addition, a high slip rate results from the relatively fast decomposition of the cigarette butts. Paper and tobacco residues can be biodegraded. In contrast, the filters, which are mainly made of cellulose acetate, cannot be biologically degraded. The filters decompose into their individual fibres after some time (Schneider and Gäth 2016). Schneider and Gäth (2016) investigated the decomposition of cigarette filters in different media. After five weeks, the weight loss of cigarette filters made of cellulose acetate in the media street/paving, meadow and soil was between 60-75 wt.% (Schneider and Gäth 2016). In the water medium, the weight loss after five weeks was 30-55% by weight.

10.8.1 Coast

MARLIN (2015) contains quantity-related data on littered cigarette butts on coastal sections. On rural, suburban and urban coastal sections in the Baltic Sea area 49.4 pcs./100 m, 111.5 pcs./100 m and 301.9 pcs./100 m were counted. The cleaning slip of these counts is estimated at 10 pcs.%. The reason for this estimation is that Schernewski et al. (2017) collected an average of 10 pcs.% of the total amount of waste (from cleaning and control) during the inspection of five beach sections already collected. Thus, for the amount of littered cigarette butts on rural, suburban and urban coastal sections in the Baltic Sea area, 54.9 pcs./100 m, 123.9 pcs./100 m and 335.4 pcs./100 m respectively are obtained.

In chapter 10.7.5.2 it was assumed for plastic litter that it is replaced once a month on a stretch of coast and that within the month the entry is six times the stock. The latter was neglected with regard to cigarette butts, as cigarette butts are less likely to be blown away due to the small surface area of attack and the possible increase in weight caused by water. Thus the factor twelve remains, with which the above values (rural: 54.9 pcs./100 m; suburban: 123.9 pcs./100 m; urban: 335.4 pcs./100 m) have to be multiplied to obtain the annual cigarette butt input at the Baltic Sea coast (rural: 658.7 pcs./(100 m*a); suburban: 1,486.7 pcs./(100 m*a); urban: 4,025.3 pcs./(100 m*a)). It was assumed that these figures are representative for the German coast.

For the length estimation of urban coastal sections along the German coast, the lengths of the seaside bathing areas were used (see chapter 10.7.2.1: 399 km). For the length estimation of the suburban coastal sections along the German coast the lengths of the other bathing sites were used (see chapter 10.7.2.2: 196 km). For the length estimation of the rural coastal sections along the German coast the lengths of the other coasts were used (see chapter 10.7.2.3: 1,308 km). The cigarette butt input of the other inland coast of MV (see chapter 10.7.2.4: 1,541 km) amounts to 3.2% of the cigarette butt input of the other coast. The reason for this conversion factor can be found in chapter 10.7.1.3.

Compared to the slip rates for beach litter in general, the slip rates for cigarette butts in particular were estimated to be higher because of the assumed small size of the litter. Enquiries to the owners and providers of bathing sites (see chapter 10.7.3), it was assumed that in the comparison of the individual categories, automatic cleaning takes place mainly in seaside resorts.

The beach cleaning machine manufacturers Kässbohrer Geländefahrzeug AG (n.y.) and H Barber & Sons (n.y.) state that the use of their machines makes it possible to remove cigarette butts. However, the manufacturers do not state any cleaning performance with regard to cigarette butts. Based on this, the slip rate for cigarette butts in seaside resorts was estimated at 50% by weight (range 25-75% by weight), because even with a cleaning performance of 100%, there are periods of time between cleanings during which cigarette butts can be blown away or washed away. Furthermore, it is possible that some areas on the beach are not covered by the cleaning machines and have to be cleaned manually. Manual cleaning is considered less thorough than machine cleaning, as cigarette butts covered with sand are overlooked and machine cleaning extends to a depth of 15-30 cm. For all other categories, a slip rate of 95% by weight (range: 90 - 100%) was assumed, since within these categories, manual cleaning is predominant, if at all. This results in a total amount of remaining cigarette butts of 3.5 t/a (2.6 4.3 t/a) (see Table 100).

Table 100: Factors and results of the estimation of cigarette butt input and fate caused by coastal litter

No.	Calculated variable	Calculation	Seaside resorts	Other bathing sites	Other coast	Other inland coast of MV	Total amount
[1]	Cigarette butt input [pcs./(100 m*a)]		3,622.8	1,338.0	592.8	18.9	-
[2]	Average weight [g/Stk.]		0.2	0.2	0.2	0.2	-
[3]	Weight cigarette butt [g/(100 m*a)]	= [1] * [2]	725	268	119	4	-
[4]	Length [km]		399	196	1,308	1,541	-
[5]	Slip rate base value [wt.%]		50%	95%	95%	95%	-
[6]	Slip rate range [wt.%]		25%-75%	90%-100%	90%-100%	90%-100%	-
[7]	Remaining cigarette butts base value [t/a]	= [3] * [4] * [5]	1.4	0.50	1.5	0.055	3.5
[8]	Remaining cigarette butts range [t/a]	= [3] * [4] * [6]	0.72-2.2	0.47-0.52	1.4-1.6	0.052-0.058	2.6-4.3

The litter input for the other inland coast of MV is 3.2% of the litter input on the other coast (see chapter 10.7.1.3).

10.8.2 Inland bathing sites

The estimation of cigarette butt input and fate is based on the estimation of other bathing places in chapter 10.8.1. A cigarette butt entry of 1,338 pcs./(100 m*a) and a slip rate of 95% (90-100% by weight) is also assumed. With a total length of 215 km (see chapter 4.10.1), this results in a quantity of remaining cigarette butts of 547 kg/a (518-575 kg/a).

Table 101: Factors and results of the estimation of cigarette butt input and fate caused by litter on inland bathing sites

No.	Calculated variable	Calculation	Other bathing sites
[1]	Cigarette butt input [pcs./(100 m*a)]		1,338
[2]	Average weight [g/pcs.]		0.2
[3]	Weight of cigarette butts [g/(100 m*a)]	= [1] * [2]	268
[4]	Length [km]		215

No.	Calculated variable	Calculation	Other bathing sites
[5]	Slip rate base value [wt.%]		95%
[6]	Slip rate range [wt.%]		90%-100%
[7]	Remaining cigarette butts base value [t/a]	= [3] * [4] * [5]	0.55
[8]	Remaining cigarette butts span [t/a]	= [3] * [4] * [6]	0.52-0.58

10.8.3 Riverside strip

Of the total 141,726 km of all rivers with a catchment area of more than 10 km² (BfN 2004), it is estimated that 80% are located in rural areas and 20% in urban areas (see chapter 10.6.1). For urban areas, cigarette inputs were assumed to be equal to cigarette inputs from urban coasts (see chapter 10.8.1: 1,207.6 pcs./(100 m*a)). For rural areas, the values of the rural coast were not used because the rural coast was considered to be a greater attraction for tourists than rivers with a catchment area of more than 10 km², and because many riversides with smaller catchment areas are poorly or not at all accessible. Based on this, the cigarette intake in rural areas was estimated to be 1% of the urban area (12 pcs./100 m*a). The slip rate on riversides in urban areas was estimated at that of parks (base value: 50 wt.%; range: 25-75 wt.%). The slip rate on riversides in rural areas was estimated to be 95% by weight (90-100% by weight) due to infrequent cleaning and long cleaning intervals. This results in a total amount of remaining cigarette butts on riversides of 60 t/a (42 79 t/a).

Table 102: Factors and results of the estimation of cigarette butt input and fate based on litter on riverside strips

No.	Calculated variable	Calculation	Urban area	Rural area	Total amount
[1]	Cigarette butt input [pcs./(100 m*a)]		1,207.6	12	-
[2]	Average weight [g/pcs.]		0.2	0.2	-
[3]	Weight of cigarette butts [g/(100 m*a)]	= [1] * [2]	2,415	24	-
[4]	Length [km]		28,345	113,381	-
[5]	Slip rate base value [wt.%]		50%	95%	-
[6]	Slip rate range [wt.%]		25-75%	90%-100%	-
[7]	Remaining cigarette butts base value [t/a]	= [3] * [4] * [5]	34	26	60
[8]	Remaining cigarette butts span [t/a]	= [3] * [4] * [6]	17-51	24-27	42-79

10.8.4 Roadsides

Due to unavailable literature data, the inputs at roadsides of the motorways were oriented towards those of the urban coast. An entry of 1,000 pcs./(100 m*a) was assumed (see Table 103). For the other road categories, with the exception of other roads, a gradation was used to determine the cigarette butt input based on this value in accordance with the DTV (see Table 103). The cigarette butt input of the category other roads was estimated to be about two thirds of the input of the district roads. The reason for this is that the amount of waste collected from other roads (15 kg/(km*a)) was also about two thirds of the amount of waste collected from district roads (22 kg/(km*a)) (see chapter 10.2.4.3). The slip rate was estimated to be 95% by weight (range 90-100% by weight), as it was assumed that roadsides are mainly cleaned manually and cigarette butts are easily covered by plants due to their small size and are thus overlooked. In addition, it is likely that the focus of roadside cleaning is on larger wastes, as these contribute more to visual pollution for drivers and locals. Taking into account the distances of the individual road categories, the total amount of remaining cigarette butts is 97.6 t/a (92.5 102.8 t/a) (see Table 103).

Table 103: Factors and result of the estimation of cigarette butt input and fate based on litter at roadsides

No.	Calculated variable	Calculation	MW	FR	SR	DR	oR	Total amount
[1]	Cigarette butt input [pcs./(100 m*a)]		1,000	186	80	50	33	-
[2]	DTV [vehicle/24 h]		50,149	9,323	4,000	2,500	-	-
[3]	Average weight [g/pcs.]		0.2	0.2	0.2	0.2	0.2	-
[4]	Cigarette butt input [g/(km*a)]	= [1] * [3]	2,000	372	160	100	66	-
[5]	Slip rate base value [wt.%]		95%	95%	95%	95%	95%	-
[6]	Slip rate range [wt.%]		90-100%	90-100%	90-100%	90-100%	90-100%	-
[7]	Length [km]		12,996	38,069	86,970	91,939	600,000	-
[8]	Remaining plastic litter base value [t/a]	= [4] * [5] * [7]	24.7	13.4	13.2	8.7	37.6	97.6
[9]	Remaining plastic litter range [t/a]	= [4] * [6] * [7]	23.4-26.0	12.7-14.2	12.5-13.9	8.2-9.2	35.6-39.6	92.5-102.8

The abbreviations used stand for the following street categories: MW - motorway, FR - federal roads, SR - state roads, DR - district roads, oR - other roads. The information on the length of the MW, FR, SR and DR roads is taken from Destatis (2017a). The route length of the oR is taken from BMVI (2016). The DTV's data for the MW are from (BASt 2017) and refer to the year 2015. The DTV's data for the FR are from (BASt 2013) and refer to the year 2010. The DTV's data for the SR and DR are own estimates (see chapter 10.2.2).

10.8.5 Pedestrian zones

Ableidinger (2004) has also conducted counts of cigarette butts in the pedestrian zones of the five European cities. In Barcelona, Brussels, Frankfurt, Prague and Vienna 4,895.9 pcs./(ha*d), 7,150.5 pcs./(ha*d), 2,700.5 pcs./(ha*d), 4,126.3 pcs./(ha*d) and 1,592.8 pcs./(ha*d) were determined (mean value: 4,093.2 pcs./(ha*d)). For pedestrian zones in Germany, the input was estimated to be 2,000 pcs./(ha*d), since the pedestrian zones investigated by Ableidinger (2004) were heavily frequented by tourists, which is why a higher *litter input* from cigarette butts is to be expected there than on average pedestrian zones in German cities. Due to the fact that the cleaning of cigarette butts with sweepers is relatively easy if they are located on level surfaces, but relatively costly if they collect in joints or tree discs, and that a not negligible portion is also discharged into the environment via the sewerage system and receiving water (Berliner Wasserbetriebe 2017), the slip rate was estimated at 15% by weight (5-25% by weight). Overall, this results in an input of 19 t/a (6-32 t/a) (see Table 104).

Table 104: Factors and result of the estimation of the cigarette butt input and fate caused by litter in German pedestrian zones

No.	Calculated variable	Calculation	Pedestrian zone
[1]	Cigarette butt input [pcs./(ha*d)]		2,000
[2]	Average weight [g/Stk.]		0.2
[3]	Cigarette butt input [t/(km²*a)]	= [1] * [2]	15
[4]	Slip rate base value [wt.%]		15
[5]	Slip rate range [wt.%]		5-25
[6]	Pedestrian zone area [km²]		8.86
[7]	Remaining plastic litter base value [t/a]	= [3] * [4] * [6]	19
[8]	Remaining plastic litter range [t/a]	= [3] * [5] * [6]	6-32

10.8.6 Parks

On the basis of the investigations by Ableidinger (2004), the cigarette butt input in parks was estimated to be one percent of the input in pedestrian zones (see Table 105). The reason for this is that parks are generally less frequented than pedestrian zones, especially in winter. The slippage rate was estimated to be higher than in pedestrian zones because the use of mechanical cleaning, which is considered to be more thorough, is often not possible (base value: 50% by weight, range: 25-75% by weight). This results in a total amount of remaining cigarette butts from litter in parks of 29 t/a (14-43 t/a).

Table 105: Factors and result of the estimation of cigarette butt input and fate caused by litter in German parks

No.	Calculated variable	Calculation	Parks
[1]	Cigarette butt input [pcs./(ha*d)]		2,000
[2]	Average weight [g/Stk.]		0.2
[3]	Cigarette butt input [kg/(km²*a)]	= [1] * [2]	146
[4]	Slip rate base value [wt.%]		50%
[5]	Slip rate range [wt.%]		25-75%
[6]	Park area [km²]		392
[7]	Remaining cigarette butts base value [t/a]	= [3] * [4] * [6]	29
[8]	Remaining cigarette butts span [t/a]	= [3] * [5] * [6]	14-43

10.8.7 Rest stops

There was no literature data available on cigarette butt input at rest stops. In order to estimate the cigarette butt input at rest stops, the quotient of the cigarette butt input from parks (see chapter 0: 146 kg/(km^2*a)) and the waste input from parks (see chapter 10.4.5: 258 t/(km^2*a)) was calculated. This quotient (rounded 0.06 wt.%) was then multiplied by the litter input from rest stops (1,809 t/a, see chapter 10.3.5) to calculate the cigarette butt input from rest stops (1.3 t/a). The quotient was calculated with reference to the parks, as these are the most similar to the rest stops compared to the other land use types. The slip rate was assumed to be comparable to that of the parks and was also estimated to be 50% by weight (25-75 % by weight). This results in a quantity of remaining cigarette butts of 0.7 t/a (0.3-1.0 t/a) (see Table 106).

Table 106: Factors and results of the estimation of cigarette butt input and fate caused by litter at rest stops

No.	Calculated variable	Calculation	Rest stops
[1]	Cigarette butt input [t/a]		1.3
[2]	Slip rate base value [wt.%]		50%
[3]	Slip rate range [wt.%]		25%-75%
[4]	Remaining cigarette butts base value [t/a]	= [1] * [2]	0.7
[5]	Remaining cigarette butts span [t/a]	= [1] * [3]	0.3-1.0

10.8.8 Summary of results: annual remaining quantity of cigarette butts

Table 107 lists the results of the estimation regarding the quantities of remaining cigarette butts for the land use types considered. The sum of the quantities of all land use types considered is 210 t/a (158-262 t/a). Cigarette butts were also examined in the area of plastics applications. Here, a quantity of 162 to 1,620 t/a was determined, whereby the upper limit of 10% assumed here on the basis of the fate classes is to be assessed as tending to be too high in the view of the experts. However, as concrete data for a justified deviation from the assumed environmental impact category were not available, this upper limit was nevertheless expected. In principle, therefore, the results of both calculation approaches are of the same order of magnitude.

Table 107: Quantity of remaining cigarette butts for the land use types under consideration with total sum

Type of land use	Remaining cigarette butts [t/a]
Roadsides	98 (93-103)
Rest stops	0.7 (0.3-1.0)
Parks	29 (14-43)
Pedestrian zones	19 (6.5-32)
Riverside strips	60 (42-79)
Coast	3.5 (2.6-4.3)
Inland bathing sites	0.55 (0.52-0.58)
Total amount	**210 (158-262)**

11 Appendix B: Product group – "fact sheets"

The brief descriptions of the product groups considered in the following serve to assess the current data status.

A simple triple scale was chosen to assess the data quality of the quantities placed on the market and the derivations made:

- good (data/information – qualified statistical data, own reports or information from market participants – are available which allow a reliable statement on the quantities placed on the market and estimates of the fate quantities)
- medium (there is some information that allows an estimate to be made, but this will need to be validated in case of further prioritisation)
- poor (the data are based on little information or estimates, the reliability of which cannot be conclusively verified within the given project framework)

11.1 Characterisation of the product groups in the product category construction sector

11.1.1 Construction films (1-01)

Product description: plastic films with various applications in the construction industry. Often made of the plastics PE and PP as well as PVC.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and discussions with experts. Statistics on production quantities available.

Overview and naming of relevant additives: flame retardants, plasticizers, stabilizers, antistatics, dyes, fillers.

Description of the input mechanism, input category and characterisation of the input by input location: remain within the construction site area. Input occurs by chipping, separation of smaller particles after/during use. Places of discharge are settlement areas or construction area/near buildings/after use: dismantling/removal.

Description of the input time horizon: < 1 year

Assumption for the fate factor: min. 0.005/base 0.01/max. 0.015. Estimate by Consultic based on internal study.

Assessment of data quality: medium. Production statistics appear valid (Prodcom). A problem is the inconsistent categorisation in the production statistics.

11.1.2 Geotextiles (1-02)

Product description: flat or three-dimensional textiles. Used primarily in civil engineering, waterways and traffic route construction. Consists among others of PP, PA, and PES.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and discussions with experts. No statistics on quantities used in Germany.

Overview and designation of relevant additives: no data available.

Description of the input mechanism, input category and characterisation of the input by input location: weathering/abrasion by pollution, remaining in the environment after use, missing/not complete removal after use. Settlement areas - mainly roads as well as gardens and landscaping.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.5/base 0.7/max. 0.9. Estimate by Consultic based on internal study.

Assessment of data quality: medium.

11.1.3 Facade elements (1-03)

Product description: facade panels e.g. in wall optics. Often made of PVC.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and discussions with experts. There are no statistics available.

Overview and naming of relevant additives: flame retardants, stabilizers, plasticizers, dyes, antistatics.

Description of the input mechanism, input category and characterisation of the input by input location: remain within the construction site area. Input occurs by separation/chipping (e.g. weathering) of small particles during use. The place of input is on settlement areas and in the construction area close to buildings. After use: dismantling/removal.

Description of the input time horizon: 10 - 30 years.

Assumption for the fate factor: min. 0.00005/base 0.0001/max. 0.00015. Estimation by Consultic based on an internal study.

Assessment of data quality: poor.

11.1.4 Storage tents (1-04)

Product description: plastic tents for storage purposes. Many tents are made of PVC.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study) and discussions with experts. Statistics are available. A problem is the imprecise categorisation in the production statistics.

Overview and naming of relevant additives: plasticisers.

Description of the entry mechanism, input category and characterisation of the input by input location: input occurs during use (abrasion & weathering or by leaching). After use, removal takes place. To be found both on settlement areas and in agricultural areas.

Description of the input time horizon: <1 year

Assumption for the fate factor: min. 0.00005/base 0.0001/max. 0.00015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.1.5 Palisades (1-05)

Product description: screening palisades e.g. for balconies, palisades for bordering flower beds, gardens. Various types of plastics such as PVC, PP, PE-LD, PE-HD are used.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and discussions with experts. No production statistics available. Definition of the category is problematic.

Overview and designation of relevant additives: flame retardants, stabilizers, plasticizers.

Description of the input mechanism, input category and characterisation of the input by input location: remain within the construction site area. Input occurs by separation/chipping (e.g. weathering) of small particles during/after use.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.005/base 0.01/max. 0.015. Estimate by Consultic based on internal study.

Assessment of data quality: poor.

11.1.6 Grass paver (1-06)

Product description: structural reinforcement of trafficable and at the same time greened traffic areas, such as garden and footpaths, driveways or parks. Mainly plastics such as PE-LD, PE-HD are used.

Data basis for quantities placed on the market: estimation based on internally available data (consultative study) and discussions with experts. No production statistics available.

Overview and naming of relevant additives: plasticizers, antistatics**.**

Description of the input mechanism, the input category and characterisation of the input by input location: Input is by separation/chipping (e.g. weathering) of small particles during or after use or by incomplete removal after use. Places of input are settlement areas as well as sports fields and recreational facilities/after use: partial removal.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.01/base 0.055/max. 0.1. Estimate by Consultic based on internal study.

Assessment of data quality: poor.

11.1.7 Drainage channels (rain gutters) (1-07)

Product description: component for line drainage of surfaces. A large part of the gutters is made of PVC.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study) and discussions with experts. No production figures available.

Overview and naming of relevant additives: plasticizers.

Description of the input mechanism, the input category and characterisation of the input by input location: Input is by separation/chipping (e.g. weathering) of small particles during/after use or by incomplete removal after use. Input occurs mainly in settlement areas and technical infrastructure/after use: removal, if used in the soil, possibly where it remains.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.01/base 0.055/max. 0.1. Estimate by Consultic based on internal study.

Assessment of data quality: poor.

11.1.8 Cable sheathing (1-08)

Product description: insulation material for cable insulation. Mainly PVC and PE are used for insulation.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study) and discussions with experts. Production figures are partly available (Prodcom).

Overview and naming of relevant additives: flame retardants, stabilizers, plasticizers, antistatic agents, dyes, fillers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by separation/chipping (e.g. weathering) of small particles during/after use. Input locations are urban areas and the area of technical infrastructure.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.005/base 0.01/max. 0.015. Estimate by Consultic based on internal study.

Assessment of data quality: poor.

11.1.9 Pipes (1-09)

Product description: supply and sewage pipes. Mainly underground supply networks. Often made of PVC, PE, and PP.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and discussions with experts. Production statistics are available (Prodcom), as well as statistics from the Plastic Pipes Association KRV.

Overview and naming of relevant additives: flame retardants, stabilizers, plasticizers, antistatics, dyes, fillers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by separation/chipping (e.g. weathering) of small particles during/after use or by incomplete removal after use.

Description of the input time horizon: > 30 years

Assumption for the fate factor: min. 0.01/base 0.055/max. 0.1. Estimate based on DWA study (German Water and Wastewater Association) – calculation over the length of laid pipes in Germany.

Assessment of data quality: medium. Production statistics appear valid.

11.1.10 Formed parts (1-10)

Product description: dowels, tubular elements (e.g. T-pieces). Often consist of PVC, PE, and PP.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and discussions with experts. Calculation on the basis of information regarding the laid pipe kilometres. Statistics are available (Destatis) as well as statistics from the Plastic Pipe Association KRV, which covers the fittings required for pipes.

Overview and naming of relevant additives: flame retardants, stabilizers, plasticizers, antistatic agents, dyes, fillers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by separation/chipping (e.g. weathering) of small particles during/after use or by incomplete removal after use.

Description of the input time horizon: strongly varying – for fittings used for pipes >30 years, otherwise depending on the type of application or use of the fitting.

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Data quality assessment: poor.

11.1.11 IBC storage tanks above ground (1-11)

Product description: Intermediate Bulk Containers (IBC) are used for transport and storage of liquid and free-flowing materials. They are used in the production of chemicals, foodstuffs, cosmetics and pharmaceuticals. Often consist of PVC.

Data basis for quantities placed on the market: statistics on import and export figures are available for containers with a capacity of more than 300 litres (Prodcom), but no production figures are available, so the quantity placed on the market cannot be determined.

Overview and naming of relevant additives: stabilisers, plasticisers, fillers.

Description of the input mechanism, input category and characterisation of the input by input location: input occurs by separation/chipping (e.g. weathering) of small particles during locations of input are urban and agricultural areas. After use: withdrawal.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.1.12 Roof coverings (1-12)

Product description: plastic roof panels, corrugated plastic for e.g. summer houses. Often consist of PVC or PC.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study) and discussions with experts.

Overview and naming of relevant additives: flame retardants, stabilizers, plasticizers, colorants.

Description of the input mechanism, the input category and characterisation of the input by input location: input occurs over the useful life by leaching and by separation/chipping (e.g. weathering) of small particles. The input occurs mainly in urban and agricultural areas.

Description of the input time horizon: 10 < 30 years

Assumption for the fate factor: min. 0.00005/base 0.0001/max. 0.00015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.1.13 External insulation (1-13)

Product description: exterior insulation for buildings. For example EPS panels for thermal insulation. PS, EPS, XPS are used as materials.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and technical discussions with experts

Overview and designation of relevant additives: flame retardants, stabilizers, dyes.

Description of the input mechanism, the input category and characterisation of the input by input location: input occurs to a very small extent over the useful life by separation/chipping (e.g. weathering) of small particles. Entry sites are particularly common in urban areas.

Description of the input time horizon: >30 years

Assumption for the fate factor: min. 0.00005/base 0.0001/max. 0.00015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.1.14 Cable channels (1-14)

Product description: a system for laying electrical cables. Serves to protect and mechanically relieve the cables. Among others PVC, PE and GFK are used, e.g. along railway lines.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and technical discussions with experts.

Overview and naming of relevant additives: flame retardants, stabilisers, plasticisers, dyes, fillers.

Description of the input mechanism, input category and characterisation of the input by input location: input occurs over the useful life by leaching and by separation/chipping (e.g. weathering) of small particles after use. Input points are urban areas and technical infrastructure sites.

Description of the input time horizon: > 30 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.1.15 Polymer Cement Concrete (PCC) (1-15)

Product description: polymer-modified mortar/concrete, in which certain fresh and hardened mortar properties are favourably influenced by the addition of a plastic. Can consist of numerous types of plastic (PVA, PAE, EP), most frequently used for pipe and gutter systems.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and technical discussions with experts. No statistics available. In the future possible enquiries to/discussions with producers.

Overview and designation of relevant additives: no data available.

Description of the input mechanism, input category and characterisation of the input by input location: input occurs over the useful life by leaching and by separation/chipping (e.g.

weathering) of small particles after use. The main places of entry are urban areas and the building sector close to buildings.

Description of the input time horizon: >30 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: medium. Difficult data situation, as PCC is a specialized product group.

11.1.16 Plastic windows (1-16)

Product description: plastic frame for the use of window glass. Mainly used in houses. Various plastics are used, for example PVC, PU, PE, WPC (Wood-Plastics-Composites).

Data basis for quantities placed on the market: estimation based on internally available data (consultative study) and discussions with experts.

Overview and naming of relevant additives: flame retardants, stabilizers, plasticizers, colorants

Description of the input mechanism, the input category and characterisation of the input by input location: input is made over the useful life by leaching and by separation/chipping of small particles after use. (E.g. during removal or replacement of windows); entry sites are mainly urban areas and the building area close to buildings.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.00005/base 0.0001/max. 0.00015. Estimation by Consultic based on internal study

Assessment of data quality: poor.

11.1.17 Seepage blocks (1-17)

Product description: drainage system to drain off rainwater. Plastic drainage systems often consist of PE and PP.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study) and discussions with experts. There are no statistics available. In the future, enquiries or discussions with producers could be considered. It is particularly difficult to identify individual additives in the seepage blocks.

Overview and naming of relevant additives: fillers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by separation/chipping of small particles after use during dismantling. Input is by retention in soil or by incomplete removal after use. Input sites are urban areas and the building area close to buildings.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min 0.01 /base 0.055 /max. 0.1. Estimate by Consultic based on internal study.

Assessment of data quality: poor.

11.1.18 Noise protection walls (1-18)

Product description: on average 4 m high walls along roads for planting/noise protection for trains with plastic problematic due to high suction effect and the need for special permits.

Data basis for quantities placed on the market: noise protection statistics 2015, discussions with manufacturers.

Overview and naming of relevant additives: stabilizers, plasticizers, colorants.

Description of the input mechanism, the input category and characterisation of the input by input location: input occurs to a lesser extent during dismantling, which usually takes place after a very long period of time, in problematic cases even after a few years (e.g. when plastic walls cannot support the weight). Low levels of contamination may also be caused by game browsing.

Description of the input time horizon: usually >10 years

Assumption for the fate factor: min. 0.0005 /base 0.001/max. 0.0015

Data quality assessment: Medium,

11.1.19 Construction paints (1-19)

Product description: paints for exterior use on buildings.

Data basis for quantities placed on the market: Ökopol data and estimation of the proportion of plastics in paints based on own research and expert discussions (Association of the German Paint and Printing Ink Industry). Assumption of the proportion of plastics in all relevant paints is 20-25%, therefore a proportion of 22.5% was used for the calculation.

Overview and naming of relevant additives: stabilizers, dyes, antistatic agents, flame retardants.

Description of the input mechanism, the input category and characterisation of the input by input location: input is usually caused by weathering during use.

Description of the input time horizon: usually >10 years

Assumption for the fate factor: min. 0.0025 /base 0.005/max. 0.0075 (data from external studies are available that differ from the fate factors otherwise used)

Assessment of data quality: good.

11.2 Characterisation of the product groups in the product category vehicles/traffic

11.2.1 Tyres (2-01)

Product description: rubber tyres for cars/truck/motorcycle. Synthetic and natural rubber.

Data basis for quantities placed on the market: calculation based on data from a study by the German Environment Agency on tyre wear per kilometre driven per tyre in combination with data from the Federal Highway Research Institute on kilometres driven in Germany for cars, trucks and motorcycles (and the number of tyres per means of transport). In addition, assumptions were made on the basis of the figures by the Federal Highway Research Institute for the proportion of kilometres travelled within the city.

According to a Continental study, tyre abrasion is composed of approximately 42% rubber, 34% carbon black, 17% mineral oils and 9% other.

Statistics on production figures are available, but were not used for methodological reasons.

In addition to car, truck and motorcycle tyres, the agricultural use of used tyres could also play a role in the environmental input. However, no reliable figures are available for this.

Overview and designation of relevant additives: stabilizers, plasticizers, fillers.

Description of the input mechanism, the input category and characterisation of the input by input location: abrasion in use. Input occurs during the entire period of use. Place of input is the road network.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: (min. 0.05/base 0.1/max. 0.15.) Calculation is backwards based on assumptions for abrasion, not, as otherwise in the study, taking into account the quantity placed on the market with the respective fate factor.

Evaluation of data quality: good (except agricultural use of used tyres). Conformity of the underlying value e.g. with assumptions in the Federal Ministry of Education and Research (BMBF) project DENANA. In the further finalisation a methodological approach should be developed to make a more precise estimate of the proportion of inner-city driven kilometres per vehicle type, since it can be assumed that inner-city abrasion is fed into a regular disposal system via sweepers or sewers and is therefore not relevant for the study.

11.2.2 Barriers (2-02)

Product description: road closures for traffic flow control, blocking of entrances, roads etc. They often consist of PVC and PE.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study). No statistics are available. In the future, enquiries to road traffic offices could be considered.

Overview and naming of relevant additives: stabilizers, plasticizers, colorants.

Description of the input mechanism, input category and characterisation of the input by input location: input is by leaching and separation/chipping (e.g. weathering) of small particles during use. The primary point of input is roads and the building area close to the building.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.2.3 Road markings (2-03)

Product description: plastic marking film which is applied on traffic routes. Types of plastics including PVC, PE. PES.

Data basis for quantities placed on the market: Ökopol Study on water- and solvent-based road markings, figures on thermoplastic and cold-plastic systems and adhesive films still to be determined – Evonik is currently working on a study on this and has supplied data.

Overview and naming of relevant additives: PVC, PE, PES.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by separation/chipping (e.g. weathering) of small particles during use. No remaining after use. Place of entry is the road network.

Description of the input time horizon: <1 year

Assumption of the fate factor (for water- and solvent-based markings and thermoplastic systems): min. 0.5/base 0.70/max. 0.90. Estimate by Consultic based on discussions with Evonik and road maintenance authorities.

Data quality assessment: medium. Comparative study available for other countries.

11.2.4 Guide elements (2-04)

Product description: elements for traffic guidance on all traffic routes. For example, for traffic flow control in road works. Often made of PE-HD, PVC or PP.

Data basis for quantities placed on the market: estimate based on internally available data (consultative study). No production statistics available. Consider requesting authorities in the future.

Overview and naming of relevant additives: plasticizers, stabilizers, colorants.

Description of the input mechanism, input category and characterisation of the input by input location: input is by leaching and separation/chipping (e.g. weathering) of small particles during use. The point of entry is all transport routes.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.2.5 Beacons (2-05)

Product description: pylons, mostly in red and white for traffic control in construction sites, e.g. illuminated with yellow light. Are mainly made of PE.

Data basis for quantities placed on the market: estimate based on internally available data (consultative study). No statistics available. In the future, possible enquiries to the Water and Shipping Authority.

Overview and naming of relevant additives: stabilizers, dyes.

Description of the input mechanism, input category and characterisation of the input by input location: input is by leaching and separation/chipping (e.g. weathering) of small particles during use. Entry sites can be inland bathing sites or the North Sea and Baltic Sea coasts.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study

Assessment of data quality: poor.

11.2.6 Base plates (2-06)

Product description: base of traffic signs or beacons for fixing traffic signs on the road, mainly made of PVC, often recycled material.

Data basis for quantities placed on the market: estimate based on internally available data (consultative study). No statistics available.

Overview and naming of relevant additives: plasticizer, carbon black for black colouring, no data available.

Description of the input mechanism, input category and characterisation of the input by input location: Input is by separation/chipping (e.g. weathering, roadkill by cars and trucks) of small particles during use. The place of entry is all roads.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.005/base 0.01/max. 0.015. Estimation by Consultic based on internal study and discussion with road maintenance department.

Assessment of data quality: poor.

11.2.7 Vehicle parts (2-07)

Product description: plastic components in vehicles e.g. engine compartment covers. They are either directly exposed to the environment and are subject to weathering or are released into the environment through accidents. Can consist of various types of plastic such as PA, PE, GFK (fibre-reinforced plastic material).

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study. Statistics on the number of cars registered in Germany available.

Overview and naming of relevant additives: flame retardants, colorants, plasticizers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by leaching and dropping of parts during use (e.g. covers) the point of entry is the road network.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.2.8 Waste bins (2-08)

Product description: plastic containers for waste storage. Often made of PE or PVC.

Data basis for quantities placed on the market: the quantities stated are estimates based on a discussion with a leading manufacturer (2.75 million new tonnes at 8 kg + 265,000 new tonnes at 42 kg = approx. 33,100 t); production figures for waste containers from Destatis show quantities three times higher.

Overview and designation of relevant additives: no data available.

Description of the input mechanism, input category and characterisation of the input by input location: input is by leaching and separation/chipping (e.g. abrasion) of small particles during use. The point of entry is all urban areas.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015 (estimated value).

Data quality assessment: medium.

11.2.9 Ship paint (2-09)

Product description: external painting of watercraft, no data available on plastics used.

Data basis for quantities placed on the market: base quantity from Destatis data and figures by the Association of the German Paint and Printing Ink Industry.

Overview and naming of relevant additives: stabilizers, dyes, antistatics, flame retardants.

Description of the input mechanism, the input category and characterisation of the input by input location: input is made during the whole period of use, partly remaining after use of decommissioned vehicles.

Description of the input time horizon: no data available, estimate: >10 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015

Assessment of data quality: good.

11.2.10 Bicycle tyres (2-10)

Product description: rubber tyres for cars/truck/motorcycle. Synthetic and natural rubber.

Data basis for quantities placed on the market: rough own calculation based on the stock of bicycles and an assumption of the average tyre wear.

Overview and naming of relevant additives: stabilisers, plasticisers, fillers.

Description of the input mechanism, the input category and characterisation of the input by input location: abrasion in use. Input occurs during the entire period of use. Place of input is the road network.

Description of the input time horizon: 1 - 10 years

Assumption on the fate factor: calculation is based on various assumptions for the average abrasion (15, 20 and 25 g per year and tyre) and the number of bicycles in Germany, not, as otherwise in the study, taking into account the quantity placed on the market with the respective fate factor.

Assessment of data quality: medium.

11.2.11 Shoes (2-11)

Product description: footwear with plastic soles. Often made of leather, natural latex, mixture of natural latex and artificial rubber, PE, PU or TPU.

Data basis for quantities placed on the market: not analysed in detail. First estimates were made on the abrasion of the soles per year mentioned by experts, which can be roughly assumed to be 10 to 20 g (sole weighs between 50 and 300 g). In thought, it was assumed that one pair of shoes is worn all year round. With around 160 million shoes, it can therefore be assumed that between 1,600 and 3,200 tonnes remain.

Overview and naming of relevant additives: stabilizers, plasticizers (proportion approx. 20%), dyes-

Description of the input mechanism, the input category and characterisation of the input by input location: Input occurs primarily by abrasion during the entire period of use. The input occurs mainly in settlement areas, but in principle all areas where people wear shoes are relevant.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: Not used here, calculation was based on abrasion per sole.

Assessment of data quality: poor.

11.3 Characterisation of the product groups in the product category agriculture and horticulture

11.3.1 Pond liners (3-01)

Product description: plastic foil for sealing ornamental ponds or otherwise. Pond systems often consist of PVC or PE-LD.

Data basis for quantities placed on the market: estimated value. No statistics available. In the future possibly enquiry to manufacturer.

Overview and designation of relevant additives: stabilisers, plasticisers.

Description of the input mechanism, the input category and characterisation of the input by input location: Input is by retention in soil or incomplete removal after use. Place of input is agricultural land or gardens of private individuals/after use: mainly removal.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.01 /base 0.055 /max. 0.1 (estimated value).

Assessment of data quality: poor.

11.3.2 Agricultural/harvesting films (3-02)

Product description: plastic film for use in agriculture. An example of application is the protection of the crop by covering (asparagus cover). The films are often made of PE or PP.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study). There are no known production quantities for Germany. The earth collection system of RIGK has been contacted.

Overview and designation of relevant additives: stabilisers.

Description of the input mechanism, the input category and characterisation of the input by input location: Input is by retention in soil, drifts or incomplete removal after use. The place of input is mainly agricultural land or gardens.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.01/base 0.055/max. 0.1

Assessment of data quality: medium.

11.3.3 Silage film (3-03)

Product description: film for airtight packaging of silage (animal feed). Often made of PVC.

Data basis for quantities placed on the market: estimate based on internally available data (consultative study). No statistics available. RIGK's earth collection system has been contacted.

Overview and designation of relevant additives: Plasticisers.

Description of the input mechanism, input category and characterisation of the input by input location: Input is by separation/chipping (e.g. abrasion) of small particles during use. The input is primarily via agricultural land.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.01/base 0.055/max. 0.1.

Assessment of data quality: medium.

11.3.4 Baler twines (3-04)

Product description: plastic threads to tie the hay bales together. Today, mainly synthetic binding twine made of PP is used.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study). No production quantities for Germany are known. In future, enquiries should be made to farmers. The quantities used there can be extrapolated to Germany.

Overview and naming of relevant additives: plasticisers.

Description of the input mechanism, the input category and characterisation of the input by input location: Input is by drifts, or incomplete removal after use. The place of input is mainly agricultural land.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.01/base 0.055 /max. 0.1

Assessment of data quality: poor.

11.3.5 Drainage (3-05)

Product description: drainage systems in film or net form, often made of non-woven fabric.

Data basis for quantities placed on the market: estimate based on internally available data (consultative study). No statistics available.

Overview and designation of relevant additives: plasticizers.

Description of the input mechanism, the input category and characterisation of the input by input location: Input is by retention in soil or incomplete removal after use and by wear or leaching. Entry sites can be both urban and rural areas.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.01/base 0.055 /max. 0.1

Assessment of data quality: poor.

11.3.6 Planting pots (3-06)

Product description: open container to hold the root system of plants or to store seedlings. Often made of PP, PVC or PE.

Data basis for quantities placed on the market: estimate based on internally available data (consultative study). No statistics available.

Overview and naming of relevant additives: plasticizers, colorants.

Description of the input mechanism, input category and characterisation of the input by input location: Input is by separation/chipping (e.g. abrasion) of small particles during use or incomplete removal after use. Entry sites can be both urban and rural areas.

Description of the input time horizon: < 1 year

Assumption for the fate factor: min. 0.01/base 0.055/max. 0.1. Estimate by Consultic based on internal study.

Assessment of data quality: poor.

11.3.7 Agricultural nets (3-07)

Product description: harvesting aids such as potato bags or leaf protection nets.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study). No statistics available. Manufacturers should be asked about production and sales volumes.

Overview and naming of relevant additives: fillers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by retention in soil after use (drifts, improper, incomplete disposal). Inputs are primarily via agricultural land.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.01/base 0.055/max. 0.1. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.3.8 Fertiliser (3-08)

Product description: pure substances and mixtures of substances used in agriculture, forestry and horticulture to supplement the nutrient supply for cultivated crops. Modern fertilisers contain a proportion of EPS to loosen the soil.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study). No statistics available. Manufacturers should be asked about production and sales volumes.

Overview and designation of relevant additives: no data available.

Description of the input mechanism, input category and characterisation of the input by input location: Input is by retention in soil after/during use (retention is part of use). The input is primarily via agricultural land, partly degradable plastics which dissolve after a few months (so-called depot fertilisers).

Description of the input time horizon: < 1 year

Assumption for the fate factor: min. 0.95 /base 0.975 max. First estimate by Consultic based on internal study

Assessment of data quality: poor.

11.3.9 Greenhouses (3-09)

Product description: translucent construction that allows the protected and controlled cultivation of plants. Are made of PE, PVC and PP, among others.

Data basis for quantities placed on the market: Estimate based on internally available data (Consultic Study). No statistics available. Greenhouse operators or nurseries could be questioned.

Overview and naming of relevant additives: plasticisers.

Description of the input mechanism, input category and characterisation of the input by input location: Input is by leaching or separation/chipping (e.g. abrasion) of small particles during use. The input is via agricultural land and urban areas.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.0005 /base 0.001 /max. 0.0015. Estimate by Consultic based on internal study.

Assessment of data quality: poor.

11.3.10 Fences (3-10)

Product description: area boundaries for outdoor areas such as gardens in private households. Often made of PVC or WPC (Wood-Plastics-Composites).

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study). No statistics available. Bauhaus could be asked about existing quantities.

Overview and designation of relevant additives: plasticizers, dyes.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by leaching or separation/chipping (e.g. weathering) of small particles after/during use. The input is via agricultural land and urban areas. Especially allotment gardens or single-family houses can generate inputs**.**

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.3.11 Gates (3-11)

Product description: Access to land and buildings. Often made of PVC.

Data basis for quantities placed on the market: Estimate based on internally available data (Consultic Study). No statistics available. Bauhaus could be asked about existing quantities.

Overview and naming of relevant additives: plasticizers, colorants.

Description of the input mechanism, the input category and characterisation of the input by input location: Input is by leaching or separation/chipping (e.g. weathering) of small particles after/during use. The input is via agricultural land and urban areas.

Description of the input time horizon: 1 - 30 years

Assumption for the fate factor: min. 0.0005 /base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.3.12 Other landscape design elements (3-12)

Product description: Decorative elements or other plastic fixtures. Various plastics are used, including PP, PE and PVC.

Data basis for quantities placed on the market: Estimate based on internally available data (Consultic Study). No statistics available. Hardware stores could be asked about existing quantities.

Overview and naming of relevant additives: depending on the respective design element.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by leaching or separation/chipping (e.g. weathering) of small particles after/during use. The input is via agricultural land and urban areas. Private gardens and allotment gardens are particularly noteworthy.

Description of the input time horizon: 1 - 30 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.3.13 Fishing industry nets (3-13)

Product description: textile structure with meshes and openings which is used for private and commercial fishing.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study). No statistics available. Fishing companies could be contacted.

Overview and designation of relevant additives: no data available.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by loss of material. The place of entry is the North Sea and Baltic Sea coasts or inland bathing areas/waterways.

Description of the discharge time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.005 /base 0.01/max. 0.015. Estimate by Consultic based on internal study.

Assessment of data quality: poor.

11.3.14 Buoy/fender (3-14)

Product description: Floats used as markers for shipping traffic or signal buoys for divers and swimmers. Often made of PVC.

Data basis for quantities placed on the market: estimate based on internally available data (Consultic Study). No statistics available. Fishing companies could be contacted.

Overview and designation of relevant additives: lubricants, dyes, plasticizers.

Description of the input mechanism, the input category and characterisation of the input by input location: input occurs over the useful life by leaching and small chipping (weathering). The place of discharge is the North and Baltic Sea coasts or inland bathing areas/waterways.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.0005/base 0.001/max. 0.0015. Estimation by Consultic based on internal study.

Assessment of data quality: poor.

11.3.15 Browsing protection (3-15)

Product description: protective netting or grating to secure young plants against animals. Often made of PVC or PE.

Data basis for quantities placed on the market: estimated value. No statistics are available. In the future, enquiries could be made to the forestry companies.

Overview and naming of relevant additives: plasticisers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is due to weathering, falling in forests, green areas. Contact by animals (wild boar, roe deer) or by incomplete removal after use; some composites, PVC protection rather foil, PE clips for tree tops.

Description of the input time horizon: 1 - 10 years

Data basis for quantities placed on the market: estimated value. No statistics are available. In the future, enquiries could be made to the forestry companies/after use: mainly withdrawal.

Assumption on the fate factor: min. 0.01/base 0.055/max. 0.1

Assessment of data quality: poor.

11.3.16 Sewage sludge (3-16)

Product description: Sewage sludge contains a small proportion of impurities, including plastics, which are introduced into the sewage treatment plants via the wastewater and do not remain completely in the screens and filter systems.

Data basis for quantities placed on the market: estimates based on data from the Federal Statistical Office, studies and discussions with experts. Although there are some studies available in which plastic contents in sewage sludge were investigated, some of them only determined the number of particles without size or weight distribution (e.g. Mintenig et al. 2014: around 1,000-24,000 micro plastic particles per kg dry matter sewage sludge) or contain only a few data sets. A legal limit value of max. 0.5% of the DM (dry matter) for impurities >2 mm (of which max. 0.1% foil plastics and max. 0.4% other impurities including hard plastics) applies to sewage sludge that is to be spread. However, smaller particles are not included in the limit value. The quantities were calculated on the basis of the maximum permissible plastics content, taking into account the available data on plastics contents from various studies.

Overview and designation of relevant additives: dyes, plasticizers, stabilizers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by application of the sludge on agricultural land.

Description of the input time horizon: <1 year

Assumption for the fate factor: -/base 1/ - (plastics contained in the sewage sludge go directly onto the surfaces)

Data quality assessment: medium.

11.3.17 Digestates (3-17)

Product description: Digestate is a liquid or solid residue resulting from the fermentation of biomass in biogas plants.

Data basis for quantities placed on the market: estimation based on data from the Federal Statistical Office as well as technical discussions with experts. For this study, the quantities that are of primary importance are those that originate from the collection of municipal bio waste, as these contain a relevant proportion of plastic waste (usually bags and mislaid waste). Therefore, only fermentation residues from biological treatment plants were taken into account, fermentation residues from pure biogas plants (renewable resources) were not. The proportion of plastics in liquid fermentation residues is very low; according to current data from the Federal Compost Quality Association (Bundesgütegemeinschaft Kompost, BGK), the proportion of plastics in quality-assured plants is 0.009% to 0.016%. However, particles smaller than 2 mm are not considered.

Overview and designation of relevant additives: dyes, plasticizers, stabilizers.

Description of the input mechanism, the input category and characterisation of the input by input location: the biogas fermentation residues are an important component of agricultural fertilisation and are applied accordingly on agricultural land. According to information from the German Biogas Association, almost all fermentation residues from municipal bio waste are composted before they are released into the environment, so that the plastics contained in the compost are produced. Only the liquid biogas residues contain very small amounts of plastics.

Description of the input time horizon: <1 year

Assumption for the fate factor: -/base 1/- (plastics contained in the (mainly liquid) fermentation residues go directly onto the surfaces)**.**

Data quality assessment: medium.

11.3.18 Composts (3-18)

Product description: compost is organic waste after decomposition in specially constructed facilities used for fertilisation and soil improvement in agriculture, horticulture, park management and private gardens.

Data basis for quantities placed on the market: calculation on the basis of Destatis data on sold quantities of compost from biological treatment plants, analyses by the Federal Compost Quality Association (Bundesgütegemeinschaft Kompost, BGK) on the proportion of plastics in various types of compost (on average 0.038% plastics in dry matter, DM), supplementary expert discussions and other studies on the subject from the EU (which assume 0.086% to 0.3% plastics in DM). About 70% of the plants operated in Germany are combined in the BGK, which is why a potentially higher proportion of plastics can be assumed for 30% of the plants. There is a legal limit of max. 0.5% of the DM for impurities >2 mm (of which max. 0.1% foil plastics and max. 0.4% other impurities incl. hard plastics) for compost to be spread. However, smaller particles are not included in the limit value. If one assumes that the total compost spread has a plastic content of 0.038% (according to BGK data), this results in a calculated input of 1,090 t per year. If one assumes a higher plastic content of 0.3% for 30% of the plants, this results in an input of 3,370 t per year.

Overview and designation of relevant additives: dyes, plasticizers, stabilizers.

Description of the input mechanism, the input category and characterisation of the input by input location: Input is by application on agricultural land, but also in parks and gardens.

Description of the input time horizon: <1 year

Assumption for the fate factor: -/base 1/ - (plastics contained in the compost go directly onto the surfaces)

Assessment Data quality: good.

11.3.19 Biocarrier (3-19)

Product description: packing elements are installations in apparatus in process engineering and apparatus construction. In chemical processes, they are used to increase the effective surface area while maintaining low flow resistance. They are used in columns, for example. Among other things, PE is used as a plastic.

Data basis for quantities placed on the market: estimation based on internally available data (Consultic Study) and discussions with experts. There are no statistics available. In the future, enquiries or discussions with producers could be considered.

Overview and designation of relevant additives: no data available.

Description of the input mechanism, the input category and characterisation of the input by input location: input occurs, for example, by flushing out in the sewage treatment plants during the use of the packing or by chipping, separation of smaller particles. The input takes place in settlement areas and areas of technical infrastructure, e.g. water treatment plants.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.005/base 0.01/max. 0.015. Estimate by Consultic based on internal study.

Assessment of data quality: poor.

11.4 Characterisation of the product groups in the product category sports, games, recreation and events

11.4.1 Granulate for artificial turf pitches (4-01)

Product description: granules of PVC, PU and/or rubber applied to artificial turf pitches.

Data basis for quantities placed on the market: estimated value for stock of artificial turf pitches in Germany, discussions with manufacturers and operators about the need for replacement granulate per square metre for new and existing pitches.

Overview and naming of relevant additives: plasticisers, stabilisers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is via adherence to clothing and footwear and via urban areas by leaching into sewers. Possible double counting of plastics present in the sludge cannot be quantified**.**

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.4/base 0.5/max. 0.6

Data quality assessment: medium.

11.4.2 Toys/play equipment (4-02)

Product description: Lego, sand moulds, buckets, etc. which are used or stored outside. Various plastics are used such as PE-HD, PS, PVC, PE, PP or ABS (acrylonitrile-butadiene-styrene copolymer).

Data basis for quantities placed on the market: estimated value.

Overview and designation of relevant additives: flame retardants, stabilizers, plasticizers, dyes, fillers.

Description of the input mechanism, input category and characterisation of the input by input location: input is by leaching or separation/chipping (e.g. weathering) of small particles during use. The input is primarily via urban areas. Gardens of families with children may be particularly responsible for entries (toys lying around on the lawn).

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.005/base 0.01/max. 0.015

Assessment of data quality: poor.

11.4.3 Garden decoration items (4-03)

Product description: plastic decorative elements, e.g. plastic ducks on the garden pond. Are often made of PE, PP or PVC.

Data basis for quantities placed on the market: estimated value.

Overview and designation of relevant additives: plasticizers, dyes.

Description of the input mechanism, input category and characterisation of the input by input location: input is by leaching and separation/chipping (e.g. weathering) of small particles during use. The input is primarily via urban areas. Agriculture and gardens: Private gardens are often decorated with plastic figures (e.g. garden gnomes).

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.0005 /base 0.001/max. 0.0015

Assessment of data quality: poor.

11.4.4 Fishing line (4-04)

Product description: a line used for fishing, which, for example, breaks off, is improperly disposed of; bait is not included in the quantities mentioned.

Data basis for quantities placed on the market: estimated value. No data available. In the future, please contact the manufacturer.

Overview and naming of relevant additives: dyes.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by chipping, separation of smaller particles (material loss). The place of discharge is the North and Baltic Sea coasts or inland bathing areas/waterways.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.005 /base 0.01 /max. 0.015

Assessment of data quality: poor.

11.5 Characterisation of the product groups in the product category consumer products

11.5.1 Garden/terrace furniture (5-01)

Product description: Furniture for the garden area. Often made of PE, PVC, PP, PC or WPC.

Data basis for quantities placed on the market: estimated value. No data available. In the future, please contact manufacturers.

Overview and naming of relevant additives: dyes, plasticizers.

Description of the input mechanism, input category and characterisation of the input by input location: input is by leaching and separation/chipping (e.g. weathering) of small particles during use. The primary point of entry is urban areas, especially single family houses.

Description of the input time horizon: 10 - 30 years

Assumption for the fate factor: min. 0.00005/base 0.0001/max. 0.00015

Assessment of data quality: poor.

11.5.2 Balloons (5-02)

Product description: balloons that are hung up for decorative purposes or released into the environment. Often consist of natural/synthetic rubber, polyester or PVC.

Data basis for quantities placed on the market: estimated value. No data available. Several contacts with balloon manufacturers and distributors did not result in reliable estimates of the market volume.

Overview and designation of relevant additives: stabilizers, plasticizers, fillers.

Description of the input mechanism, the input category and characterisation of the input by input location: input occurs mainly during use or incomplete removal after use, mainly by drift. Primarily densely populated urban areas are the site of discharge. Balloons remain in the environment, e.g. on fields, in forests and everywhere where no regulated cleaning takes place/can take place.

Description of the input time horizon: < 1 year

Assumption for the fate factor: min. 0.0001 t/base 0.0002/max. 0.0003

Estimated proportion of use-related input: 80%

Assessment of data quality: poor.

11.5.3 Fireworks (rocket caps) (5-03)

Product description: rocket head of firework rockets. Are made of PE and other materials.

Data basis for quantities placed on the market: own research: turnover 133 million 2015 with New Year's Eve fireworks. Rockets 20% of turnover (~27 million) according to CPI (75% imported goods). Price per rocket (assumption) 2.5 €: -->10.8 million rockets sold, 90% of them with plastic caps (9.72 million). Assumption plastic cap weighs 5 g, which corresponds to a total plastic weight of 48.6 t.

Overview and designation of relevant additives: dyes, fillers.

Description of the input mechanism, the input category and characterisation of the input by input location: input is by use, followed by leaching and small chipping (weathering). Primarily densely populated urban areas are the place of entry. Rocket caps remain in the environment, e.g. on green areas and everywhere where no regulated cleaning takes place.

Description of the input time horizon: < 1 year

Assumption for the fate factor: min. 0.0005 /base 0.001 /max. 0.0015

Assessment of data quality: poor.

11.5.4 Cigarette filters (5-04)

Product description: filter of filter cigarettes consisting of cellulose acetate (chemically processed cellulose).

Data basis for quantities placed on the market: data of the cigarette association and results according to desk research. Production data available.

Overview and designation of relevant additives: no data available.

Description of the input mechanism, the input category and characterisation of the input by input location: careless throwing away, abrasion/weathering or incomplete removal (e.g. by cleaning measures), remains as waste especially in gutters of urban areas or at road traffic stops (traffic lights, stop signs), on beaches, green areas.

Description of the input time horizon: <1 year

Assumption for the fate factor: min. 0.01/base 0.055/max. 0.1. Production statistics (Prodcomm) are available.

Assessment of data quality: medium. Assumptions on number of discarded cigarettes worsen quality. Association data appear valid.

11.5.5 Lighters (5-05)

Product description: lighters with electric, flint ignition. Polyoxymethylene (POM) is used for production.

Data basis for quantities placed on the market: no data so far, approx. 20 million smokers (2013), assumption: 2 lighters per household in Germany, which corresponds to 82 million lighters in 41 million households. Weight of a lighter is approx. 11-20 g, the average weight is assumed to be 15 g; 10 g (= 2/3) is assumed for the plastic content; this results in 820 t of plastic for lighters. Of this, approx. 3-4% is not disposed of properly: range 25-33 t; mean value 29 t.

Overview and designation of relevant additives: Flame retardants, dyes.

Description of the input mechanism, the input category and characterisation of the input by input location: input occurs during use by chipping, separation of smaller particles or after use. Especially in settlement areas an input can occur.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.005/base 0.01/max. 0.015

Assessment of data quality: poor.

11.5.6 Cosmetics (5-06)

Product description: for example peelings for face and body, dental care. An example of application is dental care products with plastic pellets to improve the cleaning effect. They consist for example of polyethylene (PE), acrylate copolymer (AC) or acrylate crosspolymer (ACS).

Data basis for quantities placed on the market: studies and statistics are available.

Overview and naming of relevant additives: plasticizers, colorants.

Description of the input mechanism, the input category and characterisation of the input by input location: micro plastic particles in the products remain in the waste water (e.g. toothpaste) after use of the products. Remaining is part of the use, agricultural areas (via applied sewage sludge) are the main input points. Potential double counting with the plastics present in the sewage sludge cannot be quantified.

Description of the input time horizon: <1 year

Assumption for the fate factor: min. 0.95 /base 0.975/max. 1, based on a study by German Environment Agency (Essel et al. 2015).

Assessment of data quality: good.

11.5.7 Clothing fibres (5-07)

Product description: synthetic fibres in any clothing worn by people. Often made of polyethylene terephthalate (PET) or polyamide (PA).

Data basis for quantities placed on the market: results based on the Consultic Study "From land to sea - model for the collection of land-based plastic waste" (BKV 2016), calculations based on fibre quantities per wash.

Overview and naming of relevant additives: plasticizers, stabilizers, colorants, flame retardants.

Description of the input mechanism, the input category and characterisation of the input by input location: abrasion/weathering during the entire period of use, input locations are in particular urban areas and agricultural areas as a result of the application of sewage sludge.

Description of the input time horizon: 1 - 10 years

Assumption on the fate factor: Fate factors are not necessary, as a calculation is based on the Consultic Study "From Land to Sea - Model for the Collection of Land-Based Plastic Waste" (BKV 2016(BKV 20XX) (fibre quantities per wash, see above).

Assessment of data quality: good.

11.5.8 Plastic decorative elements (5-08)

Product description: little hearts, birthday numbers, stars, figures. Are made of various plastics such as PET.

Data basis for quantities placed on the market: estimated value. Realistically, the amount put on the market is insignificant. According to the authors' estimation, it is mostly only used in regularly cleaned environments (church square, market place or closed room). Input into the sewage treatment plant via the sewer system where probably 95% are filtered out.

Overview and naming of relevant additives: stabilizers, plasticizers, colorants.

Description of the input mechanism, the input category and characterisation of the input by input location: input is made during the entire period of use or by incomplete removal after use. Input points are urban areas.

Description of the input time horizon: 1 - 10 years

Assumption for the fate factor: min. 0.01/base 0.055/max. 0.1

Assessment of data quality: poor.

11.5.9 Other paints and varnishes (5-09)

Product description: paints for outdoor application on products, buildings etc., no data available on plastics used.

Data basis for quantities placed on the market: base quantity from Ökopol data, estimations of plastic percentages based on internet research and expert discussions.

Overview and naming of relevant additives: flame retardants, stabilizers, colorants.

Description of the input mechanism, input category and characterisation of the input by input location: leaching or abrasion/weathering during use (depending on application), remaining after use (depending on application), location of use is difficult to determine as various applications are conceivable (e.g. buildings, railings, fences)

Description of the input time horizon: depending on application

Assumption for the fate factor: min. 0.0005 /base 0.001/ max. 0.0015

Assessment of data quality: good.