TEXTE
32/2022

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publisher:
German Environment Agency

German Environment Agency

Umwelt Bundesamt

TEXTE 32/2022

Ressortforschungsplan of the Federal Ministry for the Environment,
Nature Conservation, Nuclear Safety and Consumer Protection

Project No. (FKZ) 3719 34 302 0

Report No. (UBA-FB) FB000553/ENG

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Imprint

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Pohlandstraße 17
01309 Dresden
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Report completed in:
March 2021

Edited by:
Section III 1.5 – Waste Management, Transboundary Movement of Waste
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Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4359

Dessau-Roßlau, March 2022

Abstract: Evaluation of the collection and recovery of selected waste streams for the further development of circular economy

As part of the general producer responsibility regulated by the German Circular Economy Act, there are special legal regulations for the collection and environmentally sound disposal of certain waste streams (e.g. for packaging, batteries, waste electrical and electronic equipment, end-of-life vehicles). These require producers to set up collection systems for the disposal of the corresponding waste and to achieve certain recycling and, in some cases, collection rates. The research project examined whether and how resource conservation and environmental relief potentials can be realized for other waste streams - especially end-of-life tyres and used textiles - through improved collection and recovery.

In addition, there are other waste streams for which it can be assumed that the current regulations are insufficient to realize the inherent recycling potential in these waste streams. Bulky waste, mattresses, furniture, carpets, artificial turf and diapers were identified as such waste streams.

The project examined the waste streams in terms of collection and utilization practices, identified barriers to resource-efficient waste management, and derived measures to improve prevention, preparation for reuse, and recycling of these waste streams.

In a first step, the material flows of the waste streams were analyzed with regard to their quantity and used disposal routes. For this purpose, statistics and secondary sources were reviewed and interviews were conducted.

In a second step, the identified disposal routes were evaluated with regard to ecological criteria, including pollutant aspects and resource conservation potentials, as well as economic criteria.

From this assessment, conclusions and measures have been derived that can improve the recycling of the individual waste streams in terms of a resource-saving circular economy. The measures were prioritized based on various criteria.

The results of the project were discussed in three technical meetings with the stakeholders involved in the individual waste streams.

Kurzbeschreibung: Evaluation der Erfassung und Verwertung ausgewählter Abfallströme zur Fortentwicklung der Kreislaufwirtschaft

Im Rahmen der generell durch das KrWG geregelten Produktverantwortung existieren für bestimmte Abfallströme spezielle rechtliche Regelungen zur Erfassung und umweltverträglichen Entsorgung (bspw. für Verpackungen, Batterien, Elektro- und Elektronikaltgeräte, Altfahrzeuge). Diese Regelungen verpflichten die Hersteller, Erfassungssysteme für die Entsorgung der entsprechenden Abfälle einzurichten und bestimmte Verwertungs- und teilweise Erfassungsquoten zu erreichen. Im Rahmen des Forschungsprojektes wurde überprüft, ob und wie bei weiteren Abfallströmen – vor allem Altreifen und Alttextilien – durch eine verbesserte Erfassung und Verwertung Ressourcenschonungs- und Umweltentlastungspotenziale realisiert werden können.

Darüber hinaus existieren weitere Abfallströme, bei denen zu vermuten ist, dass die gegenwärtigen Regelungen nicht ausreichen, um das in diesen Abfallströmen innewohnende Recyclingpotenzial auszuschöpfen. Als derartige Abfallströme wurden Sperrmüll, Matratzen, Möbel, Teppiche, Kunstrasen und Windeln identifiziert.

Das Vorhaben hat die Abfallströme hinsichtlich der Praxis der Erfassung und Verwertung untersucht, Hemmnisse einer ressourcenschonenden Abfallbewirtschaftung aufgezeigt und

Maßnahmen abgeleitet, um die Vermeidung, die Vorbereitung zur Wiederverwendung und das Recycling dieser Abfallströme zu verbessern.

Dabei sind in einem ersten Schritt die Stoffströme der benannten Abfallarten hinsichtlich des Aufkommens und der genutzten Entsorgungswege analysiert worden. Hierfür wurden Statistiken und Sekundärquellen gesichtet und Befragungen durchgeführt.

In einem zweiten Schritt sind die identifizierten Entsorgungswege hinsichtlich ökologischer, einschließlich der Schadstoffaspekte und Ressourcenschonungspotenziale, sowie ökonomischer Kriterien bewertet worden.

Aus dieser Bewertung sind Schlussfolgerungen und Maßnahmen abgeleitet worden, welche die Verwertung der einzelnen Abfallströme im Sinne einer ressourcenschonenden Kreislaufwirtschaft verbessern können. Anhand verschiedener Kriterien wurden die Maßnahmen priorisiert.

Die Ergebnisse des Vorhabens wurden in drei Fachgesprächen mit den in die einzelnen Abfallströme involvierten Akteuren diskutiert.

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a	Year (annus)
AltholzV	German Ordinance on Waste Wood (Altholzverordnung)
CAC	Civic amenity centre
CB	Carbon Black
CHP plant	Combined heat and power plant
CO_2	Carbon dioxide
ElektroG	German Electrical and Electronic Equipment Act (Elektro- und Elektronikgerätegesetz)
ELT	End-of-life tyre
ELV	End-of-life vehicle
EPR	Extended producer responsibility
EU	European Union
Destatis	German Federal Statistical Office
GWP	Global warming potential
HPHTS	High-pressure high-temperature sintering
kg/inh*a	Kilogram per inhabitant and year
KrWG	Circular Economy Act (Kreislaufwirtschaftsgesetz)
LAGA	Joint Waste Commission of the Federal States (Bund/Länder-Arbeitsgemeinschaft Abfall)
n.d.	no date
NIR	Near-infrared spectroscopy
NR-BR	Natural rubber-butadiene rubber
öRE	Public disposal providers (öffentlich-rechtliche Entsorgungsträger)
PA	Polyamide
PAH	Polycyclic aromatic hydrocarbons
PU	Polyurethane
PVC	Polyvinyl chloride
rCB	Recovered Carbon Black
REACH	Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals
RFID	Radio-frequency identification
RDF	Refuse-derived fuel
SVOC	Semi-volatile organic compounds
t/a	Metric tons per annum
TPE	Thermoplastic elastomers
TVOC	Total volatile organic compounds
VOC	Volatile organic compounds

VKU	German Association of Local Public Utilities (Verband kommunaler Unternehmen)
VVOC	Very volatile organic compounds
WEEE	Waste electrical and electronic equipment
wt.-%	Weight-%

Summary

Regulations on extended producer responsibility exist for certain waste streams. These regulations require producers to set up collection systems for end-of-life products and to achieve certain collection and, in some cases, recovery rates.

In the context of this research project, the waste streams bulky waste, mattresses, furniture, carpets, artificial turf, diapers, waste tyres and used textiles were selected because they are significant in terms of volume and it can be assumed that the current regulations are insufficient to realize the recycling potential inherent in these waste streams. Uniform criteria were used to evaluate derived measures to improve recycling. Finally, the waste streams presented were prioritized.

Bulky Waste

Bulky waste is generated by private households and businesses and is mainly collected by public waste management authorities. There are different collection and fee systems depending on the public authority. According to the municipal waste balances of the federal states, the annual amount of bulky waste per capita is about 30 kg/(inh*a) and the total amount is about 2.5 million tons per year. Bulky waste consists of approx. 60% wood, upholstered and composite furniture, furthermore mainly carpets, mattresses and other wood. It is currently mainly used for energy recovery or treated in sorting facilities.

In sorting facilities, recyclable materials such as metals, hard plastics, plastic films and paper/cardboard are separated and recycled. Wood is also separated and sent for energy recovery as mixed waste wood of waste wood category III, for example in biomass combustion facilities. The sorting residues as well as mattresses, upholstered furniture and carpets are also used for energy recovery.

An increase in recycling of bulky waste can be achieved, among other things, by expanding its treatment in sorting facilities or increasing separate collection.

Furniture

Furniture is made in all kinds of shapes, sizes, colours and materials for a wide variety of uses. At the end of its use phase, it is mainly disposed of in bulky waste. There are no explicit statistics on the amount of waste produced by furniture. Sorting analyses have estimated that around 1.7 million tons of furniture are disposed of annually in municipal bulky waste. In addition, there are quantities that are collected separately as waste wood or disposed of as commercial waste, chopped up with residual waste or disposed of by other means. It was determined that around 3.6 million tons of furniture are purchased annually in Germany and become waste after their use phase. Due to the high share of wood-based materials and various composite materials, the potential for increasing recycling of furniture is limited. The greatest challenge in the recycling of furniture is the ability to dismantle it. Recycling rates can be improved through standardized design criteria at EU level, which are negotiated with the manufacturers, as well as the introduction of an extended producer responsibility (e.g. as a staggered environmental fee).

Mattresses

In Germany, the market for sleeping accommodations is dominated by bed frames, slatted frames and classic support mattresses. Mainly PUR foam mattresses and innerspring mattresses are used. Latex and wool mattresses or mattresses made of other materials play a minor role. Domestic production covers only about half of the demand. There is an increasing trend from Anglo-American countries towards box-spring beds, in which the bed frame, upholstery and suspension are combined to form a single piece of furniture, similar to upholstered furniture.

The total demand for mattresses from the private, hospitality and medical sectors is estimated at around 80.7 million mattresses. In addition, many households have mattresses from former household members and guest mattresses. The average use phase of a mattress is 10 years.

Typically, mattresses from private households are disposed of with bulky waste. According to sorting analyses, bulky waste contains approximately 225,000 tons per year of old mattresses. In addition, some retailers offer to take back old mattresses. In Germany, old mattresses are mainly used for energy recovery. Manual disassembly and resale of the raw materials contained is only carried out in one facility in Germany. Internationally, there are already examples of automated disassembly processes. The biggest obstacles to recycling old mattresses are the complex mattress design, the collection structure where moisture penetration cannot be ruled out, economic competition with energy recovery and insufficient sales markets for the recyclable materials.

Strengthening recycling can be helped by funding demonstration facilities, in which future opportunities and obstacles to mattress recycling can be assessed. By agreeing on a design for recycling and its widespread implementation, the foundations for high-quality recycling are laid. The introduction of extended producer responsibility can also be recommended for the mattress waste stream.

Carpets

Carpets include wall-to-wall carpeting, rugs and carpets for other applications (automobile sector, sports sector, etc.). The latter are not considered in this study. Carpets do not have their own waste code and are mainly disposed of via non-hazardous mixed construction and demolition waste (AS 17 09 04) or via bulky waste (AS 20 03 07). After a strong decline in sales around the turn of the millennium, the mass of carpets sold in Germany is about 200,000 tons per year (carpeting and rugs). A large part of the carpeting is produced in the EU. Carpets account for about a quarter of the German flooring market and are subject to CE marking as construction products. Carpets consist of several tightly interwoven layers of different materials. The wear layer consists of dyed textile fibers, the intermediate layer stabilizes the fibers of the wear layer, the carpet backing is responsible for the overall stability of the carpet and often consists of plastics / latex and fillers. The overall share of renewable raw materials in carpet production is low.

In Germany, carpets are used for energy recovery. Since the insolvency of Polyamid 2000 in 2003, there has been no carpet recycling in Germany and there are only a few examples internationally. The challenges in recycling carpets are the tightly woven mixed materials, the technically challenging material sorting and the lack of recycling options. In addition, there is no collection system that allows for a clean, uniform and dry collection of carpets. Accordingly, the main need for carpets is for uniform design criteria that exclude mixed materials as far as possible and guarantee sorting and separation of the individual layers from each other. Furthermore, there is a need for research and development of recycling processes and demonstration facilities.

Artificial Turf

Artificial turf is mainly used in sports field construction. It is also used in playground construction, as carpeting in the trade fair and event sector, in private gardens, balconies or as green roofs. The majority of artificial turf fields are owned by municipalities.

The turf carpet consists of a synthetic backing fabric onto which plastic fibers are tufted in small tufts. To fix the turf tufts, the underside of the backing is coated with latex or PU. The turf fibers are usually made of PE, and the backing fabric is made of PP. In fully and partially filled artificial turf systems, a layer of quartz sand is used to stabilize the tufts and weigh down the carpet. This may be followed by a shock-absorbing layer of elastic granules. In the past, synthetic granules were mainly used. However, due to the planned ban on microplastics, either plant-based granules or granule-free systems have been used since 2020.

The real generation and recycling routes are largely unknown. Information is generally based on expert estimates. Because of the difficult traceability, whether a secure material recycling takes place depends heavily on the commitment of the sports field owner. There are only a few providers who can prove that the entire system has been fully recycled. The available facility capacities are currently below the annual volume of old artificial turf.

In order to promote recycling, the use of mono-material artificial turf should be tied to sports facility funding. Also, the tender for the artificial turf removal should include criteria for traceability.

Diapers

Diapers, feminine hygiene and incontinence products consist of superabsorbent polymer, cellulose fibers and other plastic parts (fleece liners, foils, rubber and adhesive tapes). Urine and feces make up more than half of the mass of diaper waste. The generation of this waste in Germany is estimated to be 1.5 million tons per year.

In Germany, diapers are mainly disposed of with residual waste and used in energy recovery. For some years now, recycling facilities have been in operation in the Netherlands, Italy and Great Britain, which thermally sanitize separately collected diaper waste and recover superabsorbent polymer, cellulose and plastics for recycling. Feces and urine can then be treated in a sewage treatment facility.

The biggest problem for diaper recycling is the need for a separate collection. Since diaper waste is highly decentralized, a completely new and close-knit collection structure would have to be created for it. Therefore, the initiation and financial support of a separate collection system in a pilot municipality is recommended in order to estimate the required effort and the additional costs. Alternatively, separate collection can be implemented in high-volume facilities such as nursing homes and day-care centres for children.

End-of-Life Tyres (ELT)

Tyres consist of a large number of fundamentally inseparable components such as tread and casing. Around 800-900 different substances are used in tyre production. In addition, the types of rubber used are highly resistant to many known solvents, bases and acids, which makes recycling very difficult. For this reason, the main recycling method is granulation of the rubber. The granules can be further processed into powders.

<u>Waste generation and collection</u>

According to industry information, the return of and-of-life tyres (ELT) from end users to points of collection and car repair shops works well. However, the annual amount of ELT and their utilisation routes can currently not be tracked, as there are registration obligations only for waste management companies, but not for upstream or downstream activities. Based on the sales figures for new tyres from the BVR, the GAVS (now wdk) calculates the potential amount of ELT and their utilisation routes every year. According to GAVS statistics, the generation of ELT was around 571,000 tons in 2019 in Germany.

The German ELT utilisation industry is currently in a critical situation. This is mainly due to very strict preventative limits for the content of polycyclic aromatic hydrocarbons (PAH) in some of the established sales markets for tyre recyclates, which caused uncertainty of the markets and consumers, even in markets that are not affected by the regulation. This inhibits the growth of recycling and thus the willingness to invest in new products and processes overall. Furthermore, the industry is burdened by a sharp decline in energy recovery of old tyres in cement works as well as a generally low level of prices on the primary raw material market.

The ELT utilisation industry also criticizes a lack of redistribution of disposal charges raised from end consumers. Only about 25% of the contributions paid by consumers reach the utilisation companies. Under the existing conditions, raising the gate fee by ELT recyclers increases the incentives for illegal disposal of ELT by some tyre collectors.

In order to sustainably fund the collection and recycling of ELT and reduce illegal disposal by improving traceability, the introduction of an extended producer responsibility or fee-based system is recommended. By changing the market system, most of the collection and sorting problems can be solved. One problem that cannot be solved through this is that of demand for secondary raw materials or substitute fuels.

Preparation for reuse of ELT

The greatest potentials for expanding the recycling of ELT are in granule- and powder-based applications, road construction, and retreading (especially passenger cars).

In the passenger car sector, the share of retreaded tyres in the tyre market was well below one percent in 2018, while in the truck sector it was around 29%. According to industry information, there is capacity in Germany to expand the retreading of truck tyres to 40%. Typically, suitable car tyres are retreaded once, while truck tyres are retreaded up to three times.

Due to competition from inexpensive new tyres, demand for retreaded car tyres is very low. To increase demand, the primary requirement is to improve the cost structure in retreading. Facility automation is of central importance in this respect. In addition, further development of materials and production technology is necessary to bring retreading up to the performance level of modern car tyres. However, the combination of a lack of demand on one hand and necessary investments in materials and product development as well as process automation on the other hand represents a conflict that is difficult to overcome for medium-sized retreaders. Appropriate funding as well as research and development programs can provide support here.

The availability of suitable ELT is another factor limiting the expansion of retreading in the passenger car sector. Retreading companies often import a high proportion of their casings. There does not appear to be sufficient motivation in Germany to sort ELT accordingly. Existing sorting criteria should therefore be declared generally binding. In addition, a design change in the construction of new tyres is necessary for increasing the share of retreadable tyres. In cooperation with manufacturers, retreaders and recyclers, binding standards for a retreadable tyre design should be developed, ideally at EU level.

Recycling

The use of tyre recyclates in new tyres is possible only to a very limited extent. The recyclates are therefore mainly used in the form of granules, for example as infill for artificial turf, in sports and playground mats and simple molded parts. The first secondary products based on rubber powders are currently being manufactured, some of which are already on a par with products made from primary raw materials. However, the complexity of such new developments, the relatively small niche markets and the persistently low level of primary raw material prices limit the quantitative importance of such approaches. A transfer of technology and knowledge between the tyre manufacturing and the tyre recycling industries would lead to a significant improvement in the quality and cost-effectiveness of material recycling and should therefore be promoted.

The previous PAH content limits are being revised in many areas. The introduction of binding measuring procedures based on Barrero-Moreno et al. (2018) would result in higher measured PAH contents than is the case using other currently permitted methods. Accordingly, tyre recyclate could no longer be used in some applications or a significant reduction in the share of recyclate would be required. Even if the PAH regulations only cover part of the market for tyre recyclates, the general uncertainty also dampens the demand in adjacent areas of application.

As part of the review of PAH limit values, the introduction of hazard-related migration and emission-based measurement methods instead of extraction-based content limit values should be implemented at EU level. According to the current state of research, tyre recyclates and products made from them do not appear to pose a significant health risk to humans or the environment with regard to migration and the emission of hazardous substances.

One of the largest, so far hardly developed growth markets for the tyre recyclates is their use in road construction. The rubber modification of bitumen leads to an improvement in individual performance parameters of roads and can also enable a reduction of the layer thickness. Based on the current state of knowledge, the use of scrap tyre recyclates therefore appears to be economically sensible and due to current developments for lowering the paving temperatures of asphalt mean that it can be used without any significant risk to people or the environment. The primary requirement here is the development of regulations at the federal states level as a basis for taking such modified asphalts into account in tenders.

Used Textiles

Overall, it should be noted that there is no reliable data on the collection of used textiles. Based on the available information from various studies, the collection volume for 2018 is estimated at around 1.0 million tons and the collection rate at around 64%.

44% of used textiles are collected by commercial collectors, followed by non-profit collectors with 28.6%. The municipal waste management authorities (örE) collect 26.9% of the quantity. Collection in the context of voluntary take-back plays a minor role with 0.5%. Illegal collections hardly play a role today due to the lower market prices. Due to the expected negative changes in the quality of used textiles, it can be assumed that the price trend will continue downwards. In this respect, the extent of illegal collections will remain low.

The main collection system is the bring bank container with 96%. The remaining collection systems (street and basket collection, take-back by retailers or collection via household waste bins) are insignificant with a total of 3.3%.

It can be assumed that at least 50% of the collected quantity is exported from Germany and sorted for the most part in Europe. According to the Textile Study 2020 of the bvse, approx. 62% of the sorted quantity is sold as second-hand goods after preparation for reuse. The recycling of used textiles takes place mainly in other European and non-European countries. Around 14% are processed into cleaning rags and 12% into torn goods. Around 8% of the sorted used textiles are used in energy recovery and around 4% are disposed of.

Collection and sorting of used textiles

Various collection systems were evaluated with regard to the material-friendly collection and the collection potential of the system. Included were the collection at the CAC, via clothing chambers/shops, the street and basket collection, the bring bank collection with manual emptying and with hook lift system, the household collection via the duo bin and the online collection. As a result, the bring bank containers with manual emptying together with the street and basket collection are the most balanced collection system in terms of quality and collection potential.

The various sorting systems were assessed in terms of costs, potential for preparation for reuse and recycling potential. Negative and partial sorting, full sorting and automatic sorting were considered. As a result, full sorting is the only sorting process that can add value to the collected used textiles in accordance with the waste hierarchy.

Recycling of used textiles

The resource conservation and environmental relief potential in the recycling of used textiles was evaluated along the five-stage waste hierarchy. The exact effects vary greatly depending on the material and processing. In general, it can be assumed that recycled fibers reduce water and energy consumption as well as CO2 consumption in textile production.

By preparing them for reuse, the life cycle of textiles is extended and resources for the production of new textiles are saved. Since the textile industry is global, it does not matter whether second-hand goods are sold in Germany or in other sales markets.

If textiles are neither wearable nor marketable, various recycling processes are available for substituting primary raw materials. These used textiles are usually processed into industrial cleaning rags or torn into fibers. The textile fibers are thermally and acoustically insulating so that they can be used as fleece in many areas. The production of yarn from old textiles is an absolute exception today, as the old textile fibers do not meet the requirements for material purity and color composition. Many projects are working on this textile recycling process in order to meet market requirements. Chemical recycling processes can also be used for the recovery of used textiles. There are a large number of technologies for this which are currently being tested in research and pilot projects. There are only a few that are available on an industrial scale. Energy recovery is an option for used textiles that cannot be recycled. Disposal as the last step in the waste hierarchy is generally not an option for used textiles sorted in Germany, as there is access to energy recovery facilities.

Proposed measures and recommendations for action

In order to promote the preparation for reuse and the recycling of used textiles, the relevant topics for the development of recommendations for action were identified as the sensitization of consumers to sustainable consumption and the handling of textiles, as well as the involvement of manufacturers and retailers in consumer advice and the development of new business models.

The objectives for the development of the measures were to maintain the high level of separately collected quantities of used textiles, even if these will develop into a material stream requiring additional payment, to create transparency within the material stream and to promote high-quality recycling routes in Germany and Europe.

After evaluating all the proposed measures, it can be stated that overall the introduction of extended producer responsibility, despite the high administrative and organizational effort, has the greatest positive effects on the promotion of the textile circular economy and offers solutions for all identified issues. For this reason, the introduction of extended producer responsibility is recommended. Due to the long implementation horizon, the next steps suggested are:

1. Government resolution to introduce extended producer responsibility for textiles
2. Implementation of the measures to promote the consumption of sustainable products and the implementation of information and advisory obligations at all levels
3. Initiation of a stakeholder dialogue with a business game "Introduction of extended producer responsibility"

Zusammenfassung

Für bestimmte Abfallströme existieren Regelungen über die erweiterte Herstellerverantwortung. Diese Regelungen verpflichten die Hersteller, Erfassungssysteme für die Altprodukte einzurichten und bestimmte Erfassungs- und teilweise Verwertungsquoten zu erreichen.

Im Rahmen dieses Forschungsprojektes wurden die Abfallströme Sperrmüll, Matratzen, Möbel, Teppiche, Kunstrasen, Windeln, Altreifen und Alttextilien ausgewählt, da diese mengenmäßig bedeutsam sind und zu vermuten ist, dass die gegenwärtigen Regelungen nicht ausreichen, um das in diesen Abfallströmen innewohnende Recyclingpotenzial auszuschöpfen. Mittels einheitlicher Kriterien wurden abgeleitete Maßnahmen zur Verbesserung der stofflichen Verwertung bewertet. Abschließend wurden die vorgestellten Abfallströme priorisiert.

Zusammenfassung Sperrmüll

Sperrmüll fällt in privaten Haushalten und im Gewerbe an und wird überwiegend durch die öffentlich-rechtlichen Entsorgungsträger (örE) gesammelt. Es gibt je nach örE unterschiedliche Erfassungs- und Gebührensysteme. Gemäß den Siedlungsabfallbilanzen der Länder liegt das einwohnerspezifische Sperrmüllaufkommen bei ca. 30 kg/(E*a), das Gesamtaufkommen bei ca. 2,5 Mio. t jährlich. Sperrmüll besteht zu ca. 60% aus Holz-, Polster- und Verbundmöbeln, des Weiteren vor allem aus Teppichen, Matratzen und sonstigem Holz. Sperrmüll wird derzeit überwiegend energetisch verwertet oder in Sortieranlagen behandelt. Dabei werden meist Wertstoffe, wie Metalle, Hartkunststoffe, Folien und Papier/Pappe abgetrennt und einer stofflichen Verwertung zugeführt. Holz wird in Sortieranlagen ebenfalls abgetrennt und als gemischtes Altholz der Altholzkategorie III einer energetischen Verwertung zugeführt, zum Beispiel in Biomassefeuerungsanlagen. Auch die Sortierreste von Sperrmüllsortieranlagen sowie Matratzen, Polstermöbel und Teppiche werden energetisch verwertet. Eine Steigerung der stofflichen Verwertung von Sperrmüll kann unter anderem durch eine Ausweitung der Sperrmüllbehandlung in Sortieranlagen oder verstärkte Getrenntsammlung erreicht werden.

Zusammenfassung Möbel

Möbel werden in allen möglichen Formen, Größen, Farben und Materialien für die verschiedensten Einsatzbereiche gefertigt. Nach dem Ende ihrer Nutzungsdauer werden sie überwiegend im Sperrmüll entsorgt. Es gibt keine einheitliche Statistik zum Abfallaufkommen von Möbeln. Durch Sortieranalysen wurde abgeschätzt, dass jährlich rund 1,7 Mio. t Möbel über den kommunalen Sperrmüll entsorgt werden. Hinzukommen die Mengen, die als Altholz separat erfasst werden sowie als Gewerbeabfall, zerkleinert über den Restabfall oder über andere Wege entsorgt werden. Es wurde ermittelt, dass rund 3,6 Mio. t Möbel jährlich in Deutschland angeschafft und nach ihrer Nutzungsdauer zu Abfall werden. Aufgrund des hohen Anteils an Holzwerkstoffen und den verschiedenen Verbundmaterialien besteht bei Möbeln nur ein begrenzt abschöpfbares Potenzial zur stofflichen Verwertung. Größte Herausforderung bei der stofflichen Verwertung von Möbeln ist die Zerlegbarkeit der Möbelstücke. Eine Verbesserung der stofflichen Verwertung kann durch einheitliche Designkriterien auf EU-Ebene erreicht werden, welche mit den Herstellern ausgehandelt werden sowie eine Einführung einer erweiterten Herstellerverantwortung (z.B. als gestaffelte Beiträge).

Zusammenfassung Matratzen

In Deutschland wird der Markt für Schlafgelegenheiten von Bettgestell, Lattenrost und klassischer Auflagematratze dominiert. Hauptsächlich werden PUR-Schaum-Matratzen und Federkernmatratzen eingesetzt, Latex- und Wollmatratzen bzw. Matratzen aus sonstigen Materialien spielen eine untergeordnete Rolle. Die inländische Produktion deckt nur ungefähr die Hälfte des Bedarfs. Zunehmend ist der Trend aus dem angloamerikanischen Raum hin zu Boxspringbetten zu beobachten, bei denen Bettgestell, Polsterung und Federung zu einem Möbelstück, ähnlich einem Polstermöbel, verbunden sind.

Der Bedarf an Matratzen wird in Summe aus privatem Bereich, Gastgewerbe und medizinischem Bereich auf ca. 80,7 Mio. Matratzen geschätzt. Zusätzlich sind in vielen Haushalten Matratzen ehemaliger Haushaltsmitglieder und Gästematratzen vorhanden. Die durchschnittliche Nutzungsdauer einer Matratze liegt bei 10 Jahren.

Üblicherweise werden Matratzen aus privaten Haushalten mit dem Sperrmüll entsorgt. Im Sperrmüll sind laut Sortieranalysen ca. 225.000 t/a Altmatratzen enthalten. Zudem bieten einige Händler die Rücknahme von Altmatratzen an. In Deutschland werden Altmatratzen hauptsächlich energetisch verwertet. Eine manuelle Zerlegung und der Weiterverkauf der enthaltenen Rohstoffe wird nur in einer Anlage in Deutschland durchgeführt. International gibt es schon Beispiele automatisierter Zerlegungsverfahren. Größte Hindernisse für das Recycling von Altmatratzen sind das komplexe Matratzendesign, die Sammelstruktur, bei der das Eindringen von Feuchtigkeit nicht ausgeschlossen ist, die ökonomische Konkurrenz zur energetischen Verwertung und ungenügende Absatzmärkte für die rückgewinnbaren Materialien.

Zur Stärkung der stofflichen Verwertung kann eine Förderung von Demonstrationsanlagen beitragen, in der zukünftige Möglichkeiten und Hindernisse beim Matratzenrecycling abgeschätzt werden können. Durch die Einigung auf ein recyclinggerechtes Design und die breitenwirksame Umsetzung werden die Grundlagen für ein hochwertiges Recycling gelegt. Auch die Einführung einer erweiterten Herstellerverantwortung kann für den Abfallstrom Matratzen empfohlen werden.

Zusammenfassung Teppiche

Zu Teppichen gehören Wand zu Wand Teppichböden, abgepasste Teppiche und Teppiche für sonstige Anwendungsbereiche (Mobilitätssektor, Sportbereich etc.). Letztere werden in dieser Studie nicht betrachtet. Teppiche haben keinen eigenen Abfallschlüssel und werden vor allem über ungefährliche gemischte Bau- und Abbruchabfälle (AS 17 09 04) oder über den Sperrmüll (AS 20 03 07) entsorgt. Nach stärkeren Umsatzrückgängen um die Jahrtausendwende liegt die in Deutschland verkaufte Masse an Teppichen bei ca. 200.000 t/a (Teppichböden und abgepasste Teppiche). Ein Großteil der Teppichböden wird in der EU produziert. Teppichböden machen etwa ein Viertel des deutschen Marktes für Bodenbeläge aus und unterliegen als Bauprodukte einer CE-Kennzeichnung. Teppiche bestehen aus mehreren fest miteinander verknüpften Schichten verschiedener Materialien. Die Nutzschicht besteht aus gefärbten textilen Fasern, die Zwischenschicht stabilisiert die Fasern der Nutzschicht, der Teppichrücken ist für die Gesamtstabilität des Teppichs zuständig und besteht häufig aus Kunststoffen / Latex und Füllstoffen. Der Anteil nachwachsender Rohstoffe ist bei der Teppichherstellung insgesamt gering.

In Deutschland werden Teppiche energetisch verwertet. Seit der Insolvenz der Polyamid 2000 im Jahr 2003 gibt es in Deutschland kein Teppichrecycling mehr und auch international gibt es nur wenige Beispiele. Die Herausforderungen beim Recycling von Teppichen bestehen in den fest verknüpften Mischmaterialien, der technisch herausfordernden Materialsortierung und den fehlenden Verwertungsmöglichkeiten. Zudem gibt es kein Sammelsystem, das die saubere, einheitliche und trockene Erfassung von Teppichen ermöglicht. Demnach besteht bei Teppichen in erster Linie Bedarf an einheitlichen Designkriterien, die Mischmaterialien soweit möglich ausschließen und die Sortierung und Trennung der einzelnen Schichten voneinander garantieren. Des Weiteren besteht Bedarf an Forschung und Entwicklung von Recyclingverfahren und Demonstrationsanlagen.

Zusammenfassung Kunstrasen

Kunstrasen wird hauptsächlich im Sportplatzbau verwendet. Er kommt außerdem im Spielplatzbau, als Auslegeware im Messe- und Veranstaltungsbereich, in privaten Gärten, Balkonen oder als Dachbegrünung zum Einsatz. Die Mehrheit aller Kunstrasenplätze befindet sich in kommunalem Besitz.

Der Rasenteppich besteht aus einem synthetischen Trägergewebe, auf welches Kunststofffasern in kleinen Büscheln getuftet werden. Um die Rasentufte zu befestigen, wird die Unterseite des Trägergewebes mit Latex oder PU beschichtet. Die Rasenfasern bestehen meist aus PE, das Trägergewebe aus PP. In voll- und teilverfüllte Kunstrasensysteme wird auf den Rasenteppich eine Schicht Quarzsand eingebracht, um die Rasentufte zu stabilisieren und den Teppich zu beschweren. Darauf kann eine stoßdämpfende Schicht aus elastischem Granulat folgen. Früher wurde vor allem synthetische Granulat verwendet. Aufgrund des geplanten Verbots von Mikroplastik werden seit 2020 aber entweder pflanzliche Granulate oder granulatfreie Systeme genutzt.

Das genaue Aufkommen und die Verwertungswege sind größtenteils unbekannt. Angaben basieren in der Regel auf Expertenschätzungen. Ob eine gesicherte stoffliche Verwertung stattfindet, ist aufgrund der mangelnden Nachverfolgbarkeit stark vom Engagement der Sportplatzeigentümer abhängig. Es gibt nur wenige Anbieter, die für das Gesamtsystem eine vollständige stoffliche Verwertung nachweisen können. Derzeit liegen die verfügbaren Anlagenkapazitäten unter dem Jahresaufkommen an altem Kunstrasen.

Um die stoffliche Verwertung zu fördern, sollte an die Sportstättenförderung die Verwendung von Monomaterial-Kunstrasen geknüpft sein. Auch sollte die Ausschreibung des Kunstrasenausbaus Kriterien für die Nachverfolgbarkeit enthalten.

Zusammenfassung Windeln

Windeln, Damenhygiene- und Inkontinenzprodukte bestehen aus Superabsorberpolymer, Zellstofffasern und weiteren Kunststoffteilen (Vlieseinlagen, Folien, Gummi- und Klebebänder). Im Windelabfall machen Urin und Fäkalien mehr als die Hälfte der Masse aus. Die Abfallmenge wird in Deutschland auf 1,5 Mio. t pro Jahr geschätzt.

In Deutschland werden Windeln überwiegend über den Restabfall entsorgt und energetisch verwertet. Seit einigen Jahren sind in den Niederlanden, Italien und Großbritannien vereinzelt Recyclinganlagen in Betrieb, welche getrennt erfassten Windelabfall thermisch hygienisieren und Superabsorberpolymer, Zellstoff und Kunststoffe zur stofflichen Verwertung rückgewinnen. Fäkalien und Urin können anschließend in einer Kläranlage behandelt werden.

Das größte Problem beim Windelrecycling ist das Erfordernis einer separaten Sammlung. Da Windeln stark dezentral anfallen, müsste eine komplett neue und engmaschige Sammelstruktur für den Abfallstrom geschaffen werden. Deswegen werden die Initiierung und finanzielle Förderung eines separaten Sammelsystems in einer Pilot-Kommune empfohlen, um den erforderlichen Aufwand und die zusätzlichen Kosten abzuschätzen. Alternativ kann eine separate Sammlung in Einrichtungen mit hohem Aufkommen, wie beispielsweise Pflegeeinrichtungen und Kindertagesstätten, umgesetzt werden.

Zusammenfassung Altreifen

Reifen bestehen aus einer Vielzahl grundsätzlich untrennbar verbundener Komponenten wie zum Beispiel Laufstreifen und Karkasse. Darüber hinaus sind die verwendeten Gummiarten sehr widerstandsfähig gegenüber vielen bekannten Lösungsmitteln, Laugen und Säuren, was ein Recycling stark erschwert. Daher kommt vor allem das Zerkleinern zu Granulaten und Pulvern zum Einsatz.

Sammlung und Aufkommen

Der Rücklauf von Altreifen von den Verbraucher*innen zu den Sammelstellen und Werkstätten funktioniert nach Branchenauskunft gut. Die anfallende Menge der Altreifen sowie deren Entsorgungswege lassen sich aber derzeit nicht nachverfolgen, da aktuell nur für die Entsorgungsunternehmen Registerpflichten bestehen, nicht jedoch für vor- oder nachgelagerte Tätigkeiten. Gemäß der Statistik der GAVS zum Aufkommen vielen 2019 rund 571.000 t Altreifen in Deutschland an.

Aktuell befindet sich die deutsche Altreifenentsorgungsbranche in einer kritischen Situation. Eine wesentliche Ursache ist dabei eine starke präventive Begrenzung des Gehaltes an polyzyklischen aromatischen Kohlenwasserstoffen (PAK) in Teilen der etablierten Absatzmärkte für Altreifenrezyklate sowie eine damit verbundene Verunsicherung der Märkte und Verbraucher*innen, auch in Märkten, die nicht von der Regulierung betroffen sind. Dies hemmt das Wachstum der stofflichen Verwertung und damit die Investitionsbereitschaft in neue Produkte und Verfahren insgesamt. Des Weiteren wird die Branche durch einen starken Rückgang der energetischen Verwertung von Altreifen in Zementwerken sowie ein allgemein niedriges Preisniveau am Primärrohstoffmarkt belastet. Die Altreifenentsorgungsbranche kritisiert zudem, dass nur etwa 25% der von Verbraucher*innen gezahlten Beiträge bei den Entsorgungsbetrieben ankommen. Eine Anhebung der Annahmepreise der Altreifenrecycler erhöht unter den bestehenden Voraussetzungen die Anreize zur illegalen Entsorgung von Altreifen durch einige Altreifensammler.

Um die Finanzierung der Sammlung und Verwertung von Altreifen nachhaltig zu sichern und die illegale Entsorgung durch eine Verbesserung der Nachverfolgbarkeit zu reduzieren, wird die Einführung einer erweiterten Herstellerverantwortung oder eines abgabenbasierten Systems empfohlen. Durch die Änderung des Systems lassen sich die meisten Probleme der Sammlung und Sortierung lösen. Ein Problem, dass sich nicht darüber lösen lässt, ist das der Nachfrage nach Sekundärrohstoffen bzw. Ersatzbrennstoffen.

Verwertung von Altreifen

Die größten Potenziale für eine Ausweitung der stofflichen Verwertung von Altreifen liegen in granulat- und feinmehlbasierten Anwendungen, im Straßenbau und in der Runderneuerung (insbesondere Pkw).

Runderneuerung

Im Pkw-Bereich lag der Anteil der runderneuerten Reifen am Reifenersatzmarkt 2018 deutlich unter einem Prozent, im Lkw-Bereich bei etwa 29%. Nach Branchenauskunft bestehen in Deutschland die Kapazitäten, um die Runderneuerung von Lkw-Reifen auf 40% auszuweiten. Typischerweise werden geeignete Pkw-Reifen einmal, Lkw-Reifen bis zu dreimal runderneuert.

Aufgrund der Konkurrenz durch günstigen Neureifen ist die Nachfrage nach runderneuten Pkw-Reifen sehr gering. Um die Nachfrage zu erhöhen bedarf es primär einer Verbesserung der Kostenstruktur in der Runderneuerung. Von zentraler Bedeutung ist dafür die Anlagenautomatisierung. Des Weiteren ist eine Weiterentwicklung der Werkstofftechnik und der Fertigungstechnologie notwendig, um in der Runderneuerung auf das Leistungsniveau moderner Pkw-Reifen aufzuschließen. Die Kombination aus mangelnder Nachfrage auf der einen Seite und notwendiger Investitionen in Werkstoff- und Produktentwicklung sowie Prozessautomatisierung auf der anderen Seite stellen jedoch für die mittelständisch geprägten

Runderneuerer einen schwer zu überwindenden Konflikt dar. Hier kann durch passende Förderprogramme unterstützend eingegriffen werden.

Die Verfügbarkeit geeigneter Altreifen ist ein weiterer Faktor, der die Ausweitung der Runderneuerung im Pkw-Bereich begrenzt. Runderneuerungsbetriebe beziehen oft hohe Anteile ihrer Karkassen aus dem Ausland. Es erscheint keine hinreichend hohe Motivation in Deutschland zu bestehen, die Altreifen entsprechend zu sortieren. Bereits vorhandene Sortierkriterien sollten daher für allgemein verbindlich erklärt werden. Zusätzlich ist eine konstruktive Änderung der Karkassen von Neureifen im Hinblick auf eine bessere Runderneuerung notwendig. In Zusammenarbeit mit Herstellern, Runderneuerern und Verwertern sollten, am besten auf EU-Ebene, verbindliche Standards für ein runderneuerungsfähiges Reifendesign entwickelt werden.

Stoffliche Verwertung

Eine Rückführung von Altreifenrezyklaten in neue Reifen ist nur sehr eingeschränkt möglich. Die Rezyklate werden daher heute überwiegend in der Form von Granulaten eingesetzt, etwa als Einstreu für Kunstrasen, in Sport- und Spielplatzmatten sowie einfachen Formteilen. Derzeit werden erste Sekundärprodukte auf Basis von Feinmehlen hergestellt, die teilweise bereits Produkten aus Primärrohstoffen ebenbürtig sind. Die Komplexität derartiger Neuentwicklungen, die relativ kleinen Nischenmärkte sowie das anhaltend niedrige Preisniveau der Primärrohstoffe begrenzen jedoch die mengenmäßige Bedeutung derartiger Ansätze. Ein Technologie- und Wissenstransfer zwischen Neu- und Altreifenbranche würde hier zu einer deutlichen Verbesserung der Qualität und Wirtschaftlichkeit der stofflichen Verwertung führen und sollte daher gefördert werden.

Die bisher bestehenden PAK-Gehaltsgrenzen sind in vielen Bereichen in Überarbeitung. Die Einführung von verbindlichen Messverfahren nach Vorbild der Methode nach Barrero-Moreno et al. (2018) würde höhere gemessene PAK-Gehalte ergeben, als dies nach den bisher zulässigen Methoden der Fall ist. Entsprechend würden einige Anwendungen entfallen oder einer signifikanten Absenkung des Rezyklatanteils bedürfen. Auch wenn sich die PAK-Regelungen nur auf einen Teilbereich des Marktes für Altreifenrezyklate erstrecken, führt die allgemeine Verunsicherung auch zu einer Dämpfung auf angrenzende Anwendungsgebiete.

Im Rahmen der Überprüfung geltender PAK-Grenzwerte sollte die Einführung von gefährdungsbezogenen migrations- und emissionsbasierten Messverfahren anstelle von extraktionsbasierte Gehaltsgrenzwerten auf EU-Ebene umgesetzt werden. Nach aktuellem Stand der Forschung scheinen von Altreifenrezyklat und daraus hergestellten Erzeugnissen im Hinblick auf Migration und Emission von gesundheitsgefährdenden Stoffen keine signifikante Gefährdung für Mensch und Umwelt auszugehen.

Einer der größten, bisher kaum erschlossenen Wachstumsmärkte für die stoffliche Verwertung von Altreifen ist der Einsatz im Straßenbau. Die Gummimodifizierung von Bitumen führt zu einer Verbesserung einzelner Leistungsparameter von Straßen und kann auch die Reduktion der Schichtdicke ermöglichen. Auf Basis des aktuellen Erkenntnisstands erscheint der Einsatz von Altreifenrezyklaten daher ökonomisch sinnvoll und kann durch aktuelle Entwicklungen zum Absenken der Einbautemperaturen von Asphalt ohne nennenswerte Gefährdung von Mensch und Umwelt erfolgen. Hier bedarf es primär der Erarbeitung von Regelwerken auf Länderebene als Grundlage zur Berücksichtigung derartig modifizierter Asphalte bei Ausschreibungen.

Zusammenfassung Alttextilien

Insgesamt ist festzustellen, dass es keine verlässlichen Daten zur Sammlung von Alttextilien gibt. Auf Basis der vorliegenden Informationen aus verschiedenen Untersuchungen wird für das Jahr 2018 die Sammelmenge auf ca. 1,0 Mio. t und die Sammelquote auf ca. 64% abgeschätzt.

Die Sammlung von Alttextilien erfolgt zu 44% durch gewerblichen Sammler, gefolgt von den gemeinnützigen Sammlern mit 28,6%. Die örE sammeln 26,9% der Menge ein. Die Sammlung im Rahmen der freiwilligen Rücknahme spielt mit 0,5% eine untergeordnete Rolle. Illegale Sammlungen spielen heute aufgrund der gesunkenen Marktpreise kaum eine Rolle mehr. Vor dem Hintergrund der zu erwartenden negativen Qualitätsveränderungen der Alttextilien ist davon auszugehen, dass der Preistrend weiter nach unten gehen wird. Insofern wird das Ausmaß der illegalen Sammlungen gering bleiben.

Das Hauptsammelsystem bilden die Depotcontainer mit 96%. Die restlichen Sammelsysteme (Straßen- und Körbchensammlung, Rücknahme im stationären Handel oder Sammlung über Abfallbehälter am Haushalt) sind mit insgesamt 3,3% unbedeutend.

Es ist davon auszugehen, dass mindestens 50% der Sammelmenge aus Deutschland exportiert und größtenteils in Europa sortiert wird. Hinsichtlich des Verbleibs nach der Sortierung wird auf die Mitgliederbefragung des bvse im Rahmen der Textilstudie 2020 verwiesen. Danach werden ca. 62% der sortierten Menge nach der Vorbereitung zur Wiederverwendung als Second-Hand-Waren verkauft. Die stoffliche Verwertung von Alttextilien findet hauptsächlich im europäischen und außereuropäischen Ausland statt. Rund 14% werden zu Putzlappen und 12% zu Reißware verarbeitet. Rund 8% der sortierten Alttextilien werden energetisch verwertet und ca. 4% gelangen in Beseitigungsverfahren.

<u>Sammlung und Sortierung von Alttextilien</u>

Es wurden verschiedene Sammelsysteme hinsichtlich der materialschonenden Erfassung und dem Sammelpotenzial des Systems bewertet. Dabei wurden die Sammlung am Recyclinghof, in Kleiderkammern/Shops, die Straßen- und Körbchensammlung, die Depotcontainersammlung mit manueller Erfassung und mit Hakenliftsystem, die haushaltsnahe Sammlung über die Duo-Tonne und die Online-Sammlung mit einbezogen. Im Ergebnis sind die Depotcontainer als manuelle Sammlung zusammen mit der Straßen- und Körbchensammlung das ausgewogenste Sammelsystem in Bezug auf Qualität und Sammelpotenzial.

Die verschiedenen Sortiersysteme wurden hinsichtlich der Kosten, des Potenzial zur Vorbereitung zur Wiederverwendung sowie das Verwertungspotenzial bewertet. Es wurden die Negativ- und Teilsortierung, die Vollsortierung sowie die automatische Sortierung betrachtet. Im Ergebnis ist die Vollsortierung das einzige Sortierverfahren, das die Wertschöpfung der gesammelten Alttextilien gemäß Abfallhierarchie umsetzen kann.

<u>Verwertung von Alttextilien</u>

Die Ressourcenschonungs- und Umweltentlastungspotenziale bei der Verwertung von Alttextilien wurden entlang der fünfstufigen Abfallhierarchie bewertet. Die genauen Effekte sind je Material und Verarbeitung sehr unterschiedlich. Generell kann davon ausgegangen werden, dass Recyclingfasern den Wasser- und Energieverbrauch sowie den CO2-Verbrauch der Textilherstellung verringern.

Durch die Vorbereitung zur Wiederverwendung wird der Lebenszyklus von Textilien verlängert und Ressourcen für die Herstellung neuer Textilien eingespart. Da die Textilindustrie global aufgestellt ist, spielt es keine Rolle, ob Second-Hand-Waren in Deutschland oder in anderen Absatzmärkten verkauft werden.

Sind Textilien weder trag- noch marktfähig, so stehen verschiedene Recyclingverfahren für die Substitution von Primärrohstoffen zur Verfügung. Diese Alttextilien werden meist zu industriellen Putzlappen verarbeitet oder zu Fasern gerissen. Die Textilfasern sind thermisch und akustisch isolierend, sodass diese in vielen Bereichen als Vlies einsetzbar sind. Die Garnherstellung aus Alttextilien ist Stand heute eine absolute Ausnahme, da die Alttextilfasern den Anforderungen an die Materialreinheit und Farbzusammensetzung nicht entsprechen. Viele Projekte befassen sich mit diesem Textilrecyclingverfahren, um den Marktanforderungen gerecht zu werden. Chemische Recyclingverfahren kommen auch bei der Verwertung von Alttextilien in Betracht. Hierzu gibt es eine Vielzahl an Technologien, die derzeit in Forschungs- und Pilotprojekten getestet werden. Es gibt nur einige wenige, die im industriellen Maßstab verfügbar sind. Die energetische Verwertung ist eine Option für Alttextilien, die keinem Recycling zugeführt werden können. Die Beseitigung als letzte Stufe der Abfallhierarchie kommt für die in Deutschland sortierten Alttextilien grundsätzlich nicht in Betracht, da ein Zugang zu energetischen Verwertungsanlagen besteht.

Maßnahmenvorschläge und Handlungsempfehlungen

Für die Förderung der Vorbereitung zur Wiederverwendung und der stofflichen Verwertung von Alttextilien wurden als relevante Themenbereiche für die Ableitung von Handlungsempfehlungen die Sensibilisierung der Verbraucher*innen zum nachhaltigen Konsum und Umgang mit Textilien sowie die Einbindung der Hersteller und des Handels bei der Verbraucher*innenberatung und der Entwicklung neuer Geschäftsmodelle identifiziert.

Ziele der Maßnahmenentwicklung waren die Aufrechterhaltung des hohen Niveaus der getrennt erfassten Mengen an Alttextilien, auch wenn diese sich zu einem zuzahlungspflichtigen Stoffstrom entwickeln werden, die Schaffung von Transparenz innerhalb des Mengenstromes und die Förderung hochwertiger Verwertungswege in Deutschland und Europa.

Nach Bewertung aller Maßnahmenvorschläge kann insgesamt festgehalten werden, dass die Einführung einer erweiterten Herstellerverantwortung trotz des hohen administrativen und organisatorischen Aufwands die größten positiven Effekte auf die Förderung der textilen Kreislaufwirtschaft hat und Lösungen für alle identifizierten Themenbereiche bietet. Aus diesem Grund wird die Einführung einer erweiterten Herstellerverantwortung empfohlen. Aufgrund des langen Umsetzungshorizonts werden als nächste Schritte vorgeschlagen:

1. Regierungsbeschluss zur Einführung einer erweiterten Herstellerverantwortung für Textilien
2. Umsetzung der Maßnahmen zur Förderung des Konsums nachhaltiger Produkte und der Umsetzung von Informations- und Beratungspflichten auf allen Ebenen
3. Initiierung eines Stakeholder-Dialogs mit Planspiel „Einführung einer erweiterten Herstellerverantwortung“

1 Introduction

1.1 Examined waste streams

Section 6 of the German Circular Economy Act specifies the five-step hierarchy according to which waste prevention has the highest priority, followed by preparation for re-use, recycling and recovery. A final disposal of waste is only the last possible option.

For certain waste streams, regulations exist on extended producer responsibility (e.g. for packaging, batteries, waste electrical and electronic equipment, end-of-life vehicles). These regulations oblige producers to set up collection systems for end-of-life products and to achieve certain collection and, in some cases, recycling rates. It can be assumed that such regulations are also suitable for other waste streams.

Within the scope of this research project, further material streams without specific waste stream-related regulation were examined and evaluated regarding this assumption. Waste streams were selected that are quantitatively significant and for which it can be assumed that the current regulations are insufficient to fully exploit the recycling potential inherent in these waste streams.

The selected waste streams are:

- Bulky Waste
- Mattresses
- Furniture
- Carpets
- Artificial Turf
- Diapers
- End-of-life tyres
- Used Textiles

In some cases, the individual waste streams overlap, as the boundaries are fluid, as is the case with bulky waste and furniture.

1.2 Methodology

The individual waste streams are first examined with regard to the practice of collection and recovery. Obstacles to resource-conserving waste management are to be identified and options for action derived in order to improve the prevention, preparation for reuse and recycling of these waste streams. In a concluding chapter, the waste streams are compared with each other and prioritised according to a defined evaluation scheme.

1.3 Assessment of the proposed measures

All derived measures for the respective waste streams are evaluated according to uniform criteria.

1.3.1 Criteria

- Bureaucratic effort

- Legal aspects
- Statistical aspects
- Organizational effort
- Implementation horizon
- Bindingness
- Improvement of collection
- Contribution to the financing of recycling
- Strengthening of recycling
- Acceptance
- Public relations

The criteria are briefly presented below.

1.3.1.1 Bureaucratic effort

The introduction of new recovery routes can be time-consuming and costly due to the involvement of various agencies and actors, the organisation of planning and processes, and compliance with various requirements and verification obligations.

This criterion is used to estimate how high the bureaucratic effort is to implement a measure on a permanent basis.

Table 1 Evaluation of the criterion "Bureaucratic effort"

1	3	5
No additional bureaucratic effort required.	The additional bureaucratic effort can be integrated into existing formalities or can be carried out by involved actors with proportionate effort.	For many actors involved, the measure leads to an unreasonable bureaucratic burden and the associated unreasonable additional costs.

1.3.1.2 Legal aspects

A legal basis is required for the introduction of new recovery routes such as new separate collection systems or levy models, but this is not necessary for voluntary measures. This criterion assesses the extent to which the legal framework for implementing a measure exists or needs to be created or changed.

Table 2 Evaluation of the criterion "Legal aspects"

1	3	5
No legal changes/additions are required for the implementation of the measure.	The legal framework (e.g. authorisation for the federal government to issue ordinances) is already in place.	There is no legal framework to implement the measure.

1.3.1.3 Statistical aspects

The waste streams examined do not always have a statistical record of waste quantities or recovery routes. The criterion of statistical aspects is used to assess whether the measure can contribute to improving this. If a waste stream is already fully statistically recorded, the criterion is removed from the evaluation.

Table 3 Evaluation of the criterion "Statistical aspects"

1	3	5
The measure completely ensures the statistical recording of the waste stream.	The measure improves the statistical recording of the waste stream.	The measure has no impact on improving the statistical recording of waste flows, although this is deficient.

1.3.1.4 Organizational effort

While Bureaucratic Effort describes how burdensome it is to implement a measure, this criterion assesses the effort involved in introducing a measure.

Table 4 Evaluation of the criterion "Organizational effort"

1	3	5
The organizational effort for the introduction of the measure is low.	There is a medium organizational effort involved in introducing the measure. Constructive and targeted communication between several actors is required.	The organizational effort for the introduction of the measure is high. The necessary agreement between different actors is difficult to achieve.

1.3.1.5 Implementation horizon

Some measures can be introduced or implemented at short notice, whereas other measures require longer lead times for preparation or planning.

Table 5 Evaluation of the criterion "Implementation horizon"

1	3	5
Short term (1-2 years)	Medium term (3-5 years)	Long term (over 5 years)

1.3.1.6 Binding character

Measures that are mandatory to implement can have a greater impact than non-binding measures that are only implemented by individual actors.

Table 6 Evaluation of the criterion "Bindingness"

1	3	5
Highly binding (e.g. due to legal basis)	Binding (e.g. voluntary commitments)	Non-binding (e.g. based on individual decisions of the actors)

1.3.1.7 Improvement of collection

An increase in the collection volume increases the potential for resource conservation and environmental relief. The criterion assesses the extent to which a measure improves the collection of the waste stream.

Table 7 Evaluation of the criterion "Improvement of collection"

1	3	5
The measure improves the collection of the waste stream.	The measure has no impact on the collection of the waste stream.	The measure worsens the collection of the waste stream.

1.3.1.8 Contribution to the financing of recycling

In addition to organisational obstacles and acceptance problems, the implementation of material recycling often faces financial disadvantages compared to energy recovery.

The criterion assesses the extent to which a measure can contribute to the financing of recycling.

Table 8 Evaluation of the criterion "Contribution to the financing of recycling"

1	3	5
The measure secures the financing of recycling.	The measure ensures the financing of recycling to a large extent or has a positive effect on the economic viability of recycling processes.	The measure does not contribute to the financing of the recycling. The financing must be secured in some other way.

1.3.1.9 Strengthening of recycling

This criterion maps the ecological impact of a measure and is the most important criterion in relation to the objectives of this study.

Table 9 Evaluation of the criterion "Strengthening of recycling"

1	3	5
The measure results in an increase in the recycling of the entire waste stream.	The measure creates better conditions for recycling or only affects the recycling of part of the waste stream.	The measure has no influence on the increase in recycling.

1.3.1.10 Acceptance

In order to introduce a measure and implement it in the long term, it requires the acceptance of the respective actors concerned. The more actors accept a measure, and no intensive communication has to be carried out to convince them, the better a measure can work and, for example, overcome initial difficulties in the introduction.

Table 10 Evaluation of the criterion "Acceptance"

1	3	5
Measure accepted by a majority of stakeholders.	Measure accepted by some of the stakeholders mentioned.	Measure accepted by a minority of stakeholders.

1.3.1.11 Public relations

This criterion goes hand in hand with the criterion Acceptance and is particularly important for measures that affect consumers and require their participation.

Table 11 Evaluation of the criterion "Public relations"

1	3	5
No or hardly any additional communication or public relations work is needed to implement the measure.	The measure requires a moderate amount of communication or public relations work.	The measure requires intensive communication or public relations work.

1.3.2 Weighting of the criteria

For each criterion, evaluation points from 1 to 5 are allocated[1] according to the definitions in Table 1 to Table 11. A weighted average is calculated from all criteria. The lower the score, the better the practical feasibility and impact of a measure.

Due to its ecological relevance, the criterion Strengthening recycling is rated higher than the other criteria and is given three times the weighting in the evaluation. The other criteria are given a single weighting.

There are no knock-out criteria. The measures are considered as a whole.

1.3.3 Stakeholders and conclusion

Finally, the evaluation of the measures indicates which addressees a measure is aimed at. In a conclusion, the measures are summarised and classified on the basis of the previous evaluation. If the evaluation finds that several criteria indicate that a measure is not effective, this is taken into account in the conclusion.

[1] Intermediate evaluations of the above definitions are possible.

2 Bulky waste

2.1 General information

Bulky waste, in other parts of Europe also referred to as bulky household waste or bulky refuse, is waste which accumulates in private households and businesses and comprises items that are considered too large to be accepted as part of the regular collection of the ordinary residual waste. Examples include furniture, larger-sized toys, sports equipment, home furnishings and similar items, but not electrical or electronic equipment, as these must be collected separately in accordance with the Electrical and Electronic Equipment Act. The great variety of products it may contain results in different materials, such as wood, metal, plastic or glass that are being found in this waste, often even as a composite. For estimating the volume of this waste stream, a product-related approach is therefore not actually helpful.

2.2 Collection

2.2.1 Collection systems

Bulky waste is mainly collected by the public disposal providers.[2] The decision about the arrangement for the collection is left at the discretion of the local disposal providers and differences can consequently be found in the applied systems.

In a nationwide survey on the collection of bulky waste[3], the public disposal providers were asked whether the collection is carried out by themselves or by third parties and, if a tandem pickup model is applied for collection and which are the types of separated waste streams.

Responses provided from 220 public disposal providers form the data basis for the presentations following hereafter. The surveyed providers handle the waste of around 40.7 million inhabitants or around 49 % of the German population in total.

The public disposal providers could choose from the following options to specify their collection systems (multiple selection possible):

- Collection free of charge on certain days of the year
- Collection free of charge on a requested or allocated date
- Collection against the payment of fees on specific days
- Collection against the payment of fees on a requested or allocated date
- Drop-off for free at the civic amenity centre
- Drop-off against the payment of fees at the civic amenity centre.

An explanatory sentence to the survey provided the explanation that free of charge here means that no additional fees are charged for the service, as this is already covered by a basic fee. Since

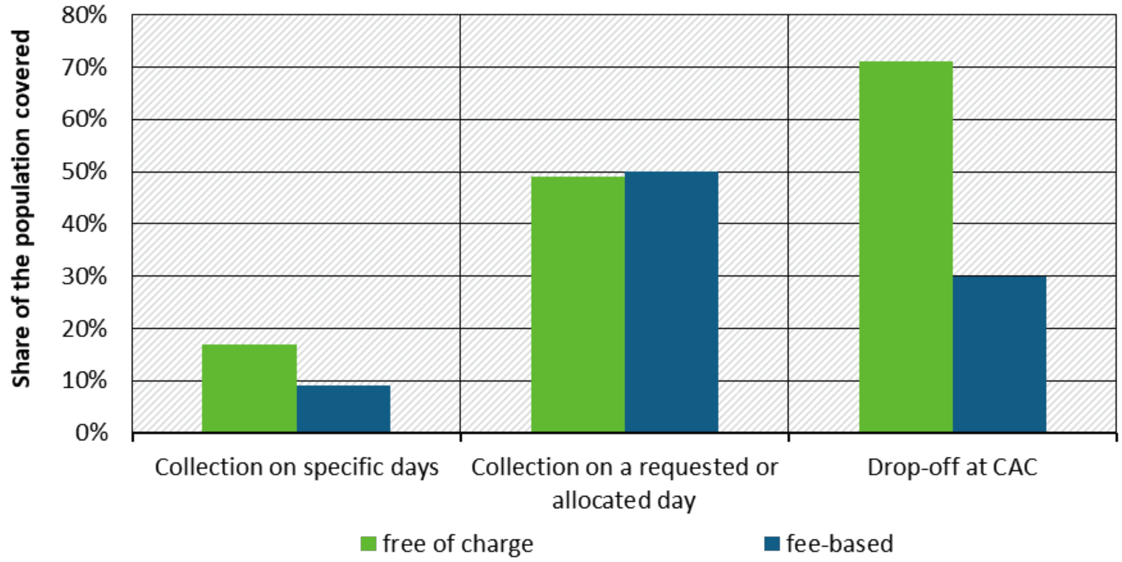
[2] However, according to a ruling by the Federal Administrative Court in February 2018, bulky waste, unlike residual waste, is not mixed municipal waste and therefore not subject to obligatory handover to the local authority in the sense of the KrWG, which consequently allows a commercial or non-profit collection model too (https://www.bverwg.de/de/230218U7C9.16.0). Of what influence this ruling will be on the existing disposal structures cannot yet reliably predicted.

[3] Survey: "Evaluation of the collection and recovery of selected waste streams for the further development of the circular economy" conducted in the period 02.03.-03.04.2020.

some public disposal providers have a quantity limit on acceptance for free, an option had been given to indicate this limiting quantity in supplementary fields.

Most of the public disposal providers offer a combination of pickup service and bring system for the collection of bulky waste (154 providers representing 85% of the population covered). 55 public disposal providers (representing 11% of the surveyed population) offer only a pickup service whereas nine public disposal providers (representing 4% of the surveyed population) offer the collection only via a bring system in form of a civic amenity centre (CAC). The most frequent collection offer made by the public disposal providers is a pickup service free of charge on a requested or allocated date and drop-off for free at their CAC.

Figure 1 Collection of bulky waste by the public disposal providers, here related to the population covered in the survey



CAC - civic amenity centre

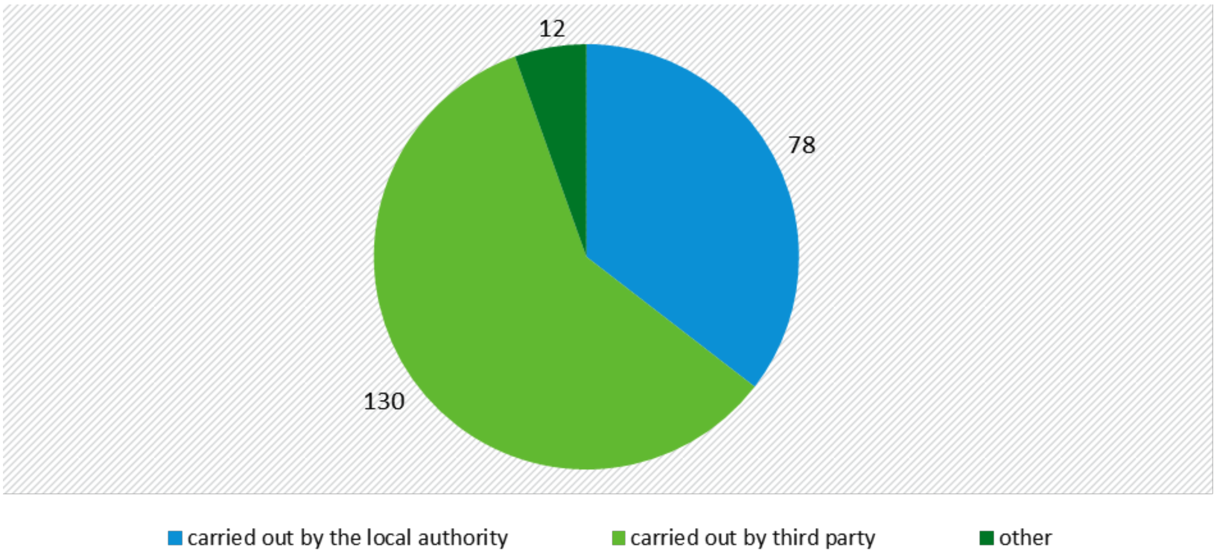
Source: Data and graphic of INTECUS

The applied fee models differ depending on the public disposal provider. With 99 public disposal providers (representing 36% of the population covered), bulky waste disposal is entirely free of charge, whilst extra fees always must be paid with 38 providers (representing 10% of the population covered) regardless of whether the bulky waste is collected via a pickup service or households must deliver it to the local CAC.

At most of the public disposal providers, one disposal option (pickup service or drop-off at the CAC) is covered by the obligatory basic fee and, if necessary, an additional service is subject to an extra fee. Where a certain volume/quantity is exceeded, the public disposal providers sometimes opt to charge an additional fee.

Asked from whom the collection is actually carried out 59% of the surveyed providers responded that third parties are commissioned for this service. 5% of the public disposal providers (12 providers) did commission several public/private service providers such as their own subsidiaries, third parties or subcontractors for the collection and/or to run the corresponding services at the CAC.

Figure 2 Implementation of collection (number of public disposal providers)



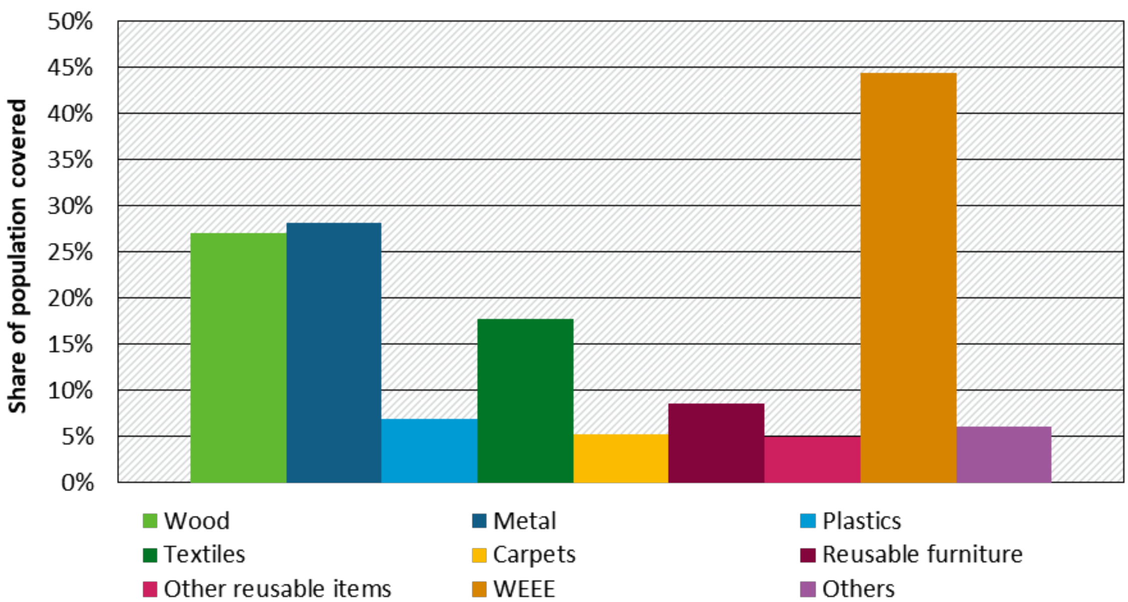
Source: Data and graphic of INTECUS

Tandem pickup model

Nearly half of all surveyed public disposal providers (107 providers representing 57% of the population covered) state that they carry out a tandem pickup model within their jurisdiction which means that they already separate the individual material components when collecting the bulky waste, usually using several vehicles for that.

During the tandem pickup, mainly wood, metals and waste of electrical and electronic equipment are being separated. Items made of plastics, carpets and other fractions such as reusable furniture or other reusable items are hardly separated at all.

Figure 3 Waste fractions separated in the course of applying tandem pickup models



The percentage values shown refer to the number of 40.7 million inhabitants as the total population covered in the survey.
WEEE - waste electrical and electronic equipment
Source: Data and graphic of INTECUS

Finally, the public disposal providers were requested to indicate the quantities collected annually via tandem pickup and the percentage distribution of the individual separated waste fraction. Public disposal providers had the opportunity to enter estimates, since experience has shown that not all public disposal providers record the quantities from tandem pickup and for the individual waste fractions separately. The quantity estimates obtained this way differ widely, with 18 tons per annum as the minimum value by one local authority and 45,000 tons as the maximum by another local authority. It cannot be ruled out, however, that the authorities indicated the tonnage of the annually collected bulky waste and not only the quantity of the waste collected via the tandem pickup. On average, around 2,450 tons are collected annually by tandem pickup. With regards to the percentage distribution, only a few public disposal providers were able to provide specific figures or estimates, thus making an evaluation of this part less meaningful.

Less than 20% of the public disposal providers still conduct post-sorting operations on the bulky waste after collection. In these sorting processes, metals are primarily sorted out, in many cases also wood and only in a few cases (hard) plastics (VKU, 2020).

Many public disposal providers support the reuse of still usable goods by supplying used products themselves or in cooperation with second-hand shops, clothing shops, the Red Cross or similar organisations to secondary users. On their websites, the public disposal providers often integrate information and links to regional vintage swap meet and gift exchanges where citizens offer their still usable items. In their own or supported charity workshops, old goods are prepared for reuse. According to the member survey of the Association of Municipal Enterprises (Verband Kommunaler Unternehmen e.V.), a quarter of the municipalities offer a second-hand goods exchange or a second-hand goods market, and about 40% operate an online give-away market on their own or in cooperation with partners (VKU, 2020).

Bulky waste from commercial sources

Pursuant to Article 3, paragraph 1 of the Commercial Waste Ordinance, producers and owners of bulky waste from trade and industry are obliged to collect it separately and segregated by the material types paper, glass, plastics, metals, wood and textiles, or otherwise to hand it to pre-treatment, i.e. material sorting, if separate collection is technically impossible or economically unreasonable. The obligation of pre-treatment does not apply if the costs of treating the mixtures and the subsequent recovery of the waste are disproportionate to the costs of recovery for which no pre-treatment is required. To commercial municipal waste the priority for preparation for re-use or recycling must be applied. If this proves impossible, a proper, harmless and high-quality recovery shall take place, which in most cases means energy recovery (GewAbfV, 2017).

Owners of commercial waste are free in their decision whether to recycle this waste themselves or to commission a waste service provider. Numerous public disposal providers also offer commercial customers the collection of bulky waste or its acceptance by the local CACs against the payment of a fee. Where the bulky waste from commercial sources is disposed via the services of the public disposal provider, it gets handled together with the municipal bulky waste, for which an obligation to pre-treat mixed waste streams does not yet exist and which therefore in many cases is forwarded directly for energy recovery.

2.2.2 Waste statistics/collected quantities

In the German Ordinance on the European list of waste (Verordnung über das Europäische Abfallverzeichnis, Abfallverzeichnis-Verordnung - AVV) which transposes Commission Decision on a list of wastes (2000/532/EC) and certain requirements of the Waste Framework Directive (2008/98/EC) into national law, bulky waste has its own waste code 20 03 07 ("bulky waste").

To assess the total collected volume of this waste in Germany, both the Fachserie 19, Reihe 1 of the Federal Statistical Office (Destatis) and the statistics contained in the municipal waste balances of the Federal States were analysed.

2.2.2.1 Statistics of the Federal Statistical Office

The per capita volume of bulky waste in Germany stands at around 30 kg/(inh*a), a quantity that has increased slightly in recent years. Table 12 displays the total volume of bulky waste handled from 2013 to 2017at the different waste management facilities in Germany.

Table 12 Quantities of bulky waste handled between 2013 and 2017 by waste management facilities in Germany

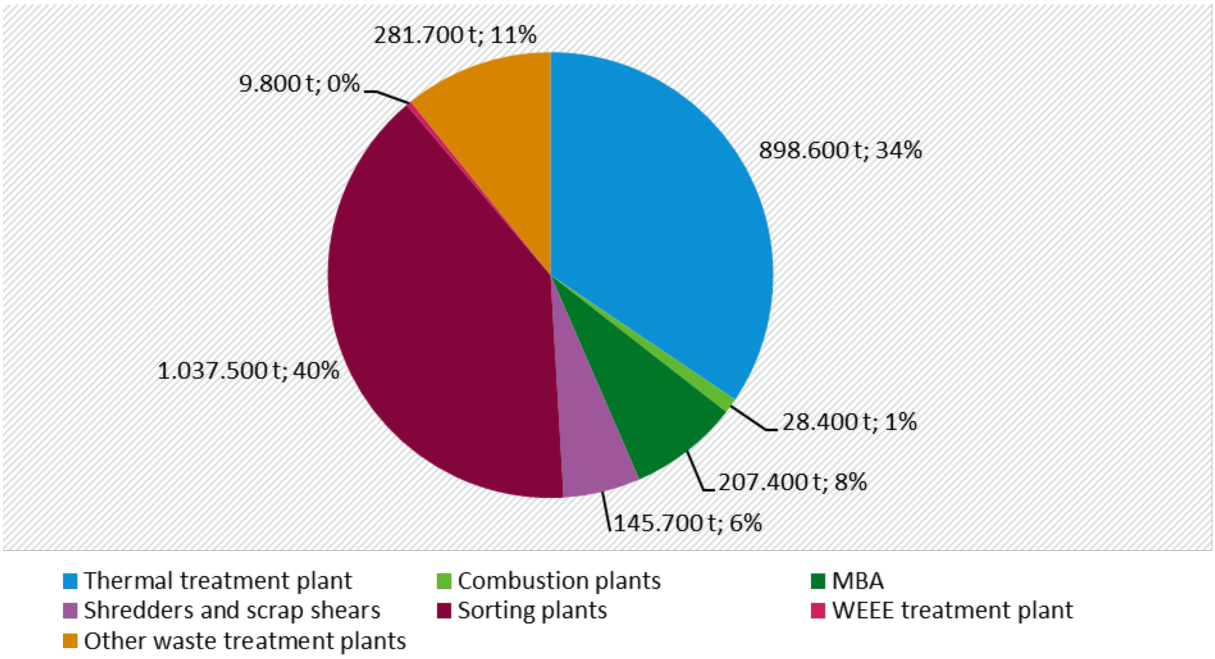
Year	Waste management facilities	Input amounts			
	total	total	of which		
			generated within the facility	supplied from	
	Number	1,000 t		domestic sources	abroad
2013	477	2,486.5	1.8	2,484.6	0.1
2014	508	2,475.2	0.9	2,474.1	0.1
2015	519	2,494.7	10.5	2,484.1	0.1
2016	520	2,547.5	13.2	2,527.4	6.9
2017	522	2,610.1	22.8	2,585.2	2.1

Source: Destatis, 2015-2019

Whilst the input of bulky waste to the waste management facilities was rather constant in the years 2013-2015, an increase has occurred in the years 2016 and 2017 respectively. The volume of treated bulky waste from abroad has also increased slightly in this period.

At which proportions the various facilities contributed to the management of the bulky waste in 2017 can be seen in Figure 4.

Figure 4 Input of bulky waste amounts to the various waste management facilities in 2017

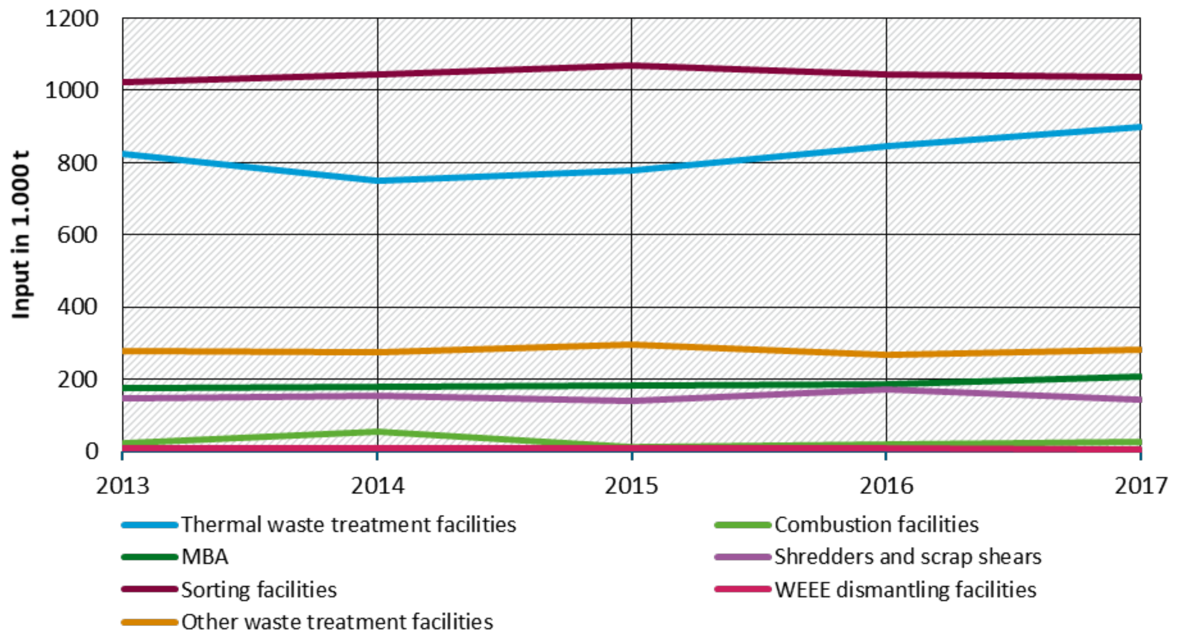


Source: Graphic of INTECUS based on data from (Destatis, 2019c)

Accordingly, most of the bulky waste is thermally treated or processed in sorting facilities. The proportion of bulky waste imported from abroad is exclusively thermally recovered.

Which development the bulky waste input with waste code 20 03 07 has taken to the waste management facilities over the years is shown in Figure 5.

Figure 5 Input of bulky waste to waste management facilities during the period 2013–2017



MBA - mechanical-biological treatment facility
Source: Graphic of INTECUS based on data from (Destatis, 2015-2019)

The above graphic reveals that the bulky waste input into the respective types of facilities has remained constant over the years, only in the case of thermal waste treatment facilities an upward trend can be seen.

Due to extending its scope of application to all electrical and electronic equipment, an increasing number of products have fallen under the German Electrical and Electronic Equipment Act (ElektroG) and are to be handled under this particular management regime since August 15, 2018. Many of these items were previously assigned to bulky waste. Examples are furniture with permanently installed lights or electrically adjustable seating furniture. Also, the amendment of the ElektroG is expected to cause the total input of bulky waste into the treatment facilities to further decrease. Conversely, the output flow of bulky waste from WEEE dismantling facilities will presumably increase. Statistics supporting this assumption are at this moment not available yet.

2.2.2.2 Statistics provided by the Federal States

To provide a breakdown of quantities for the different regions of Germany, an analysis of the annual waste balances of the Federal States for 2017 was undertaken. In most of these balances, the treatment paths for the waste are also reported.

A total amount of 2,355,300 tons of bulky waste is reported in the balances from the municipal sector and thus approx. 250,000 tons less the quantity that, according to Destatis (2019), the different waste management facilities handled in the same year. Other possible sources for this waste include, for example, trade and industry or amounts disposed from public facilities.

The per capita volume of bulky waste ranges from 16.6 kg/(inh*a) in Bavaria to 46.6 kg/(inh*a) in the Saarland. Weighted according to the number of inhabitants in each of the Federal States gives an average per capita volume of bulky waste in Germany in the amount of 28.2 kg/(inh*a).

Numerous public disposal providers collect wood waste separately from bulky waste. The amount of wood waste collected separately from bulky waste in 2017 amounted to 1,191,910 tons, that is 14.4 kg/(inh*a). Only Bremen and Lower Saxony do not mention any separately collected wood waste quantities in their waste balances. In addition, some public disposal providers also remove metals from the bulky waste before it enters the records. The mass of metal recovered this way cannot separately be found in the waste balance, however.

Table 13 Amounts and management of bulky waste as per the Federal States waste balances for 2017

Federal State	Total bulky waste amount	Recycling	Other waste treatment	Mechanical-biological treatment	Thermal treatment	Recovery at landfill site	Bulky waste amount per capita	Separately collected waste wood	Waste wood generation per capita
	[1,000 t]						[kg/inh*a]	[1,000 t]	[kg/inh*a]
Baden-Württemberg	223.1	74.2	1.2		147.8		20	271	25
Bavaria	215.4				mostly thermal		16.6	306.368	23.6
Berlin	65.94	3.56			62.38		18.2	59.442	16.5
Brandenburg	85.957						35	10.676	4.3
Bremen	22.419						39.6		
Hamburg	35.7						19.6	30.1	16.5
Hesse	171.475	43.247		21.547	106.419	0.262	27	83.407	13
Lower Saxony	267.879						34		
Mecklenburg-Vorpommern	74.469						46	1.54	1
North Rhine-Westphalia	659.578		29.1	312,502	317.976		36.8	211.068	12
Rhineland-Palatinate	127.596		50.778		76.817		31	92.68	22.5
Saarland	46.34						46.6	11.665	11.7
Saxony	111.338		75.509	15.514	20.315		27	28.694	7
Saxony-Anhalt	65.303	7.859	18.115		39.33		29.3	25.399	11.39
Schleswig-Holstein	98.192	63.166		16.597	18.429		41.6	38.586	13.4
Thuringia	84.614		16		43	26	39	8.59	4
total	**2,355.30**						**28.2**	**1,179.22**	**14.4**

2.3 Recovery of bulky waste

2.3.1 Composition

The main components and average composition of bulky waste in Germany can be seen in Table 14. Furniture accounts for the largest share with 20.6 kg/(inh*a), followed by mattresses and floor coverings (2.7 kg/(inh*a) each). Counting the material fractions independently of their origin results in wood having the most significant share with just under 50% by mass. Various sorting analyses have established the share of wood to range between 40 to 60%, depending on the municipality and collection arrangement applied. The next largest portion are composite items made from textiles, such comprise upholstered furniture, mattresses and carpets, together making up about 30% of the overall bulky waste mass. Other components such as metals, plastics and miscellaneous waste items are of subordinate importance, each accounting for less than 10% of the total mass (Dornbusch et al., 2020; INTECUS (div.); Hahnenkamp and Tuminski 2017).

Table 14 Material characteristics of bulky waste in Germany

Material fraction	mass-%	kg/(inh*a)
Upholstered and composite furniture	22.2	7.5
Wooden furniture	38.5	13.1
Carpets and other floor coverings	8.0	2.7
Plastics	4.7	1.6
Metals and metal composites	6.9	2.4
Mattresses	8.1	2.7
Other wood materials	6.8	2.3
Other bulky items	2.1	0.7
Miscellaneous waste	2.6	0.9
Total	**100.0**	**33.9**

Source: Dornbusch et al., 2020

2.3.2 Routes of recovery

Bulky waste, as outlined already in chapter 2.2.2 above, is predominantly used for energy recovery in thermal treatment facilities (34%) or processed in sorting facilities (40%). It is often not the quality of the bulky waste that influences the disposal route but cost aspects and the long-term disposal contracts which the public disposal providers have concluded.

Sorting facilities can be operated only where a minimum throughput of 40,000 tons/a and an additional payment from disposal fees are ensured, because the revenues from the sale of secondary raw materials cannot offset the investment and operating costs (Hahnenkamp and Tuminski 2017). Sorting processes can include the following steps:

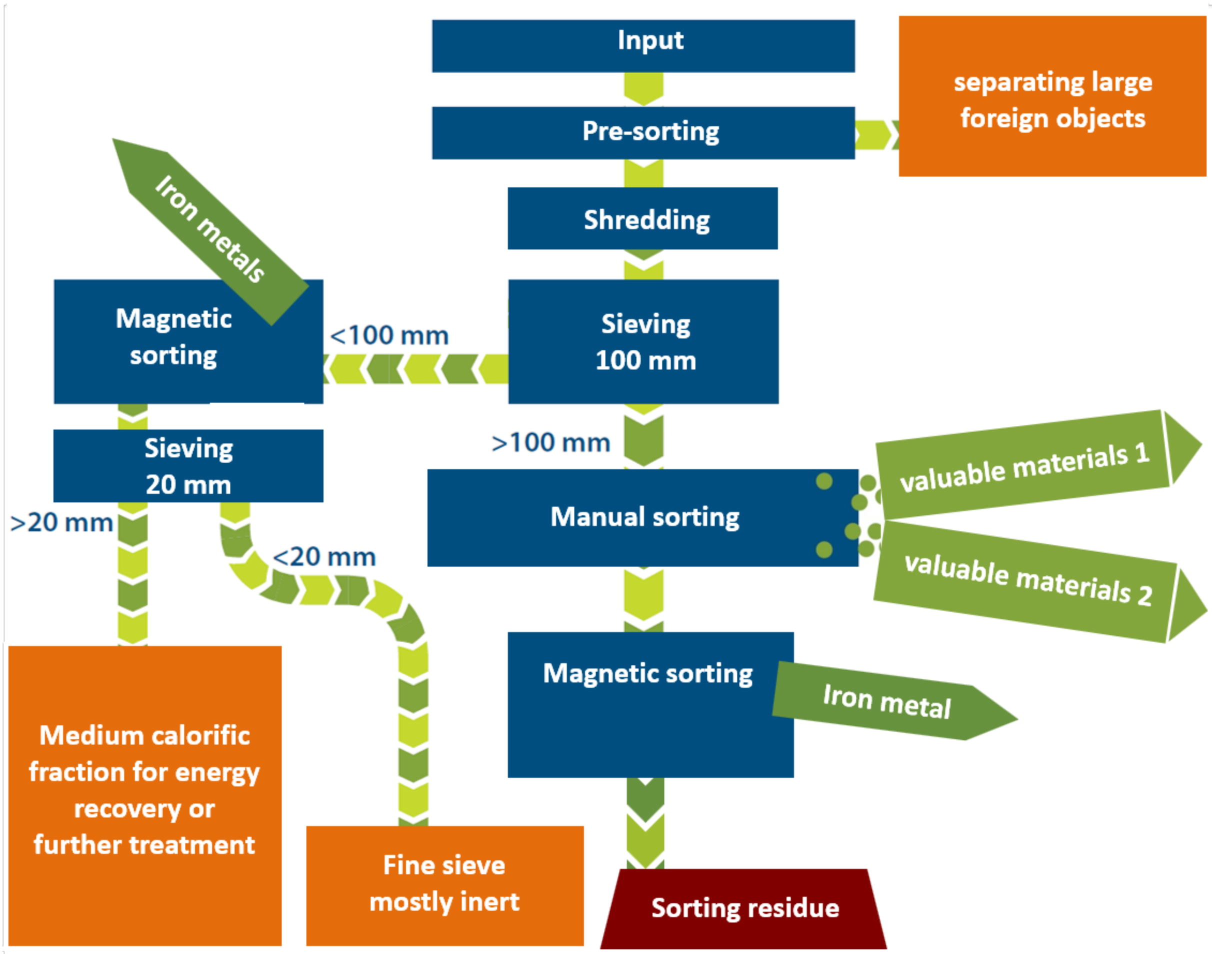
- Pre-sorting/dredger sorting of large-sized pieces (e.g. carpets, mattresses, composite items)
- Shredding
- Metal separation by magnetic sorting

- Sieving
- Manual sorting of recyclable fractions

Separating the valuable material fractions, such as metals and single-variety plastic parts, is of primary importance in the sorting facilities. These materials are predominantly recycled. Nevertheless, the percentage recycling rate of the input in sorting facilities often stays in the single-digit range only given the low proportion of valuable fractions contained in commercial bulky waste.

The sorting residues are forwarded to thermal waste treatment facilities, which in Germany generally fulfil the energy efficiency criterion for the R1 recovery process pursuant to Annex 2 of the German Circular Economy Act and are therefore considered recovery facilities. Substitute fuels can be produced from the high-calorific material fractions such as wood and textile composites. Figure 6 gives an impression on how schematically the sorting of bulky waste can be organized.

Figure 6 Exemplary process scheme for the sorting of bulky waste



Source: Graphic of INTECUS based on Bilitewski et al., 2018

Materials that are significant in terms of their quantity in the bulky waste and which occur in furniture as well as in other bulky items are discussed hereafter in more detail. For information covering further materials contained in furniture and about the waste fractions carpets and mattresses, please be referred to the chapters 34 and 5 in this document.

2.3.2.1 Wood and wood-based materials

Waste wood from bulky waste, according to Annex I of the German Ordinance on Waste Wood (AltholzV), may be recycled as wood chips or wood shavings if it is assigned to the waste wood categories A I (untreated solid wood) or A II (wood and wood-based materials not containing halogen-organic compounds in the coating) and compliant with the limit values of Annex II of the AltholzV. Waste wood categorized A III may only be recycled if coatings and varnishes have been largely removed by pre-treatment or are removed as part of a treatment process. In practice, however, such a cleaning is rarely carried out due to the efforts it involves, so that energy recovery is taking place instead. Mixed waste wood from bulky waste must be assigned to category A III according to the AltholzV, as approximately 5% of this wood contains halogen-organic compounds. In the case of sorting the bulky wood waste according to the different categories of the AltholzV, the majority of the wood would likely have to be grouped under category A II (approx. 80%) and a small part into category A I and thus in principle would be permitted for recycling if, in addition, the pollutant limit values are complied with. In practice though, sorting mixed assortments from bulky waste according to the wood waste categories is no economically feasible option (Flamme, 2020).

Separating wood waste from other materials when collecting bulky waste is already performed from about one third of all public disposal providers, according to the survey of the public disposal providers (Chapter 2.2.1). Secondary sorting to separate metals, wood waste and/or hard plastics also occurs but is less widespread (VKU, 2020). Often, wood waste is collected separately at the CACs. In facilities engaged in bulky waste pre-treatment and/or sorting, wood and wood-based materials are usually separated and shredded in order to be used for energy recovery, for example as substitute fuel or in biomass combustion facilities. In the overall, only 15% of the wood waste from all sources in Germany is material recycled. More than three quarters are used for energy recovery, considering that the demand from wood recyclers is regionally limited and wood waste is suitable as a renewable energy source because of its good fuel properties (Flamme, 2020).

Wood waste is almost exclusively recycled in chipboard production. Its use in the production of other wood-based materials, such as fibreboard or oriented strand board, is unusual due to technical obstacles or requirements on the shape of the wood chips. In chipboard production, wood chips are compressed and bound under the addition of approx. 10% adhesive (e.g. melamine-urea-formaldehyde resins) and hardener (e.g. ammonium sulphate) (Rüter and Diederichs, 2012). In 2015, wood waste has had a share of 24.5% in the total wood input to German chipboard production on average (Döring et al., 2017). From a technical point of view, the share of wood waste in this production segment could still be increased by a certain percentage in Germany, for example to 40% (Flamme, 2020). In other EU countries, the share of wood waste in the chipboard industry is partly higher, this is for example the case in Italy, Denmark and Belgium. In Italy, recycled wood with 95% is taking the highest proportion in comparison of European chipboard producers (EPF, 2020). However, in Germany other quality requirements in terms of pollutant concentration and adhesive content do apply. In addition, the transportation distances to the chipboard manufacturer, the requirements for chipboard products in their respective area of usage and the wood waste quality also must be taken into account so as to avoid, for example, excessive migration and the accumulation of pollutants into new products (Flamme, 2020; Strohmeyer, 2019).

Just around the year 2000, the company Nolte (today: Rheinspan) operated two facilities which conducted a material recycling of used chipboards in Germany but these are no longer in operation today (Nienhaus, 2002; Hahnenkamp u. Tuminski 2017). The recycling of chipboard is thus technically feasible, although at present this material is mainly used for energy recovery. This is because conditions must exist for an economically efficient recycling of chipboard on the one hand, and this is currently not the case on the wood market. On the other hand, the material recycling of chipboard must also comply with the limit values set by the German Ordinance on Waste Wood (AltholzV). Several studies indicate that a relevant share of wood waste from various categories, with chipboard in particular, exceeds the limits of the AltholzV for recycling (Bayerisches Landesamt für Umwelt, 2015; Hahnenkamp and Tuminski, 2017; Riedel et al., 2014). Recycling hence should be strengthened primarily for solid wood furniture and other wood waste of the category A I (in as far as reuse is impossible). Recycling of chipboard only makes sense if it means that primary wood, which is suitable for material use, is not increasingly used for energy recovery.

Medium-density fibreboard (MDF) is another wood-based material that has become increasingly popular in recent years. For this product, finely shredded wood is glued into panels instead of wood chips. A lot of research has already been done on the recycling of MDF sheets but it has not been possible yet to set up a facility at larger scale. In the meantime, there is a large-scale test facility in Great Britain that recovers up to 5 tons of wood fibres per hour from MDF sheets with the help of electroconductive or 'ohmic' heating (MDF Recovery, n.d.).

In recent years, the use of wood-polymer composites (WPC) has increased significantly, for example for decking boards. Therefore, an increasing presence of WPC can also be expected in the coming years in waste streams, especially in bulky waste or mixed construction and commercial waste. Wood waste and re-granule, for example from plastic products and furniture, can be used for producing WPCs. With ISO 20819-1:2020-04, there exists already a standard for WPC made from recycled material. The recycling of WPC which involves grinding, melting and extrusion to generate new WPC, is theoretically possible as long as the compatibility of the polymer is guaranteed. However, given the relatively small quantities of this material so far, no structures for recycling have yet emerged in the market (Urbanrec, 2018; KC aktuell, 2016a).

2.3.2.2 Metals

Metals are often used in the furniture sector as frames, for example for tables and chairs, and combined with other materials such as wood or plastics. Other applications include filing cabinets, shelves, lockers, drying racks, ironing boards, ladders, bicycles and other metal items and furniture. Where bulky waste is separately collected and sorted, items and furniture made from metal are primary targets for the separation and sale for recycling. Getting metals recovered from the slag after energy recovery is also possible. Consequently, there is no acute need for action in order to improve the conditions for the recycling of metals.

2.3.2.3 Rigid plastics

The usage of rigid plastics is, distinctively from plastic film and packaging, among other things, characteristic for furniture, toys, sports equipment and household goods (e.g. laundry baskets and watering cans). 3-4% of all plastics produced in Germany are processed in the furniture industry and another 3.4% go into the leisure and household goods sector (GKV, n.d.). Furniture made exclusively from plastic are less common in the market, however, mainly in the form of garden furniture such can be found also. Here, polypropylene and polyethylene are particularly common plastic types (the latter, among others, as the so-called polyrattan).

A recycling is already well established for rigid plastics originating from production waste, as many types of plastic can be re-melted and directly used in a new shape as long as these occur in single pure fractions. Technically feasible processes exist for recycling sorted post-consumer plastic waste, these processes lead to the generation of re-granule that are readily suitable for the (partial) replacement of virgin material. However, such re-granule always must compete on the market with virgin material, and especially in times of low crude oil prices the economic viability is still not ensured (Hahnenkamp u. Tuminski, 2017; KC aktuell, 2016b).

To increase mechanical recycling, it is hence of crucial importance that rigid plastics are consequently separated during bulky waste collection and at the CACs and sorted afterwards, for example with the help of near-infrared spectroscopy. Some municipalities in Germany already pursue such a strategy (Abfallwirtschaft Landkreis Lörrach, n.d.; Abfallwirtschaft Vechta, n.d.; ZAW-SR, n.d.).

2.3.2.4 Miscellaneous and inert materials

There are also some other materials that, in addition to the materials described above and the waste streams discussed in detail later on in this document, are playing a role in the bulky waste or furniture sector. These are used to a lesser extent however and the relevance for the recycling industry is therefore lower compared to those mentioned above. As a consequence, no push was so far given to the recycling processes for these materials from bulky waste.

In addition to rigid plastics, there are also flexible plastic products made of PVC, rubber, latex or multilayer plastic films in bulky waste that cannot be recycled like hard plastics. These include, for example, air mattresses, inflatable toys, hoses, pipes and much more other items (Hahnenkamp and Tuminski 2017). For PVC, nowadays traded as 'vinyl', some new recycling approaches exist (VinylPlus, n.d.). However, just a few years ago, many PVC products still contained high levels of harmful substances (e.g., phthalates and polycyclic aromatic hydrocarbons), and mechanical recycling could thus lead to a transfer of these unwanted substances into new products. Switching to 'vinyl' as the new marketing term was accompanied from a reduction of toxic additives in the production processes or the replacement with non-toxic alternatives (VinylPlus, 2020).

Mirrors are used especially in bathroom and bedroom furniture or sold as floor or wall mirrors with a frame. They are made of sheet glass that is covered with a very thin layer of aluminium or silver and sealed from a lacquer. In a few cases, crystal glass or transparent plastic is used instead of sheet glass. Small mirrors or the fragments from broken mirrors are usually disposed of with the residual waste. At present, there are no separate routes for the recycling of mirrors, which is mainly due to the difficulty to get the critical quantities accumulate and bundled.

Glass is also a frequently used material for tables, display cases or cabinets. Sheet glass, also called float glass, in principle can be easily remelted and processed into new glass, as long as the glass does not contain any additives. However, the production of float glass requires more clean feedstock materials than the production of container glass, which is why glass cullet from production waste is preferably used in manufacturing it. Polluted material and disturbing particles lead to rejects even in the container glass segment. At the time when glass furniture and furniture with glass content become waste and are handed to collection, it often is unknown which type of glass has been used in production and of what composition it is. In some cases the glass is coloured, substances have been added to attain a turbid effect (milk glass) or there exists combinations with other materials. All this is making it difficult to recycle glass from bulky waste. Foam glass and expanded glass is less demanding and the production on a large scale is undertaken with a high proportion of recycled glass or glass cullet (> 66%) involved (Deilmann et al., 2017). Some CACs do indeed collect sheet glass separately and sent it off to recycling in applications like the aforementioned ones.

Other inert materials, such as ceramics or concrete, do not make up a relevant proportion of bulky waste and do not suit for a recycling or energy recovery under this perspective.

2.3.3 Environmental potential and expenditures

The largest potential to relieve the environment lies in the reuse of suitable components from the bulky waste and the reduction of bulky waste generation. According to estimates, 6-8% of the bulky waste in Germany can be reused, mostly furniture, but also 3% of flooring products (Dornbusch et al., 2020; Ludmann and Vogt, 2019). Reuse as a big challenge is, however, not the topic to be investigated and considered in this study.

Under the study perspective a potential relief for the environment through a recycling of bulky waste components only occurs where the corresponding materials can be sorted and pre-treated with reasonable effort and a substitution of new material is taking place elsewhere in production by the materials recycled. This is conceivable, for example, with a mechanical recycling of plastics, but here too, limits apply for the utilisation of the recyclate and therewith the market demand due to material engineering and design issues.

The longest possible cascading use of wood before final energy recovery is a pattern which, in principle, guarantees the lowest environmental impact (Gärtner et al., 2013; Vis et al., 2016). Processing wood waste for which subsequently no further recovery can be found nevertheless leads to an unnecessary consumption of energy.

Separately collecting and/or sorting heterogeneous bulky waste involves significant financial and energy expenses. The best place to implement a separate collection for this waste stream is at the CACs, as long as the space to place several containers is available and trained personnel can be assigned. However, the largest share of bulky waste, approx. 60%, is nowadays collected in pickup arrangements, and only approx. 40% via the CACs (VKU, 2020).

2.3.4 Evaluation and conclusions

Bulky waste, with the metals and oil-based polymer (plastic) components it contains, has a promising raw material potential for material recycling. However, wood-based materials account for the largest share in bulky waste. Recycling this material portion in the overall is difficult though, considering that in some cases there are unknown amounts of pollutants involved, an oversupply of wood waste in relation to recycling capacities is observed, and wood waste is classified a renewable energy source.

The possibility for recycling bulky waste depends on its separate collection or sorting. 40% of the bulky waste in Germany is processed in sorting facilities. At these facilities most of the recyclable materials, such as metals, rigid plastics, plastic film, paper and cardboard are separated and sold to recycling. Wood is also separated here and, as a mixed material fraction classified under the waste wood category A III, forwarded to energy recovery, for example in biomass combustion facilities. Residues from sorting bulky waste as well as mattresses, upholstered furniture and carpets are also thermally treated and the energy is thereby recovered.

Both, the tandem pickup of bulky waste and its processing in sorting facilities are firmly established practices in Germany, even if tandem collection is not adopted on a nationwide scale. However, by considering the pronounced patchwork and close-knit network of municipal waste management companies, it can be rightly assumed that a readjustment according to the market conditions and local circumstances is always taking place.

In order to increase the result of recycled bulky waste, a larger proportion of this waste stream would have to be treated in sorting facilities. This is already stipulated in the provisions set in the Commercial Waste Ordinance for the commercial part of the bulky waste. Corresponding requirements for the municipal sector have not yet been promulgated. However, to increase the sorting intensity of bulky waste only makes sense if there is a demand for the respective materials on the market. Demand and price for using wood waste as an energy source or in material recycling are also linked to the availability of wood or sawmill residues in general. The situation on the wood waste market at present shows that, against the backdrop of the currently high supply of wood, material recycling is not expected to significantly increase in a medium-term perspective (euwid, 2020).

2.4 Proposed measures

Recommendations for practicable actions are to be formulated under the aim to identify holistic measures which strengthen the circular economy in that both, collection and aggregation of material quantities in a recyclable state and the creation of further suitable framework conditions for long-term, economic and environmentally benign recycling are enabled. Using secondary material in the production of new goods is belonging to this context and must be likewise promoted.

Bulky waste as a mixed waste material stream predominantly composed of wood (mainly wood-based materials), about 7% metals and metal composites, less than 5% pure plastic components and many composite materials offers a rather limited potential for recovering valuable materials for recycling.

In the following, various measures for improving the material recovery of bulky waste are described and evaluated according to the criteria mentioned in chapter 1.3.1.

2.4.1 Mandatory pre-treatment for municipal bulky waste

A sorting is already obligatory under the Commercial Waste Ordinance for the mixed commercial waste. In contrast, there exists no obligation to separate recyclable materials from municipal bulky waste, i.e. to process it in sorting facilities is not yet a legal requirement. Making it legally mandatory to sort the municipal bulky waste would put bulky waste from private and commercial sources on an equal level and let these two similar waste streams become subject to the same obligations.

Table 15 Evaluation of the measure "Mandatory sorting for municipal bulky waste" in case of its mixed collection (e.g. in the pickup model)

Criterion	Evaluation	Points
Bureaucratic effort	is comparable to the sorting of bulky waste from commercial sources	3
Legal aspects	mandatory sorting requires a legal stipulation based on Section 8 (2) of the KrWG	3
Statistical aspects	*not relevant, since statistics already exist for this separate waste code*	
Organisational effort	sorting facilities must be built, as the currently available capacity is most likely insufficient; after expiration of the contracts, bulky waste recycling including associated logistics must be put out to tender again	4
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding	1
Contribution to financing the recycling	*not relevant since bulky waste management is already financed by the waste fees imposed from public disposal providers;* *Economic implications: The investment in and operation of a sorting facility is expensive. In the case of public disposal providers that operate their own waste incineration facilities, the utilization of the plant is reduced, so that waste fees could rise overall.*	
Improvement of collection	the measure has no impact on the collection of the waste stream	3
Strengthening of recycling	mandatory sorting ensures that recyclable components of bulky waste are recycled, however, low proportions of recyclable materials are contrasted by high energy and cost expenses for the sorting	2
Acceptance of relevant actors	the obligation is viewed less positively by the public disposal providers and operators of waste incineration facilities; operators of sorting facilities on the reverse will welcome such measure; implementing this measure moreover could lead to increasing waste fees for citizens	4
Public information needs	low information need for the public	1
Weighted result		**3.0**
Key addressees	German government, public disposal providers, sorting facility operators	
Summary	Mandatory sorting of bulky waste puts municipal bulky waste on the same level as commercial bulky waste and thus ensures equal treatment of these similar waste streams. Against the mandatory sorting speaks the fact that bulky waste often contains few recyclable materials in relation to the effort and energy required for sorting, and a large proportion of the input is eventually still sent as substitute fuel, biomass (wood) or sorting residues for energy recovery. The measure is currently not recommended, since the economic and ecological advantages remain unclear and rather disputable.	

2.4.2 Expansion and control of material separation at the CACs (for separable materials)

In particular, collecting plastic components separately at the CACs should be implemented on a nationwide scale, as this has the potential to increase material recycling. An intensified separate collection of untreated solid wood (wood of category A I) also enables an increase in recycling if options for a secondary material usage of the wood in recycling applications exist in the surrounding area. A separation of the remaining wood waste from the bulky waste into the categories A II and A III does not make sense given the limits existing for recycling this kind of wood waste in Germany.

Table 16 Evaluation of the measure "Systematic expansion and control of material separation at the CACs (for separable materials)"

Criterion	Evaluation	Points
Bureaucratic effort	increases slightly as the public disposal providers have to manage more waste flows and a control of the material separation must be conducted	2
Legal aspects	changes or amendments to the existing legislation aren't necessary; according to Article 20 (2) No. 7 KrWG, bulky waste must be collected in such a way that it can be prepared for reuse and recycled	1
Statistical aspects	*not relevant, since statistics already exist for this separate waste code*	
Organisational effort	partially an expansion and/or retrofit of the CACs must be undertaken	3
Implementation timeline	medium-term (3-5 years)	3
Binding character	Binding	3
Contribution to financing the recycling	*not relevant since bulky waste management is already financed by the waste fees imposed from public disposal providers;* *Economic implications: More staff must be deployed at the CACs. The recycling of the separated additional materials cannot compensate for this, so that waste fees may have to be increased.*	
Improvement of collection	the measure has no impact on the collection of the waste stream	3
Strengthening of recycling	expanding the separate collection at the CACs, recycling can be better realized, but it does not necessarily have to be material recovery; the share of bulky waste collected in pickup arrangements is not affected by this measure	3
Acceptance of relevant actors	the obligation is viewed less positively by the public disposal providers, other actors including the general population are neutral in their judgement about	3
Public information needs	implementation of this measure involves a certain amount of PR/PA work and individual waste counselling; in addition, the CACs must be furnished with new and/or additional sign boards	3
Weighted result		**2.7**
Key addressees	Public disposal providers	

Criterion	Evaluation	Points
Summary	The measure leads to an improvement in material recovery for easily separable, recyclable materials at rather low incremental costs.	

2.4.3 Waste counselling on the separate collection and reuse possibilities

Intensive waste counselling can increase the acceptance and use of the CACs on the side of the general population. Individual waste counselling and the production of information material is already an integral part of the tasks of the public disposal providers but could be intensified and expanded in some public disposal providers. As bulky waste is concerned, the aim is to offer information and opportunities for the separate collection of different materials, especially at the CACs, and to enhance waste preventing and reuse activities at the same time. The RAL-quality mark 950 for Re-Consumption, which has been in existence since 2017 and is awarded to functional points of collection, offers itself as a quality assurance mechanism.

Table 17 Evaluation of the measure "Waste counselling on the separate collection and reuse possibilities"

Criterion	Evaluation	Points
Bureaucratic effort	increases slightly for the required quality assurance	2
Legal aspects	changes or amendments to the existing legislation aren't necessary; Article 46 KrWG obliges public disposal providers to provide waste counselling, however, the scope and manner of waste counselling are left at the discretion of the responsible public disposal provider	2
Statistical aspects	*not relevant, since statistics already exist for this separate waste code*	
Organisational effort	no significant additional effort is necessary	1
Implementation timeline	short-term	1
Binding character	waste counselling is obligatory for public disposal providers but they are free in the means and intensity in which it will be applied	2
Contribution to financing the recycling	*not relevant since bulky waste management is already financed by the waste fees imposed from public disposal providers;* *Economic implications: More staff must be likely deployed for PR/PA measures, so that waste fees may have to be increased*	
Improvement of collection	measure can have a slightly positive influence on the collection result for this waste stream	2
Strengthening of recycling	reuse is strengthened and material recycling enhanced by improved motivation and awareness on separate collection	3
Acceptance of relevant actors	acceptance does in general exists among the public disposal providers and general population	2
Public information needs	*not relevant, the measure is more or less part of PR standard work*	
Weighted result		**2.1**
Key addressees	Public disposal providers	

Criterion	Evaluation	Points
Summary	An intensified public relations work raises awareness among the population and increases the service it gets provided with. Nevertheless, public disposal providers cannot expand too much the public relations work in order to be able to offer citizens the management of the waste furthermore at reasonable costs.	

2.4.4 Final synopsis

The option of reusing suitable bulky waste components offers the greatest potential to alleviate burdens for the environment within the segment of the bulky waste stream. Therefore, the following measures are recommended as a matter of priority:

1. Waste counselling on separate collection and reuse possibilities.

In addition to information on separate collection and reuse possibilities, increased public relations work can also be implemented directly at the CACs.

2. Systematic expansion and control of material separation at the CACs.

With the help of a consistent expansion and control of material separation at the CACs, the awareness for recycling can be raised among the population.

Mandatory sorting of bulky waste from municipal collection is recommended as a measure of subordinate priority, considering that the associated ecological and economic advantage and benefits are small due to the low proportion of actually recyclable fractions this waste contains. These target fractions (especially plastics) should be collected separately with higher priority in general.

3 Mattresses

3.1 General information

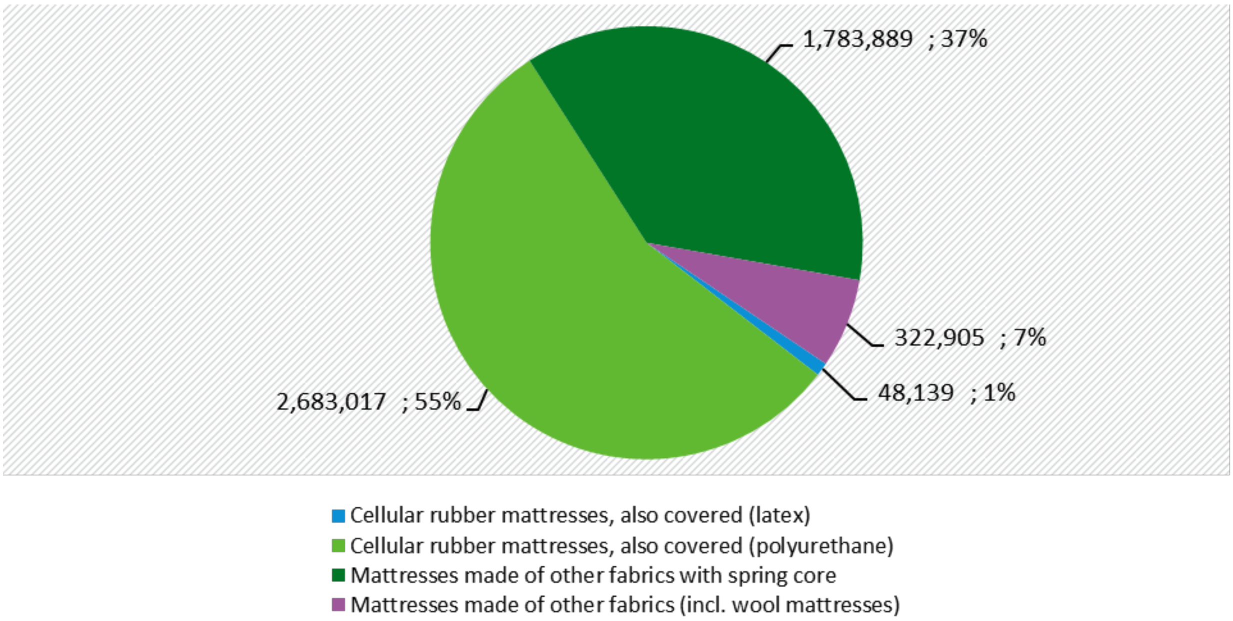
Manufacturers of mattresses distinguish between the following types of mattress products:

- Mattresses with PUR foam,
- Mattresses with steel spring core,
- Mattresses with latex foam.

In addition, a large number of other mattress types exists (e.g. wool mattresses), which, however, are of no major importance in the market.

Figure 7 is showing the amount of mattresses produced in Germany in total numbers; these relate to the "classic" type mattresses, i.e. no waterbeds or similar products are included.

Figure 7 Number of mattresses of the classic type produced in Germany in 2018



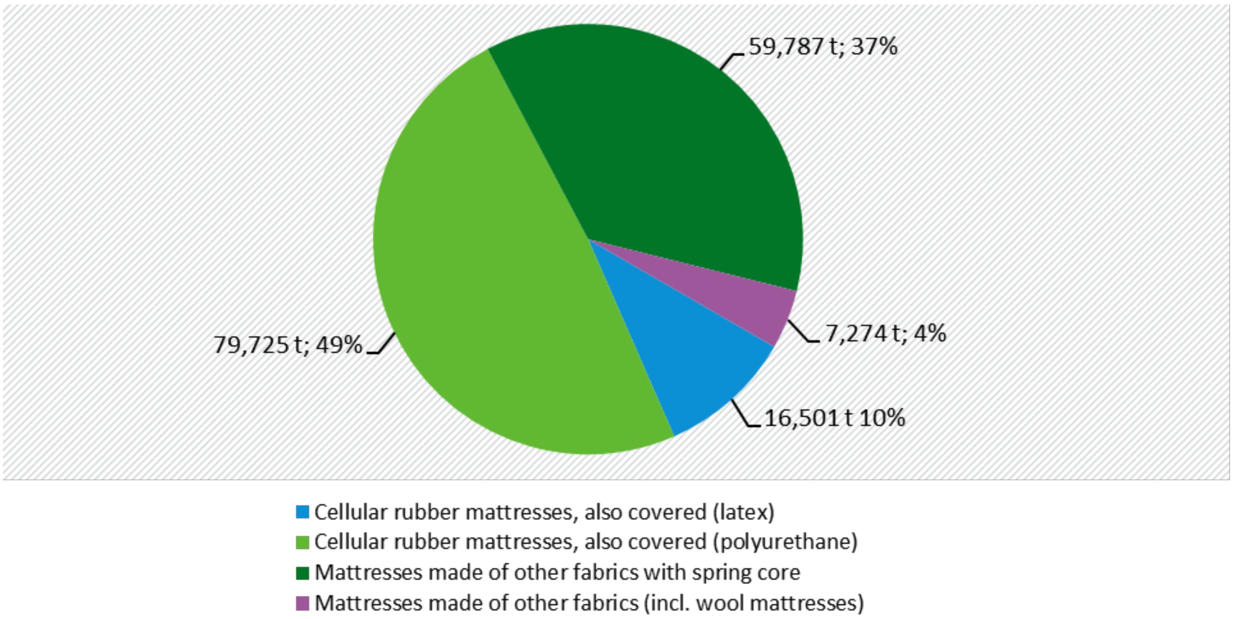
Source: Graphic of INTECUS based on data from (Destatis, 2019b)

A total quantity of around 4.8 million mattresses were produced in Germany in the year 2018. Comparing the last few years, the production is slightly down.

In order to generate the picture for Figure 8, the numbers from Figure 7 were taken and converted into a mass equivalent[4] which was subsequently offset against the quantity of mattresses imported and exported to determine the total mass of mattresses remaining in Germany.

[4] a mass of 20 kg was assumed on average per each mattress for this calculation

Figure 8 Total tonnage amount of mattresses which remained in 2018 for use in Germany



Source: Graphic of INTECUS based on data from (Destatis, 2019b) in conjunction with (GENESIS, 2019)

There are no official statistics on the number of mattresses actually used in Germany and their disposal. In the following, the three major areas in which mattresses are used are therefore considered. A top-down approach is adopted to estimate the number of beds and thus the number of mattresses in use. Then the expectancy for a mattresses' usage cycle is considered to derive at a picture on how many mattresses may eventually become waste.

To establish a realistic order of magnitude for this amount, it is further considered where and how mattresses are usually disposed of. An estimation of the total quantities becomes necessary as there is no separate waste code allocated to these items when becoming a waste.

A further chapter in this document will then shed light on the recycling of mattresses.

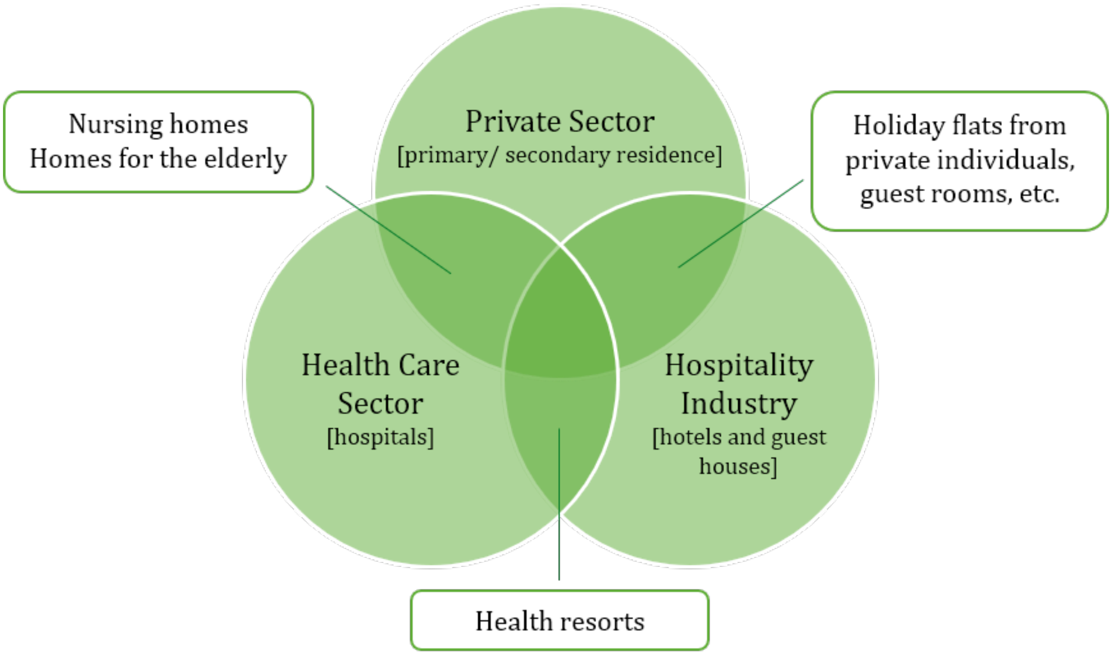
3.1.1 Top-down approach - estimating the number of beds

In the following an estimate of the number of beds and mattresses in Germany is presented. It has been derived based on statistics from the Federal Statistical Office. Considerations which have been guiding this procedure are explained hereunder.

In principle, it seems possible and reasonable to allocate the sleeping places to three main areas, although partial overlaps be also noted in between these areas:

- Private sector
- Healthcare sector
- Hospitality industry

Figure 9 Division and typology of sleeping places



Source: Graphic of INTECUS

3.1.1.1 Private sector

The private sector comprises the largest portion of beds and mattresses this involves. Apart from nursing homes where the number of beds and elderly or disabled people receiving residential care are, for example, kept in separate statistics, it can be assumed that every inhabitant of Germany has at least one sleeping place. Germany in 2017 (as the reference year used for this study) had a registered 82,792,351 inhabitants (as per 31.12.2017) (Destatis, 2019). It must be taken into account, however, that not every person uses a bed or standard mattress for sleeping.

The choice of beds or mattresses is influenced by very individual habits and factors. Aside from, for example, different hardness, thickness, zoning for sleeping comfort and sizes, mattresses are differentiated by their structural and material construction. The most common models are made of cellular plastic (polyurethane or similar) including covered versions, cellular rubber (latex) including covered versions, other fabrics with spring core or further type fabrics (including wool mattresses). Combinations of various types are also possible. There are also other bed models, such as waterbeds, which are not comparable with the beds using classic mattresses.

In recent years, the share of box-spring beds has been increasing, at least in the private sector and in the hospitality industry (Dierig, 2015). These type beds consist of several layers, including mattresses and toppers.

A survey on the sleeping habits of the population in Germany (statista, 2016) revealed that 5% of the population sleep on a sofa bed and 4% prefer other sleeping arrangements (e.g. waterbeds). From this can be concluded that 9% of the inhabitants of Germany do not use a classic mattress.

For the calculation furthermore considered must be the inhabitants of Germany who use a second home with sleeping places, for example in the form of holiday homes for exclusive private use or as commuters. There exist no official statistics for this subject. According to estimates, this may concern a number of around 2 million households (Handelsblatt, 2017).

Mattresses for children are often smaller and narrower than standard mattresses for adults. They are often used by several siblings, so that a lifespan similar to that of mattresses for adults can be assumed. These mattresses are not accounted separately since the influence this may have on the total number is presumably small.

Conclusion: Number of mattresses used in the private sector

82,792,351 inhabitants ≙ 82,792,351 sleeping places

minus the share of non-traditional mattresses such as sofa beds or waterbeds (-9%)

plus second homes, private holiday homes and the like (+ approx. 2 million mattresses)

→ about 77.3 million mattresses in total

3.1.1.2 Healthcare sector

According to the Federal Statistical Office, there were 1,942 hospitals with a total number of 497,182 beds operated in Germany in 2017. The number of hospitals and beds has seen a decline in recent years, whereas the number of cases requiring treatment[5] has been rising slightly. Table 18 provides an overview of the figures for the last few years.

Table 18 Official statistical figures on hospitals, hospital beds and occupancy

Year	Hospitals	Hospital beds set up	Cases	Calculated/ occupancy days	Average Duration of stay	Bed occupancy rate
	total no.	total no.	total no.	in 1,000	in days	in percent
2013	1,996	500,671	18,787,168	141,340	7.5	77.3
2014	1,980	500,680	19,148,626	141,534	7.4	77.4
2015	1,956	499,351	19,239,574	141,281	7.3	77.5
2016	1,951	498,718	19,532,779	142,170	7.3	77.9
2017	1,942	497,182	19,442,810	141,152	7.3	77.8

Source: Destatis, 2018

The number of beds in nursing homes is statistically recorded as displayed in Table 19.

Table 19 Official statistical figures for preventive care or rehabilitation (nursing) facilities

Year	preventive care or rehabilitation (nursing) facilities				Average	
	Facilities	Beds	Patients	Inpatient days	Duration of stay	Bed occupancy rate
	total no.	total no.	total no.	in 1,000	in days	in percent
2013	1,187	166,889	1,953,636	49,455	25.3	81.2
2014	1,158	165,657	1,972,853	49,837	25.3	82.4

[5] this is synonymous for the number of patients treated (inpatient, day-care, outpatient). Each patient is counted once during a hospital stay (Deutsches Krankenhaus Verzeichnis, n.d.)

Year	preventive care or rehabilitation (nursing) facilities				Average	
	Facilities	Beds	Patients	Inpatient days	Duration of stay	Bed occupancy rate
	total no.	total no.	total no.	in 1,000	in days	in percent
2015	1,151	165,013	1,970,595	49,877	25.3	82.8
2016	1,149	165,223	1,984,020	50,211	25.3	83.0
2017	1,142	164,266	1,974,248	50,098	25,4	83,6

Source: Destatis, 2019a

Information from several hospitals suggest that the mattresses for hospital beds are mainly foam mattresses, much more seldom mattresses with latex cores are used. Spring mattresses are not in use because of the need to have adjustable lying surfaces.

Hospitals as well as nursing homes to some extent use special mattresses that are intended to reduce the development of pressure marks during long periods of hospitalization. The so-called decubitus mattresses are roughly divided into soft support systems, alternating pressure systems and micro-stimulation systems and can be equipped with electrical components depending on the structure and design (Matratzenwissen 2019). According to information from several hospitals, the share of decubitus mattresses amounts to less than 1%, their use mainly occurs in the area of patients under intensive care.

Conclusion: Number of mattresses used in the healthcare sector

497,182 hospital beds

plus 164,266 beds set up in preventive care or rehabilitation (nursing) facilities

→ 661,448 mattresses in total

3.1.1.3 Hospitality industry

As the hospitality industry is concerned, hotels, inns and guesthouses, which account for the majority of lodging offers with sleeping opportunities, must be taken into account. Sleeping places at campsites are not considered in this study, as these are mainly accommodation services without greater relevance for the consumption of mattresses.

The number of sleeping places offered in the hospitality industry in the last five years is listed in Table 20 below.

Table 20 Number of sleeping places offered in the different lodging segments

Year	Hotels, Inns, Guesthouses	Holiday accommodation and similar places of accommodation[6]	Other lodging offers of relevance for tourism[7]	In total numbers
2013	1,758,230	685,809	236,753	2,680,792
2014	1,764,907	684,212	234,160	2,683,279
2015	1,780,168	676,496	235,436	2,692,100

[6] accommodation establishments, recreation facilities and centres, holiday resorts, holiday homes and holiday flats, youth hostels and mountain huts

[7] preventive care and rehabilitation clinics, training centres

Year	Hotels, Inns, Guesthouses	Holiday accommodation and similar places of accommodation[6]	Other lodging offers of relevance for tourism[7]	In total numbers
2016	1,785,369	673,348	230,503	2,689,220
2017	1,811,026	683,438	231,345	2,725,809

Source: Destatis, 2014-2018

As a result, the following number of sleeping places in the hospitality industry can be considered for the number of mattresses in 2017as the reference year:

Conclusion: Number of mattresses used in the hospitality industry

1,811,026 beds in hotels, inns and guesthouses

plus 683,438 beds in holiday accommodations and similar places of accommodation

plus 231,345 beds for other lodging offers of relevance for tourism

→ 2,725,809 mattresses in total

3.1.1.4 Conclusion for the total number of mattresses

Summing up the numbers of mattresses established for the three principal areas of usage results in a total amount of approx. 80.7 million mattresses. With their use extending over time periods of different length, the disposal of these mattresses is also taking place in varying cycles.

3.1.2 Durability and life span of mattresses

No general statement can be made about the durability of mattresses. Most manufacturers and online advisory platforms recommend replacing a mattress after five to seven years, at the latest after ten years, partly for hygienic reasons, partly due to material fatigue resulting in the development of 'hollows' (Matratzentester n.d., FOCUS online 2019, Stiftung Warentest 2019). Various surveys however suggest that mattresses in private use are replaced by most households in Germany only after 10 to 14 years (Helping, 2017). Thus, in the following, a life time of ten years is assumed for this segment. In the hospitality industry, mattresses are usually replaced earlier, mostly for hygienic reasons also (IHA, 2016). Thus, in the following, the average service life is assumed to be six years in this segment.

How and after what time box-spring beds will be handed to disposal is yet rather unpredictable. With the possibility to replace single components, this system can be more durable in the overall, however, individual components may be replaced more quickly then. The impact box-spring beds will have on the development of waste disposal in Germany cannot yet be assessed with sufficient accuracy. However, strong differences to classic mattresses are not expected, so that the same time span for service life has been anticipated for this segment.

Because of the high utilisation frequency of beds in the healthcare sector, it can be assumed that mattresses will be quite regularly replaced here, like in the private sector primarily for hygienic reasons. There exists no regulation for this, however. Hospital bedsteads can be depreciated after 15 or, in the case of intensive care beds, after eight years. No depreciation rates are specified for the mattresses used. Hospital mattresses as a general rule are replaced depending on the usage intensity, according to several hospital operators, this usually happens after 5-8 years. Furthermore, a replacement occurs as a result of the purchase of new beds and according to the volume of the investment. Since intensive care beds are more heavily used, the mattresses are also replaced earlier here due to faster staining.

In the following, an average service life of eight years is assumed for hospital mattresses. For beds from preventive care or rehabilitation facilities, seven years is assumed due to the high stress to which they are exposed.

Theoretically derived amount of mattresses becoming waste
77.3 million mattresses in the private sector after a service life of ten years
plus 497,182 mattresses from beds in hospitals after a service life of eight years
plus 164,266 mattresses from beds in preventive care or rehabilitation facilities after a service life of seven years
plus 2,725,809 mattresses in the hospitality industry after a service life of six years
→ approx. 8.27 million old mattresses accumulate in Germany each year

For the private sector can be assumed that a large number of additional mattresses are being used for the accommodation of guest, parents moreover often still keep equipped beds for children who have already moved out. The number of these mattresses cannot be estimated, however.

3.2 Collection

3.2.1 Collection systems

3.2.1.1 Collection from private households

Usually, mattresses from private households are disposed of with bulky waste. Depending on the municipality/city/county, various options are available for collection, such as the pickup of bulky waste or drop-off at the CACs (see Chapter 2.2.1). Many retailers offer to take back old mattresses for disposal when the customer purchases or gets delivered a new mattress from them, sometimes this is associated with a fee[8,9]. Mattresses which have remained in very good condition in some cases can be handed over to charity organisations. Often, however, there are restrictions for passing on used mattresses due to hygienic concerns.

3.2.1.2 Collection from the hospitality industry

The private sector comprises the largest portion of beds and mattresses this involves. Apart from nursing homes where the number of beds and elderly or disabled people receiving residential care are, for example, kept in separate statistics, it can be assumed that every inhabitant of Germany has at least one sleeping place. Germany in 2017 (as the reference year used for this study) had a registered 82,792,351 inhabitants (as per 31.12.2017) (Destatis, 2019). It must be taken into account, however, that not every person uses a bed or standard mattress for sleeping.

[8] https://www.dormando.de/dormando-altprodukte-entsorgung/

[9] https://www.betten.de/magazin/bett-und-matratze-entsorgen.html

Mattresses from the hospitality industry are collected via the system for commercial waste collection and disposal. Smaller quantities are disposed of via the systems offered by the public disposal providers for collection.

3.2.1.3 Collection from the healthcare sector

According to statements received from several hospitals, used mattresses are passed on as donations as long as they are in a state which permit for this. Alternatively, the mattresses are disposed of as bulky waste via the ordinary collection systems. Mattresses which come from areas with exposure to infections must be disinfected beforehand.

3.2.2 Collected quantities

Mattresses are not assigned a separate waste code. When forwarded to the waste services offered by the public disposal providers, they are assigned to the bulky waste fraction (waste code 20 03 07). Consequently, there are no specific waste statistics available for the waste stream of mattresses.

The weight of mattresses of different sizes, materials and manufacturers, on average can be assumed to be about 20 kg per single piece. With the 8.27 million mattresses determined as total annual amount in Chapter 3.1.2, this gives a mattress waste equivalent to 165,400 tons, of which 154,600 tons originate from the private sector alone. Based on current sorting analyses from various public disposal providers, the proportion of mattresses in bulky waste is about 8%, which corresponds to 2.7 kg/(inh*a) or a total quantity of about 225,000 tons (Dornbusch et al., 2020). The difference of approx. 70,000 tons between the determined quantity of old mattresses from the private sector and in the bulky waste stream presumably results from the additional mattresses kept by private households, the number of which could not be estimated in the top-down approach (e.g. guest beds, beds of children who have moved out, double beds of deceased life partners, etc.).

Problematic in collecting and transporting mattresses are the large dimensions (bulky size) and relatively low bulk density. One ton of uncompacted mattresses has a volume of approx. 23 m^3 only (Chapman and Bartlett, 2015), which results in a volume of old mattresses of approx. 5 million m^3 per year in Germany.

3.3 Recovery of mattresses

3.3.1 Routes of recovery

Due to the fact that the disposal of mattresses from private households is usually carried out as part of the public disposal providers' service offers for bulky waste, it is almost unavoidable that soiling and damages occur during the provision of the bulky waste collection and disposal services. Energy recovery is consequently the usual route of recovery of this waste in Germany at present. Within the EU, mattresses are mostly landfilled (45%) or incinerated (33%) (PUReSmart, 2020).

In Germany, the recovery of raw materials from mattresses is not an issue of concern for the consumers. According to a survey conducted by the European Bedding Industries' Association (EBIA) in 2011, the environmental friendliness of a mattress was a criterion for only 15% of the respondents whereas recyclability was not mentioned at all (EBIA, 2011).

Mattresses are made of different materials depending on the type and design. Table 21 shows the average material composition of a mixed stream of waste mattresses in Germany and thus provides an overview of which materials could be recovered in a material recycling process.

Mixed textiles (polyester fleece, felt, cotton, wool and other natural materials) as well as soiled or moist foams are not separately displayed because there are currently no recycling options, apart from energy recovery, existing for these materials in Germany and recyclers therefore do not individually account them. Theoretically, these materials could be used to produce insulating goods or, after defibration, felt or nonwovens, however, due to the low quality of these mattress materials, there are no buyers interested in them.

Table 21 Average material composition of mixed mattress waste

Material	Average share by weight (mass-%)
PUR foams	34
Latex foams	4
Spring cores (without adhesion)	14
Spring cores (with adhesion of PP fleece)	12
Textiles as well as PUR and latex foams unsuitable for recycling	36

Source: Weiner, 2020

3.3.1.1 Dismantling of mattresses

To recycle old mattresses, the individual material components must be separated from each other. Meanwhile there are many mattress manufacturers who offer removable covers, though for recycling the internal structure of a mattress is the decisive factor. Mattresses with a simple foam core (PUR or latex) are the best to disassemble. However, such a simple structure often does not match the individually desired lying comfort. For having such achieved, combinations of different materials are used in many mattresses. For example, different types of foam are glued together, intermediate layers made from fleece or cotton are inserted or glued on, other models use spring cores packed in individual polyester fabric pockets. As a result, more effort is required to disassemble the mattresses at the end of their useful life in order to obtain recyclable materials from them.

Especially in countries or federal areas where extended producer responsibility (EPR) regulations for mattresses are incorporated in legislation, such as in France or California, collection structures and facilities for the subsequent dismantling of mattresses have been established in recent years. The process of dismantling is carried out either manually, half-automated, or automated (Dri et al., 2018). An example for the manual disassembly can for instance be found in the Australian company "soft landing". In this process, the company primarily hires people who are facing difficulties in the regular labour market (soft landing, 2020). Accordingly, the jobs created in the manual process for mattress recycling are well suited for low-skilled or socially deprived people. It can be assumed that 10,000 to 12,500 mattresses can be dismantled per each worker within a year (Dri et al., 2018).

In the dismantling process of the Canadian recycling company Recyc-Mattress, manual work steps are coupled with automated ones (Recyc-Matelas, n.d.). The Dutch company RetourMatras operates an automated dismantling process. The textile materials obtained in this process are first processed into yarn and then into new textile products in a Moroccan textile factory (RetourMatras, 2020).

In Germany, a company located in Wesel (North Rhine-Westphalia) has specialized for more than 10 years in the professional dismantling of mattresses. The D & E Entsorgung GmbH dismantles about 2,000 tons of mattresses per annum in a recycling facility of about 1,200 m^2, this number corresponds to about 130,000 mattresses. The mattresses mainly come from municipal bulky waste collections, for example from the urban territories of Essen, Dortmund or Bochum. All types and sizes of mattresses (except box-spring beds) can be delivered to the facility in Wesel for an additional payment. The PUR and latex foams and the steel scrap obtained from the dismantling process are sold as secondary raw materials and hence can be accounted as recycled. The textiles and other materials are utilized for energy recovery. In the best case, approx. 80 -90% of a mattress can be material recycled after dismantling (Asbestos Group, n.d.; Weiner, 2020).

The process flow for the dismantling of mattresses usually involves the following steps (Dri et al., 2018):

1. Thermal or chemical hygienisation of the mattresses
   This step is not always performed but is especially important for occupational health and safety reasons in manual dismantling processes. Hygienisation can be done either thermally or by treatment with a disinfectant (e.g. exposing the mattresses in a separate room to a spray mist).
2. Separation of the different mattress types (foam, innerspring, box-spring)
   With the help of metal detectors, innerspring mattresses can be automatically separated from foam mattresses.
3. Cutting and pulling off the mattress cover
   This can be done manually using carpet cutters or angle grinders on a suitable work table. In the automated process, the cover is cut open laterally with cutting rollers and removed with two removal rollers.
4. Separation of the individual materials from each other
   This step comprises the separation of cotton components and other textile materials, the removal of the spring core and shredding of the steel. Pocket spring cores would usually need to be separated from the fabric pockets to find a buyer. Different types of foam can be separated by manual sorting or with the help of near infrared technology.
5. Compressing the sorted foam and textile materials into bales or storing metal as well as other materials in containers for sale to recycling companies.

At present, such dismantling facilities can only be operated economically with additional payments being made to them. Selling the recovered materials does not cover for the full process expenses. The amount of co-payment needed depends on the process design, the number of mattresses treated, and the prices achievable for the secondary raw materials on the market. In a study for the EU, the required co-payment for a mattress dismantling process representing best practice was estimated to be in a range between €6.00 and €7.50 per mattress (Dri et al., 2018). This is equivalent to at least €300 per ton and thus exceeds the co-payment for energy recovery of bulky waste in Germany which stands between €100-200 per ton.

Locally, the required co-payments of individual providers are determined depending on the specific circumstances. As long as there are no regulations for extended producer responsibility in place, mattress dismantling companies often have to orient for the required co-payment on the offers for energy recovery in the near surroundings in order to remain at the competitive edge with their service.

Being ensured a sufficient availability of waste mattresses in adequate quantity and quality for an economical collection and transport is the primary difficulty faced in planning dismantling facilities. Automated processes in particular require a steady supply of several thousand tons of waste mattresses per year due to the high investment costs. Another challenge is the separation of metal and PP fleece pocket casings of spring mattresses. With some effort, this is technically possible with the help of shredding and sorting. However, the economic viability of such process depends heavily on the steel prices, so not all mattress dismantlers can recycle pocket spring cores within their particular circumstances. To reduce the expense required to recycle pocket spring cores, an automated machine that separates the metal springs of a mattress within a 2.5 min time frame has, among others, been developed in 2016 by the UK-based TFR Group (TFR Group, 2020).

A mattress' design suitable for recycling, i.e. allowing easy dismantling of the mattresses for example, is of key importance for choosing recycling as option. Similar to upholstered furniture, box-spring beds can currently only be dismantled with great effort (Hahnenkamp and Tuminski 2017). In the case of mattresses, too, increasing foam compounds or material composites make it more difficult to disintegrate these products into single-type material streams. In contrast, some mattress manufacturers are already making efforts to produce recyclable mattresses, even if only a few such mattresses are already regularly available for purchase. One example comes from the Auping company who, in co-operation with DSM-Niaga, has placed a dismountable mattress on the market. The mattress consists of pocket springs and air permeable textiles that are connected with special glue and thread so that they can be easily separated from each other. In addition to recycling, this enables the replacement of individual components and can thus also extend the service life of mattresses (Auping, n.d.).

3.3.1.2 Recycling of flexible foam

Material recycling routes for plastics, such as PUR foam, (e.g. flake composites, particle composites, powder filling, extrusion, injection molding) have thus far been established on larger scale for production waste only. For flexible foam from post-consumer waste, the marketing options in Europe have remained limited so far.

In the mechanical recycling of flexible foams, the foam sheets are shredded, usually separately by grade, and then re-bonded and pressed as a flake composite. This process is called 'rebonding'. The resulting sheets can be used, for example, as an insulation, as carpet underlays, or in sports mats (Cormatex, 2020; European Commission 2020). However, the rebonding process decreases the material value of the flexible foam. At the same time, when recycling used mattress foam, it must always be taken into account that there is a hygienic risk emerging from dust mites, bed bugs and allergens. This is making it difficult to achieve an equivalent recycling level through mechanical recycling on the one hand side and it reduces the acceptance of recycled products among users on the other hand. Production waste for this reason is the primary focus of mechanical recycling until to date.

In order to increase consumer acceptance, sufficient hygienisation, inspection of the recycled products and certification or a safety label are needed. In the URBANREC research project, flexible foam for mattresses was produced from shredded post-consumer PUR foams by way of hot pressing. Subsequent testing found no biohazardous germs, no chemicals relevant under REACH, and only one chemical in higher concentration than required by the Oeko-Tex standard (UrbanRec, 2019). The French recycler and mattress manufacturer Secondly undertakes a dismantling of mattresses after hygienisation and uses the so-called AIR LAY technology to produce new fluff composite foam sheets from the soft foam (PUR and latex). These sheets are then being used, for example, in the in-house mattress production or in upholstered furniture manufacturing. The textiles are defibered and processed into felt. In this way, 90% of the 200,000 mattresses dismantled in a year are eventually recycled (Secondly, n.d.; Dri et al., 2018; European Commission, 2020).

Chemical recycling processes can also be used for the recycling of flexible foam. Here, the purity of the input materials and the use of various additives during PUR production are challenging as well. In general, therefore, it is technically easier to recycle production waste, whereas to chemically degrade post-consumer PUR foams into reusable polyols is yet essentially a subject of research. This research has advanced recently in Germany but also other countries so that first processes are by now being developed or already scaled up. Solvolysis processes (e.g. glycolysis, acidolysis, aminolysis), in which the polymer chains of the polyurethane are split up with the help of a solvent (depolymerization) are mainly considered for the chemical recycling of PUR foam. Although the objective is to recycle flexible PUR foams, many processes have so far achieved the recovery of adhesives or rigid foams only. These can be used in other applications as mattress foam.

As part of the European research project URBANREC, the research participant RAMPF EcoSolutions GmbH developed a solvolysis process which allows that polyols can be won from the PUR foams of used mattresses by means of glycolysis and acidolysis. These polyols serve as a feedstock material in PUR production, thus enabling a closed-loop system to produce, for example, pillows, mattresses, insulation foams, and adhesives with the secondary materials recovered in this process (RAMPF, 2019).

A similar approach is being adopted by the H&S Anlagentechnik GmbH, from which is said that a facility for recycling PUR foam from production waste already operates in Dendro (Poland). The facility allegedly has an annual capacity for 1,000 tons of residual materials that are used to produce 2,400 tons of polyol in a year (H&S Anlagentechnik, 2019). According to the company, a proportion of at least 20% of the recycled polyols can be used in the production of new PUR foam mattresses without affecting the mechanical properties. The cost of the recovered polyol is expected to be 25-30% below the market price of virgin polyether polyol base material. By the year 2021, the first industrial facility for post-consumer mattress recycling in France is also expected to be operational (H&S Anlagentechnik, 2020).

Starting from 2019 up to 2022, another EU-wide collaborative research project will put the focus on the recycling of PUR foam. The issues this project covers range from collection and sorting to chemical disintegration and the manufacture of new products in recyclable design from the recovered monomers (PUReSmart, 2020). The companies BASF and Covestro are also testing chemical recycling processes for PUR foams from post-consumer mattresses. Initial pilot tests have been running since mid-2020 and 2021, respectively (BASF, n.d.; bvse, 2020, Königsreuther, 2021).

3.3.1.3 Recycling of further materials from mattresses

For the materials steel and for wood from box-spring beds there are already established recycling routes and corresponding markets in Germany which come into play as soon as the separated materials are available.

For recycling polyester materials by depolymerization, an industrial-scale facility already operates in Japan and first pilot installations for patented processes exist (gr3n sagl, n.d.; Loop Industries, n.d.; Schmidt et al., 2016). With the depolymerization process a wide variety of PET and polyester materials can be treated. Studies on the potential costs and environmental impacts of these processes are not yet available though.

An overview showing which components of mattresses can be recycled into which products can be found in Table 22. The information companies provide on the proportion that can be processed from the collected mattresses and sorted into single-type material streams ranges from 80 to 98% (Dri et al., 2018; MRC, 2019; European Commission, 2020).

Table 22 Materials that can be recovered from mattresses and their recovery routes

Material	Recovery routes
PUR foam	- Chemical solvolysis for the production of recycled polyols, which can be used (partial) for the production of new PUR (flexible) foam products or adhesives - Shredding and bonding to form insulation boards, carpet backing or new mattress or upholstery foams (rebonding)
Metal springs	- Secondary raw material for the steel industry
Textile cover	- shredding: defibering for the production of needle fleece or felts - Polyester: chemical recycling - Production of insulation - Refuse derived fuels
Felt, fleece, innerspring covers	- Refuse derived fuels - Production of insulation - Polyester: chemical recycling
Wood (box-spring beds)	- Chipboard production
Latex foam	- Compressed into carpet backing - Rebonding
Other components (dirty textiles, miscellaneous materials)	- Refuse derived fuels

3.3.2 Environmental potential and expenditures

In many countries worldwide, but also in the EU, mattresses are landfilled after their useful life. It has been seen in several life cycle assessments that, compared to landfilling, the processes of material recycling result in lower overall greenhouse gas emissions and a reduction in negative environmental impacts (Dri et al., 2018; Geyer et al., 2012). In Germany, mattresses may not be landfilled without a prior pre-treatment and mainly they are used for energy recovery. A study conducted in Germany on the ecological impact of the production and material recycling of different mattress materials pointed out different results of the ecological assessment compared to energy recovery. In dependence from the recycling efforts and quality that is achievable for the secondary material, the impact of recycling compared to material incineration was estimated in the areas of greenhouse gas emissions, resource consumption and demand in primary energy. Material recycling processes for steel and the chemical recycling of polyester were found to be ecologically advantageous, the defibration of cotton and rebonding of PUR foam in contrast were classified as ecologically disadvantageous as the current state-of-the-art is concerned. For latex foam (natural latex or synthetic material), both material (rebonding) and energy recovery can be beneficial, depending on the environmental indicator looked at. Other mattress materials and the chemical recycling of PUR foam were not investigated in that study (Teubler and Bickel, 2019).

In the frame of an expert discussion held on February 19, 2019 at the premises of the Deutsche Umwelthilfe e.V. (DUH) in Berlin, the participants came to the conclusion that the recycling of mattresses from the bulky waste fraction cannot be realized under the current conditions of the disposal market in the short and medium-term perspective, although there is consensus that an increased material use of the bulky waste components would make sense. Two principal reasons make the recycling in the case of mattresses particularly difficult, as such can be named that:

1. the composition of mattresses is too heterogeneous and separating the individual components too complicated.
   In addition, the mattresses collected with bulky waste can be very old, in some cases more than 20 years, so that today's changes in product design only take effect in the waste stream in the long term.
2. the material quality of the mattresses collected with the bulky waste is very poor.
   A laborious source segregation and storage without exposure to wetness would be required to ensure a material quality that is sufficiently good for a material recycling.

In addition, it would be necessary to create a market demand for the produced secondary raw materials (VKU, 2019). The demand for PUR foam could in fact increase if a facility for the chemical recycling of post-consumer PUR foam is indeed commissioned in Germany.

Dismantling involves a certain amount of effort. Manual processes are often applied, with just under 10 minutes of working time per mattress needed for the job of disassembling alone. With an automated facility, the investment costs are higher but the operating costs are lower. However, automated systems require a higher input supply (e.g. > 120,000 mattresses/year) to cover the investment costs.

The low bulk density of mattresses and the high specific transportation costs and emissions this causes render the proximity to the sourcing location of the used mattresses to become a crucial factor. New cold foam mattresses in particular are often rolled up, compressed or vacuum-packed in a film before delivery to save space. However, such techniques are not available for the decentralized waste collection, so the volume and unhandy dimension of the unfolded mattress must be taken into account here. Mattress dismantlers recommend distances of less than 100 km between the dismantling facility and the points of collection. In France, where an extended producer responsibility for mattresses applies, significantly longer distances for the transport of mattresses are to be assumed. With a total of 7 treatment facilities for mattresses the country (excluding overseas territories) has theoretically one installation for an area of 78,000 km^2 (Eco-Mobilier, 2020). As orientation for the recycling of PUR foam, a distance of 300 km can be assumed as a maximum between the collection place of the old mattresses, the dismantling facility and PUR recycling facility.

3.3.3 Evaluation and conclusions

Old mattresses make up a relevant waste stream in Germany in terms of volume. Energy recovery of mattresses provides for a recovery route with low space requirements, reasonable costs and moderate greenhouse gas emissions.

In Germany, the recycling of mattresses is not economical within the current framework conditions, including the competition which exists with incineration, the cost of dismantling and the lacking market for the secondary materials, except for the metal components. However, mattresses are not also an easy-to-handle waste stream for thermal waste treatment facilities given, among other factors, their bulky size. Therefore, mattresses are allowed in small proportions only in the collection of mixed bulky waste. Mono-batches of mattresses are only accepted in incinerators when shredded.

To set up a recycling system, collection logistics would also have to be established so that a sufficient quantity of mattresses of sufficient quality can be bundled as input into a large-scale process. In bulky waste collection, mattresses are often soiled or soaked, so that material recycling afterwards is severely limited.

Internationally, there are meanwhile some viable and large-scale processes for recycling post-consumer mattresses existing which can recycle approx. 90% of the material components. In addition, research continues in this area and new equipment is being developed and patented. Large companies are also getting involved in mattress recycling. A distinction is made between facilities for disassembling mattresses into their components and facilities for recycling the (purchased) sorted materials. The dismantling of mattresses is technically possible and the investment costs are kept within reasonable limits, especially for manual dismantling processes. For a manual dismantling facility, investment costs of €30,000 are assumed in a study for the European market, whereas for a fully automated facility these can be €2,000,000 (Dri et al., 2018). The dismantling of mattresses, due to the resulting personnel or depreciation costs, can only be operated economically with an additional payment. In Germany this is currently a big challenge because of the competition with energy recovery. However, it can be assumed that energy recovery capacities will become more scarce and their costs could also increase in future (Obermeier and Lehmann, 2020). Mattresses that are deliberately designed with a view also for recycling help to ensure and simplify the disintegration into the individual materials, which in turn improves the cost-benefit ratio of mattress dismantling and recycling processes.

For the further recovery of waste materials, the market for secondary and recycled products should be strengthened in Germany, especially for flexible foams and textile covers. However, the primary aim should be the recycling directly in mattress production in order to close material cycles and open up manufacturers their own material source with the help of mattress designs that are suitable for recycling. In the case of PUR foam, the next few years will show whether chemical recycling is technically and economically viable. If direct recycling is not possible, a cascading use should be supported instead of direct energy recovery. This could include, for example, the use of flexible PUR foam or textile materials as an insulating material. Mattress production itself uses small proportions of secondary materials at present only in a few models, considering that mattresses have to meet high hygiene and quality standards.

3.4 Proposed measures

Due to the current framework conditions, a lack of mattress recycling facilities and collection structures for bundling critical quantities of old mattresses for recycling can be observed in Germany. In the following, various measures for improving the recycling of mattresses are described and evaluated according to the criteria mentioned in chapter 1.3.1.

3.4.1 Negotiating uniform design criteria at EU level that simplify recycling and adopt them in standards or labels

In order to facilitate material recycling in the future, mattresses should be designed in a way that easy dismantling and the use of recyclable materials is ensured. Towards this end, transparent design criteria must be specified and negotiated with manufacturers, dismantling and recycling companies. Since today's changes in the product design of mattresses only become relevant for the management of the waste when the products useful service life ends, i.e. in about ten years, incentives for recyclable products must be set as early as possible.

In addition, labelling of the materials used for mattress production can simplify sorting during dismantling. In the case of mattresses, this can even be done invisibly under the cover. With the help of a QR code on the mattress, a reference could also be implemented to a database in which further information, for example on possible recycling routes or facilities can be integrated. For this, suitable methods would have to be found to realize such labelling uniformly and to ensure readability also after a long period of use.

Seals, labels or norms help to create uniform standards for the industry and to inform consumers about environmentally friendly products. For example, according to the criteria for the EU-Ecolabel 2014/391/EU, manufacturers must ensure that mattresses can be easily disassembled. In order not to confuse consumers with new labels it appears advisable to expand well-known labels, such as the Blue Angel, to include criteria for recycling-friendly design and the use of recycled materials.

Table 23 Evaluation of the measure "Negotiation of uniform design criteria at EU level that simplify recycling and their adoption in standards or labels"

Criterion	Evaluation	Points
Bureaucratic effort	no compulsory measure, therefore no additional administrative burdens expected	1
Legal aspects	no changes or amendments to legislation required	1
Statistical aspects	no influences on the statistical recording	5
Organisational effort	high organisational effort since a coordination between all stakeholder groups is required, however reaching an agreement on non-mandatory criteria is supposedly easier than on such that are obligatory in nature	3
Implementation timeline	medium-term (3-5 years)	3
Binding character	adopting a recycling-friendly design is non-binding but the implementation in the form of labels or standards ensures that the design criteria are indeed realized	4
Contribution to financing the recycling	is not contributing or ensuring the financing of recycling but recycling-friendly design can reduce the cost of dismantling and increase the revenue from the sale of secondary materials	4
Improvement of collection	does not affect the collection of the waste stream	3
Strengthening of recycling	eco-friendly mattress designs simplify recycling and allow waste management companies to better specialise in the treatment and dismantling of used mattresses	3
Acceptance of relevant actors	discussion on technical concepts of recovering raw materials from mattresses is supported by a majority of stakeholders and possibilities towards their adoption are being investigated by many manufacturers already	1
Public information needs	special PR efforts are not required	1
Weighted result		**2.7**
Key addressees	manufacturers, recyclers, chemical industry, politics/ministry of environment (BMU), quality assurance organisations, standardisation institutes	
Summary	Recycling-friendly design criteria will improve cooperation between manufacturers and recyclers and promote further technical development. Although this measure alone has little effect, it is useful as a basis for further measures.	

3.4.2 Voluntary commitment by manufacturers to implement recycling-friendly mattress designs and by retailers to expand take-back systems

The German mattress sector and chemical industry are found to have already a visible interest in recycling and a circular use of resources as well as in eco-friendly materials and processes. A voluntary commitment by the concerned industries would require manufacturers, material suppliers and the recycling industry to come together EU-wide to set mandatory targets for the collection and recycling of end-of-life mattresses.

Another obstacle to recycling mattresses is that they can become soiled or wet in the course of collection and drop-off services offered by the public disposal providers. Some retailers already offer to take back old mattresses as a service when buying new mattresses. However, there are challenges here as well, since new foam mattresses are often mechanically compressed before being transported or when sold to consumers whereas for old mattresses certain more space and hygiene measures are needed. The establishment of take-back systems can only be done by retailers since mattress manufacturers do not maintain contacts to the end consumers and retailers are always acting as intermediate between manufacturers and consumers.

Table 24 Evaluation of the measure "Voluntary commitment by manufacturers to implement recycling-friendly mattress designs and by retailers to expand take-back systems"

Criterion	Evaluation	Points
Bureaucratic effort	in order to verify the achievement of the targets set by the commitment, all producers, traders and the recycling sector must centrally record the quantities put on the market and collected as well as their routes of further recovery	3
Legal aspects	needs a regulation based on Article 26 para. 1 KrWG in order to give the agreed objectives a legal framing	3
Statistical aspects	enhances the statistical recording in that mattresses taken back by the retail sector must be counted in order to verify the objectives set with the voluntary commitment are being met	3
Organisational effort	high organisational effort since a coordination between all stakeholder groups is required and targets must be negotiated at the EU level	4
Implementation timeline	long-term (more than 5 years)	5
Binding character	binding as it represents a voluntary commitment made by the industry	3
Contribution to financing the recycling	producers and trade participate in financing recycling solutions	3
Improvement of collection	improves collection through take-back systems and public targets	2
Strengthening of recycling	can improve the possibilities for recycling in the long term but is voluntary	3
Acceptance of relevant actors	manufacturers: medium (associated with high effort and changeover, but less economic risk for individual manufacturers in implementing a recycling-friendly design) retailer: low (associated with high additional effort, necessary space and logistics must be created and are not available yet at every retailer)	3

Criterion	Evaluation	Points
Public information needs	requires a medium effort for public relations, consumers must be informed when other structures for the collection of old mattresses are created	3
Weighted result		**3.2**
Key addressees	Manufacturers and manufacturers' associations, retail sector, recycling industry, quality assurance organisations, standardisation institutes, ministry of environment (BMU)	
Summary	The measure addresses the obstacles for recycling that are currently found in product design and collection. The biggest challenge will be to negotiate uniform criteria for mattress design and to set targets. The impact of the measure depends on the extent of the specifications which are eventually achievable at the EU level. The collected quality in take-back systems can be considered good though also in future not all but only a certain portion of mattresses will continue to be collected in take-back systems.	

3.4.3 Extended producer responsibility/implementing graduated contributions

With the revenues from secondary material sale covering a small part of the costs for dismantling only, additional payments are necessary for dismantling processes as these currently cannot compete with the costs for energy recovery. In order to build up a recycling system, financing would have to come from other sources. Here, an extended producer responsibility in the sense of a financial contribution per mattress by the manufacturers to a recycling organisation could work as a remedy. It would make sense to prescribe a contribution graduated according to the recyclability of the mattresses in order to reflect the effort required to recycle the mattress and to reward manufacturers who implement a recyclable design or use secondary materials in production. The money could be used to finance covered containers for a separate mattress collection at CAC and (voluntary) take-back systems by retailers as well as improvements to mattress dismantling at several locations in Germany. It is important that both online and stationary retailers are equally involved and that both classic mattresses and box-spring beds are included.

The financing can either be provided directly from the manufacturers or importers or by passing on the financial contribution for recycling as part of the product price to the consumer. The option of a contribution passed on and perhaps separately indicated to the consumers requires more effort for public information. However, the method also offers the advantage that consumers are made aware of the advantages of recycling and can choose the product that is easier to recycle by means of simple criteria used also as a basis for graduated contributions.

Table 25 Evaluation of the measure "Extended producer responsibility/implementing graduated contributions"

Criterion	Evaluation	Points
Bureaucratic effort	costly and burdensome to prepare and supervise	4
Legal aspects	a regulation on the basis of Article 23 para. 4 KrWG or a specific provision in (form of) an EU Directive is needed	3
Statistical aspects	collection of statistical data on quantities is ensured due to the reporting obligations of producers and disposers in a system of extended producer responsibility.	1

Criterion	Evaluation	Points
Organisational effort	very high, also considering the necessary co-ordination between all stakeholder groups to let this approach become acceptable	5
Implementation timeline	Long-term (more than 5 years)	5
Binding character	highly binding as it will be imposed on the basis of a legislative act	1
Contribution to financing the recycling	finance for collection and recycling is part of an extended producer responsibility regulation and thus ensured by it, a change is effected from the predominantly flat-rate financing via basic fees (covering bulky waste disposal services) to a consumption-oriented (user) financing in the form of incorporating advanced disposal costs into the sales price.	1
Improvement of collection	strengthens and improves the collection of the waste stream	1
Strengthening of recycling	recycling is strengthened depending on the legally required collection and recycling quotas and the incentives actually set for sustainable product design (e.g. graduated contributions); the measure affects all mattresses sold in Germany	1
Acceptance of relevant actors	manufacturers, retailer: low (facing high additional efforts) consumers: indifferent (small increase of prices is possible) waste management industry: high (higher quality pathways for disposal are facilitated)	3
Public information needs	medium to high efforts for public information are needed, consumers must be informed about the purpose for which an additional levy/higher price needs to be paid, what has been achieved by it and where they can hand in their old mattresses in future	4
Weighted result		**2.4**
Key addressees	German government, manufacturers, retail sector, importers, public disposal providers	
Summary	A high level of effectiveness in realizing ecological, economic and statistical objectives is contrasted by high burdens for the implementation as well as the low level of acceptance among manufacturers and retail sector which also results in a long period to get the producer responsibility model up and running. Producer responsibility must be designed in such a way that the EU internal market remains undistorted.	

3.4.4 Promotion of demonstration facilities (e.g. for chemical recycling of PUR foam) and pilot projects

Germany is lacking an adequate spectrum of facilities and processes suitable for recycling the materials obtained from mattress dismantling which in turn would create sufficient demand for secondary materials as well. Together with the mattress industry, all industries must be encouraged to engage in research and development projects on techniques that help replacing virgin materials with secondary materials. In the chemical industry in particular, some companies are already involved in PUR recycling. Here, cooperation between the various sectors using flexible PUR foam as a material (e.g. upholstered furniture, car seats), waste service firms, recyclers and the chemical industry is necessary in order to identify appropriate ways to bundle quantities of suitable quality for a recycling process.

Table 26 Evaluation of the measure "Promotion of demonstration facilities and pilot projects"

Criterion	Evaluation	Points
Bureaucratic effort	*not relevant, individual locations and circumstances govern implementation*	
Legal aspects	legislative basis already exists	1
Statistical aspects	*not relevant*	
Organisational effort	stays within the scope of the usual operational activities for the construction of larger-scale facilities	2
Implementation timeline	medium-term (3-5 years)	3
Binding character	*not relevant*	
Contribution to financing the recycling	helps to secure financing for certain new installations during the project period and stimulates investment	3
Improvement of collection	has no influence on the collection of the waste stream	3
Strengthening of recycling	lays the foundation for a future increase in recycling, the ecological effects of the developed techniques/processes should be analysed within the respective projects with the help of life cycle assessments	3
Acceptance of relevant actors	high, considering that research and implementation of projects on resource and energy conservation have a positive image in the overall	1
Public information needs	*not relevant; public relations work can be carried out as part of the project implementation by the participating industry and research institutes themselves*	
Weighted result		**2.4**
Key addressees	Ministries, espec. ministry of environment (BMU), manufacturers, research institutes, chemical industry	
Summary	The implementation of demonstration projects and pilots is a good opportunity for assessing future possibilities and obstacles in mattress recycling	

3.4.5 Final synopsis

In the mattress industry, efforts are already being made to close material cycles or, alternatively, to perform a cascading use of raw materials including as many stages as possible and the least possible alteration of material properties per each stage. Towards this end, clear and reliable framework conditions framework conditions are necessary which also ensure the competitiveness of recycled products and offset the difference between primary raw material prices and the currently more expensive secondary materials. Therefore, following measures are recommended to support this:

1. Negotiating design criteria

Negotiating suitable criteria with all stakeholders to come to a design-for-recycling and transferring these criteria into standards or adopting them for known labels can create a joint and workable basis for manufacturers as well as the recycling industry, supports ecological purchasing behaviour and provides a useful starting point for further measures. This approach shall be therefore recommended as the first step in the chronological sequence of actions.

2. Promoting demonstration facilities and pilot projects

In parallel, the development of technical solutions for closing material cycles or further extending cascading use should be promoted by the state.

3. Introducing extended producer responsibility

Building further upon the aforementioned measures, an extended producer responsibility can be implemented to enhance the financing of recycling, the organisation and quality of collection and the statistical monitoring of used mattresses. It is important that all manufacturers, traders and importers of mattresses and box-spring beds are equally involved and that the additional effort for those involved is well balanced with the goals of increasing recycling outcome and efficiency.

4 Furniture

4.1 General information

4.1.1 Characteristics

Furniture is manufactured in all kinds of shapes, sizes, colours and materials for a wide range of applications. Essentially, the following materials are used for furniture:

- Wood-based materials (solid wood, chipboard, fibreboard)
- Metal
- Glass/ceramics/porcelain
- Plastics
- Fibreglass/glass fibre/glass fiber reinforced plastic
- Paper/cardboard
- Concrete/stone/stoneware
- Textiles
- Rattan
- Composites of several materials

Furniture is needed and used in virtually all areas of life, further to the private households these are the hospitality industry, offices, shops, restaurants, schools, healthcare and industrial facilities. The majority of furniture is used indoors, garden furniture and the like are also used outdoors.

The selection and demand of furniture are certainly linked with functional properties and price aspects but mainly take orientation on personal taste, emotions and trends also. The product range is correspondingly diverse, including furniture with permanently installed electrical components that must be disposed of as waste electrical and electronic equipment. The increasing integration of everyday objects and electrical and electronic devices in network systems (internet of things) can also be observed in the furniture segment, an example for that are so-called smart furniture. In this case the risk exists that furniture will be used for shorter periods of time due to certain technical functions becoming obsolete or outdated (Zapfl, 2018).

4.1.2 Furniture production

The majority of furniture is nowadays the produce of mass production processes carried out in furniture factories. Furniture made in Germany generated domestic sales of almost €18 billion in the year 2018 (Möbelkultur, 2019), an amount of around €33 billion in total was spent in the country on furniture in the same year (Welt online, 2019).

Of the furniture purchased in Germany, 65% is imported, mainly from Poland, China and the Czech Republic (Welt online, 2018). Since it is mainly furniture from the lower price segment that is imported, around two-thirds of the turnover of the German furniture industry is generated within Germany (pwc, 2017). In the German export business, kitchen furniture accounts for the largest share of turnover (Ambista, 2019).

In Division 31 of the List of Goods for Production Statistics, the following groups and classes of goods are distinguished:

- Seating furniture and parts for this and other furniture
- Office furniture, shop furniture of wood
- Kitchen furniture of wood
- Mattresses
- Other furniture
- Finishing of new furniture (excluding upholstery of seating furniture).

4.1.3 Furniture reuse

Furniture in good condition or worth a refurbishment is quite frequently resold by private individuals at flea markets, via second-hand shops or online portals and advertisement. The bulky nature of certain furniture, such as large wardrobes, and limitations that exist for shipment by postal services and privately available transportation capacities give cause that furniture resale often occurs in a limited distance radius. The intensity by which a reuse of second-hand furniture is taking place depends in particular on the demand for individual pieces of furniture. For example, the demand for high-quality solid wood furniture generally tends to be good. However, in the case of demountable second-hand furniture, supply often exceeds demand. Apart from this, damage caused by assembly and disassembly, transportation and delivery of furniture limits the supply of potentially reusable furniture (Bayerisches Staatsministerium für Umwelt und Verbraucherschutz, 2019). The same finding was made in a survey among companies active in the field of reuse in the Free State of Saxony (ÖKOPOL/INTECUS, 2016).

As part of a tandem pickup for bulky waste collection, reusable pieces of furniture can be diverted from the other bulky waste to be handed to charity organisations or sold in second-hand shops. However, in the survey conducted on the collection of bulky waste among public disposal providers, only four public disposal providers stated that they separate reusable furniture items in the course of tandem collection services. It is estimated that the share of reusable furniture in bulky waste is in a range of around 10%. Using this potential would save about 200,000 tons of bulky waste per year in Germany (Dornbusch, 2020).

4.2 Collection

4.2.1 Collection systems

Used furniture is usually disposed of as bulky waste (waste code 20 03 07), depending on the material and size. If wooden furniture is collected separately within the frame of special arrangements for bulky waste collection (e.g. tandem pickup), accumulation and classification typically occur under the category wood waste of the non-hazardous sort (AS 20 01 38 wood other than that mentioned in 20 01 37). Furniture has not been allocated a separate waste code in the European Waste Catalogue. The collection is thus organized analogous to bulky waste or separately collected wood waste (see chapter 2.2.1).

Where electrical/electronic components for smart furniture are permanently integrated into the product, the furniture is classified waste electrical and electronic equipment and must be disposed of in accordance with the regulations of the German Electrical and Electronic

Equipment Act (ElektroG). In addition to collection by public disposal providers, this waste can be returned to retailers[10].

Used furniture from the commercial sector, according to Article 3 para. 1 of the Commercial Waste Ordinance, must be collected separately according to materials as long as this is technically and economically reasonable (GewAbfV, 2017).

4.2.2 Collected quantities

A large proportion of the used furniture is collected as municipal bulky waste or wood waste. Furniture accounts for 61% by weight of bulky waste. Correspondingly, a quantity of approx. 1.7 million tons of used furniture is disposed of in municipal bulky waste per year (Dornbusch, 2020). Another portion of the furniture is collected together with other wood waste, waste electrical and electronic equipment or scrap metal. A disposal via the residual waste stream cannot also be excluded when furniture or furniture parts are small enough (i.e. suitable to be dumped into garbage bins).

Because of the above described diversity of the furniture waste stream and different ways applied for the collection, it is impossible to precisely quantify the collected quantities. In the following, an estimate of the potential generation of waste from furniture in Germany is presented on the basis of figures available on the production and im-/export of furniture. The production statistics of the Federal Statistical Office for the manufacturing industry (Fachserie 4, Reihe 3.1) were used for this purpose (Destatis, 2019b). In addition to the number of units produced, the production value of various goods are listed in this statistic but no mass data. For the transboundary trade of furniture, statistics on the German export and import of goods are available (Genesis, 2019). This source lists the mass and value of imported and exported goods, but does not list the traded units. Of the two statistics, the years from 2016 to 2018 were used for the calculation.

The individual goods designation in the nomenclature of goods for the production statistics do not fully correspond to the commodity codes in the nomenclature of goods subject of foreign trade, whereas a more precise differentiation is made in the production statistics[11].

In order to be able to compare the two statistics, an average unit weight was assumed for the individual goods in the production statistics. Information provided by furniture and mail-order companies for similar furniture products gave the basis for the assumptions. Average values were estimated.

The average number of units produced multiplied by the assumed unit weights gave a figure for the mass of the production goods. Then, in accordance with the allocation, the mass of the production goods was added to the mass of the imported goods and the mass of the exported goods was subtracted.

The total mass of furniture that remains in Germany[12] each year has been assessed with 3.6 million tons, details how this result has been derived are displayed in Table 27.

[10] as retailers under this obligation are considered those with a sales area for electrical and electronic equipment of at least 400 square meters; in online retail, any storage and shipping areas for electrical and electronic equipment are considered under the obligation

[11] For example, there is an entry "upholstered seating furniture, with metal frame" contained in the list of goods whereas the production statistics distinguish between "upholstered seating furniture, with metal frame for offices" and "other upholstered seating furniture, with metal frame".

[12] For another calculation approach to determine the mass of furniture that remains in Germany each year, specific ratios were first determined using the above statistics (for the production statistics pieces/euro and for the import/export statistics mass/euro, separated into import and export), so as to calculate an average unit weight by product group (wood, metal, upholstered plastic and

In a next step, the goods were assigned an average useful life which has been determined, for example, on basis of depreciation tables (AfA-Tabellen) and can be seen in the information provided in Table 27 also. Depending on the type of furniture, the average useful life ranges between 8 and 15 years, although must be noted that in individual cases very large differences in the useful life can be found. In practice, depreciated products are not disposed of immediately, so that the estimates based on AfA tables tend to represent figures for minimum useful life spans. Surveys conducted in the private sector suggest that living rooms in Germany on average get refurnished every 9 years (Möbelkultur 2008) whilst kitchens are used for an average of 15 years (Welt online, 2016). For upholstered furniture a useful life of around 8 years is given.

From the 3.6 million tons of furniture added to the total stock in Germany each year, 1.7 million tons can be deducted as the amount disposed of with the bulky waste. Solid wooden furniture in some cases might also be recorded as wood waste, depending on the collection system. A further large portion, the mass of which cannot be reliably estimated, is disposed of as commercial waste from offices, retail and commercial facilities, etc.. Population growth and other trends such as the rising number of single-person households, living space per person and the increase in employment lead to an increase in furniture consumption in Germany in addition. For this reason, it can be assumed that the quantities of used furniture in bulky waste and commercial waste will also increase in the future.

Table 27 Estimation of the annual generation of furniture waste

Goods Commodity codes based on the nomenclature of goods	Weighted unit weight Based on estimates [kg]	Volume produced / sold in Germany Production in Germany minus exports plus imports [tons]	Useful life time Based on AfA-tables and estimates [a]
Swivel chairs with adjustable seat height	17	53,348.2	13
Seating furniture, with metal frame, upholstered	53.2	164,353.0	8
Seats, with metal frame	4.8	110,935.6	10
Seating furniture convertible into couches	87.5	150,543.2	10
Seats made of cane, wicker, etc.	8	812.6	10
Seating furniture, with wooden frame, upholstered	31.5	368,574.1	8
Seating furniture, with wooden frame	9.5	47,098.4	10
Seating furniture, not elsewhere specified	7.1	32,441.1	10
Metal desks for offices, height up to 80cm	25	93.5	13
Metal furniture for offices, <=80cm, and others	22.7	13,618.2	13
Metal cabinets with doors or shutters	25	9,632.6	13

composite furniture) by dividing these two specific ratios for each type of furniture. Eventually this resulted in a similar total quantity (3.8 million tons of furniture remaining in Germany) as with the value calculated above. However, since the unit weights for some subcategories were not conclusive with this calculation method, the method presented above was ultimately chosen for the assessment. Since both methods produced similar results, the calculated furniture mass can be considered plausible.

Goods	Weighted unit weight	Volume produced / sold in Germany	Useful life time
Metal filing cabinets and other metal cabinets	70	15,041.5	13
Metal furniture for offices, >80cm, and others	15	10,038.4	13
Wooden desks for offices, height up to 80cm	25.3	84,284.7	13
Wooden furniture for offices, height up to 80cm	26	1,185.6	13
Wooden cabinets for offices, height over 80cm	25	17,679.1	13
Wooden furniture for offices, height over 80cm	25	12,377.9	13
Wooden furniture of the type used in stores	30	365.3	8
Built-in wooden kitchen elements	20	277,933.3	15
Wooden furniture of the type used in kitchens	25	13,657.4	15
Metal furniture (excluding seating, beds and office furniture)	17.7	303,919.1	10
Metal beds	20.1	17,527.1	10
Wooden furniture of the type used in bedrooms	152.2	1,080,316.4	10
Wooden furniture, used in dining and living rooms	36.7	575,617.3	10
Other wooden furniture	13.5	249,344.2	10
Plastic furniture (excluding seating furniture)	11.3	29,299.8	8
Furniture made of cane, wicker, etc.	15	11,069.9	10
Total sum of goods		**3,651,107**	

4.3 Recovery of furniture

4.3.1 Routes of recovery

The disposal of used furniture is mainly done via the bulky waste where there is no tandem pickup practiced for this waste stream and still usable individual items aren't sorted out for (preparation for) reuse (see Chapter 2.2.1). Depending on the public disposal providers, metals or wood waste are for example still separated from this waste stream.

The routes of recovery are generally the same as for bulky waste (see Chapter 2.3.2).

In addition to companies in the social and charity sector as well as second-hand outlets organized by some public disposal providers, carpentry workshops and handicraft businesses have in some cases specialized in the refurbishment of old furniture and manufacturing of new products from recovered furniture components. In the overall this involves only small quantities, however. (Schöner Wohnen, n.d.).

Furniture consists of a variety of different materials that, as described in Chapter 4.1.2, other bulky waste items may also contain and material recycling therefore depends on the separation of these individual materials. Dismantling the furniture for material recycling does incur high costs and thus requires higher additional payments to be made than is the case for energy recovery. Although recyclable components can be sorted out for material recovery after shredding also in sorting facilities, the majority of furniture is processed into substitute fuels or fuel for biomass combustion facilities.

In France, the instrument of extended producer responsibility is used to finance the recovery of used furniture since 2012. The adopted scheme obliges manufacturers to organize the disposal of their used products themselves or to pay a graduated environmental fee per piece of furniture to an accredited recycling organization. The rate of the environmental fee depends on the category and size (especially weight) of the piece of furniture and it is eventually paid as an "eco-contribution" by the end consumer at the time of purchase. The rate is determined with the help of an 11-digit code that must be entered for each piece of furniture and roughly characterizes it by category, type, materials and other features. If a piece of furniture is made of at least 75% of certified solid wood or metal and does not contain PVC or inert materials, a lower payable fee amount applies as such furniture is deemed more recyclable in nature. Up until 2019 furniture that were ‘growing’ with the user (for example baby/children's beds) and thus allowing a longer useful life still had been subject to a lower environmental fee. This bonus was abolished with the tariff adjustment in 2020, as it was rarely used. The environmental fees collected this way go either to "Eco-mobilier", or in the case of commercial furniture to the "Valdelia", both organization the furniture manufacturers and retailers have founded to organize the collection and recycling of used furniture. Consumers can hand in their old furniture and mattresses to charity organizations specialized in preparing them for reuse, and to municipal points of collection. Take-back in stores is voluntary. With this system, Eco-mobilier achieved a recycling rate of 57% in 2019, unfortunately there is no indication on how the recycling rate was actually calculated. 36% of the collected furniture was used for energy recovery and the remaining 7% was otherwise disposed (Eco-mobilier, 2020; Knupp, 2015).

The current status for separating individual materials in bulky waste collection in Germany is explained in Chapter 2.2 whilst in Chapter 2.3.2 the recovery routes of common bulky waste materials are presented. In the following, particular features of the waste streams for specific types furniture will be described.

4.3.1.1 Upholstered furniture

Upholstered furniture are composite products which may contain wood, textiles (cover fabrics and nonwovens), foam, rigid plastics, metals, genuine or imitation leather and other materials. During their production cover fabrics are usually attached to the frame or upholstery material with staples or adhesives. This makes it difficult for classic upholstered furniture to be disassembled into its individual materials later on. A design for recycling has not yet been able to establish itself in this product segment, with the exception of seating furniture in which cushions lie unattached on a visible frame. Further complicating the introduction of recycling-friendly design is the fact that more than half of the upholstered furniture sold in Germany is of foreign production (Schardt and Weinert, 2003). Where a dismantling for the separation of individual materials is not technically and economically feasible, energy recovery provides for a suitable recovery route. Currently this is the practiced kind of disposal in Germany. Where dismantling becomes feasible as the result of recycling-oriented design, or when separating different materials through a process of shredding and automated sorting is possible, material recycling concepts similar to those described for mattresses and box-spring beds in Chapter 3.3.1 can be applied.

For artificial leather and other fabrics with PVC coating, there is a recycling process in which the artificial leather from industrial waste is shredded and pressed into large-format sheets that are suitable, for example, as underlays for riding arenas, marquees or greenhouses. This process has not yet been adopted for post-consumer waste since the input must be dry, clean and free of metals (Recycling Magazin, 2017).

4.3.1.2 Lightweight furniture and cardboard furniture

In the meantime, lightweight furniture has also become established on the market. This kind of furniture often consist of a honeycomb structure made of cardboard or plastic, which is finished with thin cover layers of cardboard, lacquered plastic or wood and sometimes also with veneers. Recycled material is usually used for the cardboard structure. The material recycling of this lightweight furniture depends strongly on the combination with or separability from other materials. There are individual manufacturers who only use cardboard, so that this furniture can be disposed of in paper waste after use (Stange Design GmbH, n.d.; pappcultur, n.d.). However, the majority of lightweight furniture is combined or glued with plastics, chipboard or fibreboard. Together with paints or varnishes this is to generate a high-quality appearance of the furniture and to increase the stability or useful life. The disassembly of this furniture is difficult and recovering recyclable fractions from it usually not possible, which is why energy recovery is the disposal option used instead.

4.3.1.3 Other composite furniture

In addition to the upholstered furniture described above, various other composite furniture is available on the market in which, for example, wood, metal, glass, mirrors or plastic are combined with each other. There is also furniture that integrate electrical components and therefore must be disposed as waste electrical and electronic equipment. The latter kind furniture is not further dealt with in this study.

When designing composite furniture, the following criteria should be taken into account to facilitate their disassembly and the recovery of materials for recycling (UrbanRec, n.d.):

- Use of as few different materials per piece of furniture as possible
- Use of accessible and detachable connections and as few connection types as possible
- Provision of information as to the materials used and their proportions in the product
- Avoidance of harmful substances (e.g. flame retardants, formaldehyde, heavy metals)[13]

Flame retardants are used in upholstered furniture due to applicable fire safety regulations and thus cannot be omitted by manufacturers without further ado. Formaldehyde is used in chipboard, among other things. Here, the quantities have already been significantly reduced in recent years, but formaldehyde can be unintentionally introduced into the product through adhesion to the material when using wood waste.

4.3.1.4 Label and quality standards

Many product certifications already include recycling-friendly design, product labelling and the absence of harmful substances as criteria.

The VDI guideline 2243 on recycling-oriented product development addresses, among other things, the selection of recyclable materials, the chance to identify clearly the used materials, the accessibility and possibility for loosening connections and the time needed for disassembly.

[13] the candidate list of Substances of Very High Concern (SVHC) according to Regulation (EC) No 1907/2006 and the hazard classification of substances and mixtures according to Regulation (EC) No 1272/2008 (CLP Regulation) indicate which substances should be avoided or used in the lowest possible concentrations

The EU-Ecolabel, by way of Decision 2016/1332/EU, already requires at least 30% recycled content in plastic parts if a piece of furniture is composed of more than 20% plastic. In addition, the use of wood from secondary sources or from sustainably managed forestry operations is required. Furniture products made of several components must be designed to be dismountable, i.e. disassembling them with common tools and without prior technical knowledge must be possible. In addition, consumer information must be provided, including the best disposal options and clear instructions for dismantling. Since the end of 2019, there has been a sharp increase in certifications for furniture, yet the number of products with the EU Ecolabel is still low with a total of 766 furniture and mattresses certified across the EU (European Commission, 2020).

The RAL Quality Mark 430 also requires a recyclable design according to VDI 2243 and the avoidance of preservatives and halogen-organic compounds, which is particularly necessary for the recycling of wood waste. In addition, the replacement of wear parts must be ensured for at least five years and plastic components excessing 50 g in weight must not contain any additives that prevent recycling.

4.3.2 Evaluation and conclusions

High proportions of wood-based components and various composite materials which are characteristic for furniture put quite some limits to the exploitable recycling potential for these products.

The system for mixed bulky waste collection in Germany is particularly suitable to bundle the quantities which are considered necessary for energy recovery processes or pre-treatment in facilities where recyclable metals and plastics are separated and/or a processing into substitute fuels is taking place. Apart from that, many public disposal providers offer the possibility to collect furniture and furniture parts made of a single material, e.g. wood, glass or plastic, separately at the CAC or during a tandem pickup. With the amendment of the German Circular Economy Act (KrWG) in 2020, the obligation of the public disposal providers for collecting the bulky waste separately was legally fixed (Article 20 para. 2 no. 7 KrWG). The large dimensions of the individual waste items and the associated difficulties in placing them in normal waste containers had long since ensured the establishment of these separate collection services in the public disposal providers, however. What is new here is the requirement in the amended regulation to collect the bulky waste in a manner "that enables the preparation for reuse and the recycling of the individual components". In the legislator's view, the collection of mixed bulky waste exclusively with a compactor truck, i.e. without a further accompanying vehicle for prior separated items, is unlikely to meet this obligation. In an explanatory memorandum, the legislator states that "this obligation [...] takes account of the fact that the public disposal providers are already obliged to comply with the waste hierarchy principles in accordance with Article 6 KrWG under the current legal situation (Article 20 para. 1 KrWG previous version). This calls for the most resource-efficient collection possible, especially for this waste stream of high-value." An alternative to the sole collection with compactor trucks is the pickup of used furniture from the households which includes a preceding diversion of reusable furniture, that, however, is associated with high costs for the public disposal provider. Yet another alternative is waste counselling in accordance to Article 46 KrWG when registering for a bulky waste pickup. In that case citizens must be explicitly sensitized to examine the reusability of the used furniture, in addition they must also be informed about reuse services, exchange and sales platforms as well as other possibilities for reuse on site.

Wood-based materials, which often make up a large part of the furniture, are in practice taken to energy recovery, as the high supply of fresh wood attracts little demand for recycled wood and recycling requires a great deal of effort in relation to this.

Especially for upholstered furniture and other composite furniture, there are still no suitable recycling routes available. The many different materials used and the fact that these are often firmly bonded together render dismantling to become a time-consuming and expensive operation, so that no increase in such effort is to be expected in the medium term for economic reasons. In addition, as in the case of mattresses, upholstered furniture would have to be collected dry and clean to enable recycling. There is currently little market interest in most of the materials that can be recovered from upholstered furniture, for example soft foam, fleece layers or textile covers. However, the flexible PUR foam contained therein could be recycled in the same way as the flexible foam from mattresses, for example in a chemical process (see Chapter 3.3.1). The dismantling and recovery of individual materials could become interesting indeed if such a (demonstration) facility were to be built in Germany.

In some cases, labels or standards demand a recyclable design of composite furniture and the avoidance of harmful substances. However, since a wide variety of materials and joining techniques are used in the furniture industry, such design specifications do not go into detail. On the other hand, there are no specifications or incentives for the use of recycled materials in the production of furniture.

For other materials, there exist currently no collection or sorting structures nor volumes of sufficient relevance to establish material recycling paths.

The greatest potential for reducing the environmental impact of furniture lies in an extension of its useful lifetime, in the use of ecological and recycled materials and in the reuse option. Reusing furniture is saving energy, materials and manufacturing efforts, it helps avoiding greenhouse gas emissions and, in the case of wooden furniture, saves wood resources and forests. However, the environmental benefit can easily be offset if small and old furniture is only reused for a short time and longer car journeys of the individual consumers are needed to enable this (Ludmann and Vogt, 2019).

On the one hand, the trend in the furniture sector is increasingly towards environmentally friendly furniture, for example by implementing a durable design or resource- and energy-saving production. This is however contrasted in that manufacturers and retailers also try to persuade customers to regularly replace their furniture by way of low prices, stylish ideas and quality that is not designed for long-term use. If not counteracted, this may lead to an increase in the amount of mixed bulky waste or wood waste in future. It is therefore all the more important to provide incentives for durable design, long-time usage, reuse, recycling and the use of recycled materials in the production of furniture.

4.4 Proposed measures

In the following, various measures for improving the recycling of furniture are described and evaluated according to the criteria mentioned in chapter 1.3.1.

4.4.1 Negotiating uniform design criteria at EU level that simplify recycling and adopt them in standards or labels

In cooperation with furniture manufacturers and the recycling industry, standards for the eco-design of specific pieces of furniture need to be developed at EU level that facilitate repair, separation of different materials and recycling. For example, detachable joining techniques and materials that are rather suitable or unsuitable for recycling must be defined in this context. For eco-designs to achieve a relevant effect for the circular economy design criteria must be negotiated and agreed as early as possible, given the long useful life span of furniture and the time it takes until standards are adopted and fully operational.

Table 28 Evaluation of the measure "Negotiating uniform design criteria at EU level that simplify recycling and adopt them in standards or labels"

Criterion	Evaluation	Points
Bureaucratic effort	low; somewhat higher effort is required to create database for the labelling of materials	1
Legal aspects	there are no legal aspects to consider as long as design criteria do not have to be applied on a mandatory basis	1
Statistical aspects	design criteria have no influence on the statistical recording of the furniture waste stream	5
Organisational effort	specific criteria have to be negotiated for all types of furniture, this requires cooperation and agreement between manufacturers, standardisation and labelling organisations and the recycling industry	4
Implementation timeline	medium-term (3-5 years)	3
Binding character	non-binding	5
Contribution to financing the recycling	*not relevant but the recycling costs may decrease due to the chosen input materials and joining techniques if a large part of the furniture is designed for recycling*	
Improvement of collection	no impact on the collection of the waste stream	3
Strengthening of recycling	can lead to improved conditions for recycling, the measure only has an indirect effect however and does not affect all furniture (e.g. not imported goods from non-EU countries)	3
Acceptance of relevant actors	producers: low (facing high additional efforts) consumers, retail: mostly high (ecological awareness, green image) waste management industry: high (higher quality pathways for disposal are facilitated)	2
Public information needs	requires a small amount of PR/PA work, interested consumers can be expected to exert an information effort themselves	2
Weighted result		**2.9**
Key addressees	manufacturers and manufacturers' associations, recycling industry, quality assurance organisations, standardisation institutes, politics/ministry of environment (BMU)	
Summary	Criteria for recycling-friendly design improve cooperation between manufacturers and recyclers and promote further technical development. Although this measure alone has little effect, it is useful as a basis for further measures. Even if design criteria won’t become compulsory, they lay the foundation for further measures and green procurement by companies and the public sector as well as green purchasing decisions of private consumers	

4.4.2 Ecological criteria in public procurement

Due to its large contract volume, public procurement which favours product designs for recycling is a suitable lever to increase the demand for recyclable furniture at an early stage and to set incentives for the development of recycling solutions. Article 45 KrWG (applying to federal authorities) as well as the State Waste Acts oblige the public sector to contribute in an exemplary manner to the implementation of the circular economy goals. A lot has been done in this area in recent years but there is still a lack of practical assistance and widespread implementation.

Table 29 Evaluation of the measure "Ecological criteria in public procurement"

Criterion	Evaluation	Points
Bureaucratic effort	medium effort, procurement practice must be adapted	3
Legal aspects	public authorities under Article 45 (2) KrWG (federal authorities) or stipulations in the State Waste Acts are obliged to give preference to products that are, for example, made from recycled materials or are characterised by their recyclability, further requirements can be specified with the help of administrative regulations	2
Statistical aspects	ecological criteria do not influence the statistical recording of the furniture waste stream	5
Organisational effort	procurement practice must be adapted, this requires practical templates, performance sheets, suitable quality marks/labels and a supplement to the German Environment Agency's guidelines on environmentally friendly procurement	3
Implementation timeline	medium-term (3-5 years)	3
Binding character	binding as the legal basis already exists	2
Contribution to financing the recycling	ecological criteria support recycling, for example, not using harmful substances and easier disassembly of products very likely reduces the reprocessing costs	4
Improvement of collection	collection of the waste stream is not influenced	3
Strengthening of recycling	since public procurement only accounts for a part of the furniture sold and addresses office furniture in particular, the direct impact can be considered low, ecological criteria may however contribute that supposedly more expensive ecological products are more likely to be used and demand for these increases due to role model effects, manufacturers are encouraged to develop corresponding products, which should also have an effect on B2C offers	4
Acceptance of relevant actors	individual reservations may exist in view of additional efforts, a smaller range of choices or requirements that are difficult to fulfill	2
Public information needs	*not relevant, public relations work nevertheless can be useful to increase green procurement in the private sector as well*	
Weighted result		**3.3**
Key addressees	manufacturers, retailers, authorities, advisory institutions incl. German Environment Agency, quality assurance organisations	

Criterion	Evaluation	Points
Summary	Ecological or recycling-friendly criteria in public procurement are already prescribed by law but clearly defined criteria, suitable offers and concrete support for effective larger-scale implementation in practice are often lacking. Earlier measures, such as guidelines and the establishment of the Competence Centre for Sustainable Procurement (KNB) and its information offers can be further expanded. The aforementioned negotiation of design criteria is also helpful for public procurement.	

4.4.3 Quota for using secondary materials

An increased and cross-sectoral use of recycled materials in the production of furniture strengthens the circular economy by creating better market opportunities for recycled products, therewith improving the economic viability of recycling processes. In the furniture sector this is already partly implemented, as chipboard with a certain content of wood waste and sometimes recycled glass, plastic or cardboard are used. Nevertheless, it is important to increase the share of secondary materials in the furniture sector and to implement it on a broader scale. To achieve this, incentives must be created for the furniture industry, projects to increase recycled matter content must be initiated and promoted, and transparency towards consumers must be raised. The furniture sector’s environmental impact can be reduced by certifying more furniture with the EU Ecolabel and by including recycling and dismantling requirements into other well-known labels (e.g. the Blue Angel).

Table 30 Evaluation of the measure "Quota for using secondary materials"

Criterion	Evaluation	Points
Bureaucratic effort	very high, due to the fact that quotas must be fulfilled and compliance with the quotas monitored increased efforts are required all along the supply chain, purchasing practices have to be changed and producers in particular face additional bureaucracy	5
Legal aspects	a regulation on the basis of Article 23 para. 4 KrWG and on the basis of Article 23 para. 2 no. 2 is needed	3
Statistical aspects	quotas have no influence on the statistical recording of the furniture waste stream	5
Organisational effort	high, specific quotas must be negotiated for all types of furniture; this requires cooperation and agreement between manufacturers, politicians and the recycling industry	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding since implementation is based on legislation	1
Contribution to financing the recycling	does not contribute to the financing of collection and recycling, quotas for recycled matter use strengthen the demand for secondary materials which is improving the economic situation of recycling processes	3
Improvement of collection	collection of the waste stream is not influenced	3
Strengthening of recycling	quotas strengthen recycling in that they contribute to increasing secondary material use and save virgin material resources although the ecological impact also depends on the effort required for the production	3

Criterion	Evaluation	Points
	of the secondary material and the quality with which virgin material can be replaced	
Acceptance of relevant actors	producers: low (facing high additional effort and more difficulties to comply with quality requirements) consumers: mostly good (ecological awareness) but with a view on the risks of pollutant input there can be some reservations as well waste management industry: good (secure markets for secondary material sale)	3
Public information needs	requires a small amount of PR/PA work, interested consumers can be expected to exert an information effort themselves	2
Weighted result		**3.4**
Key addressees	manufacturers and manufacturers' associations, quality assurance organisations, standardisation institutes, German government, in particular ministry of environment (BMU)	
Summary	The measure generally strengthens the recycling sector. This is contrasted by major reservations regarding technical possibilities, compliance with quality requirements and the input of pollutants. Overall, differentiated specifications for secondary material use in individual types of furniture are difficult to define and implement, both technically and organisationally.	

4.4.4 Voluntary commitment by the industry for specific recycling quotas

A voluntary commitment of the industry requires manufacturers, material suppliers, the recycling industry and political bodies to come together EU-wide to set mandatory targets for the collection and recycling of different types of furniture and to determine the form of implementation. The agreement is made binding, published and compliance with the targets is regularly monitored.

Table 31 Evaluation of the measure "Voluntary commitment by the industry for specific recycling quotas"

Criterion	Evaluation	Points
Bureaucratic effort	in order to verify the achievement of the targets set by the commitment, all producers, traders and the recycling sector must centrally record the quantities put on the market and collected as well as their routes of further recovery	3
Legal aspects	needs a regulation based on Article 26 para. 1 KrWG in order to give the agreed objectives a legal framing	3
Statistical aspects	enhances the statistical recording	3
Organisational effort	high organisational effort since a coordination between all stakeholder groups is required and targets must be negotiated at the EU level, furniture manufacturers are not recyclers and can only exert limited influence on the recycling of furniture, however	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	binding as it represents a voluntary commitment made by the industry	3

Criterion	Evaluation	Points
Contribution to financing the recycling	manufacturers and retailers participate in financing recycling solutions	3
Improvement of collection	collection of the waste stream is not influenced	3
Strengthening of recycling	jointly agreed and binding recycling quotas strengthen material recycling but the effect remains limited to furniture that is not imported from other countries	3
Acceptance of relevant actors	producers: low to medium (facing a high additional effort but lower costs than EPR) consumers, retailers: mostly good (ecological awareness, green image) waste management industry: high (higher quality pathways for disposal are facilitated)	3
Public information needs	requires a medium effort for public relations, consumers need to be informed if other structures for the collection of old furniture are created	3
Weighted result		**3.3**
Key addressees	manufacturers and manufacturers' associations, retail sector, recycling industry, quality assurance organisations, standardisation institutes, ministry of environment (BMU)	
Summary	A voluntary commitment by the local industry does not constitute an effective instrument and its meaning is fading as long as is ensured that locally produced furniture is mostly of high quality, durable and spare parts are kept available. It involves the risk that the local economy is overburdened and losing in competitiveness in comparison to imported goods. In the worst case, this can have negative ecological effects. Cheap furniture with a shorter useful life is often imported and this problem can be addressed by such commitment only insufficiently.	

4.4.5 Extended producer responsibility/implementing graduated contributions

Producer responsibility enables to finance the management of used products on a consumption-based level by holding producers liable for the disposal (and the costs that incur) depending on the type and number of products put on the market, or in that the consumers pay a contribution. In order to implement extended producer responsibility, an organisational body must be created to administer these financial contributions and take care for the organisation of collection and recycling.

An example of extended producer responsibility in the furniture segment can be found in France. One advantage of such a system is that graduated levies can reward environmentally friendly and recyclable products. In addition, the levies can finance research and (pilot) projects for the recycling of individual components. In France, a total of 85% of the population agree with the environmental levy introduced under the extended producer responsibility regulation a few years ago (Eco-Mobilier, 2020). However, the system was initially criticised for making it difficult to introduce furniture from manufacturers abroad.

In order not to place an additional burden on the furniture industry due to varying regulations in different countries, a regulation at EU level (or coordinated regulations of several EU states) should be sought as a matter of priority. The secure situation for furniture disposal in Germany does not recommend to adopt a producer responsibility scheme independently of the EU at national level for the time being. An EU-wide concept would relieve manufacturers, who often sell furniture in several EU states, of the unavoidable bureaucratic burden.

Table 32 Evaluation of the measure "Extended producer responsibility/implementing graduated contributions"

Criterion	Evaluation	Points
Bureaucratic effort	very high since a regulation would have to be adopted at EU level as a matter of priority, appropriate structures would have to be created in addition	5
Legal aspects	a regulation on the basis of Article 23 (4) KrWG (or an EU-wide regulation) is needed	3
Statistical aspects	collection of statistical data on quantities is ensured due to the reporting obligations of producers and disposers in a system of extended producer responsibility	1
Organisational effort	very high, also considering the necessary co-ordination between all stakeholder groups to let this approach become acceptable; in the furniture sector there are many small and a few very large producers for whom the regulations must be equally suitable and feasible	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding as it will be imposed on the basis of a legislative act	1
Contribution to financing the recycling	finance for collection and recycling is part of an extended producer responsibility regulation and thus ensured by it, a change is effected from the predominantly flat-rate financing via basic fees (covering bulky waste disposal services) to a consumption-oriented (user) financing in the form of incorporating advanced disposal costs into the sales price	1
Improvement of collection	suitable to improve the collection of the waste stream	2
Strengthening of recycling	recycling is strengthened depending on the legally required collection and recycling quotas and the incentives actually set for sustainable product design (e.g. graduated contributions); a minimisation of pollutants through manufacturers' responsibility for recycling can be expected; the measure affects all furniture sold in Germany	1
Acceptance of relevant actors	manufacturers, retailers: low (facing high additional efforts) consumers: indifferent (as a small price increase is a likely consequence) waste management industry: high (higher quality pathways for disposal are facilitated)	3
Public information needs	medium to high efforts for public information are needed, consumers must be informed about the purpose for which an additional levy/higher price needs to be paid, what has been achieved by it and where they can hand in their used furniture in future	4
Weighted result		**2.5**
Key addressees	German government, manufacturers, retail sector, importers, consumers, recycling industry, public disposal providers	

Criterion	Evaluation	Points
Summary	A high level of effectiveness in realizing ecological, economic and statistical objectives is contrasted by high burdens for the implementation as well as the low level of acceptance among manufacturers and retail sector which also results in a long period to get the producer responsibility model up and running. Producer responsibility must be designed in such a way that the EU internal market remains undistorted.	

4.4.6 Final synopsis

The following prioritisation of the proposed measures is recommended for the next steps:

1. Negotiating design criteria.

Furniture is a waste stream characterised by a variety of materials and applications. Uniform and recycling-friendly design criteria for specific types of furniture can facilitate the dismantling of furniture and thus its recycling or repair. In view of the multiple international business relationships of the furniture industry, design criteria should be negotiated primarily at EU level. The measure serves as a basis for further actions and treating it as the first priority in terms of a sequential implementation is therefore highly recommended.

2. Adopting ecological criteria in public procurement.

With the help of negotiated ecological criteria, the public sector can serve as a role model for the procurement of recyclable furniture. As a basis for this, guidelines should be written or adapted and the information offered by the Competence Centre for Sustainable Procurement (KNB) be further expanded.

3. Implementing extended producer responsibility / graduated contributions at EU level.

Extended producer responsibility can be implemented through graduated contributions in a way that provides real incentives for recyclable design and recovery of raw materials. The advantage of producer responsibility is that not only the local industry is burdened but all furniture placed through whatever distribution channels on the market is covered from such regulation.

5 Carpets

5.1 General information

Textile floor coverings or carpet flooring are laid out by the metre or as carpet tiles over a room's entire floor surface, i.e. from wall to wall, and have a CE marking as construction products according to EU Regulation No. 305/2011 when being part of a commercial construction project. There also exist fitted carpets which are characterised by the fact that these only cover part of the floor and are sold as decorative items. Other type carpets, for example carpets used in the automotive industry, differ from carpet flooring in terms of the structural design, function and legal regulations applying and are therefore not considered as a subject in this chapter. Whereas fitted carpets are mostly imported to Germany from Asia, more than half of the carpet flooring sold within the EU is also produced in the EU, especially in Belgium and the Netherlands.

In the private sector, carpet flooring is mainly used in bedrooms and living rooms. Use of this type product is also made by the hospitality industry and in offices, mainly to serve noise reduction purposes. Textile carpet flooring accounts for about a quarter of the German floor covering market. As an alternative to textile floor coverings, wood/laminate, mineral and elastic floor coverings also have about a quarter of the market share each (GUT, 2019). Carpet flooring is for the most part replaced after a time span between 8 to 15 years, depending on the intensity of use and quality. According to AfA tables, carpets can be fully depreciated after eight years for normal qualities, and after fifteen years for the higher-quality carpet flooring (Bundesministerium der Finanzen, 2000). Carpets for trade fairs, which must be particularly robust and fire-resistant, make up a separate category within the carpet flooring segment. Often these are disposed after a single use due to the high stress they were exposed to (Bricoflor, 2018). There are also event carpets, which are as well characterised by a short service life.

Due to the interface with the building sector, Environmental Product Declarations (EPDs) according to ISO 14025 have already been prepared for some carpet flooring. In these declarations the environmental impacts throughout a building product's life cycle are specified so as to enable planners to select environmentally friendly products. Beside raw material extraction, the production, transportation and properties during use are taken into account, in addition to the recyclability or other recovery aspects.

5.2 Collection

5.2.1 Collection systems

Carpet flooring has not been allocated a separate waste code in the European Waste Catalogue. Where such products become waste during demolition or deconstruction projects these are assigned the waste code 17 09 04 (non-hazardous mixed construction and demolition waste). Carpet flooring from private or commercial sources that accumulates as waste in the residential area is usually assigned to bulky waste (20 03 07); if in case this concerns only smaller quantities or cuttings of carpet flooring and fitted carpets these are also disposed of via the residual waste services (20 03 01). Carpet manufacturers, retailers or interior decorators occasionally offer to take back used carpet flooring from customers who purchase a new carpet from their product range:

- The carpet manufacturer Interface reports that 11,000 tons of carpet were saved since 2011 through its ReEntry® take-back programme from disposal in incinerators or landfills worldwide. Among other things, the programme promotes reuse by processing and selling used carpet tiles (Interface, n.d.).

- The carpet manufacturer Tarkett collects offcuts from flooring installations and partly also used carpet tiles as part of its own take-back and recycling programme ReStart® in several countries. In the programme, installation companies can order big bags or pallets, which are then collected, sorted and in some cases sent for material recycling. Between 2017 and 2019, for example, at least 3,300 tons of various floor coverings were collected per year in America and Europe through this programme (Tarkett, 2020).

5.2.2 Collected quantities

Since carpet waste is disposed of via different routes (bulky waste, residual waste, mixed construction and demolition waste, take-back systems), the quantities can only be estimated on the basis of production volumes. Second-hand sales do not play a significant role for carpet flooring and tiles. In bulky waste, floor coverings (including carpets) have a share of 8% which corresponds to 2.7 kg/(inh*a) or approx. 225,000 tons per annum (Dornbusch, 2020).

Following a stronger decline in the sales around the turn of the millennium, the sales volume in the German carpet market has remained at roughly constant levels in recent years, with an annual growth rate of between 0.9 and 1.6% for textile floor coverings since 2016 (Branchenradar, 2017, 2018, 2020). In 2016, 176 million m^2 of carpet products were sold in Germany, of which just under half were carpet flooring (82 million m^2), about 20% were fitted carpets and runners and more than 30% were carpets in other applications, such as the automotive sector. Carpet flooring has an average mass of about 1.6 kg/m^2, with carpet tiles with more than 3.5 kg/m^2being heavier than carpet by the metre. This puts the total mass of carpet at 130,000-140,000 tons per year plus approx. 72,000 tons per annum for fitted carpets. EU-wide, approx. 1.4 million tons of carpets were sold in 2018 (ECRA, 2021).

5.3 Recovery of carpets

In this chapter, priority is given to the recycling of carpet flooring and carpet flooring material, as more experience in recycling is available for this product segment and it accounts for the majority of the generated waste.

5.3.1 Composition

Carpet flooring usually consists of three layers, that is the so called wearing surface or top layer, (carpet fibre or pile layer), the middle/intermediate/support layer and a backing layer. Depending on the manufacturing technique, intended application and quality, different materials are combined in carpets. The individual layers are woven, knotted, glued or rubberised together. Most of the carpets used today are tufted. Tufting is a manufacturing process in which yarns are looped into a fabric. Needle-punched carpets only account for just under a quarter of the carpet market in Germany and woven carpets only play a minor role.

Taking the European-wide average for carpet flooring as the basis, the share fibre take on the wear layer is 33% and 12% of the total mass respectively in the carpet backing (mainly PET and PP) whilst backing materials make up 55% of the total mass. Carpet tiles account for the smaller share compared to carpet by the metre (ECRA, 2021). Table 33 is showing the shares of fibre materials used in carpet products in Germany and in Europe as a whole.

Table 33 Fibre materials in carpet products – input in the production in Germany and the EU

Fibre materials	Mass input in Germany (Data for 2016) [kt]	Share in the total carpet material in Germany (Data for 2016) [mass-%]	Total mass input in the EU (Data for 2018) [kt]
PA 6	7.6	5.8	49
PP	22.5	17.2	107
PA 6.6	5.0	3.8	39
PET	0.4	0.4	n.a.
Wool	8	6.1	5
Natural fibres	n.a.	n.a.	9
Other materials	n.a.	n.a.	29
Sum carpet fibres	**43.6**	**33.3**	**238**
Sum polymer fibres	**35.6**	**27.2**	**224**

Source: ECRA, 2021 and GUT, 2019

The carpet backing is responsible for the stability of the carpets, therefore fillers are often used to create a certain weight. Sometimes the carpet backing must be firmly attached to the floor surface by bonding with an adhesive that can stick to the carpet backing also after the usage phase. Table 34 lists carpet backing and filler materials with their respective shares in the EU.

Table 34 Carpet backing and filler materials

Materials	Mass input in the EU [kt]	Share in the total material [mass-%]
PP	88	7
PET	99	8
PUR	7	< 1
Latex/SBR	237	19
PVC	28	2
Bitumen	58	5
Fillers (e.g. $CaCO_3$)	433	35
Aluminium hydroxide $Al(OH)_3$	210	17
Glass fibres	5	< 1
Other materials	67	5

Source: Onyshko and Hewlett, 2018

5.3.2 Routes of recovery

In Germany, waste carpet is mainly utilized for energy recovery. On the other hand, 60% of old carpets are still landfilled within the borders of the EU. Especially for carpet tiles a reuse can be realized as long as these are not bonded to the floor during installation. Ideally, the carpet tiles then can be removed and reused whole which also works as for use these must be less fixed in fit than cut-to-size carpet from the roll.

It is estimated that less than 3% of carpet sold in the EU is recycled (Changing Markets Foundation, 2018). In the UK, in particular, some waste carpet is recycled as riding arena surfacing. This involves shredding the carpets, extracting microfibres produced during the shredding process and coating the carpet chips with wax to extend their usable life time. The pre-treated carpet chips are then often applied outdoors on a backing designed to, among other things, retain the fibres (Changing Markets Foundation, 2019). This form of recycling can be part of a cascading use but cannot be considered a high-quality material recycling process. There is also a risk of plastics or pollutants, such as flame retardants, being released into the environment during this type of secondary application.

5.3.2.1 Recycling options for carpet materials

It is crucial for the recycling of carpet materials that the individual materials can be separated from each other after shredding. This is often technically challenging due to the strongly glued or interwoven structure. The possibilities range from shearing off the fibres of tufted carpets, whereby a certain loss of fibre material must be expected, to dissolving the adhesives by means of chemical processes. A further option are mechanical processes that work with impact mills or hammer mills.

Efforts to recycle carpet materials often focus on the recovery of fibre materials, since high-quality polymers are usually used here and the recycling of many plastics is technically possible. On the one hand, the recovered fibres can be spun into new fibres or materially recycled into pellets even though a decreasing material quality throughout a carpet's usage time must be considered and the colouring of the recycled fibres is limited. In addition, pollutants used in the past could be transferred to new products also. On the other hand, chemical recycling processes have been already and are still developed for carpet recycling purposes. The most advantageous are depolymerisation processes in which the respective monomers are recovered for the production of a new plastic. However, such a process is not possible for all plastics and is often energy-intensive. Furthermore, there are various processes for recovering basic chemicals from used plastics, which, after processing, can serve as feedstock for the chemical industry. An overview of the possible recycling processes for various carpet materials can be obtained from the information in Table 35 and Table 36 respectively.

The closed-loop recycling of natural fibre materials is largely impossible given the poor quality that these fibres show after a normal usage time. At most a further phase of use as an insulation material or for similar applications is conceivable.

Due to the multi-layered structure of carpet backing, recycling processes for carpet backing materials are very challenging and there exist hardly any examples for this in practice. In addition, the fibres are often fixed to the carpet backing with the help of latex, a material for which no recycling processes are as yet available and which is making a separation and thus the recycling of the other materials more difficult. Fibre blends of polypropylene and polyamide also cannot be separated during recycling (Onyshko and Hewlett, 2018).

Table 35 Recycling options for carpet fibres

Fibre material	Recycling practiced	Chemical recycling possible	Utilisation after mechanical processing
Polyamide 6 (PA 6)	Yes	Depolymerisation feasible	Plastics downcycling
Polyamide 6.6 (PA 6.6)	Yes	Depolymerisation feasible but technically challenging	Plastics downcycling
Polyester (PET)	Yes	Depolymerisation feasible but energy-intensive	Carpet backing, Plastics downcycling
Polypropylene (PP)	Yes	Recovery of basic chemicals	Carpet backing, Plastics downcycling
Wool	No	No	Insulating material, Padding
Jute	No	No	Insulating material, Carpet backing

Source: DUH, 2017 and ECRA, 2021

Table 36 Recycling options for carpet fillers and backing materials

Fibre material	Recycling practiced	Utilisation in other applications
Polyester (PET)	Yes	Carpet backing, Plastics downcycling
Polypropylene (PP)	No	Engineering plastics
Jute	No	Insulating material
Latex	No	-
Chalk	Yes	Cement, Plastics downcycling
Bitumen	Yes	Asphalt, Plastics downcycling

Source: DUH, 2017

Across Europe, polypropylene is the most commonly used feedstock for fibre material. In Germany, the high-quality and recyclable plastics PA 6 and PA 6.6 are used somewhat more frequently for fibres than this happens on average in the EU. However, when depolymerisation processes are going to be used for recycling, it must be taken into account that PA 6 and PA 6.6, although being physically and chemically similar plastics, cannot be recycled together due to their different monomers. To detect and separate the two plastics during sorting is however technically difficult, especially if they have been used together as fibre material within a carpet. Therefore, the carpet industry is currently working on switching from PA 6.6 to PA 6 (ECRA, 2021).

Labelling of the carpet materials used, the type of carpet and possibly even the feasible recycling processes can facilitate the sorting and further recovery of carpet materials at the end of their useful life. In a cooperation of the Gemeinschaft umweltfreundlicher Teppichboden e.V. (GUT) and the European Carpet and Rug Association (ECRA) that is representing 85% of European carpet production, the product information system "PRODIS" was developed. In the course of the licensing procedure of carpets by GUT (GUT-PRODIS-Label), data on the respective carpet is stored in a database. By entering a license code, every retailer or consumer can retrieve information on properties, chemicals used, material composition and from the environmental product declarations (GUT, n.d.). Currently, about 4,500 carpets are stored in the PRODIS system. Definitions for 'recycled' and 'recyclable content' are currently being developed so that the database can also be expanded to include recycling strategies in the future. The decisive factor in future will be whether the code is also available after the service life for a possible recycler to retrieve information on the material composition and the recycling options.

5.3.2.2 Attempted carpet recycling in Germany – the Polyamid 2000 case

There has so far only been one large-scale attempt to recycle waste carpets in Germany. In 1999, the Polyamid 2000 AG in Premnitz (Brandenburg) errected a carpet recycling facility with a capacity for 120,000 tons of old carpets per year. The facility went into insolvency already in 2003, however. Since no new investor could be found for the facility, it has no longer been used for recycling carpets. The process carried out for a few years in Premnitz concentrated on carpets with PA 6 fibres. In an automatic sorting process using near-infrared spectroscopy, carpets made of other materials were initially sorted out and sent for energy recovery while carpets with PA 6.6 fibres were sorted out and granulated. From the recyclable carpets, the chalk was first recovered for further recovery in cement works or brickworks. After shredding, the PA 6 fibres were depolymerised and purified by means of distillation and falling film crystallisation. In this way, the starting material Caprolactam could be recovered for the renewed polymerisation of PA 6 in the chemical industry (Nikzad, 2000). The insolvency was triggered, on the one hand, by shortcomings of the process itself, and on the other hand by a lacking availability of suitable old carpets. The facility was designed for much larger quantities of carpet than what could actually be acquired, moreover, the identification of the carpets during material sorting caused problems. The separation of the different layers from each other, the removal of adhesives and separation of fibres also did not work smoothly (Wermter et al., 2017).

From 1995 up until 1999, the EU-funded project RECAM developed ecologically sustainable and long-term cost-effective recycling processes for waste carpet material. The project researched solutions for waste collection and logistics, moreover suitable technologies for labelling, sorting, cleaning, shredding, separating and purifying the material components, and for recycling (CORDIS, n.d.). Following the insolvency of the Polyamid 2000 AG the results of the project are no longer used in Germany, however.

5.3.2.3 International look on current recycling concepts

A few carpet manufacturers have already addressed carpet recycling and recycling-friendly design. The carpet manufacturer Interface promotes material recycling alongside reuse with its ReEntry® take-back programme. Suitable carpets are separated into their main components and used as raw material for new products. The rest of the collected old carpets is forwarded to thermal recovery (Interface, n.d.).

Carpet manufacturer Tarkett, with its Desso brand, has developed a backing made of polyolefins and lime that, unlike conventional carpet backing, is 100% recyclable and uses recycled materials, albeit these are not from the carpet industry. In 2019, the Carpet Recycling Centre was opened in the Netherlands. At this facility, PA 6 yarn is separated from the carpet backing, processed in collaboration with fibre manufacturer Aquafil into recycled yarn which is then used in the production of carpet. The recycled content of post-consumer material for own brand carpets ranges between 0 and 10% (Tarkett, 2020).

The fibre manufacturer Aquafil S.p.A. has developed the PA fibre Econyl®, a recycled fibre made from post-consumer and production waste. Among other things, fishing nets, textiles or shorn carpet pile are used for production. Depolymerisation and purification processes yield the monomer caprolactam which has the same properties as caprolactam from fossil raw materials and can be polymerised into new polyamide. The recycled yarn Econyl® is already used by a number of carpet manufacturers (Econyl, n.d.).

A subsidiary firm of the Royal DSM N.V., DSM-Niaga, (both Netherlands) has developed the Niaga® technology, an easy-to-separate connection of carpet fibres with the middle or backing layer. This feature is believed to enable the recycling of carpets. The technology is now used by several manufacturers (DSM-NIAGA, n.d.). The Dutch manufacturer Donkersloot, for example, claims to be selling a carpet made of recycled materials that can be 100% recycled a number of times. In addition to the Niaga® technology, the carpet consists of PA 6 fibres and recycled PET felt as a backing material (Donkersloot, n.d.). BASF also has worked with DSM to develop a recyclable carpet made from pyrolysis oil from chemically recycled plastics (BASF, 2019).

The British carpet manufacturer Reeds Carpets, known for offering carpet flooring in the event sector that is often short-lived, has developed a recyclable carpet with its EVO assortment. Both the fibre material and the backing material of the carpet are made of PP. The EVO carpets are taken back by the manufacturer after use and can be processed into pellets which are then sold (Reeds, n.d.).

In California (USA), some new approaches to carpet recycling are currently being implemented. In the course of the extended producer responsibility for carpets introduced by law in 2010, old carpets are now collected separately. In 2015, 10% of these carpets were recycled. The company Circular PolymersTM for this purpose operates a carpet recycling facility in Lincoln where a rotary impact separator is used to separate the carpet fibres from the backing. These are sold to the chemical industry then (Circular Polymers, n.d.). In 2019, the international corporation Eastman announced that it would recycle processed PET carpet material from Circular Polymers in its own chemical recycling facility and use it to produce new plastic parts (Eastman, 2019).

In Ohio (USA), PureCycle Technologies LLC is currently building a facility to recover transparent and ultra-pure PP from Circular Polymers' purified carpet waste and other waste streams using a recycling technology from Procter&Gamble. The facility is scheduled to enter into operation in 2021. At the same time, PureCycle is already starting the site selection process for another facility in Europe (PureCycle, 2019; PureCycle, 2020).

5.3.2.4 Obstacles to material recycling

Obstacles to recycling are mainly the low-quality and/or mixed materials of the individual carpet layers, which can be separated from each other with great effort only. Carpets are designed to withstand years of stress and the components are hence firmly attached or glued together. Implementing recycling-friendly designs would only become relevant for the circular economy after more than a decade due to the long service life of carpet flooring.

Another problem is caused by the widespread absence of markets for the secondary raw materials obtained from the recycling operations. When disposing of carpets, it is often not known what materials the carpet is made of, and so a quite thorough manual or automated sorting would first have to be carried out for recycling. Due to the long service life of old carpets, high levels of soiling can be assumed. In addition, when collected with other waste, for example as part of bulky waste or mixed construction waste, various types contamination that restrict the recycling in further ways can occur.

Pollutant concentrations in carpets are another subject of concern. In order to get the desired product properties, various dyes, plasticisers, biocides, flame retardants and other additives are introduced in carpet production. In addition, source materials from polymer synthesis or process chemicals have already been detected in selected carpet products. In 2018, a study commissioned by the Changing Markets Foundation revealed that some carpets produced in the

EU contain chemicals that are suspected or proven to be endocrine disruptors, carcinogens or fertility impairers. Some of the analysed samples also contained recycled materials such as PVC or polyamide fibres. However, not all tested carpets containing recycled materials were also found to contain harmful substances. This means that it is possible to produce contaminant-free carpet from recycled materials (Onyshko and Hewlett, 2018; Changing Markets Foundation, 2018). Hazardous substance assessment and regulation in the EU is constantly being reviewed and expanded under the REACH Regulation in light of new scientific evidence. Nevertheless, pollutant concentrations in old carpets are a barrier to recycling since these could be carried over into new products during recycling. Here, labelling of the chemicals used plays a decisive role in order to be able to reliably recycle carpet in the future and exclude products contaminated with pollutants from recycling. In addition, reliable labelling has the advantage that consumers can make conscious decisions for ecologically sound products (Zimmermann et al., 2019). Certain labels for carpets (Blue Angel, GUT) already include stricter requirements for the exclusion of harmful substances in their criteria, but seeking such a certification has remained voluntary so far.

5.3.2.5 Recycling-friendly carpet design

In order to come to a recyclable and environmentally sound carpet design, attention must be paid on the following issues:

- Only a single type material should be used per carpet layer and mixed fibres should be avoided.
- Recyclable materials should be used as a priority, for example polyester or polyamide.
- For bonding carpet backing and wear layer only adhesives of a kind which allow separation at the end of the service life should be used.
- Carpet flooring should not be glued to the floor over the entire surface or removable adhesives should be used during installation. For this purpose, DIN VOB 18365 on floor covering works which stipulates full-surface bonding in Part C, must be reviewed and adapted so that installation work that is more recycling-friendly can also be accepted.
- The use of recycled products from the carpet industry or from other industries should be intensified in the production of carpets.
- Increasing the use of carpet tiles instead of products by the metre facilitates reuse and necessary repairs in that single tiles can be replaced.

A label attached to the carpet with information on the materials used will help to alleviate sorting in the recycling operations. With a reference or link to a well-maintained database attached to the carpet, access to information on the structure, recycling options and available treatment options can be provided in addition to those on the used materials. The GUT and ECRA database presented in chapter 5.3.2.1 contains data that is helpful for recycling. However, participation is linked to a GUT license, resulting in that not all carpet products are stored at the moment in the database. In addition, attaching a label to carpets in a way that it is still available and intact after the products useful life is a big challenge. A code on a carpet's underneath is often no longer legible after the installation with full-surface bonding, the long service life or once the carpet is cut to pieces. Identification helped by RFID chips that are regularly incorporated in the carpet is a technically feasible but cost-intensive option in relation to the benefits this can provide. Consequently, a need for discussion and research is still seen here as to whether and in what form labelling makes sense for the recycling of carpets.

5.3.3 Environmental potential and expenditures

Derived from life cycle assessments and environmental product declarations (EPDs), the European Carpet and Rug Association (ECRA) indicates an environmental relief of 6.5 kg $CO_{2\text{-eq}}$ per kilogram of yarn for the chemical recycling of PA 6, as virgin material can be replaced through recycling. With an annual consumption of 49,000 tons of PA 6 yarn in tufted carpets and an assumed rate of 70% material recycling, 223,000 tons $CO_{2\text{-eq}}$ could be saved per year across Europe. Thus, the recycling of PA 6 in particular offers great ecological advantages compared to virgin material. For mechanical recycling of PP fibres, the environmental relief potential is 0.9 kg $CO_{2\text{-eq}}$ per kilogram of yarn, or 48,000 tons $CO_{2\text{-eq}}$ per year across Europe, assuming an annual consumption of 107,000 tons and a material recycling rate of 50% (ECRA, 2021).

In a Californian study, a saving potential for greenhouse gas emissions was also calculated for the recycling of carpets with PA fibres. For energy recovery, a global warming potential of more than 1 kg $CO_{2\text{-eq}}$ per kilogram carpet waste was calculated and for recycling a negative global warming potential of about -2.6 kg $CO_{2\text{-eq}}$ per kilogram carpet waste. The figures also include greenhouse gas emissions from collection and transport. According to this study, in addition to increased recycling, the greatest savings in greenhouse gas emissions can be achieved by extending the useful life, for example by applying a modular design (Horvath and Masanet, 2012). An estimate made for Germany suggests that 3% of the floor covering found in bulky waste could be reused (Dornbusch et al., 2020). Increased use of carpet tiles can furthermore extend an entire carpet’s lifetime, as individual tiles can be replaced. Such practice also facilitates reuse considering that with off-the-roll floor coverings the fit often prevents the reuse option. Carpet flooring can be cleaned, dyed and trimmed before resale but must be reclaimed, collected and transported undamaged and free of any contamination for reuse.

Despite all good reasons for recycling carpets this practice currently still poses an exception. Mainly this is attributable to the recycling costs that exceed the value of the recovered materials. In addition to the process, high-quality collection structures would have to be developed to ensure that a large portion of carpets are not mixed and contaminated with other substances in construction waste or bulky waste, residual and commercial waste. The establishment of separate collection points and the necessary logistics incur costs which in the current situation are in no good correlation with the recyclability and material value of carpets (resulting from carpet design and raw material availability).

5.3.4 Evaluation and conclusions

Although recycling is an issue in the carpet industry and a subject research and associations deal with frequently, just a few approaches of that sort are currently pursued from individual manufacturers while only a fraction of old carpets is actually recycled.

Carpet products for the time being are mostly a material mix with firmly bonded carpet backings, inseparable adhesive bonds or mixed fibre materials, making it difficult to impossible to separate individual materials for recycling on a large scale. Furthermore, harmful substances have been detected in some carpets. If products containing harmful substances are recycled, there is a risk that the harmful substances will be transferred to new products and become a danger for consumers. The carpet industry as a consequence has started to implement less difficult materials (e.g. PA 6 and PA 6.6) and designs that allow for a separation.

The recycling processes developed so far mostly include sorting by carpet type, mechanical or chemical separation of carpet backing and fibres and the recycling of individual materials (PA 6, PET, chalk and backing layer). Natural fibres used in carpets have short fibre lengths at the end of the carpet’s usage phase, a fibre-based recycling is hence difficult or no longer possible.

Synthetic fibres can theoretically be recycled if they are sorted by type. However, due to the different colouring, soiling and wear of the polymers, a low-quality recyclate can be produced only from old carpets, which cannot be used for the production of new fibres. Chemical recycling processes for the recovery of basic chemicals or monomers (e.g. PA 6 or PET) also exist as a useful option for carpet materials. However, monomers cannot be recovered from all types of plastic, or the quantities of some types of plastic are too small to be able to utilise recycling facilities to full capacity. With the different carpet types and materials used by the carpet industry, bundling the necessary quantity for efficient material separation becomes even more difficult. One approach to solving this is the development of material-specific, but cross-industry and cross-national disposal and recycling paths, so that the recovery of raw materials can take place in so-called polymer pools.

Material recycling of carpets on a large scale is neither in the short nor medium term a feasible option in Germany, mainly as a consequence of the properties of waste carpets (e.g. non-recyclable design, degree of soiling and wear) but also the lack of an adequate (separate and uniform) system for collection. Creating the basis for a possible material recycling can be promoted by an appropriate set of measures, some of the most promising are outlined hereafter.

5.4 Proposed measures

In the following, various measures for improving the recycling of carpets are described and evaluated according to the criteria mentioned in chapter 1.3.1.

5.4.1 Ecological criteria in public procurement

The public sector due to its large contract volume has a crucial role to play in setting the demand for recyclable and ecologically sound carpet flooring, thus creating incentives for the development and implementation of closed loops in this product segment. In practice, however, the recycling issue of carpet is widely neglected in this sphere. For example, the guideline issued by the German Environment Agency for the environmentally friendly public procurement of textile floor coverings hardly mentions any criteria for the recycling of such products after their useful life (Umweltbundesamt, 2020). Appropriate criteria should be added here to support implementation in practice.

Furthermore, specifications and certifications in the building sector can also address the carpet segment and thus create demand for environmentally friendly carpets.

Table 37 Evaluation of the measure "Ecological criteria in public procurement"

Criterion	Evaluation	Points
Bureaucratic effort	medium effort, procurement practice must be adapted	3
Legal aspects	public authorities under Article 45 (2) KrWG (federal authorities) or stipulations in the State Waste Acts are obliged to give preference to products that are, for example, made from recycled materials or are characterised by their recyclability, further requirements can be specified with the help of administrative regulations	2
Statistical aspects	ecological criteria do not influence the statistical recording of the furniture waste stream	5
Organisational effort	procurement practice must be adapted, this requires practical templates, performance sheets, suitable quality marks/labels and a supplement to the	3

Criterion	Evaluation	Points
	German Environment Agency's guidelines on environmentally friendly procurement	
Implementation timeline	medium-term (3-5 years)	3
Binding character	binding as the legal basis already exists	2
Contribution to financing the recycling	ecological criteria support recycling, for example, not using harmful substances and easier separation of product components very likely reduce the reprocessing costs	4
Improvement of collection	collection of the waste stream is not influenced	3
Strengthening of recycling	The public sector as Germany's largest owner of buildings has a major influence on the market. This strengthens the demand for recyclable products and can also have effects in other areas through an increase in the supply of corresponding products. Nevertheless, the measure does not have a strong influence on the products actually being recycled at the end of their useful life.	4
Acceptance of relevant actors	individual reservations may exist in view of additional efforts, a smaller range of choices or requirements that are difficult to fulfill	2
Public information needs	*not relevant, public relations work nevertheless can be useful to increase green procurement in the private sector as well*	
Weighted result		**3.0**
Key addressees	authorities, advisory institutions incl. German Environment Agency, manufacturers, retailers, quality assurance and licensor organisations (Blue Angel, GUT etc.) Competence Centre for Sustainable Procurement (KNB)	
Summary	Ecological or recycling-friendly criteria in public procurement are already prescribed by law but clearly defined criteria, suitable offers and concrete support for effective larger-scale implementation in practice are often lacking. Earlier measures, such as guidelines and the establishment of the Competence Centre for Sustainable Procurement (KNB) and its information offers can be further expanded.	

5.4.2 Negotiate and standardise design criteria, possibly including labelling

Taking the duration of usage into account, a design that is suitable for recycling only becomes relevant for managing products at the end of their useful life ten to twenty years after its introduction. This underlines the importance that the requisites for recycling are to be created early in the product life cycle during design.

In cooperation with all carpet manufacturers and the recycling industry (e.g. facility operators), basic design criteria that enable recycling thus should be quickly developed and agreed. To follow up on this, a revision of the relevant standards should be expedited (including, among others, DIN EN 1307, DIN 18365 (full-surface bonding)).

Certification and marking of carpets by means of seals or labels is less suitable for increasing the demand for recyclable products in the case of durable products such as carpets. Certification plays a greater role in the selection of high-quality and low-pollutant products. Suitable seals for carpet flooring and fitted carpets already exist for this purpose (e.g. Blue Angel, GUT, TÜV, Oeko-Tex Standard).

Given the difficulties in sorting carpets, material marking and labelling of disposal options are measures to be discussed when defining design criteria. The GUT and ECRA database presented in chapter 5.3.2.1 contains information that is helpful for material recycling. However, participation is linked to GUT licensing and not all carpet products are therefore entered in the database yet. In addition, marking new carpets in a way that the respective labels are still present and intact at the end of the usage phase is a challenge. A code on a carpet's underneath is often no longer readable after the installation with full-surface bonding, the long service life or once the carpet is cut to pieces. Identification helped by RFID chips that are regularly incorporated in the carpet is a technically feasible but cost-intensive option in relation to the benefits this can provide.

Table 38 Evaluation of the measure "Negotiating and standardizing design criteria, possibly including labelling"

Criterion	Evaluation	Points
Bureaucratic effort	low; somewhat higher effort is required to create database for the labelling of materials	1
Legal aspects	there are no legal aspects to consider as long as design criteria do not have to be applied on a mandatory basis	1
Statistical aspects	design criteria have no influence on the statistical recording	5
Organisational effort	specific criteria have to be negotiated which is requiring cooperation and agreement between manufacturers, standardisation and labelling organisations, politics and the recycling industry	4
Implementation timeline	medium-term (3-5 years)	3
Binding character	non-binding	5
Contribution to financing the recycling	no influence on the financing of recycling, however, the costs for high-quality recycling can decrease if a large part of the carpets consists of recyclable materials and the separability of the individual materials from each other is ensured	4
Improvement of collection	no impact on the collection of the waste stream	3
Strengthening of recycling	leads to improved conditions for recycling through the use of recyclable materials and by making the separation of individual materials from each other easier	2
Acceptance of relevant actors	producers: low (facing high additional efforts) consumers, retail: mostly high (ecological awareness, green image) waste management industry: high (higher quality pathways for disposal are facilitated)	2
Public information needs	requires a small amount of PR/PA work, interested consumers can be expected to exert an information effort themselves	1
Weighted result		**2.7**
Key addressees	manufacturers and manufacturers' associations, recycling industry, quality assurance organisations (e.g. GUT), standardisation institutes, politics/ministry of environment (BMU)	

Criterion	Evaluation	Points
Summary	Criteria for recycling-friendly design improve cooperation between manufacturers and recyclers and promote further technical development. Although this measure alone has little effect, it is useful as a basis for further measures and supports manufacturers who have already addressed recycling-friendly design in their efforts.	

5.4.3 Quota for using secondary materials

Environmental relief can also be attained through the increased use of recycled materials in the production of carpet. The recycling of post-consumer and industrial waste from carpets as well as from other product segments can be promoted this way, for example, by pressing soft foams into carpet backing, processing fishing nets into carpet yarns or using textile waste for the production of needle felt carpets.

Table 39 Evaluation of the measure "Quota for using secondary materials"

Criterion	Evaluation	Points
Bureaucratic effort	very high, due to the fact that quotas must be fulfilled and compliance with the quotas monitored increased efforts are required all along the supply chain, purchasing practices have to be changed and producers in particular face additional bureaucracy	5
Legal aspects	a regulation on the basis of Article 23 para. 4 KrWG and on the basis of Article 23 para. 2 no. 2 is needed	3
Statistical aspects	quotas have no influence on the statistical recording of waste carpet	5
Organisational effort	high, specific quotas must be negotiated which is requiring the cooperation and agreement between manufacturers, politicians and the recycling industry	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding since implementation is based on legislation	1
Contribution to financing the recycling	does not contribute to the financing of collection and recycling, quotas for recycled matter use strengthen the demand for secondary materials which is improving the economic situation of recycling processes	3
Improvement of collection	collection of the waste stream is not influenced	3
Strengthening of recycling	quotas strengthen recycling in that they contribute to increasing secondary material use and save virgin material resources although the ecological impact also depends on the effort required for the production of the secondary material and the quality with which virgin material can be replaced	2
Acceptance of relevant actors	producers: low (facing high additional effort and more difficulties to comply with quality requirements) consumers: mostly good (ecological awareness) but with a view on the risks of pollutant input there can be some reservations as well waste management industry: good (secure markets for secondary material sale)	3

Criterion	Evaluation	Points
Public information needs	requires a small amount of PR/PA work, interested consumers can be expected to exert an information effort themselves	2
Weighted result		**3.2**
Key addressees	manufacturers and manufacturers' associations, quality assurance organisations, standardisation institutes, German government, in particular ministry of environment (BMU)	
Summary	The measure generally strengthens the recycling sector. This is contrasted by major reservations regarding technical possibilities, compliance with quality requirements and the input of pollutants.	

5.4.4 Extended producer responsibility/implementing graduated contributions

Extended producer responsibility sets incentives for recyclable design and could finance the separate collection and recycling of carpets. In order to determine the design of a producer responsibility scheme, public authorities and the chemical industry must be involved in addition to the manufacturers. Due to the long useful life of carpets, a lead time of at least ten years should be planned to allow manufacturers to take appropriate measures in the product design. Graduated contributions or product levies also make sense in the carpet segment in that manufacturers who engage in design for recycling and promote recycled material use in the production get an incentive and rewarded by this concept. As the carpet industry is mainly located in other European countries, an implementation at EU level should be sought.

However, when considering extended producer responsibility for carpets, it must be examined whether other floor coverings that compete with carpets should also be included. After all, other floor covering is usually recycled just as rarely and most of the elastic floor coverings are made from fossil raw materials. Furthermore, it makes sense to get a joint collection system established that includes all types floor covering.

Table 40 Evaluation of the measure "Extended producer responsibility/implementing graduated contributions"

Criterion	Evaluation	Points
Bureaucratic effort	very high since necessary structures have to be created first	4
Legal aspects	a regulation on the basis of Article 23 (4) KrWG (or an EU-wide regulation) is needed	3
Statistical aspects	collection of statistical data on quantities is ensured due to the reporting obligations of producers and disposers in a system of extended producer responsibility	1
Organisational effort	very high, also considering the necessary co-ordination between all stakeholder groups to let this approach become acceptable	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding as it will be imposed on the basis of a legislative act	1
Contribution to financing the recycling	finance for collection and recycling is part of an extended producer responsibility regulation and thus ensured by it, adding the disposal costs	1

Criterion	Evaluation	Points
	to the product price results in a financing based on the polluter-pays principle	
Improvement of collection	the collection of waste carpet is improved	1
Strengthening of recycling	recycling is strengthened depending on the legally required collection and recycling quotas and the incentives actually set for sustainable product design (e.g. graduated contributions); a minimisation of pollutants through manufacturers' responsibility for recycling can be expected; the measure affects all carpet sold in Germany.	1
Acceptance of relevant actors	manufacturers, retailers: low (facing high additional efforts) consumers: indifferent (as a small price increase is a likely consequence) waste management industry: high (higher quality pathways for disposal are facilitated)	3
Public information needs	medium to high efforts for public information are needed, consumers must be informed about the purpose for which an additional levy/higher price needs to be paid, what has been achieved by it and where they can hand in their used carpets in future	4
Weighted result		**2.4**
Key addressees	German government, manufacturers, retail sector, importers, consumers, recycling industry, public disposal providers	
Summary	The measure provides funding for the collection, sorting and recycling of carpet products. A high level of effectiveness in realizing ecological, economic and statistical objectives is contrasted by high burdens for the implementation as well as the low level of acceptance among manufacturers and retail sector which in turn results in a long period to get the producer responsibility model up and running. Producer responsibility must be designed in such a way that the EU internal market remains undistorted.	

5.4.5 Final synopsis

The following prioritisation of the proposed measures is recommended for the next steps:

1. Negotiating design criteria.

The main focus for carpet flooring and other carpet products is to be directed on the development of recyclable designs and their widespread implementation. This requires cooperation between all stakeholders and incentives that ensure the competitiveness of recyclable products. This can be done, on the one hand, by transferring the design criteria into well-known and accepted labels and on the other hand by revising industry-relevant standards.

2. Adopting ecological criteria in public procurement.

Especially in the case of carpets, the public sector is able to provide incentives for investment in recyclable designs by specifying recycling criteria in procurement procedures.

3. Implementing extended producer responsibility.

Even if extended producer responsibility scores best in the evaluation of different promising measures, it is recommended to first develop the technical basis for carpet recycling and to support the relevant objectives and initiatives that exist in this industry segment to date before tackling carpet collection and the financing of recycling with a mandatory producer responsibility. When discussing the introduction of such instrument, it must also be clarified in cooperation with the industry which is the most effective and sensible framework for implementation. Among others this must include the question, whether carpet flooring and fitted carpets or carpets in other applications are to be considered together or all floor coverings used in the building sector shall be covered, for example.

6 Artificial turf

6.1 General information

Artificial turf is a special synthetic carpet that is similar in appearance and/or function to natural grass. The structure with several layers is similar to that of a normal carpet. Special features result from the addition of sand or granules to improve the playability of artificial turf as a sports surface.

There are also different variants of hybrid turf, in which artificial fibres are incorporated into natural grass, either as individual fibres or as a loose, open carpet. The artificial turf fibres are supposed to serve as protection and stabiliser for the grass facilities (Artificialgrass, n.d.). However, this is more of a niche product (Dufft, 2020).

6.1.1 Types and structure of artificial turf

Artificial turf consists of a synthetic carrier fabric onto which synthetic fibres are tufted in small tufts. To fix the tufts of grass, the underside of the backing fabric is coated with latex or PU. The turf fibres are usually made of PE, the backing fabric of PP (Eunomia, 2017).

The turf fibres can be coloured as desired. To match the look of a natural lawn, fibres in different shades of green and different lengths are combined in a tuft. For functional and visual reasons, both smooth and textured fibres are used.

Artificial turf that is to be used in the sports sector in Germany must comply with DIN EN 15330-1 and DIN 18035-7. Furthermore, there is the quality label RAL-GZ 944 - Synthetic turf systems in outdoor sports facilities (RAL GGK, 2018). The RAL-GZ 944 consists of five modules for the quality assurance of individual components, the overall system and for system installation and maintenance of artificial turf.

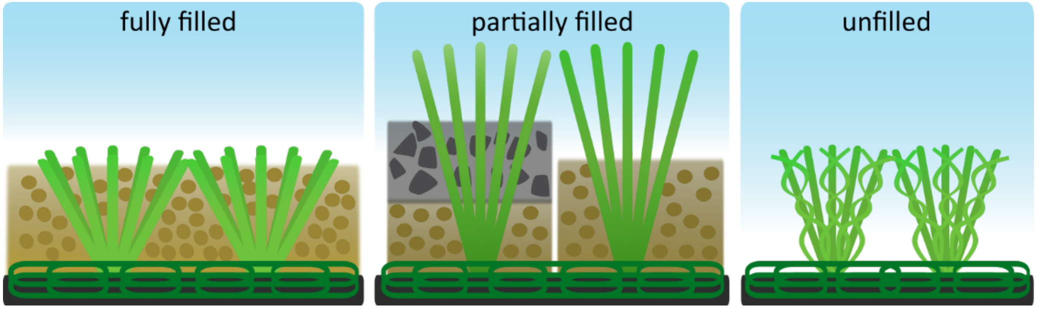
DIN 18035-7 stipulates that a 3.5 cm thick elastic base layer made of bonded rubber granulate must be installed as the top layer in sports field construction. This cushions the impact of falls and reduces the risk of injury. The artificial turf is later laid on top of this layer. The elastic base layer is designed to last twice as long as the artificial turf and is usually only repaired when the artificial turf is renovated (Labor Lehmacher, n.d.). It is therefore not part of the artificial turf waste stream under consideration.

Artificial turf is divided into fully filled, partially filled and unfilled systems (see Figure 10). Unfilled artificial turf systems consist only of the turf carpet and the elastic base layer. The artificial turf is tufted more densely and smooth fibres are combined with textured ones to increase their stability. The pile height is lower than in infilled systems (DFB, 2017).

Fully filled systems are only filled with quartz sand up to just below the tips of the turf. Here, the turf carpet serves primarily to stabilise the sand.

In partially filled systems, a layer of quartz sand is first placed in the turf. This stabilises the turf and weighs down the carpet so that it cannot slip. At the same time, the sand also serves as fire protection (DFB, 2017). A layer of elastic granulate can also be placed on top of the sand. Like the elastic base layer, the granulate serves to absorb shock and prevent abrasions and other injuries (DFB, 2017). The grain size of the granulate must be between 0.5 and 4.0 mm for sports field construction (DIN 18035-7).

Figure 10 Artificial turf systems with different infill levels



Source: Graphic of INTECUS

A range of synthetic and natural granulates are offered, although so far almost exclusively synthetic granulates have been used. The most important materials here are rubber granulates from end-of-life tyre recycling, usually referred to as SBR, and virgin materials made from plastics such as EPDM and TPE. SBR granulates are also offered with a PU coating. Among facility granulates, cork is currently the most important material. In addition, products made of coconut, hemp or olive kernels are offered (DFB, 2017). Table 41 presents the most common materials with their bulk density. While the synthetic granulates are all in a relatively similar range, the bulk density of cork is significantly lower at a maximum of 200 kg/m^3 and thus the quantity required per field is lower as well.

Table 41 Density of the different infill materials

Material	Bulk density (kg/m³)	Sources
SBR (from end-of-life tyres)	395-465	Genan GmbH, 2017
EPDM	450-650	Johansson, 2018
TPE	550-850	Johansson, 2018
Cork - expanded	70-80	Johansson, 2018
Cork - natural	100-200	RAL GGK, 2018

The service life of artificial turf depends on the intensity of use and the resulting wear and tear, as well as on the financial resources of the field owners. In the case of intensive use, a service life of 8 years is assumed. On average, the service life is between 10-12 years. The maximum lifespan is estimated at 15 years (Eunomia, 2017). Outside of sports field construction, the lifespan of artificial turf is unknown.

SBR granulate can be installed a second time in artificial turf after appropriate processing. EPDM and TPE granulates are not suitable for further reuse, as they tend to clump and adhere to the turf fibres during use (Leers, 2020; Schimmelpfennig, 2020).

6.1.2 Use and quantity

Artificial turf is mainly used in the sports sector. It is also used in playground construction, as carpeting in trade fairs and events, in private gardens, balconies or as roof greening. Some artificial turf is also used indoors, for example in conservatories.

Systems with granules are only used in the sports sector on football fields, rugby fields and multi-sports fields. Fully and partially filled systems with pure sand and unfilled systems can be found in all areas.

The exact amount of artificial turf is unknown. In Germany, the majority of all sports fields with artificial turf as a surface are owned by municipalities, however, there has been no statistical recording of these fields since 2002 (DOSB, 2019).

6.1.2.1 Tennis

In tennis, only fully infilled artificial turf systems can be used. According to the German Tennis Federation e.V. (DTB), artificial turf is only very rarely used, with the trend moving more towards hard and clay courts (Wortmann, 2020).

In 2019, there were 40,563 outdoor tennis courts in Germany (DTB, 2019). Assuming that 1% of the outdoor courts are equipped with artificial turf, this would correspond to 406 courts nationwide. The surface area of a tennis court including run-out zones is around 667 m^2 (Stadionwelt, n.d.). The grass carpet weighs around 3 kg/m^2 and the sand 30 kg/m^2. This results in a theoretical quantity of 8,936 t of artificial turf from tennis.

6.1.2.2 Football and multi-sports

In Germany, only natural or hybrid turf is permitted for matches in the 1st to 3rd football leagues. The number of hybrid turf fields is unknown.

The DFB has a database to record regular football fields with artificial turf for league matches up to the regional league. In 2019, 5,109 fields were recorded (DFB and DStGB, 2019). These are mainly partially infilled systems with granules. Around 1,500 fields are said to be filled with sand only (Schimmelpfennig, 2020).

Artificial turf on regular fields has an average weight of 35 kg/m^2. The grass carpet weighs 2.0-3.5 kg/m^2, the synthetic granulate 3-5 kg/m^2 and the sand 18-35 kg/m^2 (Dufft, 2020; DFB, 2017).

The current stock of artificial turf fields with infill contains less than 20% SBR. The remaining fields are mainly infilled with granules made of EPDM, less frequently with TPE (Baer, 2020; Schimmelpfennig, 2020; Düsseldorf City Council, 2018). According to RAL GGK, there are 400 sport fields filled with cork in Germany (Schimmelpfennig, 2020).

An analysis of the stock of individual large cities in Germany shows that around 70% of the stock are regular fields and around 30% are small fields such as the DFB's 1,019 mini fields (DOSB, 2019; Hamburg, 2019; Landeshauptstadt München, 2020).

Table 42 shows the estimated total volume of artificial turf by infill type. A maximum volume of 1.39 million tonnes of artificial turf is assumed for football.

Table 42 Estimated number and bulk density of multi-sport and football fields made of artificial turf in Germany

Type of infill	Bulk density [kg/m^2]	Number of regular sport fields	Number of small sport fields	Total quantity [1.000 t]
Sand only	20-30	1.500	2.000	263-394
Sand & SBR	28-35	722		144-180
Sand & EPDM	28-35	2887		577-721
Sand & Cork	25-32	400		71-91
Total	-	**5.509**	**2.000**	**1.055-1.387**

Source: Schimmelpfennig, 2020; INTECUS

6.1.2.3 Hockey

For hockey, almost exclusively unfilled artificial turf is used. In Germany, there are said to be around 480 fields, of which only 3-4 are designed for mixed use and contain a sand-granulate infill (Dufft, 2020; DHB, 2020). With these exceptions, unfilled artificial turf is used. To prevent the carpet from slipping, it is braced in the edge areas (Baer, 2020). The specific weight of the turf carpet is 4-7 kg/m^2 due to the high fibre density (Baer, 2020; Berghaus, 2020). The area of a hockey field with run-off zones is around 5,700 m^2 (FIH, 2018). This results in an approximate maximum quantity of 19,152 t of artificial turf carpet from hockey.

6.2 Collection

6.2.1 Collection systems

In sports field construction, renovation involves removing and replacing either the entire field or only damaged sections.

In most cases, sports fields with artificial turf surfaces are owned by municipalities. When renovating, the municipalities usually stipulate that the supplier of the new artificial turf must also take care of the utilisation or disposal of the old one. The collection is carried out by artificial turf construction companies.

Artificial turf does not have its own waste code. An infilled artificial turf is assigned to waste code 17 02 03 (construction and demolition waste - plastic). Turf carpet without infill can be disposed of under waste code 19 12 04 (Wastes from mechanical treatment of wastes - plastic and rubber) (Baer, 2020).

If artificial turf arises as waste in residential areas, it is usually assigned to bulky waste (AS 20 03 07), smaller quantities/cuttings are also disposed of via residual waste (AS 20 03 01). In some cases, artificial turf dealers or installers in the private customer sector offer to take back the old turf carpet when a new one is purchased.

6.2.2 Collection quantities

Since artificial turf does not have its own waste code number, the volume is currently not recorded separately in statistics. Due to the lack of data on the number, type and renovation status of existing artificial turf fields in Germany, information on the amount of waste collected is based on estimates by experts.

Arithmetically, 400-450 artificial turf fields per year would have to be renewed in Germany with an inventory of around 5,000 artificial turf fields (Leers, 2020; Dufft, 2020). According to various estimates, however, only around 200 to 250 fields are renewed each year. In addition, around 150 artificial turf fields are newly installed each year. This will increase the annual amount to 350 to 400 fields over the next ten years (DFB, 2017; Leers, 2020).

The average weight of infilled artificial turf is given as 200 to 250 t per pitch (Leers, 2020; van Roeckel, 2020). Assuming that all pitches are infilled, the maximum quantity is currently 40,000-62,500 tons per year of artificial turf. By 2030, this figure is expected to increase to 70,000-100,000 tons per year.

6.3 Recovery of artificial turf

6.3.1 Routes of recovery

6.3.1.1 Partial solutions

In the past, recycling was limited to the infill. This is removed from the old artificial turf on site or in an interim storage facility using special machines and sieved. In pure sand infill, the sand can often be reused in sports field construction after screening (Heiler, 2020).

In mixed infill, the sand is contaminated to varying degrees with abrasion from the granules and artificial turf fibres. It is usually not reused in new artificial turf, but either sold to other users such as the construction industry or disposed of together with the granules (Baer, 2017; Heiler, 2020). The granulate cannot be completely freed from sand and impurities in this process, which is why it is usually not reused as infill material. Instead, if it is of sufficient quality, it is used for the construction of elastic base layers, fall protection products or in the production of silent asphalt (Baer, 2020). An unknown proportion is recovered thermally.

In the past, turf carpet as such was either offered as second-hand goods if it was in sufficiently good condition, or it was recovered thermally, as recycling was considered to be too difficult and uneconomical. Today, the costs for energy recovery are estimated at 120-180 €/t (Baer, 2020; Pfitzenmaier, 2020). For the carpet of a football field, the costs are thus 1.30-1.60 €/m^2. In addition, there are the costs for the removal and transport of the artificial turf. Today, it is quite common to hand over the turf carpet to recycling companies, which shred it and sell the recycled material to the plastics industry (Baer, 2020; Berghaus, 2020).

The market for artificial turf as a second-hand product is rather limited. A study by Eunomia (2017) found that although used artificial football turf is offered internationally in large quantities, demand is very low. For Germany, too, it is assumed that at most 10% of artificial turf is sold as used goods (Baer, 2020). The main reason for the low level of further use is the condition of old artificial turf. It is usually so heavily worn that further use is out of the question. In the sports sector, the price advantage of used artificial turf over new is also limited due to the high transport costs for an entire field (Eunomia, 2017). However, it happens that sports clubs move their old artificial turf to a nearby training area. In hockey, the European Hockey Federation organises the transfer of used artificial turf to other countries. The turf must still be of sufficient quality (EHF, 2018).

6.3.1.2 Recycling of the entire artificial turf system

The complete recycling of artificial turf is technically demanding and is currently only offered by a few companies.

The Danish company Re-Match has been offering traceable recycling of artificial turf since 2016 and can process 40,000 tons of artificial turf annually. The process allows 95 wt.-% of an artificial turf to be recycled. The artificial turf is rolled up and packed with the infill when it is removed from the field. Transport to the recycling facility is by truck. Upon delivery, the turf is laboratory tested to determine the types of material. The artificial turf is pre-shredded with the infill and dried. The infill is then separated and mechanically processed. Sand and rubber granulate can be cleaned to 99% and are suitable for reuse in artificial turf pitch construction. The remaining pieces of carpet are crushed again. The PU/latex bonding is removed by sifting and screening, and the fibre material is separated into the PP and PE material groups and agglomerated. The recyclates obtained are not suitable for reuse in the production of artificial turf and are sold for the production of other plastic products (Leers, 2020; ETA Danmark, 2017).

Since July 2020, the recycling facility of GBN Artificial Grass Recycling (AGR) from the Netherlands has been in operation (GBN AGR, 2020). The facility has a capacity of 2 million m^2/a, which corresponds to approximately 70,000 tons per year. Similar to Re-Match, the artificial turf is rolled up with the infill and transported. In the facility, the infill is removed from the turf carpet in a first step. It passes through a washing system in which the sand and granulate are separated and freed from impurities and pollutants. The turf carpet is shredded and separated into fibre material, carrier and bonding by screening and centrifuging. The process can recover 95-96% by weight. The remaining 5 wt.-% is mainly impurities and smaller carpet residues (van Roeckel, 2020). As with Re-Match, the carpet material can be tracked from the point of removal at the site.

Morton Extrusionstechnik GmbH, a subsidiary of the artificial turf manufacturer FieldTurf, takes a different approach. Since 2017, the company has been offering the recycling of artificial turf carpets. Currently, the capacity is 79 artificial turf fields per year. The turf carpet is freed from the infill during removal on site and shredded and cleaned by a partner company. The latex content is removed along with the impurities and recovered thermally. The shredded turf fibres are delivered as bales to Morton Extrusionstechnik, where they are processed with production residues into elastic granulate. Separation into PP and PE is not necessary. The product is EU Cert Plast certified (Berghaus, 2020). In 2020, the recycling service was extended to include infill. This is brought to the central warehouse in the port of Dortmund and from there transported by ship to a processing company in Rotterdam, which separates and cleans the sand and granulate. One shipload holds the infill of 10-12 fields. The sand remains in the Netherlands and is used as building material. The granulate is returned to FieldTurf in Germany and is used for the construction of elastic base layers (Berghaus, 2020).

6.3.1.3 Disposal costs

If the owners demand only basic removal and disposal of their artificial turf field, the market price is 2.50 €/m^2 (Schimmelpfennig, 2020; Düsseldorf City Council, 2017). The costs for complete recycling including dismantling and transport are 3.00 to 4.50 €/m^2 for infill systems. For cost reasons, the transport distance should not exceed 600 km (Berghaus, 2020; Leers, 2020).

6.3.1.4 Research approaches

Purely mechanical separation processes cannot completely separate PP and PE. The resulting recyclates are therefore not suitable for use in fibre extrusion. A true closed-loop recycling is not possible.

Morton Extrusionstechnik is currently working on an alternative to latex bonding. For this purpose, a film is produced from turf fibre recyclate, which is later laminated to the back of the turf carpet. Separation of PE and PP is not necessary for the film production. The resulting turf carpet can later be completely recycled into new film (Berghaus, 2020). Another project envisages the mechanical recycling of fibre recyclate through pyrolysis. In this process, the molecules are broken down into ethylene, which can then be used to produce new polyethylene (Berghaus, 2020).

Re-Match is working together with the artificial turf manufacturer Polytan on a pilot project to produce fibres from recycled material. Following processing at Re-Match, the fibre material is subjected to the CreaSolv® process by Fraunhofer. In the CreaSolv process, the plastics are dissolved and separated into pure fractions by distillation processes. The resulting material is then free of impurities. The process was originally developed for the packaging industry for recycling complex plastic composites, but is also suitable in principle for artificial turf

(Andersen, 2019). The first test field with the recycled fibres will be a small football field in Berlin, the construction of which is planned for early 2021 (Leers, 2020; SenUVK, 2018).

6.3.2 Environmental potential

The environmental and health hazard potential of SBR granulate is discussed in detail in chapter 8.5.1.2. Due to the planned ban on microplastics, the synthetic granulate in artificial turf is also under discussion. As a reaction to this, some federal states have already changed their funding guidelines for sports facility construction so that artificial turf systems with synthetic granulate are no longer eligible for funding. According to various industry representatives, there is no longer any significant demand for new artificial turf systems with synthetic granules in Germany (Leers, 2020; Schimmelpfennig, 2020).

So far, there are no life cycle assessments for the different recycling routes of artificial turf, as comprehensive recycling has only been available for three years. The CO_2 emissions from energy recovery are said to be around 113 t per infilled football field (Re-Match, n.d.).

Internationally, the majority of artificial turf fields are disposed of in landfills (Eunomia, 2017). In Germany, landfilling of untreated artificial turf is prohibited. Artificial turf may only be recovered thermally or recycled.

The currently available capacities for recycling as a whole system are shown inTable 43. Of the 200-250 old artificial turf fields generated annually in Germany, around 80-100 fields are processed by Re-Match and Morton Extrusionstechnik. GBN AGR is currently fully utilised with artificial turf from the Netherlands. In the long term, however, half of the facility's capacity is earmarked for foreign goods (van Roeckel, 2020). Around 100-150 artificial turf fields are therefore currently either only recycled via partial solutions or thermally disposed of.

Table 43 Available recycling capacities for artificial turf in 2020

Company	Recycled fields per year from Germany	Current processing capacity	Planned expansion
Re-Match	50-60	40.000 t/a	2 facilities with each 80.000 t/a
GBN AGR	0	60.000 t/a	2-5 facilities with each 60.000 t/a
Morton Extrusionstechnik	30-40	70 fields	-

Sources: Leers, 2020; Berghaus, 2020; van Roeckel, 2020

Due to the discrepancy between recycling capacities and volumes, as well as poor traceability, it can be assumed that there are old stocks that exceed the deadlines for interim storage. In 2020, "Die Welt" reported on a company that offered the removal with artificial turf, but only stored it (Pfitzenmaier, 2020).

Due to the large mass per artificial turf field, the transport costs for recycling are very important. In general, a maximum range of 400-600 km per recycling facility is assumed if the entire system is transported (Leers, 2020; van Roeckel, 2020). In order to be able to cover the entire German region, both GBN and Re-Match are planning additional facilities. GBN plans to build a new facility centrally in Germany and one in France in 2021. Both will have a similar capacity to the facility in Amsterdam. In the long term, two more facilities will be added in Germany, one near Berlin and one near the Austrian border (van Roeckel, 2020). Re-Match will open a facility with 80,000 tons per year capacity near the border with Germany in the Netherlands in 2021. Another facility of the same size is planned in France (Leers, 2020).

6.3.3 Evaluation and conclusions

Old artificial turf is a waste stream in Germany that is relevant in terms of quantity, but it is difficult to estimate due to the lack of statistical recording of the existing artificial turf fields.

In addition to the amount of new artificial turf generated annually as a waste stream, there is also the problem of old stock. Due to the lack of tracking of removed artificial turf, it can be assumed that some of the old artificial turfs are stored illegally and have not been recycled.

Based on current developments on the market, it can be assumed that in the next three years the available recycling capacities will be sufficient to process the entire quantity of artificial turf from Germany.

Complete disposal of the artificial turf in accordance with the regulations is hardly verifiable at present due to the lack of traceability. Whether recycling takes place depends heavily on the commitment of the sports field owners.

The Gütegemeinschaft Kunststoffbeläge is currently working on a concept for quality control and licensing of recycling companies (van Roeckel, 2020). The new quality label should be published in early 2021 and provide a secure basis for municipal tenders for artificial turf recycling (Baer, 2020).

The pilot projects currently taking place show possibilities for creating a closed loop in artificial turf production. At this point in time, it is not yet possible to estimate whether and when the new technologies can be used on a large scale.

6.4 Proposed measures

In the following, various measures for improving the material recovery of bulky waste are described and evaluated according to the criteria mentioned in chapter 1.3.1.

6.4.1 Inventory database for artificial turf fields

At present, all information on the quantity and recycling paths is based on expert estimates and information from individual municipalities. In order to ensure a reliable database for the collection and evaluation of the artificial turf waste stream in the future, a central database of all existing and planned artificial turf fields in Germany should be established. In addition to the location and owner, this database should also contain the area size and turf characteristics such as height and type of infill, and possibly also the name of the product. Furthermore, the installation date and, in the case of renovation, the removal date and the type of recycling should be noted.

Table 44 Evaluation of the measure "Inventory database for artificial turf fields"

Criterion	Evaluation	Points
Bureaucratic effort	Medium effort for the maintenance of the system	3
Legal aspects	The legal framework at federal state level would have to be created by a resolution of the Conference of Sports Ministers (SMK).	3
Statistical aspects	The measure ensures the statistical recording of the existing artificial turf fields in the sports area. The utilisation routes are not necessarily recorded.	3
Organisational effort	Coordination between different authorities necessary	3

Criterion	Evaluation	Points
Implementation timeline	Medium-term (3-5 years)	3
Binding character	Highly binding	1
Contribution to financing the recycling	Positive effect on the financing of the utilisation of the waste stream through improved plannability of investments in treatment facilities.	3
Improvement of collection	No impact on the collection of the waste stream	3
Strengthening of recycling	Creates better conditions for recycling	3
Acceptance of relevant actors	Municipalities: low to indifferent due to additional administrative workload Sport clubs: high Recycling sector: high	3
Public information needs	No or hardly any additional communication or public relations work is needed to implement the measure.	1
Weighted result		**2.7**
Key addressees	Municipalities, German federal states, public administration, sport clubs	
Summary	After an initial set-up effort, the measure leads to a solid recording of waste flows, which can serve as a planning basis for the expansion of domestic recycling capacities. However, the 32. Conference of Sports Ministers decided in 2008 not to conduct a survey in 2010, as the sports facility statistics have no significance for concrete investment decisions by the municipalities (SMK, 2008).	

6.4.2 Promotion of recyclable artificial turf types

Due to the limited separability of PE and PP fibres during recycling, it is not possible to use the fractions in fibre production for new artificial turf. Artificial turf made of only one type of plastic is already available, but is currently a pure niche product due to the somewhat higher price. The demand by municipalities is strongly dependent on the funding guidelines for sport facility construction of their federal state. These should therefore be adapted to give preference to artificial turf carpets consisting of a single type of plastic. This leads to a simplification of the recycling effort and an improvement of the recycled material quality.

Table 45 Evaluation of the measure "Promotion of recyclable artificial turf types"

Criterion	Evaluation	Points
Bureaucratic effort	*Not relevant*	
Legal aspects	The implementation of the measure requires changes/additions to the funding guidelines for sports facilities at the federal state level.	2
Statistical aspects	*Not relevant; theoretically statistical recording via funding agency possible, but only installation, not disposal*	
Organisational effort	Medium organisational effort for the introduction of the measure. Coordination between the different federal states is necessary.	3

Criterion	Evaluation	Points
Implementation timeline	Short-term (1-2 years); amendment of the funding guidelines for sports facility construction by the federal states possible	1
Binding character	binding	3
Contribution to financing the recycling	Positive effect, as the use of recyclable artificial turf reduces the effort and cost of recycling	3
Improvement of collection	Does not influence the collection	3
Strengthening of recycling	The measure creates better conditions for the recycling of a large part of the waste stream.	2
Acceptance of relevant actors	Sport clubs/ municipalities: indifferent to high Manufacturers: low to indifferent (have wide product range that does not meet these requirements) Recycling sector: high	3
Public information needs	No or hardly any additional communication or public relations work is needed to implement the measure.	1
Weighted result		**2.3**
Key addressees	Federal states – Sports funding, municipalities and sport clubs, manufacturers	
Summary	With little effort, the measure leads to a rapid increase in demand for artificial turf with a recycling-friendly design.	

6.4.3 Tendering guide for public procurement - disposal of artificial turf fields

Recycling of artificial turf requires verifiable utilisation routes to prevent illegal storage or unwanted exports. The owners of artificial turf fields, municipalities and sport clubs, should be encouraged to demand verifiable recycling of the old artificial turf in the tender for field renovation. The Berlin verification procedure can serve as a model to ensure actual recycling (SenUVK 2018). The procedure prescribes the preparation of quantity flow balances with information on the purchasers of the recyclates. Furthermore, the future RAL quality label for artificial turf recycling (planned publication in 2021) could be included in the tender criteria. In this way, public sector contracting authorities would also fulfil their obligations under Article 45 KrWG and the corresponding state legislation.

Table 46 Evaluation of the measure "Tendering guide for public procurement - disposal of artificial turf fields"

Criterion	Evaluation	Points
Bureaucratic effort	The additional bureaucratic effort is acceptable.	3
Legal aspects	No legal changes/additions are required for the implementation of the measure; is covered by procurement law	1
Statistical aspects	Partially ensures the statistical recording of waste flows.	3
Organisational effort	Medium organisational effort for the introduction of the measure. Municipalities must incorporate Berlin guidelines into their own award criteria.	3

Criterion	Evaluation	Points
Implementation timeline	Short-term (1-2 years)	1
Binding character	Non-binding; based on voluntary participation of the municipalities	4
Contribution to financing the recycling	Secures funding for the recycling of municipal artificial turf.	3
Improvement of collection	Improves collection of the waste stream	1
Strengthening of recycling	Creates better conditions for the recycling of municipal artificial turf.	3
Acceptance of relevant actors	Municipalities: indifferent Recycling sector: high	3
Public information needs	No or hardly any additional communication or public relations work is needed to implement the measure.	1
Weighted result		**2.5**
Key addressees	Ministries, public authorities, recyclers, companies in artificial turf installation	
Summary	The measure increases the monitoring effort by the tendering authority, but effectively prevents illegal disposal and promotes recycling.	

6.4.4 Final synopsis

The following prioritisation is recommended for the next steps:

1. Change the funding guidelines for sports field construction.

Due to the long service life of artificial turf, changes in purchasing only make themselves felt in the waste stream some eight years later. Therefore, changes to the subsidy guidelines should be made promptly, as they have an immediate effect that leads to a long-term improvement in recycling.

2. Development of a guideline for the public tendering of artificial turf disposal by municipalities

The development of the guideline should be started immediately in order to support municipalities and clubs in ensuring recycling of their artificial turf. This will have a positive effect on the current waste stream. 3.

3. Building up an inventory database for artificial turf fields

The establishment of the database is feasible in the medium to long term and creates a real data basis for the evaluation of the waste stream. With the help of the inventory data, the effects of measures can be traced. At the same time, the data provides recyclers with a planning basis for building up facility capacities.

7 Diapers

7.1 General information

Disposable diapers/nappies have been predominantly used for babies and toddlers in Germany since the mid-1980s at the latest (Hug & Grow, 2014). These diapers basically consist of a composite of cellulose and plastic. To bind the excreta, polymers or so-called superabsorbents are used which swell up on contact with liquids. For some years now, the demand for washable cloth nappies has been increasing again. Many parents use them for cost reasons though ecological concerns are also mentioned. Nevertheless, the proportion of disposable diaper users is still very high and even assumed to make up a proportion of 90%.

The point in time when a child needs no or fewer nappies is very individual. Usually, a consumption of between 4,500-11,000 nappies is assumed in the first three years of a child's life (Windelmanufaktur, 2015). On average, 7 to 12 nappies a day are needed in the first months of life, this goes down to 4 to 5 a day later on. As of 31 December 2017, there were around 2,351,900 children under the age of three living in Germany (Destatis, 2019). With a daily average consumption of 6 nappies per child, around 12.7 million nappies are used per day in Germany.

In addition to the use of nappies for the group of toddlers, diapers are also needed for adults that suffer from incontinence. Around nine million persons in Germany are said to be affected and in need of aids for such problems, the number of unreported cases may be even higher (Stiftung Warentest, 2017). A distinction is made between urinary and faecal incontinence in several degrees of severity and bedwetting. Depending on the type and severity of incontinence, aids in varying types and numbers are needed (Selbsthilfeverband Inkontinenz e.V., 2015). For severe or moderate incontinence, the need per day is estimated to be between 4-5 diapers for an adult person (Beier, n.d.). However, for most cases, light to moderate incontinence is assumed, for which incontinence briefs or pads are sufficient. For a rough estimation of the diaper need for adults in Germany, problems with incontinence were assumed for all persons in need of care from care level 3 as a general rule[14]. With regard to the fact that the majority of cases are of low to moderate severity, a number of 2 diapers was estimated to be the amount required from these persons per each day. This results in a total number of 3 million nappies per day needed for this part of the population. The number of smaller and lighter incontinence briefs used in Germany per day is estimated to be higher. However, it is not possible to determine how many people use washable and thus reusable incontinence products.

7.2 Collection

7.2.1 Collection systems

The disposal of used disposable nappies is mainly taking place via the residual waste service. In some towns and municipalities, parents of children under three years of age or relatives of adults in need of care can be supplied additional residual waste bins in which nappies and incontinence material can be disposed of either exclusively or together with other residual waste. Examples of this model can be found in the counties of Mayen-Koblenz and Kitzingen (Kreisverwaltung Mayen-Koblenz, n.d.; Landratsamt Kitzingen, n.d.). Instead of the additional supply of residual waste bins, nappy sacks are made available in a number of cases. Mistakenly, nappies are sometimes disposed of in the waste bins for biodegradable discards. However, used

[14] Even though not all people in need of care upward from care level 3 can be assumed incontinent, it also children and adults of all ages not in need of care who experience problems of incontinence for a wide variety of reasons.

disposable nappies are not permissible as biowaste suitable for soil-related recycling pursuant to the Biowaste Ordinance and therefore must be regarded a foreign and interfering material in this waste stream. Used nappies regularly contain germs and pharmaceutical residues that cannot be safely inactivated or destroyed by the prescribed treatment processes (thermophilic fermentation and/or composting, possibly pasteurisation). In addition, almost all disposable nappies on the market contain a large proportion of components which are not biodegradable.

There are furthermore cases where towns and municipalities set up waste containers in which nappies are disposed exclusively as a single waste fraction. Flörsheim (State of Hesse), for example, is practising this for families with small children or relatives in need of care but also for day-care centres or toddler groups. These groups can apply to use the containers for an annual fee, and in return get provided with a key for accessing them (Stadt Flörsheim am Main, n.d.). Such a system constitutes the best starting point for collecting relevant diaper quantities for a possible recycling. Currently, this system is mainly offered to provide families with small children and relatives in need of care a financial relief in terms of the waste fees they must pay.

In the EU-funded research project "Embraced", a container-based collection system with an associated app is being developed and tested in Amsterdam since 2019 to collect sorted nappy waste from individuals for recycling. Helped by the app, users can find and open the container sites. In addition, the app motivates users by displaying the contribution each user and the corresponding neighbourhood is making to environmental protection. The containers are designed to neutralize odours and are placed in central locations, for example in front of drugstores (Embraced, 2020).

7.2.2 Collected quantities

Only estimates can be made about the total quantity of disposable nappies in the waste. When disposed of in the residual waste, the waste code 20 03 01 for mixed municipal waste does apply on them. Where used nappies accumulate in nursing homes or hospitals, they are allocated the waste code 18 01 04 (wastes whose collection and disposal is not subject to special requirements in order to prevent infection).

Based on the quantities of nappies mentioned in chapter 7.1, the total mass of waste nappies generated in Germany can be estimated. Infant and toddler nappies do have an empty mass of 30-90 g per piece while that of diapers for adults is in the range of 90-220 g (Selbsthilfeverband Inkontinenz e.V., 2015). In the further calculations the mean value is assumed in each case. About 68% of the weight of nappy waste, on average, consists of urine and faeces (Odegard et al., 2018). This means that a total of approx. 1.4 million tons of nappy material is produced as waste in Germany each year.

According to sorting analyses, approx. 13% of municipal residual waste consists of hygiene products, which includes not only nappies but also feminine hygiene products and other liners. From this can be derived the equivalent of 17.3 kg/(inh*a) or approx. 1.5 million tons of hygiene products which are generated in residual waste in Germany annually. (Dornbusch, 2020).

Possible collection volumes in day-care centres and nursing homes

A nationwide, separate collection of nappy waste from private households can be implemented with huge efforts in the medium-term only. The volume of nappy waste generated in day-care centres and nursing facilities is thus of special interest and has been made subject of an estimate, considering that separate collection of relevant quantities can be achieved with less effort and transportation expenses at these locations.

In 2019, 687,427 children under the age of three were entertained in one of Germany's day care facilities. Of these, more than half the number were children over two years old. Overall, only about 12% of the infants were in care for up to 25 hours per week, which means that the majority of children are staying for more than five hours per day in a day care facility (Destatis, 2019d). If an amount of two nappies per child and day of care is assumed, this results in a total nappy quantity of 57,000 tons per year generated during 220 days of care.

In 2017, 818,289 people in need of full inpatient care were residing in nursing facilities (Destatis, 2019e). Assuming that about 70% of these recipients of permanent care fall under the category of incontinent persons (Schmidt, 2000) with a daily need of two nappies, gives a total mass of nappy waste of about 200,000 tons per year in this group. In addition, there are numerous other facilities where larger quantities of waste nappies are produced and could be collected separately. These include hospitals, rehabilitation clinics and spa facilities.

Table 47 summarises the so established volume of nappy waste in Germany.

Table 47 Estimates for the generated quantities of nappy waste in Germany in 2017

	Pieces per year	Total annual mass [t/a]
Nappies for infants in the overall	4.6 million	869,000
Diapers for the incontinence of adults in the overall	1.1 million	542,000
Total		**1,400,000**
Hygiene products in the residual waste		**1,500,000**
of which from		
Nurseries and day-care centres for children	0.3 million	57,000
Nursing homes and care centres for adults	0.4 million	200,000
Total in facilities		**257,000**
Waste code 18 01 04*		349,600

* wastes whose collection and disposal is not subject to special requirements in order to prevent infection (for example dressings, plaster casts, linen, disposable clothing, diapers);
Source for volume: Destatis

7.3 Recovery of diapers

7.3.1 Routes of recovery

Nappies are for the most part disposed together with the residual waste for energy recovery. A thermal treatment is making sense not just for hygienic reasons, especially since nappies are soiled by human faeces and perhaps the infectious matter of sick people, but also for the destruction of pharmaceutical residues that the faeces may contain. The calorific value depends on the moisture content and is cited to lie in a range between 5 and 11 MJ/kg, therewith showing similarities to residual waste (Beckmann et al., 2007 and Schmidt, 2014).

One of the best-known facilities for energy recovery from nappy waste has been set up by the Liebenau Foundation in Meckenbeuren (Baden-Wurttemberg). The so-called "Windel-Willi" thermally treats up to 5,000 tons of nappies and other incontinence materials per year. The heat recovered from the incineration is used for the foundation's premises and an affiliated laundry (Stiftung Liebenau, n.d.).

The main technical challenge in recycling nappies arises from the high moisture content, the presence of pharmaceutical residues and pathogenic germs that must be safely destroyed during recycling, and the formation of odours, which must be kept low in the recycling facility's surroundings on the one hand, and should not degrade recyclate qualities on the other hand. However, nappies contain high-quality raw materials such as superabsorbents and cellulose fibres, both are marketable goods even as recycled materials. In addition, the recycling of single-variety streams of nappy waste yields relatively uniform recycling products compared to many other mixed plastic wastes.

7.3.1.1 Composition

The composition of nappies and incontinence products in waste and their calorific value is shown in Table 48.

Table 48 Composition of nappies and incontinence products as in the waste

Materials	Calorific value of material	Nappies for infants		Incontinence products	
		Material share	Calorific value of material	Material share	Calorific value of material
	[MJ/kg]	[mass-%]	[MJ/kg]	[mass-%]	[MJ/kg]
Superabsorbent polymer	25.0	9.7%	2.4	3.9%	1.0
Cellulose fibres	16.8	7.1%	1.2	17.9%	3.0
PP non-woven	41.6	6.2%	2.6	3.0%	1.3
Rubber and adhesive tapes	27.2	3.8%	1.0	0.3%	0.1
PE film	41.2	1.5%	0.6	1.7%	0.7
Adhesive	41.0	0.9%	0.4	0.8%	0.3
Other materials	0.0	0.3%	0.0	0.0%	0.0
Urine and faeces	-2.6	67.5%	-1.8	67.5%	-1.8
Plastic bags (PE)	41.2	3.0%	1.2	5.0%	2.1
Calorific value (MJ/kg)			**7.7**		**6.6**

Source: Odegard et al., 2018

7.3.1.2 Research work undertaken in Germany

At the Competence Centre for Energy and Environmental Systems Engineering at the TH Mittelhessen University of Applied Sciences (THM), a decentralised process was developed to produce biogas from nappies and incontinence material in an anaerobic digester and to recover plastics and superabsorbent polymers subsequently from the digestate (Theilen, 2016; Medizin&Technik, 2016).

The staff of the Chair of Waste Management at the Brandenburg University of Technology Cottbus-Senftenberg (BTU) registered a patent for separating cellulose and plastic from nappies for recycling. The incontinence material in a slurry with water is heated to 150-250 °C and stirred for several hours in an autoclave. The plastic separated in the process can be processed, for example, as a substitute fuel and the cellulose can be fermented together with liquid manure (Busch et al., 2013).

7.3.1.3 Research and development work undertaken in other EU countries

In Great Britain, Italy and the Netherlands, large-scale facilities have been developed and built in recent years in which only hygiene articles are reprocessed. The procedures usually include the following steps:

1. Separate collection and transport to the recycling facility
2. Opening and shredding of the nappies
3. Thermal treatment under high pressure to sanitise and break down the nappies
4. Shredding and sorting of PE, PP and cellulose fibres
5. Preparation of cellulose fibres for resale
6. Washing and granulation of plastics for resale
7. Treatment of the waste water in a municipal waste water treatment facility.

Because of to the high content of urine and faeces in nappies and the resulting wastewater generation, it is in many cases advisable that nappy recycling facilities are operated in close proximity or in an arrangement of coupling them to a municipal sewage treatment facility.

The company Knowaste Ltd. operated a nappy recycling facility in Arnhem (Netherlands) from 2000 to 2007, which also processed incontinence nappies from old people's and nursing homes in North Rhine-Westphalia (Schmidt, 2000). The facility was broken up in insolvency proceedings in 2008. The reasons for the insolvency were mainly an underutilisation of the facility capacities, as contracting with nursing homes was more difficult than expected and the recycling offer always stood in competition with existing waste incineration contracts of the potential suppliers (de Gelderlander, 2008). With the exception of the potential greenhouse gas emissions that showed to be lower for the energy recovery, the process was found to relief the environment also taking the transportation into account (Meyer, 2001). In 2011, Knowaste opened a facility in the UK with a capacity for the treatment of 36,000 tons of hygiene products per year. This facility was also closed in 2013 for financial reasons. Nevertheless, the company is aiming for further facilities in the UK with the goal of being able to collect the necessary quantities of hygiene waste in smaller catchment areas. In addition to nappies, the company also processed feminine hygiene products and incontinence briefs in the recycling facilities (Knowaste, n.d.; Dri et al., 2018; Date, 2013). For the UK process, a life cycle assessment found a reduction in greenhouse gas emissions of up to 71% compared to a mix of landfill (81%) and energy recovery (19%) (Deloitte, 2011).

The company Fater S.p.A. operates a recycling facility in northern Italy as a joint venture with the world's largest nappy manufacturer Procter&Gamble. The development and construction of the facility was supported by the EU-funded research project "RECALL" (RECALL, n.d.). The process aims to recycle the nappy materials into the products listed in Table 49. Within the frame of the EU-supported project "Embraced" running until 2022, the recycling facility is to be expanded by a biorefinery to treat the organic components. From one ton of used nappies, around 150 kg of cellulose, 75 kg of absorbent polymer and 75 kg of mixed plastic can be recovered and sold as secondary raw materials (UmweltMagazin, 2019). An economic benefit of € 208 per ton of waste from hygiene products and an avoidance of greenhouse gas emissions of 422 kg $CO_{2\text{-eq}}$ per ton of this waste compared to energy recovery has been calculated for the process (Embraced, n.d.).

Table 49 Possible range of recycled products from the secondary materials of nappies and incontinence products

Recovered material	Plastics	Cellulose	Superabsorbent polymers
Recycled products	School desks Accessories Pallets Clothespins Caps of detergent bottles Outdoor furniture	Technical paper Viscose Cat litter Nutrients for agriculture Industrial absorbents Biofuels	Irrigation balls Portable barriers for flood prevention

Source: Fater SpA, n.d.

In the Netherlands, the company ARN BV, in cooperation with Remondis, is operating a facility based on the research work of the Brandenburg University of Technology Cottbus-Senftenberg (BTU) since the year 2017. In 2021, this facility will be expanded to a capacity of 15,000 tons per year, thereby adopting a process principle that is slightly different from the one described earlier. Here, the nappies are treated at a pressure of at least 40 bar and a temperature of 250 °C together with about 30% digested sewage sludge in a liquid reactor, with the plastics consequently melting. When cooling, the plastic particles (70% PP and 30% PE) float on top and can be extracted and recycled separately. The resulting sludge, which makes up 93% of the mass, is then fermented into biogas. This process does not recover the cellulose fibres for material recycling, however. (ARN BV, 2017; euwid, 2020c). Compared to energy recovery, a life cycle assessment found a saving of 480 kg $CO_{2\text{-eq}}$ per ton of treated nappies for this process. In addition, a negative carbon footprint was balanced for the recycling process, assuming a superheated steam supply from a waste-to-energy facility, the superheated steam being used sequentially for two reactors and the sludge being processed into a substitute fuel after fermentation (Odegard et al., 2018).

acib GmbH in Austria is researching a nappy recycling process in which the nappies are digested in a first step with the help of enzymes. The process does not require high temperatures and dangerous chemicals. However, the process still requires several years of research and development work before becoming an option at industrial-scale (euwid, 2020a).

7.3.2 Evaluation and conclusions

Several recycling processes for nappies and incontinence products do exist and are currently being investigated in demonstration projects or already in large-scale facilities. In principle, it would be possible for companies to invest in nappy recycling facilities in Germany as well, as long as the collection of sufficient quantities can be guaranteed.

According to the process developers, the destruction of germs and pharmaceutical residues is guaranteed by treatment at high temperatures. An elimination of odours could be achieved for the recycled materials, thus making it possible to find buyers for the recycled plastics from the industrial-scale processes that were presented. Nevertheless, a concept to avoid odour emissions in the collection and recycling process is needed (Slow, 2017).

It remains a challenge to ensure the waste volumes required for the operation of a large-scale facility, as nappies are usually collected with the residual waste and no separate collection structures as yet exist for them. There are nappy bins introduced in some places in Germany but they are not treated separately from other residual waste during collection and transport. Establishing a nationwide separate collection in the system of pickup services is prevented by a shortage of space and for cost reasons.

To achieve economically viable operations, a minimum quantity of 8,000 tons of nappy waste per year is needed for a recycling facility (Dri et al., 2018). By way of a rough appraisal it can be assumed that for the collection of 10,000 tons of nappies and incontinence products per annum, an estimated 1 million inhabitants need to be connected to a corresponding collection scheme (Umweltmagazin, 2019). However, the quantities collected depend heavily on the chosen collection arrangement. This means that the most critical problem with nappy recycling is the bundling of the required quantities to enable the investment in recycling processes.

Operators of nappy recycling facilities need a co-payment to maintain economical operations. Many operators of recycling facilities try to keep the rate for co-payment between € 90-130 per ton in order to offer comparable prices to thermal treatment services and thus remain competitive (Dri et al., 2018).

Overall, the recycling processes have a positive ecological balance compared to energy recovery. However, the distances over which the nappy waste has to be transported is also a decisive parameter for the outcome of life cycle analyses. It also makes sense for hygienic reasons to focus on short distances for nappy waste until it is disinfected and rendered harmless, in addition to avoiding longer collection cycles and reloading for long-distance transportation. For this reason, nappy recycling facilities are currently being planned first and foremost in the vicinity of megacities.

7.4 Proposed measures

In the following, various measures for improving the recycling of nappies and incontinence products are described and evaluated according to the criteria mentioned in chapter 1.3.1.

7.4.1 Promotion of projects to establish separate collection systems or demonstration facilities

For nappy recycling, it is primarily important to have pilots and demonstration projects established in Germany for demonstrating the feasibility and to gain experience for a possible expansion of nappy recycling concepts. To this end, constructing a nappy recycling facility could be state-subsidised but more important is the identification and promotion of suitable collection schemes. An assured supply of several thousand tons of nappies per year from a sample metropolis, guaranteed over a few years of a project’s running term, can trigger sustainable investments into (a) nappy recycling facility(s).

Within this framework, the separate collection of already introduced nappy bins in a reference municipality could be investigated. This, however, is associated with an intense effort and public relations work which must be undertaken, beside that the service for the nappy bin should not incur an additional fee as such offer primarily serves to relieve young families and caring relatives. Here, the one-time funding via a project shall be recommended in order to appraise the costs and efforts that would have to be financed by waste fees in the case of a further rollout of the scheme.

Table 50 Evaluation of the measure "Promotion of projects to establish separate collection systems or demonstration facilities"

Criterion	Evaluation	Points
Bureaucratic effort	*not relevant, the measure is geared to estimate the bureaucratic burden*	
Legal aspects	legislative basis already exists	1

Criterion	Evaluation	Points
Statistical aspects	statistical recording shall be part of the investigations in project municipalities/cities	3
Organisational effort	is to be classified as high within the project but those efforts remain limited to the respective pilot	2
Implementation timeline	medium-term (3-5 years)	3
Binding character	*not relevant*	
Contribution to financing the recycling	helps to secure financing for certain tests and pilot installations during the project period and may serve as a basis for further implementation of separate collection and recycling of nappies and stimulate corresponding investment	1
Improvement of collection	improves the collection of the waste stream in project municipalities/cities and allows for testing optimized collection alternatives	2
Strengthening of recycling	lays the foundation for a future increase in recycling in that the best options to implement nappy recycling in Germany can be identified	1
Acceptance of relevant actors	high, considering that research and implementation of projects on resource and energy conservation have a positive image in the overall	1
Public information needs	public relations work can be carried out as part of the project implementation by the participating industry and research institutes themselves, PR/PA efforts especially start getting high if a project is to be expanded and consumers are to be motivated to collect diapers separately	3
Weighted result		**1.7**
Key addressees	Ministries, especially ministry of environment (BMU), public disposal providers and consumers in the project municipalities, research institutes, manufacturers	
Summary	The implementation of example projects is a good basis for the assessment of future possibilities and obstacles in nappy recycling.	

7.4.2 Introduction of mandatory collection and recycling as a priority for social facilities

A mandatory collection of nappy waste in care facilities and nursing homes allows only a small portion of this waste to be collected separately but the additional collection effort is less in relation to the collectable amount. Since most of these facilities already have contracts with waste incineration facilities, a longer lead time will be of crucial importance here.

Table 51 Evaluation of the measure "Mandatory collection and recycling as a priority for social facilities"

Criterion	Evaluation	Points
Bureaucratic effort	high additional effort for the documentation of proper collection and recycling by the facilities	4
Legal aspects	an amendment to the Commercial Waste Ordinance is required	4
Statistical aspects	helps improving the statistical recording for a relevant portion of nappy waste	3

Criterion	Evaluation	Points
Organisational effort	is increasing, on the side of the facilities to establish structures for separate logistics, the recycling industry must expand or create nappy recycling capacities	4
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding, as implementation is based on legislation	1
Contribution to financing the recycling	financing of separate collection and recycling is transferred to facilities	3
Improvement of collection	separate collection of part of the nappy waste becomes obligatory	2
Strengthening of recycling	a relevant part of the nappy waste starts getting recycled although only less than half of the total nappy waste will be covered from this	2
Acceptance of relevant actors	staff and operators of social facilities will have reservations with more acceptance being gained from their end once high-quality recycling with positive ecological consequences is actually achieved	3
Public information needs	low	2
Weighted result		**2.8**
Key addressees	German government, municipalities, facility operators, operators of nappy recycling facilities	
Summary	The organisational effort for separate collection in social facilities is lower than separate collection in the population. Nevertheless, the bureaucratic effort for the facilities should be kept as low as possible. Exemptions from the required documentation obligations are therefore recommended for implementation within the framework of the Commercial Waste Ordinance.	

7.4.3 Introduction of mandatory collection at the level of public disposal providers

A solution for the collection from private households could be a container-based bring system in the vicinity of a nappy recycling facility, such as is currently being tested in the research project Embraced. There exist already some examples of a collection system with nappy bring containers in Germany (see chapter 7.2.1). Especially parents with small children often want to contribute to environmental protection and the reduction of resource consumption and can be convinced on this basis to accept such a system. In this way, a relevant amount of nappy waste could also be sourced from private households in conurbations.

Table 52 Evaluation of the measure "Mandatory collection at the level of public disposal providers"

Criterion	Evaluation	Points
Bureaucratic effort	very high, public disposal providers must manage another waste stream in addition	5
Legal aspects	an amendment of the Circular Economy and Recycling Act (KrWG) is required	4

Criterion	Evaluation	Points
Statistical aspects	improves statistical recording, nappy waste would be integrated and displayed in the waste balances of the public disposal providers then	3
Organisational effort	very high, public disposal providers must manage another waste stream in addition	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding, as implementation is based on legislation	1
Contribution to financing the recycling	financing of separate collection is transferred to the public disposal providers, waste fees must be increased as a consequence	3
Improvement of collection	expands and enhances the collection of separate material	1
Strengthening of recycling	a significant increase in recycling can be expected in the long term since one of the greatest obstacles to recycling this waste will be overcome	2
Acceptance of relevant actors	Consumers: indifferent (depending on the design of the collection and the additional expense resulting from it), Public disposal providers: low (facing high additional expenses), Recycling industry (operators of nappy recycling facilities): high	4
Public information needs	very high, all consumers must be made aware on the separate collection and convinced to participate	5
Weighted result		**3.2**
Key addressees	German government, public disposal providers, consumers, operators of nappy recycling facilities	
Summary	The mandatory separate collection of nappies will most likely lead to investments by recycling operators in nappy recycling facilities in Germany. On the other hand, it will require a lot of effort, which will result in rising waste fees and a long-term implementation period. In addition, it remains unclear to what extent the population in Germany can be won engage in separate collection.	

7.4.4 Extended producer responsibility

Introducing a product responsibility could also be used as an instrument to bundle volumes for recycling and to finance this option. Under a regulation for product responsibility, the costs for the disposal and recycling of use nappies are not solely covered by the charges the general public pays for waste services but already when these products are placed on the market.

Table 53 Evaluation of the measure "Extended producer responsibility"

Criterion	Evaluation	Points
Bureaucratic effort	very high since necessary structures have to be created first, design for implementation must allow EU internal market to remain undistorted	4
Legal aspects	a regulation on the basis of Article 23 (4) KrWG (or an EU-wide regulation) is needed	3

Criterion	Evaluation	Points
Statistical aspects	collection of statistical data on quantities is ensured due to the reporting obligations of producers and disposers in a system of extended producer responsibility	1
Organisational effort	very high, considering the need to establish a completely new infrastructure for collection and recycling and also the necessary co-ordination between all stakeholders	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding as it will be imposed on the basis of a legislative act	1
Contribution to financing the recycling	finance for collection and recycling is part of an extended producer responsibility regulation and thus ensured by it, adding the disposal costs to the product price results in a financing based on the polluter-pays principle	1
Improvement of collection	the collection of diapers is improved	1
Strengthening of recycling	recycling is strengthened depending on the legally required collection and recycling quotas	1
Acceptance of relevant actors	manufacturers, retailers: low (facing high additional efforts) consumers: low (price increase and higher efforts in separating the waste)	5
Public information needs	high efforts for public information are required, consumers must be informed about how and where they can dispose of nappy waste, the purpose for which an additional levy/higher price needs to be paid and what is the benefit of this	5
Weighted result		**2.8**
Key addressees	German government, manufacturers, retail sector, importers, consumers, recycling industry, public disposal providers	
Summary	Product responsibility for nappies should not be implemented in Germany as long as there is no experience and no infrastructure for that. Moreover, extended producer responsibility usually results in products to become more expensive for customers. Unit prices for nappies are often between 20 and 50 ct. Even additional costs of a few cents per nappy lead to a price increase which is relevant for young families and caring relatives or social institutions as these groups often have few avoidance options and should not be burdened additionally as well as financially.	

7.4.5 Final synopsis

Thus far, there is no experience in implementing the recycling of nappy waste or incontinence and feminine hygiene products in Germany. Therefore, demonstration projects must be initiated as a matter of priority in order to find out the necessary expenditures, suitable framework conditions and existing obstacles explicitly for Germany. Based on this, a decision can be made as to whether and in what form separate collection should be implemented for social facilities or at the level of public disposal providers. In the Netherlands, for example, nappy waste and nappy recycling were included in the national waste management plan. It has been in this context that the separate collection of nappy waste was introduced in many municipalities.

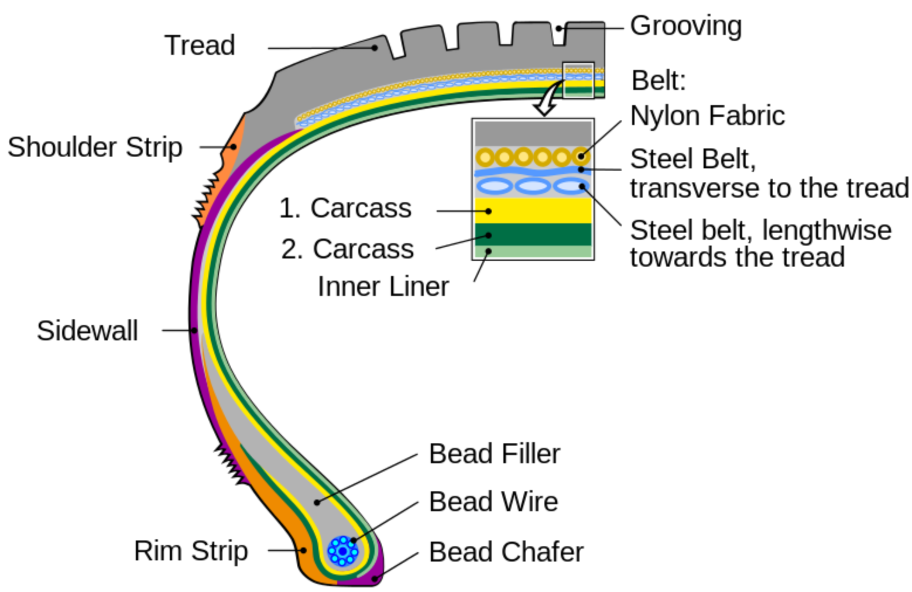
8 End-of-life tyres (ELT)

8.1 General information

8.1.1 Problem definition ELT recycling

Tyres consist of a large number of fundamentally inseparable components such as tread and casing (see Figure 11). Depending on the tyre portfolio, a total of approx. 800-900 different substances are used in production (see Table 54). The main component of tyres is rubber, an elastomer. This material is created by the cross-linking of rubber, known as vulcanization. Each tyre component has its own manufacturer-specific rubber formulation, depending on the type and model of tyre. The most common types of rubber are natural (NR), isoprene (IR), styrene-butadiene (SBR) and butadiene rubber (BR), each of which is divided into different types.

Figure 11 Structure of a radial tyre



Source: Wikimedia Commons, 2014

Elastomers can no longer be melted due to their thermally irreversible crosslinking. In addition, they are very resistant to many known solvents, alkalis and acids, which makes recycling very difficult. For this reason, tyres are mainly ground into granulates (particle size 1–10 mm) and powders (smaller than 1 mm). The tyre is first shredded in several process stages and, if necessary, rubber is separated from other materials (e.g. textile fabric or steel). The granules can then be processed into secondary products such as fall protection mats or granules for artificial turf fields.

The granules can be further refined into powders (0.5-1 mm) or fine powder (< 0.5 mm) in a further processing step, to be used for particularly high-quality products or, for example, in the manufacture of tyres. Two processes have become established for this fine grinding, which are differentiated into hot and cryogenic grinding. In cryogenic grinding, the rubber is cooled below its glass transition temperature with liquid nitrogen (approx. 1.75 kg of nitrogen per kg of rubber), thereby embrittling it and then crushing it by impact. In contrast, hot grinding is carried out at room temperature or above, by introducing high shear forces into the material.

In addition, a number of other recycling processes exist, for example with the aim of improving the processability of the recyclates. One example of this is the reclaim process. This involves replasticizing the material with the primary aim of recovering a rubber-like material through thermal and mechanical treatment of the rubber. This is associated with an improvement in flowability (viscosity), but often also leads to losses in the achievable mechanical properties when used in fresh rubber compounds.

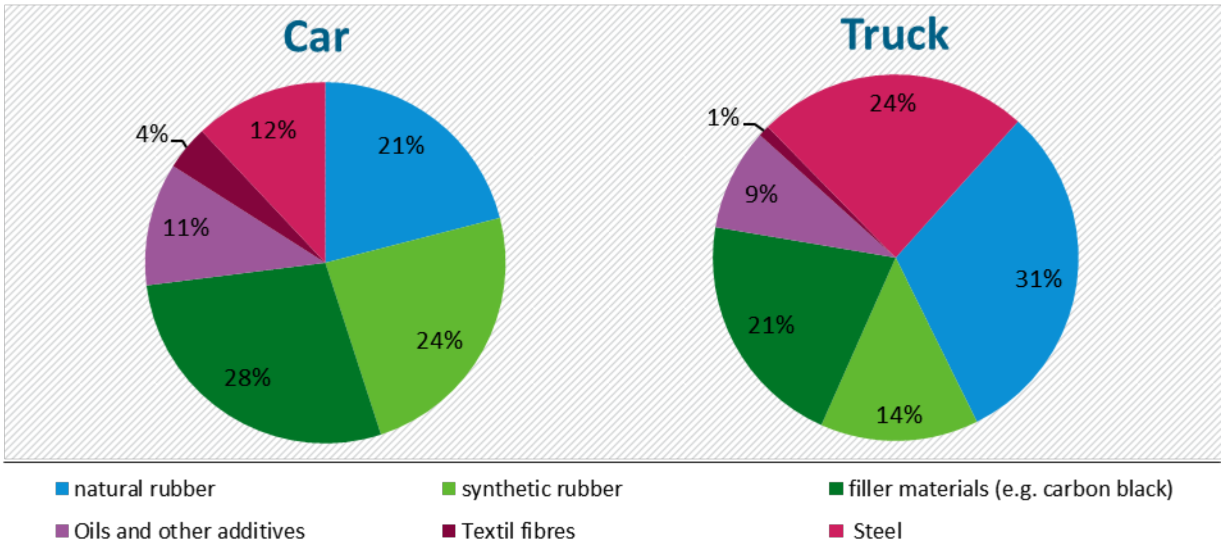
Table 54 Guidance values for the number of substances used in the manufacture of tyres

Substance group	Number of Substances
Substances used in the production of a typical range of tyres produced by a tyre manufacturer. *	800-900
Substances used in the production of a specific tyre on average. **	90
Types of rubber used in the production of a specific tyre on average. **	38 (approx. 30 synthetic and 8 natural rubber types)
Types of carbon black used for the production of a specific tyre on average. **	8

Sources: * Wirtschaftsverband der deutschen Kautschukindustrie, 2013; ** BiCon AG, 2003

A basic distinction must be made between truck and car tyres, SEAL tyres and others (motorcycle, solid rubber tyres, etc.). Truck tyres have a significantly higher natural rubber content (NR, 31%) compared to passenger car tyres (21%), whose main component is styrene-butadiene rubber (SBR, 24%), and a much higher steel content (see Figure 12). Car tyres have a significantly higher textile content (4%, mostly rayon and nylon) than truck tyres (see Figure 12) and are therefore often more difficult to recycle. Increasingly, steel cord is also being replaced by high-strength yarns and cords made of aramid fibres, which further increases the textile content. During fine grinding, for example, textiles can lead to problems such as reductions in productivity or result in a higher proportion of foreign substances in the ground material. There is also a wider range of qualities and compositions in the passenger car sector, such as summer, winter and high-speed tyres. The recycling of SEAL tyres is considered problematic as the viscous sealing material on the inside of the tyres can cause fires during the granulation and can cause granulation tools or the granulate to stick together and smear.

Figure 12 Average material composition of truck or car tyres



Sources: Data of ifeu, 1990; graphic of Hoyer

Sorting and prioritising the use of the different tyre types for specific recycling routes seems to make sense, especially in the context of the polycyclic aromatic hydrocarbon (PAH) content. For example, different ELT recyclates contain statistically significantly different PAH contents. Sorted in ascending order (from low to high): solid tyres, truck tyres, passenger car tyres, truck treads. In this respect, treads, for example, should be returned to the tyre as a matter of priority (closed-loop recycling), which would also make sense in principle from the point of view of material compatibility.

However, using the recyclates for new tyres is generally only possible to a very limited extent (see chapter 8.3.6). Today, ELT recyclates are therefore mainly used in the form of granulates in numerous secondary applications, such as bedding for artificial turf, sports and playground mats and simple moulded parts. Another aim is to produce secondary products based on fine powders (typically in the range between 100 and 800 µm), which are characterised in particular by high optical and mechanical properties that in some areas are equal to products made from primary raw materials. The quantitative significance of such approaches has so far been limited due to the complexity of such innovations, the relatively small niche markets and the persistently low price levels of primary raw materials.

8.1.2 Situation overview of ELT disposal in Germany

The German ELT disposal industry is currently in a critical situation. The main causes are in particular:

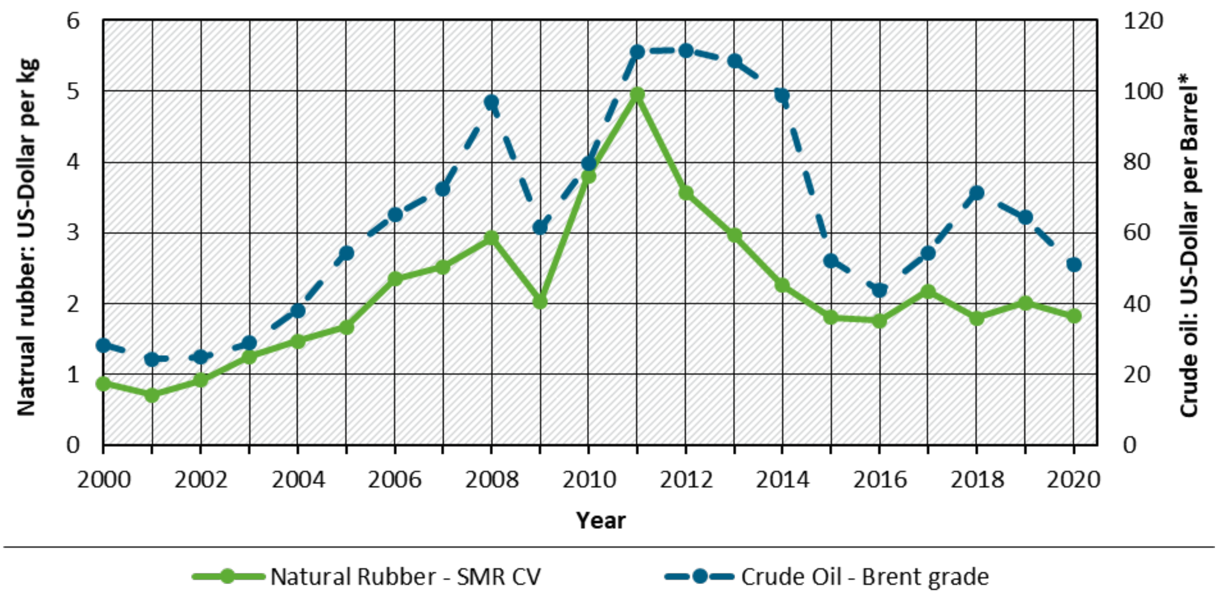
1. a strong preventive limitation of the content of polycyclic aromatic hydrocarbons (PAH) in parts of the established sales markets for ELT recyclates as well as an associated uncertainty of the markets and consumers,
2. a strong decline in the energy recovery of ELTs in cement facilities (see chapter 8.3.3), as well as
3. a generally low level of the prices on the primary raw materials market.

Regarding point 1: In large parts of the established sales markets for ELT recyclate, the PAH content in products has been preventively limited (e.g. Regulation (EU) No. 1272/2013, Model Administrative Regulation Technical Building Regulations (MVV TB 2019/1). The respective regulations do not refer directly to ELT, but to specific product groups or areas of application, such as floor coverings, for which the ELT recyclate is potentially used. Depending on the application, different regulations apply, different types and groups of PAH species are considered and different limit values are set.

Although PAH limit values have been in force in the tyre industry for the plasticizer oils used since 2010 (European Parliament 2006), the filler and reinforcing material carbon black also contains PAHs, the content of which is not regulated at EU level. There is therefore no formal limit value for the total PAH content in tyres, as would be relevant for products under Regulation (EU) No. 1272/2013. Limit values applicable to consumer products (e.g. European Commission 2013) consider the total content of PAHs in the material and not only that of the plasticiser. Accordingly, both the measuring methods and the measuring results are not comparable with those that are relevant for tyre production according to (European Parliament 2006).

Regarding point 3: The prices for the primary raw material rubber have been at a persistently low level since around 2014. Figure 13 illustrates this with the reference prices for the natural rubber type "SMR CV" (green) averaged on an annual basis. To illustrate the correlation, the price development for Brent crude oil is compared here (blue).

Figure 13 Price (annual average) for natural rubber (NR SMR CV grade) and crude oil (Brent grade) (2000-2020)



* a barrel equals 156 litres oil

Values for 2020 are mean values for the period 01.-04.2020 (SMR CV) and 01.-03.2020 (Brent)

Sources: Graphic of Hoyer, Data for natural rubber form Malaysian Rubber Board (2020) and for Brent from Mineralölwirtschaftsverband e.V. (2020)

Compared to the peak value of 2011, the rubber price today is only about 39% (USD 1.92/kg). In the course of this price decline, many rubber-processing companies drastically scaled back their recycling efforts and, in some cases, even closed down entire development departments. Some of the main technology companies in rubber recycling also had to shut down their business operations due to the sharp drop in demand (e.g. Watson Brown HSM GmbH - manufacturer of decuring machines, Deutsche Gumtec AG - recycling of technical elastomers).

The low price levels therefore severely limit the economic viability of the use of ELT recyclate, at least in the rubber processing industry (e.g. tyres). This is currently very likely to inhibit the necessary investments and developments to expand the recycling of ELT. Furthermore, the uncertain development of the PAH limit values and the associated measurement methods is causing a lack of planning security for new investments in ELT recycling.

8.1.3 Legal framework for the disposal of ELT

ELTs are listed in the European Waste Catalogue with the waste code number EWC 16 01 03 (end-of-life tyres). The code according to Annex IX, List B of the Basel Convention is B3140 (end-of-life tyres). End-of-waste criteria are given in Article 6 of Directive 2008/98/EC.

ELT are not classified as hazardous waste. Thus, producers, owners, collectors and transporters of ELT as well as waste management companies are not obliged to keep records and proof in accordance with Section 50 of the German Circular Economy Act (KrWG).

Landfilling of ELTs is prohibited in Germany. Temporary storage can be permitted for a maximum of 3 years.

8.2 Collection of ELT

Due to the lack of mandatory records for ELT, information on collection and recycling of ELT in Germany is incomplete. As part of this study, a survey was conducted among companies along the ELT disposal chain in order to gain a more complete picture (Hoyer et al., 2020a).

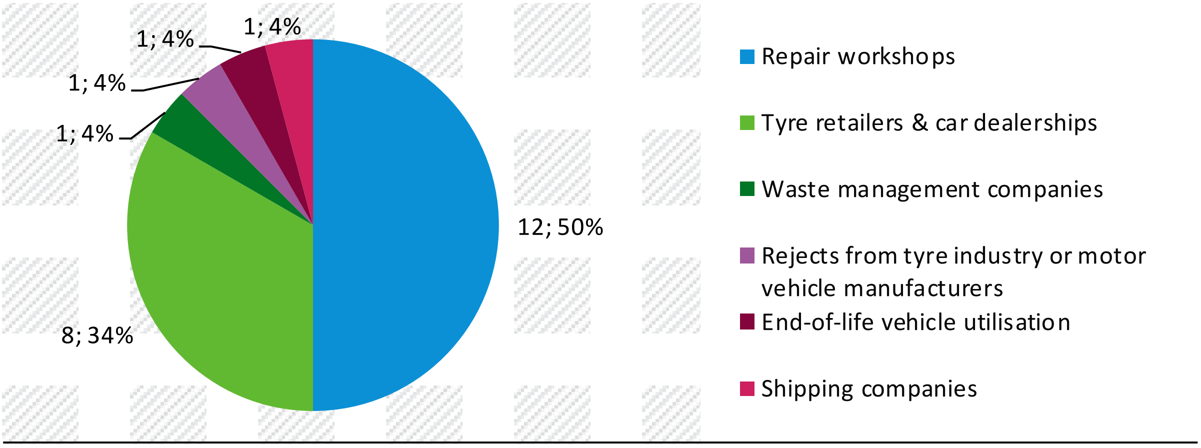
8.2.1 Points of collection

Based on the highly differentiated structure of the tyre market, Wallau (2001) puts the number of points of collection in the old federal states at about 60,000 as of 1996.

- According to estimates by Schwalbe (2019), the largest share of ELT is collected directly by tyre service companies (tyre and car parts dealers, workshops). The share of the total volume is estimated to be approx. 80-90%.
- Bilitewski and Härdtle (2013) put the share of end-of-life tyres from end-of-life vehicle recycling in the total volume at 3%.
- Wallau (2001) states that car tyres account for more than 80% of the ELT volume in end-of-life vehicle recycling.

During the survey companies along the ELT disposal chain were asked what, in their experience, are the main points of collection for ELT. The results are shown in Figure 14. The two most frequently named points of collection were repair workshops as well as tyre retailers and car dealerships.

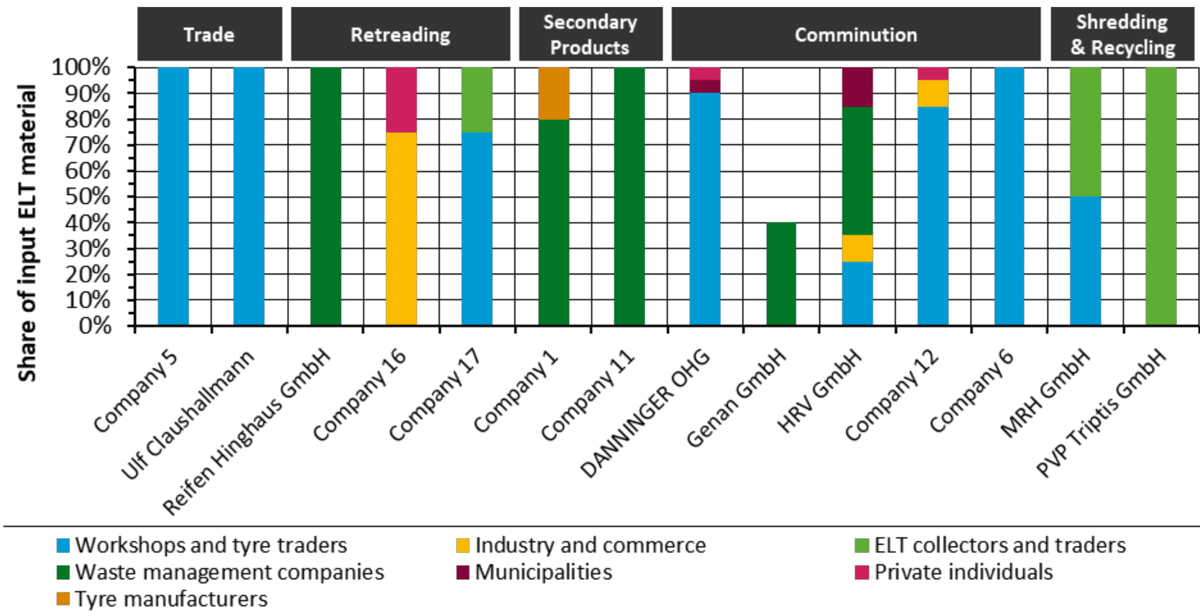
Figure 14 Number of mentions of main collection points for end-of-life tyres by 17 survey participants



Source: Graphic of Hoyer

Furthermore, companies were asked where they obtain their end-of-life tyres or secondary materials from end-of-life tyres (hereinafter referred to as ELT material). The type of supply source and the share of the total input of the respective company were recorded. The results are shown in Figure 15. The participating companies were grouped by their activity profile based on the company's focus of activity. Most companies have one or two supply sources. Only three comminution companies stated to have three or four different supply sources.

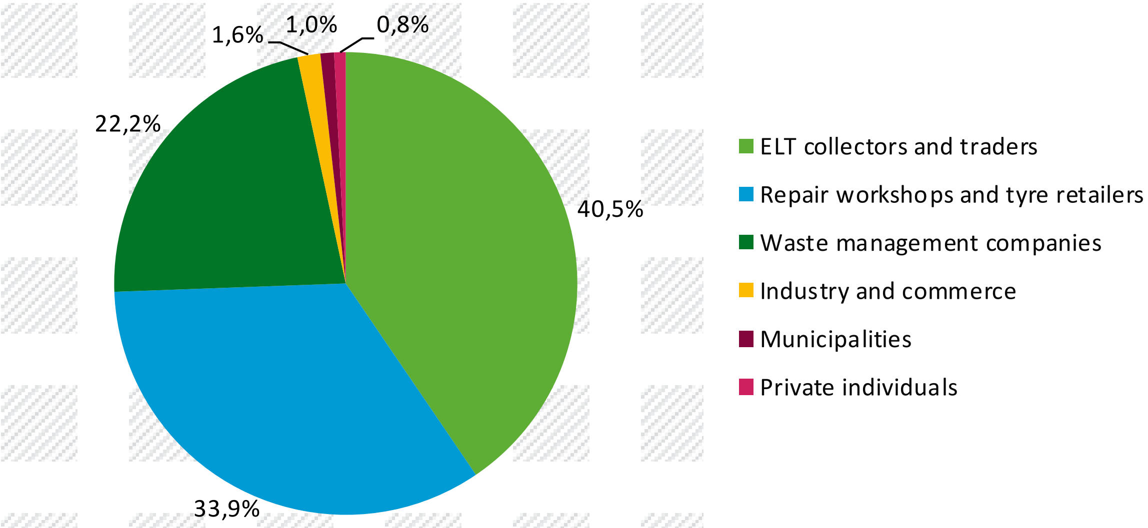
Figure 15 Percentage distribution of sources for end-of-life tyres or secondary materials among 14 survey participants



Source: Data and graphic of Hoyer

Finally, Figure 16 provides an overview of the percentage of sources for ELT material in companies with their own recycling of ELT, for example in the form of shreds, granulates or fine powders.

Figure 16 **Percentage distribution of supply sources for ELTs and secondary materials for seven ELT recycling companies with their own shredding facilities.**



Companies: DANNINGER OHG, company 6, company 12, Genan GmbH, HRV GmbH, MRH GmbH, PVP Triptis GmbH
Source: Data and graphic of Hoyer

8.2.2 Sorting of ELT

8.2.2.1 General information

All sorting or outflows of ELT upstream of the disposal companies are basically unaccounted for in the absence of applicable obligations to keep records and registers and are therefore hardly traceable or quantifiable.

ELTs are generally sorted along the entire disposal chain. This can be done by the respective waste holders and by traders and collectors. The latter can, for example, be specialised casing dealers or ELT traders who visit the points of collection on a regular basis. The collection points often pre-sort according to the needs of the traders.

In principle, the points of collection have an economic interest in selling as many ELTs as possible to dealers in order to save disposal costs or to generate additional revenue (see chapter 8.2.6). Typically, ELTs that can be prepared for reuse are sorted out directly at the points of collection. This refers in particular to ELTs with a tread depth of at least 4 mm. According to Schwalbe (2019), the share of ELTs with a corresponding residual tread that have already been sorted out is around 90%. ELTs that are suitable for retreading (primarily truck tyres) are usually bought up by casing dealers at the points of collection.

8.2.2.2 Survey data on ELT suitability for reuse or retreading

In the survey (Hoyer et al, 2020a), the companies were asked about their assessment of what portion of the ELTs they collect or receive is suitable for full reuse. No specifications were made as to which criteria an ELT must fulfil for reuse. Reuse can therefore be both a national reuse, in compliance with the relevant requirements, and an export for reuse. The results are shown in Table 55.

Table 55 Share of directly reusable ELTs among the ELTs collected or accepted

Company	generally reusable	generally reusable presorted	generally reusable not presorted	reusable truck tyres
Tyre trade and service				
Company 5	5%			
Ulf Claushallmann	10%			
Retreading				
Company 16	10%			
Company 17	20%			
Pure comminution (shreds, granulates powders)				
Company 2	20%			15%
DANNINGER OHG	5%			
HRV GmbH	15%	5%	25%	10%
KARGRO GROUP				50%
Company 11	10%			
Shredding and recycling				
Company 6	30%			

Source: Hoyer et al., 2020a

The data of the group "generally reusable" was further statistically evaluated. Based on an analytical regression estimation method, a normal distribution N (μ, σ2) was approximated to the cumulative frequency of the data for the percentage of tyres that can be reused without restrictions. Based on the data, the expected value μ is 10.3% (0.103) with a standard deviation σ of 8% (0.08). Experience shows that the proportion is strongly dependent on the region and tends to be lower in metropolitan regions.

In the survey (Hoyer et al, 2020a), the companies were asked about their assessment of what portion of the ELTs they collect or receive is suitable for retreading.

Table 56 Share of ELTs that are fundamentally suitable for retreading

	Generally retreadable	Generally retreadable presorted	Generally retreadable not presorted
Tyre trade and service			
Company 5	5%		
Ulf Claushallmann	10%		
Retreading			
Company 16	10%		
Company 17	20%		

	Generally retreadable	Generally retreadable presorted	Generally retreadable not presorted
Pure comminution (shreds, granulates powders)			
Company 2	20%		
DANNINGER OHG	5%		
HRV GmbH	15%	5%	25%
Company 11	10%		
Shredding and recycling			
Company 6	30%		
MRH Mülsen GmbH		5%	30%

Source: Hoyer et al., 2020a

8.2.3 Logistics

Pursuant to Section 53 (1) KrWG in conjunction with the Waste Notification and Permit Ordinance (AbfAEV), collectors, transporters, traders and brokers of waste must notify the competent authority of the activity of their business before commencing operations.

The logistics, i.e. the route from the points of collection to the waste management companies, are highly diversified. In principle, ELTs can be delivered directly to the waste management companies by the respective waste owners or third parties. Furthermore, the ELTs can be collected by a corresponding waste management company, some of which have established their own logistics networks or partnerships with logistics companies and also operate their own points of collection throughout Germany. Furthermore, there are often contingent contracts between individual ELT waste management companies and larger chains or dealer associations for the collection of agreed (annual) quantities. Billing can be done by piece, weight or volume (e.g. per container) and also depends on the quality of the tyres (e.g. percentage of tyres with a tread depth > 1.6 mm).

Some resellers also collect ELT from the points of collection. In some cases, lower disposal costs are offered than those of the established waste management companies. The ELTs are then usually temporarily stored and sorted by the resellers. The business model is to resell or export the ELT as profitably as possible in order to dispose of them at lower costs. Due to miscalculations or sharply rising disposal costs, there is a risk that the temporarily stored ELT can no longer be sold at a cost-covering price. In this context, the formation of unauthorised ELT stockpiles can be the consequence.

8.2.4 Waste management companies

According to Section 49 para. 1 KrWG, "disposers of waste" are understood to be the operators of facilities or companies that dispose of waste in a procedure according to Annex 1 or 2 of the KrWG.

Only when the waste tyres are received by a waste management company is an internal accounting carried out within the framework of the statutory register obligations. There is no general obligation to submit the registers to an authority or to communicate information from them. However, this can be ordered by the authorities on the basis of Section 49 para. 2 KrWG.

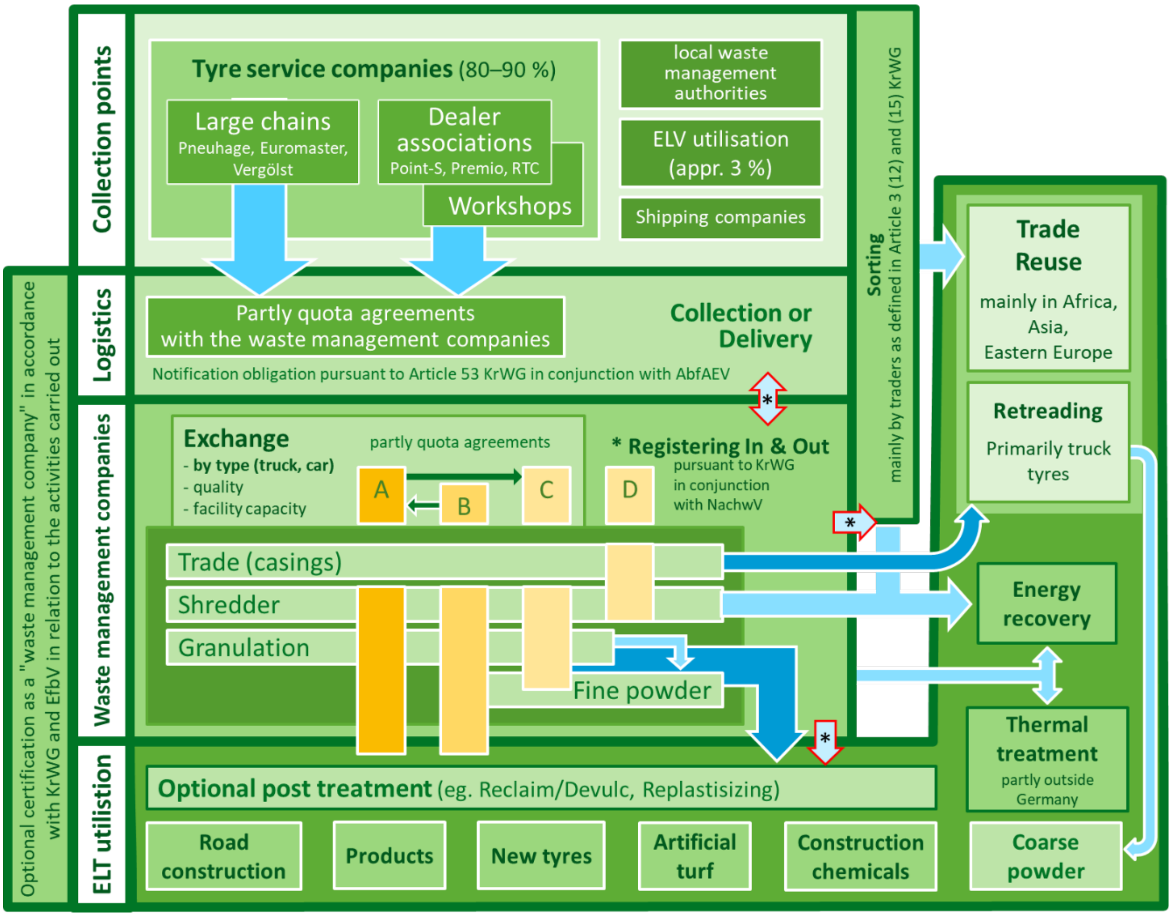
In many cases, all types of tyres (cars, trucks to bicycles) are accepted without restriction by the waste management companies, although the quantity is generally limited depending on the existing recycling capacities. Some waste management facilities only accept special tyre types (e.g. only solid tyres) or exclude the acceptance of specific tyre types (e.g. bicycle, motorcycle or wheelbarrow tyres, see HeidelbergCement AG, 2019). Furthermore, there are often specific restrictions, for example with regard to contamination or impurities, tyre age or country of origin.

According to estimates by Schwalbe (2019), the share of reusable tyres (approx. 1.6-4 mm) in non-pre-sorted containers is approx. 20-25% (truck and car tyres, see Table 56). Experience has shown that the share is strongly dependent on the region and tends to be lower in metropolitan regions.

On the premises of the waste management companies, the tyres are usually further sorted by the companies themselves and, depending on the company philosophy, occasionally also by dealers. Depending on capacity utilisation and specialisation, e.g. the exclusive recycling of truck or car tyres, there is also a mutual exchange of tyres between the individual waste management companies. Some of the companies have formed networks for this purpose and in some cases, there are also quota agreements between them.

The vertical range of manufacture at the various waste management companies varies greatly. Figure 17 shows examples of waste management companies from different operations as vertical bars with the designation A–D; the vertical extension illustrates the vertical range of manufacture. While some companies, for example, only produce refuse-derived fuels (D), others also produce granulates and, if necessary, fine powders in a second stage (C), which are then sold. Finally, there are also companies that produce granulates (A, e.g. PVP Triptis) or rubber powder (B, e.g. MRH Mülsen) themselves and process them into their own products.

Figure 17 Qualitative overview of the process of collection and disposal of ELTs in Germany



ELV – end-of-life vehicles; AbfAEV - Ordinance on the Notification and Permit Procedure for Collectors, Carriers, Traders and Brokers of Waste; EfbV - Ordinance on Waste Management Companies; KrWG - Circular Economy and Recycling Act; NachwV – Ordinance on Waste Recovery and Disposal Records

Source: Graphic of Hoyer

One of the major car-part dealers in Germany, the Auto-Teile-Unger Handels GmbH & Co. KG (A.T.U) has founded its own subsidiary, Estato Umweltservice GmbH (formerly "A.T.U Umweltservice"), which is in charge of the waste management for all branches of the A.T.U Group. According to its own information, this company has an annual capacity of 14.6 million tyres (110,000 tons). Around 8 million ELTs are processed here annually (A.T.U., 2019).

8.2.5 ELT statistics

8.2.5.1 Waste balances of the German Federal States

The waste statistics of the federal states of 2017 and, where already available, 2018 were evaluated for this study. Of the 16 federal states, eight states do not report ELTs in their waste balance sheets. Bavaria only reports at how many collection sites the public disposal providers have collected ELTs. The results of the remaining states are shown in the following table:

Table 57 Data on end-of-life tyre disposal in the waste balances of the federal states

Federal State	Collected amount by municipal waste management companies 2017	Collected amount by municipal waste management companies 2018
Berlin	603 t	Not available yet

Federal State	Collected amount by municipal waste management companies 2017	Collected amount by municipal waste management companies 2018
Brandenburg	202 t “abandoned” ELT 962 t treated ELT	225 t “abandoned” ELT 1,027 t treated ELT
North Rhine-Westphalia	3,019 t as commercial waste	Not available yet
Rhineland-Palatinate	1,412 t	1,474 t
Saxony	452 t	Not available yet
Saxony -Anhalt	345 t	Not available yet
Thuringia	265 t 14,496 ELT	178 t 15,861 ELT

Saxony reported in its 2017 waste balance a rising trend in ELT generation in recent years.

8.2.5.2 ELT statistics in ‘Fachserie 19 Reihe 1’

The Federal Statistical Office documents the input and output of ELTs in waste treatment facilities, separated by type of facility, in Fachserie 19, Reihe 1 (Destatis 2019), under the waste code 16 01 03. The data for the years 2014 to 2017 is shown in Table 58 and Table 59.

It should be noted that an end-of-life tyre can go through several treatment steps and is thus recorded several times as input or output. In this respect, it is not possible to draw direct conclusions from these figures about the actual amount of ELT produced in Germany.

Table 58 ELT Input in waste treatment facilities according to Fachserie 19 in 1,000 t/a

Year	Table 3.1 Thermal treatment	Table 4.1 Combustion facilities	Table 10.1 Shredders and scrap shears	Table 11.1 Sorting facilities	Table 13.1 other treatment facilities	Table 1.1 Total waste treatment facilities
2014	2.1	168.8	219.4	74.0	216.4	**677.3**
2015	1.1	168.6	184.4	84.5	203.7	**642.3**
2016	0.1	178.0	203.1	90.3	190.6	**662.1**
2017	0.1	191.9	138.7	73.1	200.9	**704.7**

Source: Destatis, 2015-2019

Table 59 ELT output of waste treatment facilities according to Fachserie 19 in 1,000 t/a

Year	Table 9.2 Dismantling companies for end-of-life vehicles	Table 10.2 Shredders and scrap shears	Table 11.2 Sorting facilities	Table 13.2 other treatment facilities	Total
2014	13.1	28.9	67.8	50.0	**160.7**
2015	12.9	24.7	79.1	61.1	**177.8**
2016	12.6	81.0	72.4	56.6	**222.6**
2017	14.7	94.8	57.4	55.5	**222.4**

Source: Destatis, 2015-2019

8.2.5.3 Data collection of the GAVS/wdk

The Gesellschaft für Altgummi-Verwertungs-Systeme mbH (GAVS; Society for Waste Rubber Recycling Systems), which is part of the Wirtschaftsverband der deutschen Kautschukindustrie e.V. (wdk; German Rubber Manufacturers Association), used to determine the volume of ELT in Germany on an annual basis. The GAVS was discontinued in 2018 and its tasks were transferred to Mr Stephan Rau, technical managing director of the wdk.

The quantity of ELTs is calculated by GAVS on the basis of empirically based assumptions from public statistics as well as its own data surveys in the member companies.

The GAVS first calculates the total weight of the used tyres from the replacement market figures for new tires from the German Tyre Retail and Vulcanisation Trade Association (BRV), assuming that an end-of-life tyre is incurred for each new tyre. The BRV shows the replacement market for new tyres in great detail, but only records the number of tyres (BRV, 2019). The GAVS therefore has to convert tyre numbers into mass, for which estimated or approximate values for the average unit weight of tyres of a specific vehicle group are used. In order to arrive at a total mass of the end-of-life tyres generated on the basis of the tyre replacement business, the weight loss due to abrasion is estimated and subtracted from the values determined.

The calculated ELT generation for 2012-2019 are shown in the following table. Based on the given data the material losses due to wear and abrasion (position 4) are, on average, 8.5%.

Table 60 ELT generation in Germany according to GAVS in 1,000 t/a

Pos.		2012	2013	2014	2015	2016	2017	2018	2019
1	New tyres according to BRV (tyre replacement market)	509	507	498	499	508	513	513	497
2	Retreaded tyres according to BRV (tyre replacement market)	47	43	42	37	35	34	34	33
3	**Total replacement demand for new tyres (Pos. 1+2 plus 8,000 t/a in 2015-2019)**	**566**	**560**	**550**	**544**	**551**	**555**	**555**	**538**
4	Losses due to wear and abrasion	50	49	49	43	45	45	45	44
5	**Total ELT (Pos. 3 minus Pos. 4)**	**516**	**511**	**501**	**501**	**506**	**510**	**510**	**494**

Source: GAVS/wdk

The chosen approach seems conclusive, but requires very precise estimates of the respective factors for unit weight and abrasion. In principle, it can be assumed that the GAVS and the wdk have access to reliable data. In the following, a plausibility check is carried out on the figures calculated by the GAVS for the volume of ELTs.

8.2.5.4 Plausibility check of GAVS data on ELT generation

For the plausibility check the same data for the tyre replacement market of the BRV is used, but the average unit weight for the different tyre types and the abrasion loss is calculated based on a separate data set.

For the average unit weight calculation, a data set provided by the company MRH Mülsener Rohstoff- und Handelsgesellschaft mbH was used. The data set comprised of 12 measurement series with a total number of 50,000 end-of-life tyres in 78 containers. For each measurement series the number of containers and their total weight as well as the number of received ELT per tyre type had been recorded.

The average unit weight was calculated using a Monte-Carlo-Simulation and reasonable limits for the expected value of each individual tyre type were set. The resulting approximate values were used to calculate the theoretical container weight for all 78 containers. The maximum deviation between real and theoretical container weight was -5.5% and +10%.

Based on the approximate values for the average unit weight of ELT, the total weight of ELT for 2017 and 2018 was calculated based on the BRV replacement market data. The results are shown in Table 61.

Table 61 Calculated ELT generation in Germany

Tyre type	Average unit weight [kg]	Replacement market 2017 * [tyres]	Replacement market 2018 * [tyres]	Calculated total weight 2017 [1.000 t]	Calculated total weight 2018 [1.000 t]
Cars	8.8	47,496	46,699	417.4	411.0
Light trucks	25.0	3,796	9,769	94.9	94.2
Trucks - total	55.0	2,734	2.771	150.4	152.4
Motorbike / scooter	3.5	1,737	1,694	6.1	5.9
Farm	69.0	253	251	17.5	17.3
Earth Mover	175.0	42	41	7.5	7.2
Total				**693.8**	**688.0**

Source: * BRV, 2019; Hoyer

Table 62 compares the GAVS data with the values determined in Table 61. According to the GAVS data, around 510,000 t of end-of-life tyres were generated in Germany in 2018. Using our own calculation, a volume of around 688,000 t was determined. For 2017 and 2018, the values of our own calculation are on average around 35% higher than those of the GAVS, which corresponds to a difference of around 178,000 tonnes.

Table 62 Comparison of the plausibility check and GAVS data in 1,000 t/a

Results	**2017**	**2018**
ELT generation according to GAVS (Table 60)	510	510
ELT generation – own calculation (Table 61)	694	688
Difference in 1,000 t	**184**	**178**
Difference in% based on GAVS values	**+ 36.1%**	**+ 34.9%**

Source: GAVS; Hoyer

Although the weight data of the GAVS are also calculated based on the BRV replacement market figures, there is a significant difference between the results. It is not possible at this point to assess the reason for this difference and which result better reflects reality. On the one hand, the mean unit weights determined here (Table 61) show very good agreement with reality; on the other hand, these are only estimated values obtained on the basis of mathematical optimisation methods and their significance is therefore not assured. The exact conversion factors of the GAVS are not known. After consultation with the wdk, their weight assumptions for the individual tyre types are more differentiated and, in many cases, also different from the assumptions made here. The high difference of around 35% illustrates how great the influence of corresponding conversion factors is and the limits of this accounting approach.

8.2.5.5 Share of the different tyre types in the total volume

The GAVS statistics do not differentiate the quantity of ELTs into the various tyre types. Wallau (2001) quotes sources for 1996 on the different shares of car, truck, light truck and other tyres. In Table 63, the given data was compared to the results of the plausibility check (Table 61). For the comparison, motorbike, farm and EM tyres were combined into other tyres. Overall, the two data sets are quite similar. Car tyres have the highest share in ELT generation with a little more than 60%, followed by truck tyres at about 20%. Wallau also states that car tyres account for more than 80% of the ELT volume in end-of-life vehicle recycling.

Table 63 Shares of tyre types in ELT based on plausibility check and Wallau (2001)

Tyre type	Calculated share 2017	Calculated share 2018	Average value 2017-2018	Wallau (2001) 1996
Car tyres	61.3%	60.9%	61.1%	62%
Truck tyres	22.9%	23.4%	23.2%	20%
Light truck tyres	11.1%	11.1%	11.1%	10%
Other tyres	4.7%	4.6%	4.6%	8%

Source: Wallau, 2001; Hoyer

8.2.5.6 Cross-border waste disposal of ELT

According to UBA data, there have been no transboundary shipments of ELTs as waste requiring authorisation in recent years. Only in 2009 were 3,000 t of ELTs exported.

8.2.6 Disposal costs for ELT in Germany

Currently, it is common practice in Germany for consumers to pay a disposal fee when handing in their ELTs. Based on a cost of 2.60 € per car tyre and an average weight of 8.8 kg, this results in a revenue of 295 €/t of ELTs at the point of collection. In relation to the total amount of used car tyres of 410,000 t in 2018, this corresponds to an estimated total revenue of €121 million per year for car tyres alone.

The costs for the disposal of ELTs at certified waste management companies amount to approximately 40-135 €/t. The price depends on the volume. For larger volumes over 500 tons per year, the price is on average 40-50 €/t plus collection fee.

20% of the used car tyres are resold directly at the point of collection and from used tyre dealers, respectively. The remaining ELTs are disposed of at waste management companies for an average 87.5 €/t. Since about 80% of the accepted ELTs have to be disposed of, this corresponds to relative disposal costs of 70 €/t ELT which are offset by collected disposal fees of 295 €/t. Accordingly, it can be stated that only a quarter of the disposal fees paid by consumers actually reach the waste management companies. The remaining amount is retained by tyre dealers, transporters and other intermediaries, with additional revenue generated by the sale of still usable end-of-life tyres.

8.2.6.1 Costs for recycling and recovery

Based on an electricity price of 18.55 cents per kilowatt hour (incl. taxes) and a specific energy requirement for granulation of 0.25 kWh/kg of end-of-life tyres (see Figure 30), the pure energy costs for the recycling of end-of-life tyres into granulate amount to 46.38 €/t. The disposal costs charged by certified recycling companies are thus of the same order of magnitude as the energy costs for granulation.

The cost of disposing of the end-of-life tyres in cement facilities is around 70-110 €/t. Depending on the acceptance conditions, however, the ELTs must first be pre-shredded.

8.2.6.2 Purchase prices for reuseable tyres

According to the survey results (see Table 55), about 25% of car ELTs can be reused without any pre-treatment. They are usually exported. Table 64 gives exemplary purchase prices for reusable tyres. The estimated average purchase price is given in brackets.

Table 64 Purchase prices per tyre for reusable tyres in relation to tread depth

Tyre type	> 4 mm	> 5.5 mm	> 7 mm	> 10 mm
Truck			5 – 40 € (10 €)	10 – 50 € (20 €)
Light truck			8 – 20 € (10 €)	10 – 30 € (15 €)
Car	1.50 – 3.5 € (3 €)	4 – 10 € (6 €)		

Source: Kurz Krakassenhandel GmbH, 2020

If 20% of the used car tyres are resold at the points of collection or by ELT dealers and if a revenue of €3 per used car tyre is taken as a basis, this results in additional revenue amounting to €68 per tonne of used car tyres (at 8.8 kg per ELT).

ELTs that are suitable for reuse after preparation for reuse like retreading achieve on average lower prices.

Table 65 shows the purchase prices of the retreading company Rigdon GmbH for suitable tyres without referencing tread depth.

Table 65 Exemplary purchase prices for ELTs by a retreading company

Tyre type	Price range per tyre	Average price per tyre	Average weight per tyre	Average price per tonne
Light truck	5 – 12 €	7.85 €	25 kg	314 €/t
Truck	5 – 40 €	15.87 €	55 kg	289 €/t
EM radial tyres	20 – 120 €	58.67 €	175 kg	335 €/t

Source: Rigdon GmbH, 2020

Table 66 shows the purchase prices for ELTs of a casing dealer. The purchase price for truck tyres at the casing dealer are for tread depth below 7 mm and for car tyres with a minimum tread depth of 2.5 mm.

Table 66 Exemplary purchase prices for ELTs by a casing dealer

	Price range per tyre	Average price per tyre	Average weight per tyre	Average price per tonne
Light truck	5 €	5 €	25 kg	200 €/t
Truck	5 – 30 €	10 €	55 kg	180 €/t
Car	1 – 2 €	1.5 €	8.8 kg	170 €/t

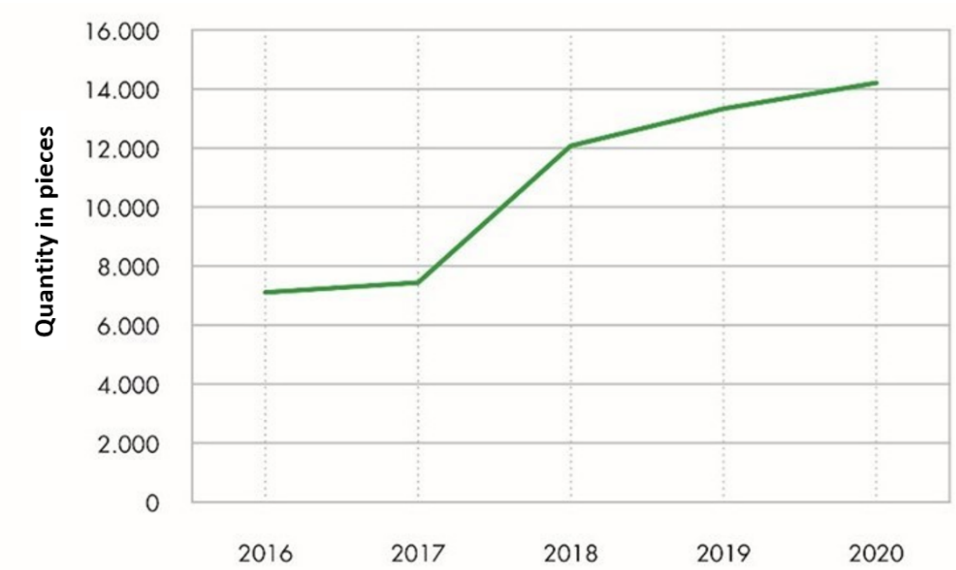
Source: Kurz Krakassenhandel GmbH, 2020

8.2.7 Illegal disposal activities

Illegal disposal includes, on the one hand, end-of-life tyre storage facilities whose permissible storage capacity or storage period of 3 years is exceeded and, on the other hand, illegal deposits and dumping outside ELT storage facilities.

The available data does not allow any conclusions to be drawn concerning the amount of illegally disposed ELT in Germany. Since 2016, the Initiative Certified Waste Tyre Disposal Company (ZARE) has been the only organisation in Germany to document cases of illegal end-of-life tyre disposal in Germany, based largely on reports from Google Alerts, press releases as well as messages from their network. The corresponding information can be viewed on their website (ZARE, 2020). According to the ZARE, there has been a strong and continuous increase in the number of cases since 2017.

Figure 18 Estimated numbers of illegally disposed ELT in Germany between 2016-2020



Source: Zare, 2020; Contains no claim to accuracy, as the figures are only estimates

According to the wdk, the return of end-of-life tyres by consumers works well. Illegal dumping of ELTs is mainly caused by dubious ELT collectors and dealers whose business model primarily consists of reselling still usable tyres. The ZARE estimates the share of illegal dumping by private individuals at 14%.

According to the state government of Saxony-Anhalt, there were four ELT depots or dumps above 100 t in Saxony-Anhalt in May 2017. About 3,040 t of ELT were stored in them (Landesregierung Sachsen-Anhalt, 2017a).

The state of Brandenburg shows "abandoned", i.e. presumably illegally dumped, ELTs in its waste balances. In 2018, the share of abandoned ELTs (225.000 t) of all ELTs collected by public waste management authorities in Brandenburg (1,027,000 t) was about 22% (MLUK, 2020).

This value corresponds to the results of a study on the volume of end-of-life tyres in the Federal Republic of Germany in 1987 (Federal Government, 1995). In this study, the fate of 20-22% of the end-of-life tyres was unknown.

8.3 Recovery of ELT

8.3.1 Introduction

In addition to the generation of ELT, GAVS/wdk also determine the volume of ELTs for the individual recycling channels. The results are shown in the table below.

Table 67 GAVS statistics on ELT recycling for the years 2012-2019 (in 1,000 t/a)

Pos.	Recycling Channel	2012	2013	2014	2015	2016	2017	2018	2019
8	Total ELT for recycling and recovery	582	582	571	568	577	584	583	571
9	Reuse, domestic	10	10	10	8	8	8	8	8
10	Export for reuse	93	84	71	64	62	67	60	55
11	Export for retreading	43	41	39	38	41	46	49	48
12	Export for energy recovery	N/A	N/A	10	10	6	6	6	6
13	Casings for retreading	38	34	34	30	28	27	27	26
14	Recycling (granulates, powders)	190	190	202	203	231	229	236	251
15	Energy recovery (cement industry)	234	234	202	215 1)	201 1)	201 1)	196 1)	175
16	unknown	N/A	N/A	3	N/A	N/A	N/A	N/A	N/A

N/A – no data available; 1) "preliminary values"

The category "Export for energy recovery" probably also includes thermal treatment of ELTs.

Surprisingly, the GAVS data show the largest increase in recycling of ELTs in the form of granulates and powders in the first year (2016) after the PAH limits under Regulation (EU) No. 1272/2013 came into force. Recycling increased that year by 13.8%.

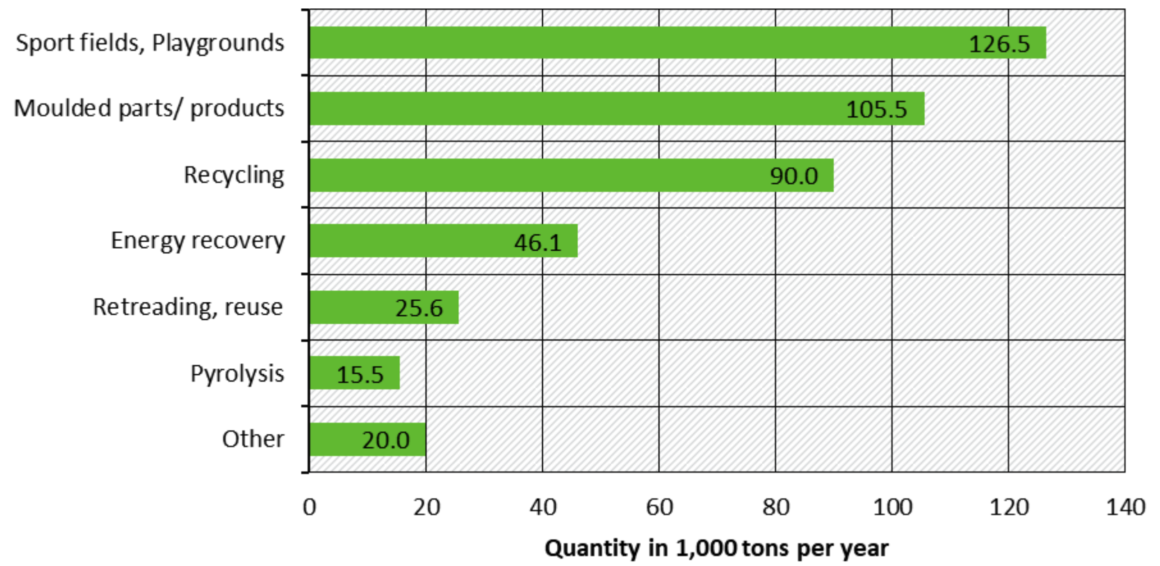
8.3.2 Sales markets for recycling products or secondary raw materials – survey results

In the survey (Hoyer et al, 2020a), the companies were asked about the sales markets for their products. Only the data from ten companies with recycling as their main purpose were taken into account. In general, "products" can include whole tyres that have been sorted out before further processing for energy recovery, shreds, granulates, powders or products made from ELT recyclates.

The question was asked what the sales markets for the secondary materials or products of the companies are and what quantity (in mass per year) these markets recycle. Figure 19 provides an overview of the mass recycled per sales market or recycling path.

It cannot be ruled out that ELT material is recorded several times here, e.g. granulates from one company serve as the basis for products from a second company. Furthermore, the data could also include imported recyclates.

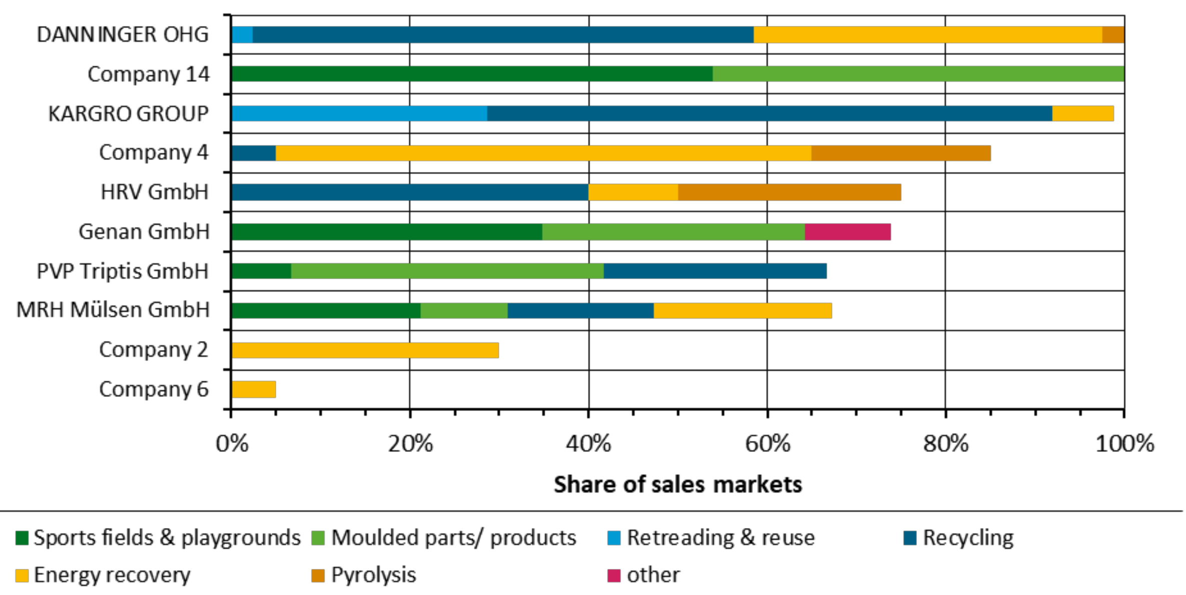
Figure 19 **Survey results for main sales markets for products or secondary raw materials from ELTs (total volume 429.200 t)**



Source: Hoyer et al., 2020a

Figure 20 shows the approximate percentage distribution within the companies in the categories sport fields and playgrounds, energy recovery, reuse and retreading, molded parts and products, pyrolysis and recycling. Most companies only provided information on some of their products.

Figure 20 **Share of the main sales markets for products or secondary raw materials from ELTs for the surveyed companies**



Source: Data and Graphic of Hoyer

8.3.3 Energy recovery in cement industry

With the annually updated "Environmental data of the German cement industry" (VDZ 1998-2019), the German Cement Works Association (VDZ) documents, among other things, the use of ELTs in clinker and cement production. The following is an overview of the data for the years 1998 to 2019.

Figure 21 ELT recovery in the cement industry in the years 1998 to 2019

Source: Data of VDZ, 1998-2019; Graphic of Hoyer

According to the Bavarian State Office (2011), ELTs have a calorific value of around 29 megajoules (MJ) per kilogram (equivalent to 7.2 to 8.9 kWh/kg). This is the equivalent of 0.7 kg of crude oil (42 MJ/kg). In principle, ELTs are well suited as a substitute fuel for cement production, as they can be completely recycled for materials and energy and have a high biogenic content.

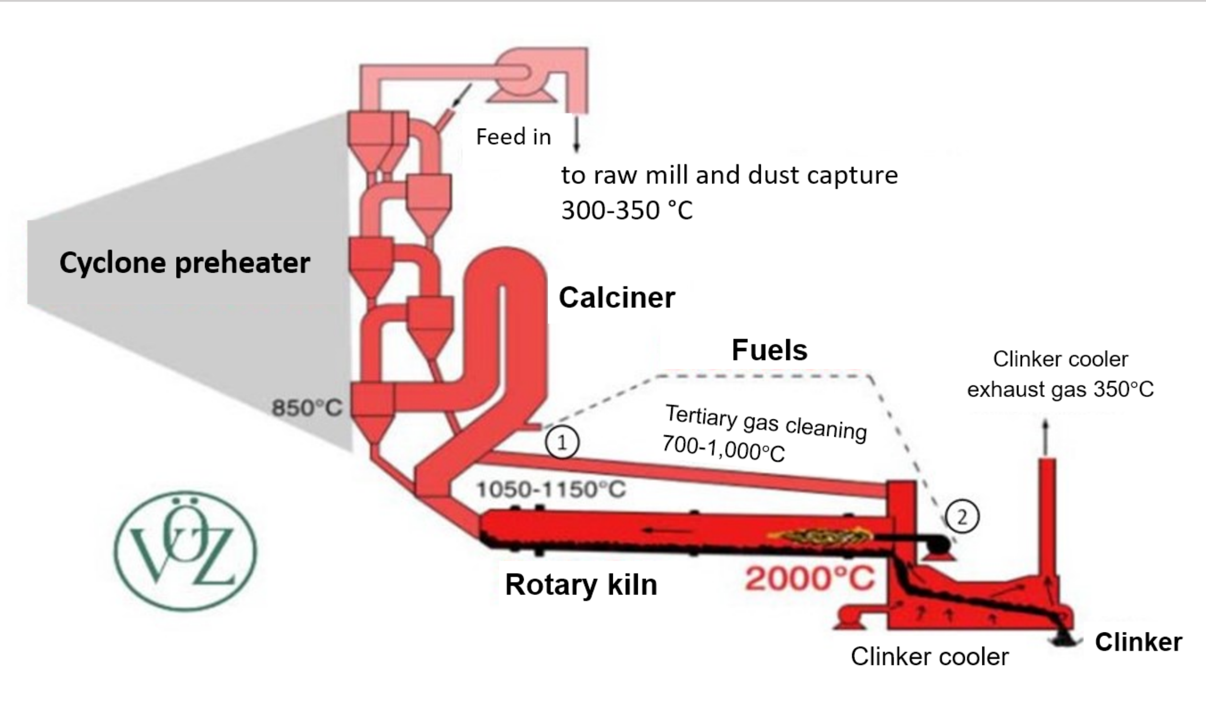
Rotary kilns are used for cement production. The end-of-life tyres are fed into the kiln inlet as whole tyres or in shredded form and transported towards the main firing (up to 2000 °C, "hot" side) by the rotary movement and the inclination of the kiln. Along the way, they are completely burnt at more than 1000 °C. The non-combustible materials (e.g. the steel) are completely incorporated into the clinker matrix as iron components. The ELTs are thus completely recycled both energetically and materially. Depending on the type of kiln, up to 25% of primary energy sources can be saved by using ELTs (Braun, 2001). According to Braun (2001), it has been scientifically proven that the secondary fuels have no negative effects on the environment if the process is managed appropriately. VDZ (2020) also states that the use of ELTs is not critical with regard to applicable emission control requirements.

The mass of ELTs recycled in the cement industry is strongly declining (Figure 21). According to Danninger (2020), the cement facilities of HeidelbergCement AG in Burglengenfeld and Schelklingen have so far recycled around 45,000 t of ELTs per year. Due to the technical conversion to short kilns, no more ELTs will be recycled in these facilities in the future. The Märker Holding GmbH cement facilities in Harburg will also reduce the energy recovery of ELTs from 30,000 tons to only 10,000 tons per year in the future due to a technical conversion of the kiln and will only accept pre-shredded tyres (probably in the size range of 2.5 cm).

In Bavaria alone, recycling capacities of approximately 65,000 tons per year will be lost. This corresponds to a share of 11% of the total volume of ELTs in Germany in 2018, or 33% of the ELTs used for energy recovery in cement facilities to date.

When asked, the Verein Deutscher Zementwerke e.V. (German Cement Works Association) provided the following explanation (VDZ 2020): In order to increase efficiency and competitiveness, cement facilities are being converted to so-called short kilns. In a short kiln, a cyclone preheater with calciner is installed upstream of the rotary kiln (see Figure 22). The rotary kiln has a length-to-diameter ratio of about 10-14. The main reaction is the deacidification of the limestone, known as calcination. It takes place in an entrained flow reactor, the calciner. In facilities without a calciner, this reaction must take place in the rotary kiln, which means that these kilns are somewhat longer with a length-to-diameter ratio of up to 18.

Figure 22 Schematic representation of a rotary kiln with cyclone preheater and calciner



Source: Braun, 2001 (modified)

In calciners, about two thirds of the total energy demand of the process is required for the endothermic reaction of calcination alone. For this, combustible fuels capable of flight are required (addition at position 1, see Figure 22), which are to be carried by the hot gases of the rotary kiln and burn in the calciner. Non-flammable fuels, such as ELTs, are therefore used to a lesser extent at these facilities. According to VDZ (2020), finer shredding or grinding of the ELTs could be a possibility.

The use of ELT as whole tyres or as shreds is not possible in the main firing system (position 2 in Figure 22). Due to the counterflow principle (gas and solids are run in opposite directions), any coarse-particle fuels would dip directly into the clinker melt. They would disrupt the clinker formation and, in particular, the steel component would no longer melt sufficiently.

It could not be conclusively assessed to what extent there are also economic interests in resorting to the current oversupply of other RDFs. This is mainly plastic waste, which is increasingly being generated due to the import ban abroad, or secondary fuels, which are increasingly being displaced from co-incineration in lignite-fired power plants. Regardless of the technical and economic causes, individual ELT waste management companies have reported a tripling of disposal costs for ELT in the cement industry. This is supposedly additionally overlaid by a low crude oil price.

Individual ELT waste management companies have forecast a further deterioration of the situation and the elimination of further quotas in Germany. There are even fears that ELTs could develop into a fraction that is no longer necessary in the cement industry. Furthermore, it can be assumed that the deficit of corresponding recycling capacities in Germany will lead to an increased export of ELT for energy recovery and thermal treatment. This is not least due to the fact that for some types of tyres there are no alternative disposal routes and thermal treatment, or ideally energy recovery, is the only option.

8.3.4 Retreading of ELTs

8.3.4.1 Overview

The retreading of ELT is a preparation for reuse according to Section 3 para. 24 KrWG. In the passenger car sector, the share of retreaded tyres in the tyre replacement market was significantly less than one percent in 2018, while in the truck sector it was around 29% (BRV 2018).

Typically, car tyres are retreaded once, truck tyres up to three times. Car tyres must not be more than seven years old. Two different methods can be used for retreading: cold or hot cure process. First, the tyres are thoroughly inspected, for which comprehensive European standards and quality specifications exist. Next the tyres are buffed. For the cold cure process the tread of the tyre and for the hot cure process the entire casing is buffed to a specific dimension. In cold cure process, an already vulcanised tread strip is applied to the removed casing and bonded to the tyre in an autoclave by vulcanising the bonding rubber layer. In hot cure processing, an unvulcanised material is applied to the tread and sidewalls. Vulcanisation and the shaping and treading of the material are then carried out in a heating press, analogous to the production of new tyres. Today, passenger car retreading is mainly carried out by hot cure processing; for retreading truck tyres, both processes are used.

Decisions 2001/507/EC and 2001/509/EC of the Council of the European Union are the basis for the harmonised technical prescriptions concerning the approval for the production of retreaded pneumatic tyres for motor vehicles and commercial vehicles and their trailers (UN/ECE Regulations Nos 109 and 108). These include, in particular, specific requirements for product characteristics, the production process and quality assurance as well as the corresponding test methods. In Germany, the Kraftfahrtbundesamt (Federal Motor Transport Authority) is responsible for carrying out conformity checks (CoP) in this regard.

With regard to the quality of retreaded tyres, the GTÜ (2015) states that they are no more noticeable than new tyres in the main motor vehicle inspection. The failure safety of retreaded tyres is decisively determined by the quality of the original carcass (BASt, 2000). In this context, the ADAC recommends that retreaded tyres should primarily be purchased from a member of the Arbeitsgemeinschaft industrieller Runderneuerer (AIR, Working Group of Industrial Retreaders). The AIR would have committed itself to an externally monitored application of various technical tests on suitable carcasses, which, according to the experience of the ADAC, works well. "We are not aware of any complaints." Michelin attests its retreaded truck tyres a comparable performance level in terms of safety, robustness, efficiency as their new tyres. However, Michelin advises against fitting these retreaded, so-called remix tyres on the first steering axle of motor vehicles.

The ADAC attests that industrial retreading is a proven technology that is subject to strict legal requirements (ADAC 2020a). Although the quality of retreaded tyres improved continuously until 2011, ADAC has not tested retreaded tyres since 2011. This was mainly due to the rapidly dwindling market significance of retreaded passenger car tyres at that time.

Some basic problems of retreaded tyres were stated by the ADAC in 2020. For one thing, retreaded tyres are basically very noisy and there is no guarantee that a set of retreaded tyres will be built on an identical casing. The associated potentially different driving characteristics could "not only be dangerous for inexperienced drivers in extreme situations".

In terms of performance characteristics, the Auto Club Europa (ACE 2020) found that a tested retreaded passenger car tyre was inferior to new tyres, even from second brands and cheaper tyres from the Far East. In particular, aquaplaning and cornering behaviour, weight and rolling resistance were criticised. Why, however, a Spanish tyre in the dimension 215/55 R17 was chosen, which cannot be counted among the most important tyre sizes (Pneuhage 2020), remains questionable. The GTÜ (2015) further generalises: "At the limit, retreaded tyres will never reach their qualities in terms of cornering speed, braking, starting and aquaplaning behaviour". The BRV, on the other hand, argues that the quality and safety standards of retreaded tyres are high and that retreaded tyres are in no way inferior to new tyres. In the truck tyre sector, the relatively high retread rates in particular seem to support this statement. In the passenger car sector, however, the situation is supposedly more complex.

Basically, the described performance deficits of retreaded passenger car tyres can be attributed to a lack of available know-how on the part of retreading companies with regard to rubber compounds and the structure of modern treads. In the new passenger car tyre sector, the so-called silica technology is increasingly used today. The rubber compounds of tyres increasingly contain silica instead of carbon black as a reinforcing filler. The use of silica tends to lead to improved traction on wet roads or snow and lower rolling resistance. The development of such rubber compounds is highly complex and lengthy. Typical rubber compound development cycles are in the range of several years and require extensive know-how from different fields of knowledge. Such developments could not be carried out by the medium-sized retreading companies, especially in a period of hardly any demand. In addition, so-called multi-compound technologies are increasingly being used, in which the tread consists of several rubber compounds lying next to and on top of each other. Here, too, there is presumably a deficit with regard to the know-how of such tread designs and the associated manufacturing technologies at the retreading companies.

The described deficits of retreaded tyres are thus primarily due to a lack of knowledge and are not to be regarded as an intrinsic problem of retreading per se. Subject to the availability of appropriate rubber compounds, for example through the supply of appropriate material qualities by the new tyre industry, it should be possible to compensate for many of the deficits that have existed to date. The problem of different carcasses could, for example, be compensated, at least in part, by a correspondingly more complex sorting and pairing of ELTs. However, it would present the retreading industry with additional logistical challenges and further reduce profitability.

8.3.4.2 Mandatory labelling of tyres

Retreaded tyres have so far been excluded from the scope of EU Regulation No. 1222/2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters. According to the regulation, every new tyre must bear a label with regard to rolling resistance, wet grip and noise emissions (tyre label). The test values necessary for the respective classification must be measured for each tyre model and dimension.

Retreaded tyres are fundamentally based on different ELT casings, even within a specific tyre model and dimension. In addition, there are further variation parameters such as casing age, treads from different suppliers, various tread variants as well as production methods and parameters. In this case, the testing effort would be correspondingly high, as basically every combination would have to be tested. With the introduction of compulsory labelling according to the current status, the profitability of retreading would therefore no longer be given in the industry's view.

However, according to Regulation (EU) 2020/740, the basic aim is to extend the labelling obligations to retreaded tyres as well. However, suitable test methods for measuring performance do not yet exist or have not yet been defined. The "ReTyre" project investigated scientifically sound and cost-effective methods for classifying retreaded truck tyres. One of the aims was to develop a computer-based simulation tool that would enable predictions of the properties of retreaded truck tyres in terms of rolling resistance, wet grip and noise (ReTyre 2014) and thus reduce the testing effort to an implementable level. According to information from the BRV, initially only a labelling of retreaded tyres of class C3 (heavy commercial vehicles) is to be introduced. In the sizes from 17.5 inches upwards, which cover about 95% of the market, about 10-15 dimensions are to be focused on. Such efforts do not seem to exist for the passenger car segment, certainly also due to its current low relevance.

The lack of the possibility of tyre labelling leads to an alleged disadvantage of retreaded truck tyres with regard to the funding conditions of the De-minimis funding programme of the Bundesamt für Güterverkehr (Federal Office for Goods Transport). Due to a lack of rolling resistance and noise emission values, retreaded truck tyres can only be subsidised by up to 50% under subsidy measure 1.9 of the De-minimis programme, whereas new tyres with the corresponding energy efficiency class can be subsidised by up to 80%. However, the BRV considers this circumstance to be of only minor importance, as the high subsidy rates of 80% for new tyres are only actually applied in very few cases in practice and thus have hardly any practical relevance.

8.3.4.3 Barriers to retreading

The main barriers to retreading or its expansion were identified by the survey participants (Hoyer et al., 2020a):

- There is high competitive and, in particular, price pressure from tyre imports from outside Europe. In this context, the European Commission has imposed provisional anti-dumping duties on certain truck and bus tyres originating in China as of November 2018 (Regulation (EU) 2018/683). However, especially in the passenger car sector, the price difference to low-priced new tyres is too small to generate sufficient demand.
- Retreading requires a great deal of effort in the incoming goods inspection and quality assessment of ELT casings. The complex technology for quality inspection, for example shearography, X-ray procedures or nail hole detection, make the process correspondingly cost-intensive and further increase the price pressure.
- The relatively low level of automation in retreading companies leads to a high proportion of manual work, especially in the sorting and quality inspection of ELTs. According to Reifen Rigdon, an increase in the degree of automation is needed to improve the competitiveness of retreading.

In the passenger car sector, the main obstacles to increased retreading named by survey participants are as follows:

- A very wide range of tyre dimensions (size variety), also across manufacturers within a specific tyre size, which entails, among other things, a high sorting effort and capital expenditure for corresponding vulcanisation tools. Reifen Rigdon suggests that the dimensions of new tyres should be standardised, as even a few millimetres difference significantly increases the effort.
- Lack of acceptance by consumers and lack of recommendation by the retailers.
- Lack of expertise in regards to rubber compounds with silica technology as well as multicompound treads, resulting in a performance deficit compared to new tyres.
- Poor availability of suitable casings due to
  - poor quality of casings that are not suitable for retreading. In this context, there have been increasing calls for the casings of new tyres to be designed for retreading from the outset, for example in terms of tolerable deformation and deflection cycles.
  - costly sorting of the casings by upstream players, as well as supposedly low purchase prices of the casings by the retreading companies, which makes exporting the tyres more attractive. This is accompanied by a supposedly more limited sorting of the tyres compared to neighbouring EU countries.

Table 68 gives an overview of how high the companies estimate the proportion of ELTs that are generally suitable for retreading to be in their accumulating quantities.

Table 68 Estimated share of ELTs suitable for retreading received by survey participants

Company	ELTs in general	Passenger car ELTs	Truck ELTs
Tyre trading and service			
Company 5			40%
Ulf Claushallmann	5%		
Retreading			
Company 16			65%
Company 17		75%	75%
Pure comminution (shreds, granulates powders)			
Company 2	30%	40%	20%
DANNINGER OHG	5%		5%
HRV GmbH	20%	20%	10%
KARGRO GROUP		10%	50%
Company 11	5%		5%
Shredding and recycling			
Company 6	5%	5%	
MRH Mülsen GmbH			45%

Source: Hoyer et al., 2020

8.3.5 Production of secondary products based on granulate and fine powder

The recycling of ELT into products is mainly in the form of granulates (1-10 mm), powders (<1 mm) and fine powders (< 0.5 mm). The mass of the applications recorded in the survey by Hoyer et al. (2020a) totals 240,000 tons per year. The share of powders and fine powders in this mass cannot be clearly delimited from the data, but is estimated at about 20,000 t. According to the GAVS data, the total mass of ELT recycled in the form of granulate and fine powder is 251,000 t in 2019 (GAVS 2019).

8.3.5.1 Recyclability of ELTs

Not all ELTs are fundamentally suitable for material recycling. According to the criteria of the CEN/TS 17045:2020 standard for the selection of ELTs for recycling, such ELTs are assessed as fundamentally unsuitable,

- which originate from stockpiles where they were mixed with other waste,
- which are partially burnt or may be contaminated with degradation products formed by fire,
- which could be contaminated by fats or oils,
- which contain polymer fillings, gels, adhesives or non-vulcanised materials.

The latter point includes in particular so-called seal, run-flat and silent tyres. The so-called seal tyres contain a sealant that seals the damaged area in the event of tyre puncture. During granulation, these sealants can cause parts of the plant or the granulates to stick together and even lead to fires in the granulation facilities. Silent tyres, where a sound-absorbing coating is glued to the inside of the tyre tread, lead to the entry of potentially problematic foreign substances. The same applies to some of the run-flat tyres if foreign materials are used for reinforcement.

8.3.5.2 Granulate-based applications

By far the largest share of ELT recycling is accounted for by granulate-based products. The granulate size ranges from about 0.5 to 7 mm, with a focus on about 2 to 4 mm. Typical products made from ELT granulates are mat systems such as sports floors, anti-slip, building protection or damping mats (sound or vibration damping), fall protection systems for playgrounds or moulded parts such as edgings or elastic paving stones (see Figure 23, left). Such products are mostly characterised by their durability and weather resistance, high elasticity and damping properties as well as slip resistance in combination with a low price. The granulates are typically pressed into moulded parts using polyurethane as a binder. The polyurethane content is in the range of about 3% to 30%, typically in the order of about 5%. The granules are completely enclosed by the polyurethane, which provides an additional barrier against the potential leaching and outgassing of components of the rubber granules.

Depending on the field of application, the ELT granulates substitute the primary raw materials rubber (especially EPDM, natural and styrene-butadiene rubber), polyurethane and polystyrene. For many fields of application, however, the use of primary raw materials instead of ELT granulates seems hardly relevant due to the then insufficient price-performance ratio. The usual market costs for ELT granulates are in the range of 0.20 €/kg. In contrast, the corresponding primary raw materials cost about 2 to 3 €/kg. More detailed information on energy demand and costs can be found in Figure 30.

8.3.5.3 Rubber powder and fine powder-based applications

A potential growth market is represented by applications based on ELT powder or fine powder (generally referred to as rubber powder in the following). These powders are already used, for example, in the construction industry/construction chemistry, e.g. as fillers for coating systems, or as oil binders, as well as in small proportions for the production of new tyres (see chapter 8.3.6).

With the very fine-particle powders, it is still possible to produce very high-quality materials that are characterised in particular by their good optical and mechanical properties (see Figure 23, right). Representative components are, for example, the products of the company matteco GmbH, Kappelrodeck. For the production of powders, however, an additional process step, the fine grinding of granulates, is necessary, which is associated with additional costs and energy requirements (see Figure 30). The price for such powders rises to about 0.50 to 0.70 Euros/kg.

Figure 23 Left: Fall protection slab made of ELT granulates (approx. 95% ELT content). Right: Floor mat made of ELT fine powder (70% ELT content)

Sources: PVP Triptis GmbH (left), PTM Mülsen GmbH (right)

The powders can be added to suitable materials in proportions of up to 80%. These can be, for example, rubber, polyurethane or thermoplastics. However, the range of application of such materials is limited. The use of rubber powder has a particularly negative influence on the fatigue behaviour of the materials. Therefore, dynamically highly stressed products appear fundamentally unsuitable because of the probability of premature component failure. In this context, safety-critical applications should also be excluded. This is also derived from the fact that in the case of recycled tyres there is a fundamental risk of contamination with foreign substances, which, especially in the case of rubber-based materials, could lead to disruptive interactions even in very small quantities and result in unexpected component failure.

8.3.5.4 Rubber-based matrix materials

Particularly high-quality materials can be produced on the basis of rubber, using rubber powders in part, which can also be processed highly productively with continuous processes. The possible co-cross-linking of the rubber powder with the rubber matrix is particularly noteworthy here. As a result, very good mechanical properties of the materials can be achieved. However, this chemical reactivity also has the disadvantage that the cross-linking reaction can easily be disturbed by foreign substances. In particular, the introduction of so-called rubber poisons must be taken into account. Rubber poisons are understood to be various (heavy) metal ions such as iron, copper, cobalt or manganese. Copper and manganese in particular can lead to severe cross-linking disorders or depolymerisation (autoxidation) of the materials within a very short time (months) after production. These substances can be introduced during comminution, for example.

The complexity of the rubber material system and the many interactions along the production chain thus represent hurdles for this recycling route and require a wide range of know-how. Especially for the mostly medium-sized ELT waste management companies, the development of such competences is difficult to implement.

ELT recyclates are not suitable as a general substitute for the entire range of elastomer materials. The use of ELT recyclates in elastomer products is limited to a narrow range of products whose requirements can basically be met on the basis of the usual tyre material formulations. Depending on the recyclate content, the properties of the overall material can only be influenced within narrow limits by the material formulation of the matrix material. In particular, there are restrictions with regard to chemical and temperature resistance, Shore hardness, deformation, friction, wear and damping behaviour. In principle, applications based on natural or SBR rubber therefore appear to be primarily relevant. However, limitations with regard to the properties must also be assumed in these cases, as the use of recycled materials generally exerts a negative influence. Especially the highly dynamically loaded components, such as Simmerrings or windscreen wipers, therefore also tend to be excluded, as well as safety-relevant applications.

ELT fine powders and powders are particularly suitable for use in rubber compounds, as especially high-quality materials are obtained. In general, however, the transition from granulate to powder-based applications greatly increases the complexity of the associated material and process developments. At the same time, many potential applications are niche markets. Moreover, there is no standard material in the rubber sector; rather, a separate compound development is carried out for each application. Development times in the range of years are quite common here. In the case of a planned use of rubber powders, an adaptation of the material system and the associated processing procedures is generally necessary, even for existing applications. The currently low level of primary raw material prices as well as the unclear development with regard to PAH regulations dampens the willingness to invest and further develop and thus hinders the development of new, high-quality applications for ELT recyclate.

8.3.5.4.1 Reference applications for ELT powders

In order to demonstrate the potential of rubber-based materials with rubber powder, the TU Chemnitz has implemented a series of exemplary model applications as part of a research project (Hoyer et al., 2019). First, based on the findings of the PAH measurements, own material formulations were developed. The proportion of rubber powder was adjusted in such a way that the PAH limits were reliably complied with. Special low-PAH carbon blacks were also used. Subsequently, the developed material formulations were produced (mixed) under industrial conditions and further optimised with regard to optimal process capability.

The mixtures were finally further processed by industry partners under industrial conditions. Rubber ropes (Figure 24) and high-quality sheeting (Figure 25) were selected as reference applications. These have been assessed as particularly relevant in terms of material stress and the underlying capacities of the relevant sales markets.

Figure 24 Round cords made by profile extrusion with 6 mm diameter (left) and rubber cords made therefrom with different sheathing (right)

Sources: Hoyer et al., 2019

The material for the products shown in Figure 24 is based on natural rubber (36%), rubber powder (40%, whole truck tyre, cryogenically ground, < 200 µm, MRH Mülsen GmbH), low-PAK carbon black (11%) and other components. The compound was produced on an industrial scale by Polymer-Technik Elbe GmbH. The extrusion of the round cords took place under industrial conditions at the companies EUG GmbH, Gummiwerk Meuselwitz GmbH and Lausitz Elaste GmbH. The rubber cords were manufactured by Estoma e.Kfm.

The material for the rubber sheeting (Figure 25) is based on natural rubber (32%), rubber powder (30%, whole truck tyre, cryogenically ground, < 200 µm, MRH Mülsen GmbH), low-PAK carbon black (17%), flow improver (Vestenamer, Evonik Industries AG) and other components. The compound was produced on an industrial scale by WAGU Gummitechnik GmbH. The sheeting was manufactured under industrial conditions at PolymerTechnik Ortrand GmbH.

Figure 25 Sheeting produced by continuous vulcanisation (Rotocure)

Left: Web width 1.25 metres, thickness 2 mm. Tensile strength: 16 MPa, elongation; 440%.
Right: Web width 1.25 m, thickness 0.6 mm, with textile reinforcement.
Source: Hoyer et al., 2019

The mixing costs (raw materials including costs for mixing) ranged between 2.50 and 3 Euro/kg. The costs for the rubber powder amount to approx. 0.70 Euro/kg. However, the associated savings in material costs are partly put into perspective by a deterioration in the processing behaviour, and thus in the production speed. In particular, the rubber powder causes an increase in viscosity, which meant that the production speed had to be reduced. This effect was partially compensated for by the use of flow improvers, but fundamentally requires further research and development work to minimise it. This has a strong negative impact on economic efficiency, especially for production in Germany.

The rubber powder was also found to have (negative) effects on the cross-linking behaviour and storage stability of the compounds. The processing time of the compound is shortened (faster scorch), which was increased with increasing storage time.

With regard to the realisable material properties, in particular the hardness, there are limits which are set by the SHORE hardness of the rubber powders. In the test series, starting from a rubber powder content of 40%, materials with a SHORE hardness of 60 to 80 SHORE A could be produced. In order to expand the range of possible applications, further research and development work is therefore required, for example with regard to plasticising the rubber powders by mechanical, thermal or chemical processes, with the aim of reducing the SHORE hardness of the powders.

The ELT rubber powders also tend to cause a deterioration in the properties of the elastomers. However, the underlying mechanisms are complex and systemic. Basically, all relevant properties are negatively affected, especially tensile strength, elongation at break, tear resistance, fatigue and abrasion. The achievable properties are, however, potentially usable for a wealth of applications. However, ELT rubber powders will accordingly not be fundamentally usable as a substitute for rubber and will remain limited to specific applications. Furthermore, ELT powders cannot be mixed into all types of rubber for compatibility reasons. Further research and development work is needed here to further optimise the property level of rubber materials with ELT recyclates and to identify relevant areas of application.

8.3.5.4.2 Conclusion

As a result of the research carried out, it can be stated that the manufacture of high-quality products with significant proportions of ELT powders is feasible while complying with the existing PAH limit values. The properties of the manufactured products are equal to their counterparts from primary raw materials in many areas. In the case of the rubber ropes, the performance was on an absolutely comparable level to the rubber filaments previously used. The sheeting also showed material properties that can be compared to primary raw materials. However, the necessary material and process developments are diverse and complex and must be carried out in principle for each new application. Furthermore, there are still a number of deficits, especially with regard to the deterioration of the processing properties, which must be remedied by further work.

8.3.5.5 Polyurethane-based matrix materials

Polyurethane-based materials represent a good compromise. Since these do not interact with the rubber powders, material development is much easier to implement. However, the properties usually do not reach the level of the rubber-based materials. Compared to rubber-based applications, there are also deficits with regard to the processing of the materials. The polyurethane-rubber powder mixtures are a mixture of solid and liquid and can therefore usually not be processed with continuous methods. Due to the high adhesion tendency, there are also difficulties in the mixing process as well as the handling of the mixtures due to the fact that the mixture tends to adhere strongly to surfaces. Another disadvantage is the reaction of polyurethane with the surface moisture of the rubber powder, or with water in general. Therefore, in the case of products with closed surfaces and higher polyurethane contents (orientation value approx. 30%), the rubber powders usually have to be dried in an elaborate process in order to avoid imperfections and bubble formation in the products.

8.3.5.6 Thermoplastic-based matrix materials

Another field of application is the compounding of rubber powders with thermoplastic polymers (Kroll et al., 2018). In individual cases, these compounds can substitute the so-called thermoplastic elastomers (TPE). However, due to the mostly high melting temperatures (usually over 180 °C), thermal decomposition of the rubber powders and the release of gaseous decomposition products occur (see chapter 8.5.3). In addition to odour nuisance during processing and from the products themselves, there are also similar issues with regard to potential health hazards, as described in chapter 8.3.7 in the context of application in road construction.

8.3.5.7 Conclusion

In view of the potential discontinuation of the use of rubber granulate as infill on artificial turf fields (see chapter 6.3.2) and the sharp decline in recycling in cement facilities, the question arises as to how this loss of recycling capacities can be compensated. In the area of granulate-based products, a fundamentally positive growth forecast was given in interviews with corresponding companies. One company reported double-digit growth rates in the past years and also forecasts such an increase in the coming years. However, such high growth rates are not reflected in the GAVS figures for the overall market, where the recycling of ELT in the form of granulates and powders has grown by an accumulated 32% in the period from 2012 to 2019. This represents an average of +4.6% over the past 7 years, as well as +3.1% in 2018 and +6.4% in 2019.

Furthermore, a dip in growth rates for consumer products due to the discussion on PAHs was reported. In this context, a significant impulse for an increase in demand is expected if new migration-based limits were introduced.

The applications based on fine powder are to be regarded as an important and sensible supplement to the existing recycling concepts based on granulates and one of the few remaining markets for ELT recycling with potential for growth. However, such applications only seem to be able to achieve quantitative significance under certain economic and scientific conditions. A short-term, quantitatively significant expansion does not seem feasible in principle, due to the extensive development effort. Especially in the area of know-how transfer, there are significant opportunities to support such developments, shorten the development time and reduce development costs.

8.3.6 Use of ELT recyclates for the production of new tyres

Using ELT recyclates in the production of new tyres is only possible to a limited extent, because elastomers are a sensitive result of their compound composition. Foreign components easily lead to disruptive interactions during the cross-linking of the rubber mixtures, the so-called vulcanisation, which is why the chemical composition as well as the degree of contamination and ageing of the recyclates used is decisive. ELT recyclates are a mixture of many substances, the composition of which cannot be specified exactly. The variety of tyre components and their manufacturer- and model-specific formulations make it impossible to separate them by recipe. Even retread material (material produced by buffing the treads) cannot necessarily be regarded as single-grade. Today, the treads of modern tyres are partly composed of several mixtures that are either mixed together or next to each other (so-called cap-and-base or multicompound technology, e.g. tyre "Aplus T706").

In-house production residues are prioritised for recycling into new tyres. With regard to ELT recyclates, fine powders and replasticised material (so-called reclaim) are also predominantly used. In the reclaim process, the material is returned to a rubber-like, conditionally flowable state under high thermal and mechanical stress. In addition to the cross-linking points, a number of macromolecules are also split, which is why the material can no longer reach the property level of primary material. If necessary, this process can be supported by chemicals, primarily with the aim of prioritising the splitting of only the cross-linking sites. Devulcanisation processes ultimately aim to split the cross-linking sites as selectively as possible, for which appropriate chemicals are used. However, devulcanisation processes, in contrast to the reclaim processes, have not gained any significant practical importance. This is due on the one hand to the "contamination" of the material with an additional chemical and its reaction products, and on the other hand to insufficient economic efficiency.

The type and quantity of material used in the production of new tyres depends, among a number of other factors, decisively on the respective manufacturing process, the used rubber compound and the stress on the respective tyre component. Furthermore, there is no "standard material" in the rubber sector, so that the introduction of recycled materials basically requires an adaptation of the material system and the associated processing procedures for each tyre component. More precise findings are hard to come by. Reference is also made to chapter 8.3.5.4.

In general, fine powders of different types (e.g. truck tread or whole tyre) in various particle sizes (mostly smaller than 200 or 400 µm) or reclaim material are used.

A particularly relevant material for recycling into tyres is buffing dust from truck treads, which mostly originate from retreading. They are characterized by a particularly high natural rubber content and are free of textile and steel. Furthermore, buffing dust does not contain any potentially troublesome butyl rubber (IIR), which is present in whole tyre recyclates due to the inner liner. The proportional addition of truck tread recyclate to a rubber compound tends to result in the best mechanical properties, in contrast to recyclate of the same grain size from truck or passenger car whole tyres (Hoyer et al., 2020b).

Recyclates are frequently used for the tread or sidewall, for example. However, it can be assumed that the use of recyclate is not possible for all rubber-based tyre components.

The use of ELT recyclate exerts an influence on the entire production chain as well as on the mechanical properties of the materials. Recyclate leads to an increase in the viscosity of the compounds, which can be mitigated by the use of reclaim, for example. The recyclates can, for example through mutual diffusion of chemicals, influence the crosslinking reaction and accelerate or even disrupt it in an unfavorable way. Finally, the mechanical properties, such as abrasion, fatigue, tear resistance, aging resistance, etc., can also be influenced in a systemic manner. Accordingly, there are clear limits to process and material optimization here, since it is based on many individual compromises and encompasses the entire process chain. If one also takes into account that the largest share of the cumulative energy expenditure (approx. 96%) in the life of a tyre is accounted for by the use phase, it is easy to see that even the smallest percentage deterioration, for example in rolling resistance, can have a serious impact on the overall eco-balance over the life cycle. In some circumstances, recycling can even have a negative impact on the overall assessment.

Information on the recycling rate is generally hard to find in the literature:

- Kleemann (1982, Chapter 23.1) mentions 5-10 phr (per hundred rubber) of rubber powder, which corresponds to a proportion of 2-5% in a single tyre component. It is also stated that the use of rubber powder is particularly suitable in tread and sidewall compounds.

- Czech-Scharif-Afschar et al. (2013, chapter 19.5) states that the upper limit for the ELT rubber dust content in tyres, below which the loss of properties remains acceptable, is on average approx. 1 - 3%. It must be assumed here that this figure refers to the tyre as a whole.
- Bridgestone promotes its "ECOPIA" tyre model with a 5% ELT recyclate in the tread compound.

Based on the above-mentioned literature, a share of 5% is assumed to be the current upper limit for the addition of ELT recyclate in an individual tyre component. Accordingly, the results of Czech-Scharif-Afschar et al. (2013) complete the data. The average value of 1-3% for the entire tyre results from the average recyclate content of the individual tyre components (Czech-Scharif-Afschar et al., 2013). However, for less demanding applications, such as construction site vehicles, higher percentages could also be realized in individual cases.

Assuming an average recycling rate of 2%, the figures for replacement tyre demand of 538.000 tons in 2019 (see Table 60) result in a mass of 10,800 tons of ELT recyclates used in new tyre production.

It seems theoretically possible to increase the recycling rate to 5% of the total tyre in new tyre production, but the associated investment and development costs, as well as the potential losses in tyre performance, are difficult to estimate. The current price level of primary raw materials also has an inhibiting effect in this context. Overall, the potential for closed-loop recycling of ELT is low in relation to the total volume of waste.

8.3.7 Use of ELT recyclate in road construction

8.3.7.1 Overview

Bitumen for use in road construction can have its properties improved by the addition of polymer modifiers. In this case, it is referred to as polymer-modified bitumen. According to Wilhelm (2018), approximately 25% of all bitumen used for road construction is modified. According to Eurobitume (2019), 1.67 million tons of bitumen were consumed for road construction in Germany in 2018. Among the large number of potential modifications, rubber powder or fine powder is also suitable in principle to achieve an improvement in the properties of bitumen. In this case, we speak of a rubber-modified bitumen. According to CTS Bitumen GmbH (2015), typical proportions of ELT recyclates in bitumen range from 6 to 45% by mass, with 12% cited as the standard. According to previous findings, rubber modification of bitumen provides advantages in terms of low-temperature and aging behaviour of asphalt as well as noise emission (Wilhelm 2018, Kraft and Wellner 2017). According to BiCon AG (2003), the use of ELT recyclates is particularly widespread in the USA and Sweden. Here, a mixture of 5% ELT recyclate is usually added to the surface course of the road pavement.

According to Kraft and Wellner (2017), the optimum rubber powder content in the binder (bitumen) is just under 15% by mass. The influence of rubber modification is greater in base course mixtures than in surface course mixtures. In base courses, a reduction in layer thickness can be achieved by using rubber-modified asphalts.

One hurdle for the use of ELT recyclates in road construction in Germany is that the current regulations and standards do not take rubber-bitumen mixtures into account. Bavaria is the only federal state that has a corresponding set of rules (State Ministry of the Interior, 2010), the application of which is recommended to the motorway directorates and state building authorities as a minimum technical condition in suitable construction contracts. In the other federal states, rubber-modified asphalts are therefore not taken into account or explicitly required in tenders due to the lack of a corresponding basis.

8.3.7.2 Emissions during the processing of rubber-modified bitumen

The Federal Highway Research Institute (BASt) has expressed concerns about the formation and outgassing of potentially hazardous degradation products during the processing of rubber-modified bitumen. According to FGSV (2003), the heating of rubber-bitumen mixtures to over 170 °C can lead to the formation and release of vapours and aerosols (see Chapter 8.5.3). During the installation of rubber-bitumen mixtures, workers occasionally experienced irritation of the mucous membranes, which was suspected to be caused by the formation of organosulphur compounds as a result of the thermal decomposition of the rubber. An analytical screening during an installation measure subsequently detected unquantifiable traces of emissions of sulphur dioxide and benzothiazole (FGSV, 2003). Furthermore, reference is made to a study of the U.S. Dept. of Health and Human Services (HHS 2001), which also confirms the presence of benzothiazole in rubber-bitumen mixtures and found a higher emission of benzene-soluble substances, polycyclic aromatics and organosulphur compounds compared to conventionally produced bitumen. At this point, however, it remains an open question whether the type and quantity of the released substances are responsible for such irritation symptoms or whether they represent a fundamental health risk at all.

Azizian et al. (2003) found a mixture of organic and metallic contaminants in the leachate of rubber-modified asphalt. Besides benzothiazole and 2(3H)-benzothiazolone, mercury and aluminium were leached "in potentially harmful concentrations". However, since neither of these metals is a substance used in tyre production, it is highly unlikely that these emissions were caused by the ELT rubber components.

Assuming a maximum processing temperature of 170 °C, Wilhelm (2018) states that, according to available findings, there are no differences in the exposure of vapours and aerosols compared to conventional asphalts. The emissions in the asphalt mixing plant would be in the same order of magnitude as in the production and reuse of conventional asphalts. Since 2008, the paving of mastic asphalt has been permitted in Germany up to a maximum of 230 °C. Rolled asphalt, the classic road construction material, is processed with a paving temperature of up to about 180 °C. Typical storage temperatures for asphalt are in the range of at least 170 °C, and temperatures of up to 190 °C can be present during and after the mixing process.

Modifiers can make it possible to lower the processing temperature of rolled and mastic asphalt by 20 to 40 °C (Rühl 2009). This temperature-lowered incorporation could enable the processing of rubber-modified rolled asphalt below the temperature limit of 170°C, which is described as critical.

Gogolin (2019) provides insight into the results of using such modified bitumen to produce an industrially used logistics surface. A reference surface was produced and tested, which contained 18% rubber powder in the bitumen of the surface and binder course. The use of approx. 5% VESTENAMER in the rubber powder (corresponds to 0.9% in relation to the bitumen content of the asphalt mixture) made it possible to reduce the laying temperature to below 170 °C. The asphalt mixture could be laid and compacted by machine without any problems. The asphalt mixture could be placed and compacted by machine without any problems. No abnormalities, such as unpleasant odours or adherence of the asphalt material to paving equipment or loading areas, were observed during paving. The surface produced was characterised by high resistance to deformation and flexibility at low temperatures.

8.3.7.3 PAH content of road pavement

In Germany, the RuVA-StB 01 guideline regulates the recycling of reclaimed asphalt in road construction. The reclaimed asphalt is divided into the following classes depending on its PAH content:

Table 69 Classification of reclaimed asphalt based on its PAH content in RuVA-StB 01

PAH content (16 EPA PAH)	Classification
Maximum 10 mg/kg	Without impurities
> 10 to ≤ 25 mg/kg	Slightly contaminated
> 25 to ≤ 1,000 mg/kg (and benzo(a)pyrene < 50 mg/kg)	Pitchy road debris
≥ 1,000 mg/kg (and benzo(a)pyrene ≥ 50 mg/kg)	Hazardous pitchy road debris – Classified as hazardous waste

Source: RuVA-StB 01

Table 70 calculates the estimated input of PAHs caused by the ELT recyclate in the asphalt. The result is an estimated input of 0.5 to 0.8 mg PAHs per kg asphalt for the sum of the eight EPA PAHs. This is less than one tenth of the limit below which the asphalt is considered free of contamination. Accordingly, it cannot be assumed that the use of ELT recyclate in road construction leads to a significant additional input of PAHs.

Table 70 Calculation of the input of PAHs through ELT recyclate

Features	Value
Bitumen content of asphalt	5-8.5%
ELT content in bitumen	approx. 18%
Absolute percentage of ELT in asphalt	0.9-1.5%
PAH content of ELTs 16 EPA PAH, maximum according to Table 80, passenger car	77.1 mg/kg
Maximum input of PAHs in asphalt	0.46-0.77 mg/kg

8.3.8 Devulcanisation and reclaim

Rubber powder is cross-linked rubber and therefore basically a solid. When added to a rubber mixture, the molecules of the rubber and the ELT powders can hardly diffuse into each other, which is why the strength of such recycled materials is usually negatively affected. Furthermore, when added to viscous liquids, such as a rubber mixture or a thermoplastic melt, the viscosity of the mixture is often greatly increased and the flowability reduced accordingly.

For example, to enable interdiffusion of the molecules or to increase the flowability of the material, a so-called replasticisation of the rubber powder is carried out. Replasticisation is generally understood to mean a partial return of the material to a rubber-like (i.e. highly viscous) state. This can generally be done by thermal, mechanical or chemical processing of the rubber, or combinations thereof. Basically, the aim is to split the cross-linking sites, mostly sulphur bridges, of the macromolecules again. However, all processes seem to have in common that they do not produce a material that is fully equivalent to the primary raw material rubber and that economic efficiency is often not given.

In the so-called reclaim process (e.g. HSM process of Watson Brown HSM GmbH), the material is brought back to a rubber-like state under high thermal (> 180 °C) and mechanical stresses. In addition to the cross-linking sites, a number of macromolecules are also split in the process (reduction of the molar mass). The material obtained therefore tends to no longer reach the full property level of primary material, but is suitable for a number of applications. Such mechanical processes can be additionally supported by chemicals, primarily with the aim of prioritising the cleavage of only the cross-linking sites (thermo-chemical processes). Finally, devulcanisation processes aim at selective cleavage of the cross-linking sites, for which corresponding chemicals are used, usually at elevated temperatures and moderate mechanical stress.

Diphenyl disulphide (DPDS) has so far proved to be the most effective chemical for the devulcanisation of tyre material (Saiwari et al., 2015). However, such processes have so far mostly only been carried out on a laboratory scale. Findings on the further processability of the material produced in this way, especially with regard to the interaction of the DPDS and the reactants of the chemical reaction with the subsequent base material, are also largely lacking. Given the high price of the chemical, about 5.83 USD per kg of rubber to be devulcanised, it cannot be assumed that the process is sufficiently economical.

8.3.9 Pyrolysis

8.3.9.1 Introduction

Pyrolysis of ELTs has been researched since the 1970s and has been technically implemented several times since then (Pohl and Quicker 2018). Internationally, most facilities use rotary kilns (Banar 2015).

In pyrolysis, organic material is carbonised in the absence of oxygen. In the process, the volatile components are transferred to the gas phase and pyrolysis coke, a solid residue of carbon and ash, is produced. Pyrolysis oil and permanent gas are obtained from the gas by condensation. The chemical composition of the products and the ratio between the three products depends on the input material and the process control (Pohl and Quicker 2018). The gas is usually used directly to generate electricity and heat for the process (Pohl and Quicker 2018). The pyrolysis oil has similar properties to diesel but a higher sulphur content. It is used as a crude oil substitute in the chemical industry.

Pyrolysis coke consists of 80-90% carbon black (industrial soot) added during tyre production, as well as 1-3% sulphur and 10-15% inorganic substances (Cardona et al., 2018). If the coke is present as fine particles, it is also referred to as recovered carbon black (rCB) (Pohl and Quicker 2018). Carbon black (CB) is used as a dye and rubber filler to increase hardness and resistance. The main consumer of CB is the tyre industry (Ceresana 2020). Due to the high proportion of impurities compared to CB from primary raw materials, rCB does not have the same effect without further processing and thus cannot completely replace CB (Cardona et al., 2018).

Alternatively, the pyrolysis coke can also be converted into activated carbon (Williams 2013).

Pohl and Quicker (2018) contains an overview of existing facilities and companies in Germany.

8.3.9.2 Semi-technical facilities

Until its insolvency in 2015, a facility with a rotary kiln was operated by TPL GmbH in Hoyerswerda (Pohl and Quicker 2018).

In 2015, Pyrolyx AG, Munich, took over cct Steglitz GmbH with its pyrolysis facility built in 2012. Until then, the facility had been operated in batch mode (Pyrolyx 2015). The facility is used as a production site and test facility. There are no publications on the technology used or the facility capacity (Pohl and Quicker 2018). In the interim consolidated financial statements June 2018, high energy costs for the Steglitz site are mentioned (Pyrolyx 2018). This could be an indication that the gas produced is not sufficient to run the process.

In autumn 2019, Pyrolyx and Continental entered into a supply agreement of rCB for tyre production. The agreement provides for an increase in the purchase volume to 10,000 tons per year of rCB within five years (Pyrolyx 2019b). Pyrolyx started construction of an industrial facility in the US in 2017, which was completed in 2019 and planned to be in continuous operation in spring 2020 (Pyrolyx 2019, 2019a). The facility has a capacity of 40,000 tons per year of ELTs (Pyrolyx 2019a). In October 2020, the American subsidiary operating the new facility had to file for bankruptcy (Pyrolyx 2020).

8.3.9.3 Industrial facilities

Currently, there is only one industrial facility for the recycling of ELTs by means of pyrolysis in Germany. It is operated by Pyrum Innovations AG in Dillingen/Saar. The facility has been in regular operation since May 2020 and has a capacity of 5,000 tons per year of ELT granulate (Boeckh 2020). The operation includes an ELT recycling facility, the pyrolysis unit and a CHP unit. Currently, a grinding unit for rCB processing is being added to the facility (Boeckh 2020).

The recycling unit has a capacity of 10,000 tons per year of ELTs. The tyres are shredded and the textile part and the steel wire are removed. The ELT rubber is then granulated to <6 mm in several steps. Up to 7,000 t of rubber granulate, 2,500 t of steel and 1,000 t of textile lint are produced annually (Boeckh 2020).

Pyrolysis takes place in an electrically heated vertical moving bed reactor at temperatures of 600-700 °C and a residence time of 2.5-3.5 hours (Pohl and Quicker 2018). There are no moving elements in the reactor. The granulate is added at regular intervals and trickles down through five segments in which the heating elements are radially installed. The gas is extracted and condensed in a separate unit. Per tonne of ELT granulate, the facility produces 440 kg of coke, 400 kg of pyrolysis oil and 160 t of gas (Boeckh 2020).

The gas is converted into electricity in the facility's own CHP unit and is used to heat the reactor. After the start-up phase, the facility is self-sufficient in energy and feeds surpluses into the electricity grid (Pohl and Quicker 2018).

The coke has a similar grain size distribution as the granulate and is too coarse when unground to achieve a good price as rCB. In the future, the coke can be ground down to 7 µm by the grinding mill, according to customer requirements (Boeckh 2020).

The main customer for the pyrolysis oil is BASF, which uses the oil in plastics production. As part of the ChemCycling™ project, the group is also investing €16 million in the expansion of the Pyrum facility with two additional lines by 2022 (Pyrum 2020).

Pyrum is also a partner in Michelin's BlackCycle project, which aims to build value chains for the recycling of ELTs and improve existing technology. The project is funded by the EU with €12 million and runs until 2023 (Cordis 2020).

8.3.9.4 Evaluation

As described at the beginning, the pyrolysis products have higher impurity contents than products from primary raw materials. Sulphur and ash content as well as organic residues in the rCB can have a negative impact on the material properties when used in tyre rubber production. The quality of the pyrolysis products is significantly influenced by the process control (Cardona et al., 2018).

At present, it is difficult to assess pyrolysis in terms of its advantages and disadvantages as a recycling route for ELT, as no process has yet become established in Germany in the long term. Previous attempts to carry out ELT pyrolysis as a profitable venture have failed.

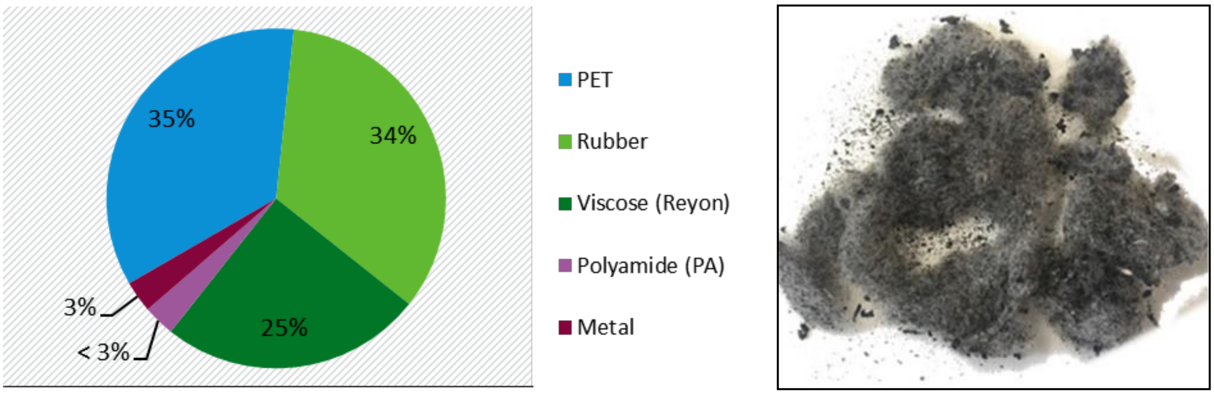
Pyrolysis has the potential to extract valuable secondary raw materials from ELTs, for which there is great interest on the part of the plastics and tyre industries. Companies such as BASF, Continental and Michelin plan to increase the recycled content in their products through the use of pyrolysis products (Cordis 2020, Pyrolyx 2019b, Pyrum 2020).

8.3.10 Textile fibre fraction from ELT recycling

In addition to granulates, large quantities of textile fibres are also produced, especially in the recycling of passenger car tyres. The average textile content of a new passenger car tyre is about 4%, that of truck tyres 1% (see Figure 12). Due to material losses due to wear and abrasion of about 8.4% (see Table 60), the calculated textile content of ELTs is 4.4% for car tyres and 1.1% for truck tyres.

The textile fibre fraction consists on average of 25% viscose and 35% PET fibres as well as 34% rubber adhesions (see Figure 26). Due to the adhesions, the share of the textile fraction in ELT recycling is about 5.9% for car tyres and 1.5% for truck tyres.

Figure 26 Mean material composition of textile fibres from car tyre granulation (left) and typical textile fibres from ELT granulation (right)



Source: Hoyer and Kroll (2019)

Based on data from previous chapters, the total volume of the textile fibre fraction is calculated to be about 12,700 t (see Table 71). However, this value does not include all types of tyres (e.g. two-wheelers) and is significantly lower than the figures of 43,000 t given by the German Environment Agency (UBA, 2020).

Table 71 Calculation of the total volume of the textile fibre fraction in 2019

Tyre type	Market share [1)]	ELT for recycling [2)]	Textile fraction	
	wt.-%	1,000 t	wt.-%	1,000 t
Car	61,1%	153.4	5.9%	9.1
Light truck	23.3%	58.2	5.5%	3.2

Tyre type	Market share [1]	ELT for recycling [2]	Textile fraction	
	wt.-%	1,000 t	wt.-%	1,000 t
Truck	11.1%	27.9	1.5%	0.4
Other	4.6%	11.5	N/A	N/A
Total		**251.0**		**12.7**

1) Table 63

2) GAVS, Table 67

So far, there is no viable material recycling concept for the textile fraction. It is mainly used for energy recovery.

8.3.11 Production of infill granulates for artificial turf fields

There is no complete survey of the number of artificial turf fields in Germany. The current estimates are presented in chapter 6.1.2.

A clear allocation to artificial turf fields cannot be derived from the information provided by the companies according to Figure 19. The mass of the output of infill granules for artificial turf fields is in the range of 38,000-44,000 tons per year. In Table 72, a rough estimate of the market for infill granules for artificial turf fields is made. The annual infill demand was calculated to be at about 11,900 tons per year. In the following it is assumed that only ELT granulate is used.

Table 72 Estimation of the market for infill granulates for artificial turf fields

Position	Description	Value	Average value	Sources
1	Number of fields	> 5,000	5,000	see 6.1.2
2	Infill requirement (granulate)	3-5 kg/m^2	4 kg/m^2	see 6.1.2
3	Service life	10-15 years	12.5 years	playground-landscape.com
4	Field size	4,050 -10,800 m^2	7,425 m^2	fussballtraining.de
5	Granulate quantity per field	Pos. 2 x Pos. 4	29.7 t	
6	Total granulate quantity	Pos. 5 x Pos. 1	148,500 t	
7	Average replacement demand	Pos. 6 / Pos. 3	11,900 t/a	

An annual increase of 150 large playing fields is generally assumed (Leers, 2020). Together with position 5, this results in a rough annual demand for granulate for the construction of new artificial turf fields of 4,500 tons. In total, the market for granules for artificial turf fields is thus roughly estimated at 16,000 tons per year.

Due to the public discussion about PAH limits and other possible health hazards that could emanate from infill granulates, the market is already in sharp decline. Individual companies put the drop in orders last year at around 25%. In January 2019, the European Chemicals Agency (ECHA, 2020b) proposed a far-reaching restriction on the deliberate use of microplastics in products placed on the market in the EU or EEA, but its introduction has not yet been finalised. Microplastics are defined as particles that are between 0.1 and 5 mm in size and consist of a mixture of polymers and functional additives. The restrictions are to apply (with specific transitional regulations to include the development of new alternatives) to the sector of polymeric infill materials, among others, to which the infill granulate for artificial turf fields is to be counted. Due to the already changed subsidy guidelines in sports field construction, the use of ELT granulates in new artificial turf constructions has been almost completely discontinued in Germany (see chapter 6.3.2).

8.4 International systems for ELT management

8.4.1 Fee-based systems

In the fee-based system, a government agency levies a fee on tyres entering the market. The fees collected are paid into a fund, which is supervised by a central body and which disburses the money to the participating companies in the recycling chain according to defined rules.

Currently, only Denmark and Croatia have fee-based systems for ELTs.

8.4.1.1 Denmark

In Denmark, a fee is levied on each tyre sold, which is used to subsidise the collection of ELTs and their transfer to recycling companies. The legal basis is the *Executive order on fees and subsidies for the recovery of tyres* (BEK No. 1347/2016, from 01.2021 BEK No. 1660). All tyres for motorised vehicles are covered by the ordinance.

Manufacturers, sellers and importers of new or retreaded tyres must register with the Danish tax authority Skatteforvaltningen (SKAT) and report each quarter the number of tyres placed on the market by type of tyre. A fee is levied per tyre type, ranging from DKK 10 (€ 1.34) to DKK 255 (€ 34.26)[15] (BEK No. 1347/2016). For a typical passenger car tyre, the charge is 25 Danish kroner (€3.36)[15]. Exempted from the levy are retreaded tyres from Danish ELT collection, tyres mounted on vehicles and ELT imported for recycling. Exported tyres and tyres that went to other registered companies are deducted from the reported number of tyres. SKAT transfers the fee collected to the Daekbranchens Miljøfond (Tyre Industry Environmental Fund) via the Environmental Protection Agency (Miljøstyrelsen) (BEK No. 1347/2016).

The Environmental Protection Agency is responsible for the registration and licensing of ELT collectors and recyclers, and the Daekbranchens Miljøfond is responsible for the assessment and payment of the subsidy for **ELT collection** (BEK No. 1347/2016). The fund is operated by Dækbranchen Danmark, the umbrella organisation of the tyre industry (Dækbranchen Danmark, n.d.).

To qualify for the subsidy, collection companies must register with the environmental authority. For the collection or acceptance of ELT, the company is not allowed to charge money to the ELT owners (BEK No. 1347/2016).

The collectors digitally report the type, quantity and origin of the collected ELT and the delivered ELT per recipient to Daekbranchens Miljøfond on a monthly basis. For this purpose, the companies also have an app at their disposal, through which the drivers can transmit the information directly (Dækbranchens Miljøfond, n.d.).

The subsidy is paid monthly for ELTs delivered to a recycling company registered with the Environment Agency. The amount of the subsidy depends on the tyre diameter and the material recycling rate of the recipient. The base value is currently DKK 1.55/kg (€ 0.208/kg)[15] for tyres < 24 inches and DKK 2.10/kg (€ 0.28/kg)[15] for tyres 24 inches and larger. Assuming an average

[15] As of 19.12.2020: 1 DKK = 0,1344 €

weight of 8.8 kg per ELT, the subsidy is thus up to an average of € 1.83 for a used car tyre. For the subsidy, this value is multiplied by the recycling rate (BEK No. 1347/2016).

To be registered as a **recycler**, companies must demonstrate a recycling rate of at least 50%. Only granulation and pyrolysis are recognised as recycling methods. Recyclers must report the weight received per tyre category and tyre collector to Daekbranchens Miljøfond on a monthly basis (BEK No. 1347/2016).

There are currently only two authorised companies for recycling ELT in Denmark. These are Imdex S/A and Genan S/A. Genan's material recycling rate is 90.6%, Imdex's 86.0% (Dækbranchens Miljøfond, n.d.). Both separate steel and textile fibres. The rubber is processed into granulates and, in the case of Genan, also into rubber powder. The textile fibres are recovered energetically in the cement industry and are therefore not included in the material recycling rate (Genan A/S, 2020a; Imdex A/S, 2020a).

The recycling companies charge a gate fee for acceptance from the ELT collectors. The ELTs must be free of impurities and contaminants. For example, silage tyres are not accepted (Genan A/S, 2020b; Imdex A/S, 2020b).

A third company, Elysium Nordic, is scheduled to start operations in 2023. In contrast to Imdex and Genan, Elysium aims to recover raw materials through pyrolysis. The target products are industrial carbon black, synthesis gas and oil, and steel. The gas will be used in the facility itself. The facility has a planned capacity of 30,000 t of ELT per year (Elysium Nordic, 2020).

Specific requirements for the PAH content of ELT recycling products (granulates, as well as oil and soot from pyrolysis) are set by BEK No. 1347/2016. Furthermore, it is mandatory to separate the steel content in recycling processes. This may not exceed 0.5% by weight in the secondary materials (rubber and carbon black).

8.4.1.2 Croatia

In Croatia, ELT management is also financed through a fee-based system, which subsidises both collection and recycling. The legal basis is the Sustainable Waste Management Act (NN 94/2013) and the Waste Tyre Ordinance (NN 113/2016). The ordinance stipulates that 80% of the separately collected ELTs must be reused or recycled annually. ELTs treated abroad are included in this figure. All types of tyres and rubber tracks, including those on end-of-life vehicles, are covered by the ordinance (NN 113/2016).

Importers register all new tyres, both as individual tyres and as part of a vehicle, with the state-owned Environmental Protection and Energy Efficiency Fund (FZOEU). The FZOEU levies a **fee** on the imported quantity of currently 1,067 HRK/t (141.48 €/t)[16]. If new tyres are imported as part of a vehicle, the fee ranges from HRK 6.79 to 174.60 per tyre (€ 0.90-23.15/tyre)[16] (NN 57/2020). When new tyres are exported, the fee is refunded. The fee is passed on to customers through the sales price (FZOEU, 2020; NN 113/2016).

Owners of ELTs are obliged to collect them separately and hand them in at workshops, tyre dealers or CACs. These are obliged to accept the ELTs free of charge and hand them over to an authorised ELT collector (NN 113/2016). The collectors sort the ELTs according to their condition and deliver them either to energy recovery or recyclers or sell them to retreaders.

Collection and treatment of ELTs in Croatia are also organised by the FZOEU. For this purpose, the fund concludes contracts with authorised companies. ELT collectors and recyclers are authorised by the Ministry of Environmental Protection and Energy. The companies submit

[16] As of 19.12.2020: 1 HRK = 0,1326 €

monthly reports to the FZOEU on the quantities accepted, processed and disposed of, as well as the quantity of tyres temporarily stored. The fund reimburses the costs for collection and recycling to the respective enterprises (NN 113/2016).

The ELT collection is put out to public tender by the FZOEU. The lowest costs for the collection are determined by evaluating the offers. This value is set as the new price that the fund pays for the ELT collection. All suitable providers must accept the price in order to be able to conclude a licence agreement with the fund (NN 113/2016). The reimbursement for ELT collection by the collector is currently HRK 350/t (€46.40/t)[16] and for temporary storage, sorting and loading for transport to the recycler HRK 70/t (€9.28/t)[16]. The transport of ELT to the recycler is remunerated at HRK 1/(t*km) (0.133 €/t*km)[16] (NN 57/2020). In 2019, there were 12 licensed ELT collectors in Croatia (MGOR, 2020).

To be approved as ELT recyclers, companies must have a permit for the R1 or R3 processes according to Annex II of the Sustainable Waste Management Act. R1 is energy recovery, R3 is recycling (under specific conditions also gasification and pyrolysis). In addition, the companies should either have their own environmental management system or participate in one. Through a contract with the fund, the companies undertake to recycle all accepted ELT as agreed (NN 113/2016). The price for recycling is 600 HRK/t (79.54 €/t)[16] and for energy recovery 100 HRK/t (13.26 €/t)[16] (NN 40/2015).

Currently, there are three approved recyclers that have signed contracts with the fund (FZOEU, 2017). Two are cement factories that use ELT for energy recovery. The third company, Gumiimpex GRP, recycles ELTs into rubber granulate or prepares them for reuse by retreading. Part of the rubber granulate is used by Gumiimpex in its own production. The facility has a capacity of 32,000 t of ELT per year (Gumiimprex, 2019).

According to the FZOEU, 25,949 t of ELT were collected in Croatia in 2019. Of these, 21,284 t were recycled. The remaining 4,665 t were either reused or were still in temporary storage on the reporting date. Of the recycled ELT, 94% were recycled and 6% were recovered for energy. This means that the annual target of > 80% material recycling was achieved (MGOR, 2020).

8.4.1.3 Advantages and disadvantages of fee-based systems

The two fee-based systems in Europe differ in how many types of tyres are covered by the system. While in Denmark only ELTs of vehicle categories M1 and N1 are collected, in Croatia all motor vehicle and aircraft tyres are the responsibility of the system.

The removal of ELT deposits resulting from illegal dumping is not financed by the systems in either case.

Despite the differences in the design of the two systems, the following advantages and disadvantages can be observed:

Advantages

- Reduced or no incentives to dispose of ELTs illegally.
- Incentive system to prioritise recycling.
- Increased incentives to inspect and sort ELTs for recyclability.
- Easier control and monitoring of the system by government agencies.
  - Subsidy regulations influence the recycling channels

- Licensing criteria for ELT collection and recycling companies

- The basic features of the free market remain largely in place.
- Better redistribution of disposal fees
- Little incentive for the export of ELTs for recycling

Disadvantages

- Increased bureaucracy for the collectors and the authorities
- Costs for the general public remain for the removal of illegally disposed ELTs

8.4.2 Extended producer responsibility (EPR)

Extended Producer Responsibility (EPR) systems legally oblige producers of a targeted product to organise and finance the collection and recycling of their product at the end of its life. The term producers refers to both producers and importers of the respective product. Depending on the system, producers can fulfil their responsibility either individually or colectively. For joint implementation, they can establish a Producer Responsibility Organisation (PRO) to fulfil their duties.

Currently, 20 EU countries have extended producer responsibility for ELT. The EPR system in the Netherlands and the French system are presented below as examples (ETRMA, 2020).

8.4.2.1 France

In France, extended producer responsibility for ELT has existed since 2004. The legal basis is provided with Sections L541-10-8 and R543-137 ff of the Environmental Code (Code de l'environnement, C. envir.) and various decrees. All tyres of vehicles listed in the Road Code (Code de la route) under R311-1 are covered by the law. If the tyres have been used for purposes other than traffic, such as covering silage or in playground design, they are not part of the system.

The law places the responsibility for collecting and recycling ELT on producers of tyres and vehicles with tyres for the national market. The national market here is not only the European part of France but also its overseas territories (C. envir., 2016). To meet its responsibilities, each producer can either maintain its own system or set up a PRO together with others. Contracts are concluded with authorised companies for collection and recycling. Collection companies need a permit from the prefect of their départment, which must be renewed every five years. In addition to nationwide collection and recycling of ELT, studies must be conducted to optimise the system and tyre design must be optimised with regard to reuse and recycling.

Collection must be free of charge for ELT owners. ELTs are taken back via the retailer. However, they can usually also be handed in at the CACs of the municipalities. The law stipulates that every retailer must take back free of charge as many tyres as they sold in the previous year. If the collection quantity is lower, the shortfall is added to the collection quantity for the next year. The increase may not exceed 10%. The collection of ELTs from retailers must be done free of charge by producers (C. envir., 2016). Tyres from end-of-life vehicles also fall under producer responsibilities and must also be collected free of charge from the centres VHU (C. envir., 2016).

All collected ELTs must be recycled or prepared for reuse. Recycling is to be preferred to energy recovery (C. envir., 2016). In the draft law, a limitation of energy recovery to below 50% of the collection volume was foreseen, but this was not introduced (Ministère de la Transition écologique, 2018). Currently, there are no quotas for recycling or reuse of ELT in France.

According to the Ministry of Ecological Transition (Ministère de la Transition écologique, MTE) (2018), only individual producers have opted for a single solution. The majority have joined a PRO. In 2018, there were six PROs in France, four of which were in overseas territories and two in Europe. The two European PROs, Aliapur and GIE France Recyclage Pneumatiques (FRP), covered 80% of manufacturers (MTE, 2018).

Aliapur has 444 members and organises collection, transport and recycling through contracts. Collection and sorting are put out to tender every four years, transport every two years. The company currently has contracts with 27 ELT collectors, 12 reprocessors and 63 recycling companies. In 2019, according to its own figures, 375,076 t of ELT were collected by Aliapur. Of this, 15% was reuse, 44% energy recovery and 41% recycling (Aliapur, 2020). ELTs from end-of-life vehicles are collected by the subsidiary Aliastocks. Aliastocks also collects and recycles ELTs that do not fall under EPR, such as ELTs from illegal dumping or silage tyres. The collection volume was 10,000 t from end-of-life vehicles and 20,000 t other tyres in 2019. Information on the recycling routes is not published (Aliapur, n.d.; Aliapur, 2020).

FRP has 259 members and contracts with seven companies for collection and recycling. In 2019, the system collected 87,422 t of ELT. Around one third of the ELT came from end-of-life vehicles. In total, 44% were recycled and 42% were used for energy recovery. 8% of the ELTs were reused (FRP, 2020).

The Environmental Code explicitly allows the export of ELTs for retreading or recycling worldwide, provided that EU Directive No. 1013/2006 is complied with (R543-147). In the case of Aliapur, only 34% of ELTs recycled in 2019 were treated in France. 20% were recycled in other European countries and 46% in various countries in Africa and Asia (Aliapur, 2020). FRP does not provide information on its own exports.

There is an agreement between the two PROs and the municipalities that only ELTs from private cars and motorbikes are collected free of charge from the CACs. Other tyres are only collected for an additional charge (Aliapur et al., 2018).

In order to collect and process old ELT deposits, the company Recyvalor was founded in 2008 through an industry agreement. The reprocessing of illegally disposed ELT was financed in equal parts by the French environmental agency ADEME, Aliapur and ARN, the PRO for end-of-life vehicles (Collet, 2017). In 2018, Recyvalor was dissolved as its mission was considered fulfilled (MTE, 2018).

Since July 2019, there has been a voluntary commitment by the tyre industry to collect and recycle silage tyres. Within the framework of this voluntary commitment, 15,000 t of silage tyres are to be collected annually. Ensivalor was founded by the tyre industry for this purpose. In cooperation with local authorities and representatives from agriculture, Ensivalor is setting up local points of collection where silage tyres can be handed in free of charge (Aliapur, 2020; AFIP et al., 2019).

8.4.2.2 The Netherlands

In the Netherlands, ELT recycling is regulated by the Decree on the Management of Vehicle Tyres (Besluit beheer autobanden, Bbab), which entered into force in 2004. The decree only applies to tyres of passenger cars and commercial vehicles of categories M1 and N up to 3.5 t and a maximum of nine seats, as well as their trailers (Bbab, 2009). The removal of illegally disposed ELT and historic stock is not part of producer responsibility (Winternitz et al., 2019).

Similar to France, the responsibility for collecting and recycling ELTs lies with the tyre producers. They can fulfil this responsibility either individually or jointly through a PRO. The decree stipulates that tyre sellers must take back as many ELTs free of charge as they sell new ones. Records must be kept of the number of tyres taken back. Owners of tyres can also hand them in at the CACs of their municipality. Producers must accept the separately delivered tyres free of charge (Bbab, 2009).

The collection volume per producer is based on its market share. Each tyre producer must therefore submit an annual report on the previous year and indicate the average market share of the last three years as well as a contact person for tyre sales. If a producer is a member of a PRO, the PRO can take over its information obligations (Bbab, 2009).

The collected ELT should either be reused or recycled, with at least 20% by weight of the collected quantity to be recycled. (Bbab, 2009)

In response to the law, the Dutch Tyre Association "Vereniging Band en Milieu" founded the PRO RecyBEM B.V., which fulfils the legal tasks and reporting obligations of the producers. RecyBEM organises the collection and recycling of ELT for its members. In order to finance the system, the Tyre Association founded the Stichting Fonds Band en Milieu (Dutch Tyre and Environment Foundation). The foundation collects a contribution from the producers for each tyre sold and transfers the money as a sum to RecyBEM. In this way, the market share of individual producers cannot be tracked through ReyBEM's financial report (RecyBEM B.V., n.d. c).

RecyBEM was declared generally binding in 2015 (Staatssecretaris van Infrastructuur en Milieu, 2015). This means that non-members of the Tyre Association are also obliged to pay the contribution and use RecyBEM.

To achieve the legal requirements, RecyBEM contracts with ELT collectors and recyclers that it has certified itself. Currently there are 20 certified ELT collectors (RecyBEM B.V., n.d. a) and six recyclers. Of these, two are located in the Netherlands, one in Belgium, two in Germany and one in Denmark (RecyBEM B.V., n.d. b).

According to the 2017 annual report, 31.9% of collected tyres were reused and 1.3% were retreaded. According to ETRMA's ELT statistics, all tyres were exported for retreading and reuse in 2016 (ETRMA, 2018). Since then, RecyBEM no longer publishes figures on the export share. According to experts, a significant share of reusable tyres and all tyres for retreading are still exported, apparently mainly to Eastern Europe and Africa (Winternitz et al., 2019; Campbell-Johnston et al., 2020).

According to an analysis of the different disposal routes for RecyBEM in 2011, the cost of recycling was at least 32% higher and the cost of energy recovery at least 17% higher than the cost of export for reuse and retreading (ARN Advisory, 2011).

ELTs from agriculture do not fall under producer responsibility. They were collected voluntarily by RecyBEM between 2007 and 2018 through the Boerenbanden project (RecyBEM, 2013; 2018).

8.4.2.3 Advantages and disadvantages of EPR systems

The advantages and disadvantages of EPR systems for ELTs strongly depend on the specific legal design of the system. For example, the European systems differ in how many types of tyres they cover. While in France almost all tyre types are covered by EPR, in the Netherlands it is only passenger car tyres. A limited choice, as in the Netherlands, increases the risk of illegal disposal of tyre types that are not included, with the costs of their disposal often having to be borne by the general public (Winternitz et al., 2019). Another critical issue in the design of an EPR system is how to deal with end-of-life deposits. In France, these have been dealt with via an industry agreement, but in the Netherlands they are not part of producer responsibility.

The examples of EPR systems considered show the following advantages and disadvantages:

Advantages

- Regulation of responsibility for the disposal of ELTs.
- Incentives for the waste management companies to check the ELTs for their recyclability and to sort them.
- Reduced to no incentives to dispose of the tyres in an illegal way.
- Control over quality and costs of collection and recycling through PRO contract regulations.

Disadvantages

- Costs to the general public remain for the disposal of illegally dumped ELT.
- Costs for the waste management of tyre types not covered by the system have to be borne by their owners and increase the risk of illegal disposal.
- Control of free riders by PRO or authorities costly.
- Export of used tyres and ELTs for retreading or recycling to non-EU countries as the cheapest disposal route.
    - No guarantee of sufficient environmental standards for recycling
    - Risk of ecologically disadvantageous disposal routes after end of use
    - Reduction of available ELTs for local recycling industry
    - Loss of raw materials
- The PRO may distribute ELTs to the detriment of individual recycling industries in order to serve the interests of its members if there are loopholes in the legal design of the EPR system.
- Trend towards a decline in recycling in some systems observable.

8.4.3 Free market

In the free market system, the state sets the framework and formulates the goals to be achieved. The stakeholders act under free market conditions to organise ELT disposal routes.

8.4.3.1 Switzerland

ELT collection and recycling in Switzerland is organised via the free market.

ELTs are classified in the Swiss waste list as "other waste subject to control without a consignment note requirement". According to the Ordinance on the Movement of Waste (VeVA), collectors, sorters, all treatment facilities and intermediate storage facilities require a VeVA permit for ELT (VeVA, 2020; BVD, 2015). The permit is only ever valid for one location, not for the entire company, and is applied for at the respective canton. Only transport without intermediate storage within Switzerland and companies that solely trade ELTs are exempt (BVD, 2015). Every company that requires a permit must report annually to the Federal Office for the Environment (FOEN) the quantity of ELT accepted and the type of treatment, as well as the quantity of ELT forwarded and the recipient's company number (VeVA, 2020).

A permit from the FOEN is required for the import and export of ELT. ELTs for reuse with sufficient tread depth do not require a permit, but must pass a quality control (RVS ASP, n.d.). ELT may only be exported to OECD and EU member countries for reprocessing, recycling and disposal (BAFU, 2019; RVS ASP, 2017).

ELTs in Switzerland can generally be handed in at ELT tyre and tyre dealers, workshops and car dealerships. These can charge the owner for taking over the ELT, although free acceptance is not uncommon (RVS ASP, 2017a). The collection points may only hand over the ELT to companies with the corresponding VeVA permit (BAFU, 2019). ELT collection via municipal systems is not intended (BAFU, 2019).

The number of recovery and collection companies in Switzerland is not published by the authorities. The Tyre Association of Switzerland (Reifen-Verband der Schweiz, RVS) lists 16 companies that are active in the ELT sector. Most of them are collection companies. Only four state that they recycle ELT or produce RDF, and two others are cement manufacturers (RVS ASP, n.d.).

There is no reliable statistical data on the volume of ELT and their disposal routes. For 2017, a volume of 60,000 Mg was estimated and it was assumed that 10,000 Mg of this was disposed of illegally (RVS ASP, 2017a).

8.4.3.2 Advantages and disadvantages of the free market

The organisation of ELT disposal through the free market has the following advantages and disadvantages:

Advantages

- Low bureaucracy
- Subsidy-free operating recycling industry

Disadvantages

- Material flows hardly traceable
- High risk of illegal dumping of ELTs
- The market tends to prioritise the most cost-effective disposal route
- Low sorting rates of the ELTs
- Lack of redistribution of disposal costs
- Distortions of competition due to unfair competition, e.g. financial incentives for illegal dumping

8.5 Emissions of pollutants and microplastic

8.5.1 Literature review

8.5.1.1 Evaluation of analytical methods for PAH measurements

The ECHA (2020) published the "ANNEX XV INVESTIGATION REPORT: Investigation of the available analytical methods to measure content and migration of polycyclic aromatic hydrocarbons, limit values in rubber and plastic articles in paragraphs 5 and 6 of Entry 50 of Annex XVII to REACH, and alternative low-PAH raw materials".

Based on the available information, the report concludes that the current PAH content limits can still be considered as an effective risk management measure to control consumer exposure. However, it further states that these content limits may not guarantee low levels of PAH migration and safe use for all types of plastic and rubber matrices. Germany would therefore have recommended to maintain or even lower the current limits. Whether a migration limit, as an exception to or in addition to the content limit, could be set to control the risk and whether the current PAH content limit additionally provides sufficient protection against risks from exposure to PAHs would require further risk assessment. The available methods for determining the content and migration of PAHs were found to be sufficiently reliable and readily available overall.

In the report, the analytical method for the determination of very low concentrations of PAHs in rubber and plastic components of articles as described in Annex II of the JRC report on Migration of Polycyclic Aromatic Hydrocarbons (PAHs) from plastic and rubber articles (Barrero-Moreno et al., 2018) was discussed in depth. (see Table 75). With the limit of quantification of this method, concentrations of PAHs up to two orders of magnitude lower can be tested than with all other methods currently used. Furthermore, the harmonised method to be developed by the European Committee for Standardisation (CEN) (European Commission, 2017) could address the remaining shortcomings: Providing peer review and ensuring applicability to all sources of PAHs, including carbon black.

The method developed by Barrero-Moreno et al. (2018) to measure migration of PAHs using 20% ethanol as the migration medium is considered a conservative approach to assess migration into both the skin and oral cavity. The method showed good performance but also high inter-laboratory variability. Measures that could help reduce variability were identified. Furthermore, it has been argued that various studies have concluded that

- a detectable migration of PAHs from plastic and rubber matrices was only observed for rubbers with a high PAH content,
- the toxicological effects of PAHs do not depend on the amount of PAHs contained in the article, but on the amounts migrating from the contact surface of the article through the skin into the human body, and
- there is no direct proportionality between the PAH content in the article and their migration.

However, overall, taking into account all available information, ECHA considers that additional risk assessment is needed to determine whether a migration limit could be set in addition or as an alternative to the content limit. The option of introducing a migration test for PAHs would need to be assessed against the specific exposure scenarios targeted by the restriction proposal. This would require additional information to understand the migration behaviour of PAHs, in particular with regard to the correlation of product thickness, type of matrix, input source of PAHs, type and content of PAHs contained and the wear of the material. ECHA has agreed in principle to carry out such a risk assessment.

In summary, a more stringent method of PAH content measurement analogous to the method of Barrero-Moreno et al. (2018) will possibly be implemented, which also includes the PAHs from the carbon black. In this respect, higher measured PAH concentrations are to be expected than is the case, for example, with the measurement method according to ISO 18287. At the same time, there are various calls or considerations to maintain or even reduce the content limit values. In a worst-case scenario, higher measured values of the PAH content, as a result of the potentially more intensive sample extraction of the measurement method, would coincide with reduced

PAH content limits. However, it is stated in this context that, based on the migration tests, an exemption with regard to the PAH content limit could be reconsidered if necessary.

8.5.1.2 Assessments of the environmental risks of ELT granulates in synthetic turf fields

The U.S. Environmental Protection Agency (EPA) conducted the multi-agency research project "Synthetic Turf Field Recycled Tyre Crumb Rubber Research Under the Federal Research Action Plan" (EPA, 2019). The project focused on the use of ELT granulates in synthetic turf fields and on playgrounds. A wide-ranging physical, chemical and microbiological characterisation of the granulates was published in the final report (part 1). However, it is explicitly stated that the research activities were not designed and are not sufficient in themselves to directly answer questions about potential health risks. Nevertheless, some conclusions are drawn:

- A number of chemicals were found in the ELT pellets, as expected, including metals and organic chemicals.
- Emissions to air of many organic compounds were typically below detection limits or test chamber background.
- The release of metals into simulated biological fluids was very low (average bioaccessibility values were about 3% in gastric fluid and less than 1% in saliva and sweat plus tallow).
- "In general, the findings from the report support the premise that while chemicals are present as expected in the tyre crumb rubber, human exposure appears to be limited based on what is released into air or simulated biological fluids." (EPA, 2019)

The French Agency for Food, Environmental and Occupational Health & Safety (ANSES) conducted a meta-analysis of academic and other studies, and expert opinions on the risks associated with the exposure of athletes and children using artificial turf fields with infill granules, as well as the risks associated with the exposure of workers involved in the installation and maintenance of these fields (ANSES, 2018).

The report comes to the following conclusions:

- The evaluated studies conclude in most cases that the health risk is negligible.
- The emission and migration simulations indicate low concentrations of heavy metals, plasticisers, additives or VOCs below the toxicological reference values given by the respective authors.
- Only low concentrations of carcinogens are emitted or released from tyre granulates, therefore the risk of carcinogenicity is considered to be low or negligible.
- Conducted epidemiological studies do not show an increased incidence of cancers, especially lymphoma and leukaemia, associated with the installation and use of synthetic sports fields.
- The available information indicates the existence of potential risks to the environment, mainly through the release of zinc and other metals and organic compounds such as phthalates and phenols. However, the information currently available is not sufficient for a conclusive assessment.
- "The use of ELT-derivated granulate infill can lead to the generation of microplastics as a result of mechanicals constraints applied to the granulates from the users or by maintenance practices on synthetic turf field sand playgrounds. The generation of microplastics and their dispersion can be amplified by environmental conditions such as the variation of

temperature, humidity, rain, etc. The microplastics generated can give rise to a serial of hazardous effects on aquatic and terrestrial organisms."

ANSES (2018) also identifies weaknesses in the studies evaluated, including:

- The representativeness of sampling in each field and the number of soils tested is questionable.
- The studies mainly focus on substances with proven carcinogenicity so that probably not all substances emitted by ELT granulate were taken into account.
- Synthetic playgrounds, due to their specific design and construction, might show more complex chemical emissions. There is only a small number of studies on synthetic playgrounds compared to synthetic sports fields available.

A similar report prepared by ECHA (2017) evaluated the possible health risks of ELT granules used as infill in synthetic turf fields. The literature review identified a number of hazardous substances commonly found in ELT granulate. These are PAH, metals, phthalates, volatile (VOCs) semi-volatile (SVOCs) organic hydrocarbons. Furthermore, exposure through skin contact, ingestion and inhalation of substances evaporating from the granulates, and dust formed by the granulates was investigated and the associated risks were assessed.

The report concludes that the overall concern for exposure to recycled rubber granulate is at most very low:

1. "In the studies that ECHA has evaluated the concentrations of PAHs in recycled rubber granules have normally been well below the limit values set in the REACH restriction relevant for such mixtures. [...] It is important to note, however, that if the concentration of PAHs would be as high as the generic limit for mixtures supplied to the general public defined in REACH, the level of concern would not be low.
   The concern for lifetime cancer risk for players and workers is very low given the concentrations of PAHs typically measured in recycled rubber granules in the EU.
2. The concern to players and workers is negligible given the available, although limited, migration data for metals, which are below the limits allowed in the current toys legislation.
3. No concerns to players and workers were identified from the concentrations of phthalates, benzothiazole and methyl isobutyl ketone in rubber granules as these are below the concentrations that would lead to health problems.
4. It has been reported that VOCs emitted from rubber granules in indoor halls might cause irritation to the respiratory track, eyes and skin."

Furthermore, the following uncertainties in its evaluation were identified:

- "There are still some knowledge gaps as regards to the substances present and their concentrations in the recycled rubber granules typically used as infill material in sport fields."
- "The combined effects of all the substances in rubber granules are not known and very difficult to assess. However, this uncertainty is not considered to affect the main conclusions of this evaluation."
- Imported tyres entering the EU may have different substance concentrations than the rubber granulates in the studies considered.

A joined research programme by ADEME, Aliapur and the artificial turf manufacturer Fieldturf Tarkett investigated the environmental and health risks of rubber granules as infill. Moretto (2007) combined the results of the programmes various studies in a technical report.

The tests used 3rd-generation artificial turf with an infill of 17.5 kg sand and 15 kg granulate. Granulates from French ELTs, virgin EPDM granulates and TPE granulates were used in the experiments. Representative artificial turf segments were investigated under artificial weathering as well as under real environmental conditions on a playing field. For this purpose, the seepage water that passed through the artificial turf was collected over a period of 11 months and analysed. Furthermore, emission tests were carried out.

The assessment of the environmental impact of the seepage water was carried out through physico-chemical analysis and ecotoxicological analyses.

In summary, it was found that, based on a comparison with the applicable French and European guideline values, the concentrations of organic compounds, metals and anions of the leachate meet the requirements for the quality of water resources and in the vast majority of cases even fulfil the requirements for drinking water. The studies conclude that, from an ecotoxicological point of view, the nature of the percolates, regardless of the type of filling granulate, has been shown to have no impact on the environment.

As a conclusion of the emission measurements, it is stated that the VOC and aldehyde emissions of the three types of infill granulates when used indoors (small and poorly ventilated gymnasiums) are not a cause for concern for human health. The exception is for workers installing artificial turfs in small and poorly ventilated gymnasiums who are exposed for more than five years. In this case, it is recommended to ensure at least two air changes per hour during installation. It is worth mentioning here that the emissions of the EPDM virgin material, which is often considered a higher quality substitute for ELT recyclates, shows significantly higher emissions after 28 days (TVOC28 days) than ELT granulate. The EPDM (490 µg/m3) emits almost 4 times the amount compared to ELT (134 µg/m3).

8.5.2 Emission of microplastics from artificial turf fields

Fraunhofer UMSICHT (2019) concluded that the discharge of granulates from different artificial turf fields varies. The interaction of the numerous identified influencing factors for the emission is still unclear. From interviews with municipalities, a replacement demand of 50 to 1,500 kg of granulates per field and year was determined. "It is not possible to draw direct conclusions about emissions from subsequent deliveries, as granulate losses are in many cases compensated for by sand or not at all. [...] Whether emissions correlate with the applied mass of free granulates or (more likely) with the area of the field should be the subject of future investigations."

According to ECHA (2017), on average 0.5 to 1 tons of infill granules needs to be added per field per year. During winter operations, an additional 3 to 5 tons are discharged with the snow during clearing.

Due to the deviating sports field construction regulations in Germany, the amount of granulate used is significantly lower than in international comparison and the discharge quantity is estimated at less than 0.5 tons per year and field (DFB and DStGB, 2019).

According to the company Genan, it is possible to almost completely prevent the discharge of microplastics with relatively simple means by requiring compliance with the corresponding regulations of the CEN/TR 17519 standard in the tender.

8.5.3 Thermally and mechanically induced release of substances from ELTs

During the shredding of ELT and the processing of recyclates, for example through compounding with thermoplastics, the rubber is sometimes subjected to high deformation and thermal stresses. This can generally result in the discharge of substances. On the one hand, tyres contain anti-ageing and anti-ozone agents, some of which are specifically intended to be discharged to the product surface through deformation (see Figure 27). In principle, it can be assumed that these substances are also released by the deformation stresses, for example during shredding.

Figure 27 Anti-ageing agent of a tyre leaked due to deformation

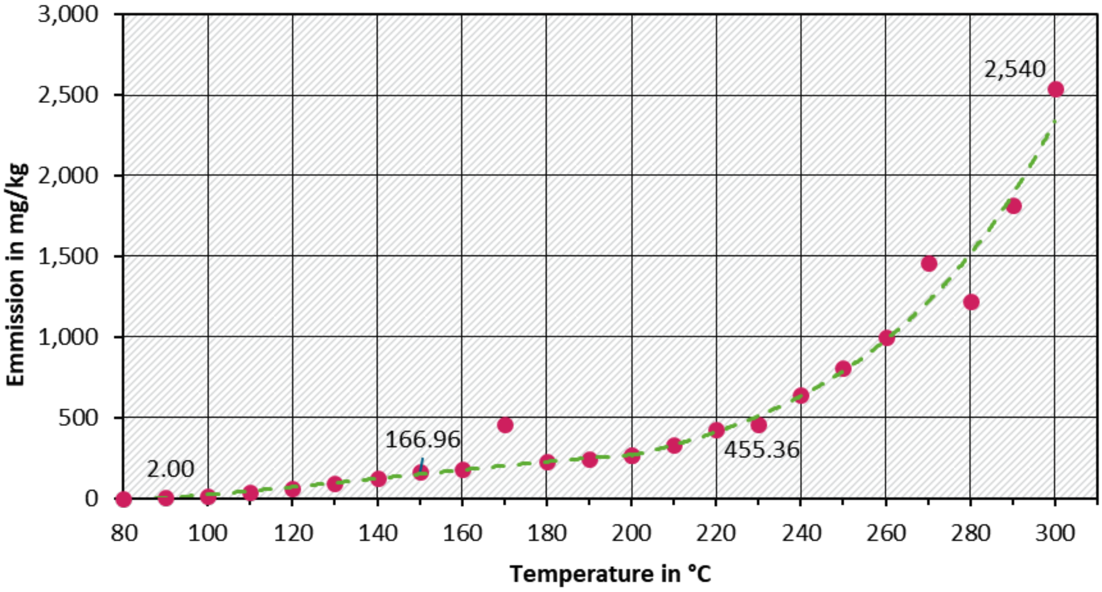
Source: Hoyer

Furthermore, ELT recyclates begin to emit more substances when subjected to thermal stress at around 100 °C and above. The maximum operating temperature range of natural and SBR rubber is about 80 °C (briefly up to 100 °C). Above these temperatures, the material degrades and volatile substances are released from the ELT recyclate, such as plasticisers, anti-ageing agents and a host of other chemical compounds.

The temperature-dependent release potential of volatile organic compounds from ELT recyclate was investigated in Hoyer and Kroll (2019) using static vapour space gas chromatography. Cryogenically ground whole truck tyres with a size of 200-400 µm were heated to temperatures between 80-300 °C in a nitrogen atmosphere and the concentration of volatiles in the vapour space was quantified. The release of substances begins at around 80-90 °C and initially increases approximately linearly with temperature (see Figure 28). From about 180 °C, the release then increases approximately exponentially with the temperature.

While at 100°C the number of components found is still manageable, the number of volatile compounds increases significantly with increasing temperature. Compounds with 1-3 carbon atoms, numerous compounds with 4-6 carbon atoms, as well as further components with 6 and more than 6 carbon atoms are found. At low temperatures, almost exclusively components C1-C4, as well as methyl isobutyl ketone, xylene, cyclohexanone and benzothiazole were found in the gas phase. While C1-C4, toluene and xylene are still characteristic at higher temperatures, the other compounds mentioned gradually disappear and a large number of components that are not more closely assigned are released.

Figure 28 Release of volatile organic compounds in a nitrogen atmosphere as a function of temperature



Source: Hoyer and Kroll (2019)

Accompanying this, the vapour of the ELT powder was analysed at selected temperatures by means of gas chromatographic methods and the organic components contained were specified. The results are shown in Table 73. It was found that the released organic compounds mainly consist of ketones, aromatic hydrocarbons and oxygenated heterocyclic compounds. However, some sulphur- and nitrogen-containing compounds were also found. The continuous use temperature of materials with ELT recyclate should therefore not exceed a temperature of 80 °C, and processing should take place below 180 °C.

Table 73 Composition of the organic fraction of the vapour space above ELT powder

Vapour space temperature	140 °C		180 °C	
Number of substances determined (Z)	162		365	
Compound class	Number of Z	Share in wt.-%	Number of Z	Share in wt.-%
Ketones	23	46.2	61	25.9
Aromatics	10	19.6	32	20.0
O-heterocycles	18	12.2	33	11.9
Alcohols	11	5.6	21	0.9
Olefins	16	5.4	37	9.9
Carboxylic acid esters	16	3.9	33	3.7
Aldehydes	6	2.8	18	10.3
S-compounds	17	2.8	18	0.8
N-compounds	16	0.6	27	3.3
Naphthenes	8	0.4	26	7.8

Vapour space temperature	140 °C		180 °C	
Carboxylic acids	6	0.2	15	2.0
N-heterocycles	8	0.2	5	0.3
n/i paraffins	3	<0.1	18	2.4
Other	4	<0.1	12	0.2
S-heterocycles	0	0	9	0.8

Source: Hoyer and Kroll (2019)

8.5.4 Polycyclic aromatic hydrocarbons (PAH)

8.5.4.1 Classification and scope of regulations on PAH content

With regard to the applicable limit values for polycyclic aromatic hydrocarbons (PAH), a distinction must be made between the areas of new tyres and secondary products which are (proportionately) manufactured from ELT recyclates.

Since 2010, Regulation (EC) No. 1907/2006 (REACH) has set PAH limits for the extender oils used in the manufacture of tyres. In addition to plasticisers, however, the main source of PAHs in tyres is carbon black, a filler and reinforcing material, the content of which is not regulated at EU level. Formally, therefore, there is no applicable limit value for the total content of PAHs in tyres.

Results of the measurement of tyres according to the regulations under Regulation (EC) No 1907/2006 can be found, for example, in Bund/Länder-Arbeitsgemeinschaft Chemikaliensicherheit (2012), ETRMA (2011a, 2011b), Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg (2010), Ministerium für Umwelt, Energie, Ernährung und Forsten des Landes Rheinland-Pfalz (2011). Sadiktsis et al. (2012), for example, show that the PAH content of the treads of various tyre manufacturers exhibited very wide fluctuation ranges before 2010. The determined PAH contents were between 3.79 and 85.2 mg/kg for a group of 15 PAH species (0.27 to 10.1 mg/kg for benzo(a)pyrene).

The types of carbon black used for tyre production are highly complex solids that are specially produced by means of special processes (mostly furnace). They are classified into different types according to ASTM standard D 1765 on the basis of a variety of different properties, such as particle size, distribution or structure, each of which is decisive for achieving defined material properties. A typical tyre contains about 8 different types of carbon black at any one time, but the total abundance of carbon black types is significantly greater. Accordingly, the multitude of carbon black types in tyre production can only be substituted to a very limited extent by those with low PAH contents or by alternatives such as silica. Nevertheless, there are a number of low-PAH carbon black types on the market, for example from the company CABOT. These could potentially be used as substitutes for carbon black types such as ASTM N650, 683, 539, 550 (e.g. SPHERON® SO-LP), ASTM N300, 200 (VULCAN® 6-LP) or ASTM N500, 600, 700 (SPHERON® 4000-LP). However, it is not known to what extent this is technically possible without restrictions and whether such carbon black types are used for the production of new tyres. In any case, not all carbon blacks, especially the high reinforcing types, will be replaceable by low-PAK types.

In large parts of the established sales markets for ELT recyclate, the PAH content in products has been preventively limited (e.g. Regulation (EU) No. 1272/2013, Model Administrative Regulation Technical Building Regulations (MVV TB 2019/1). The respective regulations do not refer directly to ELT, but to specific product groups or areas of application, such as floor coverings, for which the ELT recyclate is potentially used. Depending on the application, different regulations apply, different types and groups of PAH species are considered and different limit values are set.

However, in contrast to new tyres, the limit values applicable here consider the total content of PAHs in the material and not only that of the plasticiser. Accordingly, both the measurement methods and the measurement results are not comparable with those that are relevant for tyre production according to (European Parliament 2006).

8.5.4.2 Regulations on PAH content

8.5.4.2.1 Regulation (EC) No 1907/2006 (REACH)

The Regulation sets concentration limits for the individual REACH-8 PAHs in mixtures in entry 28 of Annex XVII of the REACH Regulation. The elastic fillers made of recycled material for plastic turf coverings are considered as a preparation (mixture) by the European Commission and the Member States (20th meeting of CARACAL held in Brussels on 8/9 March 2016) and are thus subject to entry 28 of Annex XVII of Regulation (EC) No 1907/2006 (REACH Regulation) in conjunction with Annex I (Table 3.6.2) and Part 3 of Annex VI (Table 3.1) of Regulation (EC) No 1272/2008 (CLP Regulation). The concentration limits are 1,000 mg/kg for benzo[e]pyrene, benzo[a]anthracene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene and chrysene (Table 3.6.2) and 100 mg/kg for benzo[a]pyrene and dibenzo[a,h]anthracene (Table 3.1). These can be translated into a cumulative limit of 387 mg/kg for the sum of REACH-8 PAHs using the additivity approach (ECHA 2019).

As of the eighth of September 2020, the European Commission (2020) has published a draft regulation that provides for lowering the limit value for the sum of the eight REACH PAHs in granulate and mulch to 20 mg/kg.

8.5.4.2.2 Regulation (EU) No 1272/2013 - restrictions on the use of PAHs under REACH

Regulation (EU) No. 1272/2013 has been in force since 27 December 2015 and applies to accessible plastic or rubber parts of articles. It limits the content of each of the following 8 PAHs to 1 mg/kg (0.5 mg/kg in toys or childcare products):

- benzo[a]pyrene, benzo[e]pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene and dibenzo[a,h]anthracene.

“This restriction should only apply to those parts of articles that come into direct as well as prolonged or short-term repetitive contact with the human skin or the oral cavity under normal or reasonably foreseeable conditions of use. Articles or parts thereof which are only in short and infrequent contact with the skin or oral cavity should not be included within the scope of the restriction as the resulting exposure to PAHs would be insignificant. Further guidance in this respect should be developed" (Regulation (EU) No. 1272/2013 (9)).

The Regulation does not specify how the PAH content is to be determined. The European Commission's Implementing Decision M/556 (2017) requested the European Committee for Standardisation (CEN) and the European Committee for Electrotechnical Standardisation (Cenelec) to develop draft harmonised standards for analytical concentration determination.

It further states: “By 27 December 2017, the Commission shall review the limit values in paragraphs 5 and 6 in the light of new scientific information, including migration of PAHs from the articles referred to therein, and information on alternative raw materials and, if appropriate, modify these paragraphs accordingly.’”

8.5.4.2.3 EC Water Framework Directive (WFD, Directive 2000/60/EC)

The EC Water Framework Directive (WFD, Directive 2000/60/EC (2000)) names eight PAHs in Annex X for which quality standards are to be set by the member states. In Germany, the Ordinance on the Protection of Surface Waters (Oberflächengewässerverordnung), Annex 8, Table 2 defines such environmental quality standards. "Furthermore, PAHs are classified as "priority hazardous substances" for which there is an additional "phasing out" obligation. These substances should no longer be discharged into the waters of the Community at a date to be determined" (UBA, 2016). For the discharge of wastewater into a water body or groundwater, a permit under water law is required in accordance with Articles 8, 9 and 10 of the Federal Water Act.

8.5.4.2.4 DIN EN 14041:2018-5 - Resilient, textile, laminate and modular multilayer floor coverings - essential characteristics

This European Standard applies to resilient floor coverings intended for indoor use. It refers to the same eight PAHs specified in Regulation (EU) No 1272/2013 and sets the same limit values of 1 mg/kg for each of them. Annex E provides a detailed description for the analysis of PAH content by gas chromatography-mass spectrometry (GC-MS) of toluene extracts. Compliance with this standard would in principle allow the award of a CE mark. However, this standard has not yet been published in the Official Journal of the European Union, which is why CE marking according to this standard is not yet possible.

8.5.4.2.5 Overview of affected product and application areas

Only some of the applications for ELT recyclates in secondary product manufacturing fall under the PAH content regulations (see Table 74). Their exact market share is unknown. It is estimated that 10-20% of granulate based products fall under the regulations.

Table 74 Relevant PAH regulations and potentially affected product groups

Regulations	Relevance	Examples of affected product groups
Regulation (EU) No 1272/2013	Accessible plastic or rubber parts (articles) that come into direct, prolonged or repeated contact with the skin or oral cavity for a short period of time during normal or reasonably foreseeable use.	Handles, sports articles, anti-slip mats/load protection, furniture (e.g. park benches), artificial turf. depending on the design: floor coverings, sports and fall protection mats in connection with (EC) No. 2018/1513 also footwear and clothing
EC Water Framework Directive (WFD) and Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV)	Products, especially those in direct contact with the environment, whose eluates can enter the environment, for example through rainwater.	Dike, ground protection, stable, sports and fall protection mats, artificial turf, balcony slabs, (path) edging systems, building protection (in the form of mats or coating systems), road construction, level crossing systems.
Model Administrative Regulation Technical Building Regulations (MVV TB) Edition 2019/1	Components, kits and building materials for recreation rooms and rooms not structurally separated therefrom	Floor coverings, laying underlays, sound and vibration insulation, impact and noise barriers, sports and fall protection mats

8.5.4.3 Overview of relevant analytical procedures and methods for the determination of PAH content in products and wastes

- **Grimmer method (Standard Operating Procedure (SOP PAH-0397):** This analytical method is based on the principle of stable isotope dilution using GC-MS with selective ion monitoring (SIM mode) and allows quantification of PAH content in the sub-ppb range. The Grimmer method has been validated for various matrices as part of the work of the Biochemical Institute for Environmental Carcinogens (BIU) for the environmental sample bank of the German Environment Agency (UBA) and has been published (Grimmer et al., 1997). Currently, the internal SOP PAH-0397 V16062003 is applied.
- **DIN EN 15527:2008-09:** Characterisation of waste - Determination of polycyclic aromatic hydrocarbons (PAHs) in waste by gas chromatography-mass spectrometry (GC/MS)
- **DIN ISO 18287:2006-05:** Soil properties - Determination of polycyclic aromatic hydrocarbons (PAH) - Gas chromatographic method with detection by mass spectrometry (GC-MS). Temporarily alternatively permissible (deadline 31.12.2022) for analytical detection of PAHs in accordance with the Model Administrative Regulation Technical Building Regulations (MVV TB 2019/1, issue: 15 January 2020).
- **GS Specification AfPS GS 2019:01 PAH** (as at 15 May 2019), Annex Test Guideline: Harmonised method for the determination of polycyclic aromatic hydrocarbons (PAH) in polymers. The content of the test instruction is congruent with AfPS GS 2014:01PAK. Both specifications differ only with regard to the PAH species considered. Compared to the AfPS GS PAH 2014:01, the PAH species acenaphthenes, acenaphthylenes and fluorenes have been omitted in the AfPS GS 2019:01, so that only 15 PAHs are determined instead of the previous 18. The analytical detection of PAHs according to the Model Administrative Regulation Technical Building Regulations (MVV TB 2019/1, edition: 15 January 2020) is carried out in accordance with this method (AfPS GS 2019:01).
- **Barrero-Moreno et al. (2018)**: Method for the determination of very low content concentrations of PAHs in rubber and plastic components of articles. The method is described in Annex II of Barrero-Moreno et al. (2018). With the limit of quantification of this method, concentrations of PAHs up to two orders of magnitude lower can be tested than with all other methods currently used. The method developed by Barrero-Moreno et al. (2018) to measure migration of PAHs using 20% ethanol as the migration medium is considered a conservative approach to assess migration into both the skin and oral cavity. The method showed good performance but also high inter-laboratory variability.

8.5.4.4 Comparison of the measurement methods

The analytical method of the individual procedures is based on the principle of gas chromatography with mass spectrometry coupling (GC-MS). The individual methods differ in particular in the way the PAHs are extracted from the samples and the solvents used for this purpose (see Table 75).

Table 75 Comparison of measurement procedures or methods for the determination of PAH content

Method	Sample quantity	Extraction method	Solvents	Extraction time	Limit of quantitation
DIN EN 15527:2008-09	10-25 g	Soxhlet extraction	Mixture (1:1) of acetone and a) petroleum ether b) n-hexane c) isohexane d) cyclohexane	min. 100 extraction cycles	0.1 mg/kg
DIN EN 15527:2008-09	10-25 g	Liquid–liquid extraction or ultrasonic extraction	a) acetone b) petroleum ether c) n-hexane d) isohexane e) cyclohexane	2x 30 min	0.1 mg/kg
DIN ISO 18287: 2006-05	10-25 g	Liquid–liquid extraction	Mixture (1:1) of acetone and petroleum ether	Method A: 1 h, B: 6 h	0.01 mg/kg
AfPS GS 2019:01 PAK	500 mg	Ultrasonic extraction (60 °C)	Toluene	1 h	0.2 mg/kg
SOP PAH-0397	3 g	Hot extraction (Twisselmann)	Toluene	8 h	0.001 mg/kg
Barrero-Moreno et al. (2018), Annex II	50/100 mg (<1 mm)	Hot extraction (Randall)	Toluene	3 h	0.002 mg/kg

Barrero-Moreno et al. (2018) used both ultrasonic and Randall hot extraction for the determination of the total PAH content of plastic and rubber materials. Both methods were “compared with regard to their extraction efficiency for the materials under investigation and the conditions used.”

“The contents achieved with ultrasound extraction were between 10–40% lower, depending on the specific PAH, suggesting that ultrasound extraction under these conditions may be less efficient compared to Randall hot extraction. The extraction procedure deviated from the AfPS protocol in that the AfPS protocol extracts higher weightings of sample material in lower amounts of solvent.” (Barrero-Moreno et al., 2018)

“The Randall hot extraction process represents an improvement over the classical Soxhlet extraction technique in that it considerably shortens the extraction time.” “Randall extraction is known to shorten extraction times by a factor of 4 to 5 when compared to classical Soxhlet extraction.” “Other benefits of the hot extraction process include short process paths, low solvent requirements, and a process that is gentler on the extract (due to the shorter extraction period).” Barrero-Moreno et al., 2018)

For this report, tests were conducted using the same ELT sample provided by PVP Triptis GmbH but different methods at different testing laboratories. The sample consisted of 0.05-2 mm granulates from passenger car whole tyres. The results are shown in Table 76.

Table 76 Results of the PAH analysis of ELT granulate for different test methods at different testing laboratories

Institute	Method	Benzo[e]pyrene	∑ 16 EPA-PAH
BIU Grimmer	Grimmer Methode (SOP PAH-0397)	1.45	54.6
Institut Alpha GmbH & Co. KG	DIN ISO 18287:2006-05	0.1	38.3
SGS INSTITUT FRESENIUS GmbH	DIN ISO 18287:2006-05	0.8	47.1
Eurofins Umwelt Ost GmbH	AfPS GS PAK 2014:01	1.4	47.7

8.5.4.5 Comparison of theoretical and measured mass-concentrations of PAHs

Barrero-Moreno et al. (2018) compared their results with the calculated total PAH content of natural rubber-butadiene rubber (NR-BR). The rubber materials were specially manufactured for the tests, so the composition of the blends was known. It was assumed that the carbon black and extender oils used were the only sources of PAH in the rubber materials.

“Results are generally in good agreement (Table 77) with only benzo[a]pyrene showing a higher discrepancy between the theoretical and the measured values for both NR/BR blends. Unfortunately, these results cannot be used for a fully quantitative trueness evaluation of the method as the values provided by the manufacturer for the content of carbon black and distilled aromatic extract can only be considered semi-quantitative estimates.” (Barrero-Moreno et al., 2018)

Table 77 Theoretical and measured mass-concentrations of PAHs in NR/BR blends

PAH species	NR-BR N375 TDAE			NR-BR N375 DAE		
[mg/kg]	Theoretical	Measured	Ratio	Theoretical	Measured	Ratio
Benzo[a]anthracene	0.2	0.2	100%	0.7	0.5	71%
Chrysene	0.3	0.3	100%	2.7	2.1	78%
Benzo[b]fluoranthene	1.2	0.9	75%	2.3	2.1	91%
Benzo[k]fluoranthene	0.4	0.3	75%	0.6	0.5	83%
Benzo[j]fluoranthene	0.5	0.3	60%	0.7	0.5	71%
Benzo[e]pyrene	3.6	3.2	89%	6.3	6.6	105%
Benzo[a]pyrene	4.9	3.7	76%	5.5	4.7	85%
Dibenzo[a,h]anthracene	0.3	0.4	**133%**	0.4	0.5	**125%**

DAE - Distillate Aromatic Extract (extender oil, lab use only); TDAE – Treated Distillate Aromatic Extract (extender oil, commercially used)
Source: Barrero-Moreno et al., 2018 (modified)

8.5.5 Health risk assessment of ELT recyclates through migration tests

The Bundesinstitut für Risikobewertung (BfR, 2009) stated that "for the assessment of the health risk [...] it is not so much the PAH contents in a product that are relevant, but rather the amounts released in skin contact and absorbed by the consumer".

Bartsch et al. (2016) proved that "the usage of 20% ethanol as simulant revealed good agreement to the actual exposure of human skin against B[a]P migrating out of contaminated products." The study conducted by Barrero-Moreno et al. (2018) in the STANPAHs project, confirmed the suitability of the ethanol solution as a human skin simulant.

"In May 2016 DG JRC and DG GROW signed an Administrative Arrangement (AA 34003) known as the STANPAHs project. The main objective of this contract was for the JRC to provide scientific support in the implementation and potential amendment of the restriction on polycyclic aromatic hydrocarbons, in particular concerning paragraphs 5 and 6 of entry 50 of Annex XVII to the REACH legislation. The main objectives of the project were: a) to gain a better understanding of the migration behaviour of certain PAHs in plastic and rubber components of articles, and b) to develop a reliable methodology to determine PAH migration from these matrices, under conditions simulating, to the best possible extent, dermal contact (including the oral cavity)." (Barrero-Moreno et al., 2018)

"Migration of the target PAHs into artificial sweat (EN1811) and artificial saliva (DIN53160-1) was not detected in any of the materials studied. Moreover, none of the plastic polymeric materials led to detectable release of the target PAHs in any of the migration media used in this study (i.e. artificial sweat and saliva, skin surface film liquid (SSFL), and 20% ethanol solution). Similarly, the tests with silicone materials did not result in detectable migration. Only the rubber matrices containing Distillate Aromatic Extract (DAE) as extender oil showed detectable migration when using 20% ethanol as the migration solution. In addition, the release of PAHs from coated recycled rubber granules was lower than from the uncoated granules suggesting that the coating acts as a barrier to chemical migration. According to industrial partners DAE is not used by European industries for manufacturing of parts of articles intended for skin contact. The materials containing DAE, although not representative for marketed products, have been made available to facilitate migration testing method development."

"Migration of PAHs from rubbers seems to be related to the type of extender oil used in their manufacturing process since no release was observed from rubber matrices containing treated distilled aromatic extract (TDAE). Furthermore, the fact that no release was detected in tests with silicones suggests that extender oil, which is not contained in silicone matrices, has the main impact on the PAHs release. Qualitatively it appears that PAHs contained in the extender oils migrate more easily than those in the carbon black component of the rubbers." (Barrero-Moreno et al., 2018)

Conclusions

- The determined PAH content of ELT is highly dependent on the test method chosen. Accordingly, it seems plausible to assume that a test method does not so much determine the absolute PAH content of a product as the amount of PAH that can be extracted under test conditions. The PAH contents determined and, ultimately, the limit values of the various regulations are thus only comparable to a limited extent, as different measurement methods are used.
- With the extraction time of 1h in the Soxhlet process according to DIN EN 15527:2008-09, PAHs are not completely extracted from carbon black.
- For the liquid–liquid or ultrasonic extraction methods according to DIN EN 15527:2008-09, DIN ISO 18287:2006-05 as well as AfPS GS 2019:01 PAH, significantly lower PAH contents are achieved than with the Soxhlet or hot extraction methods, due to the lower efficiency.

- With the extraction procedure according to the Grimmer method (SOP PAH-0397), a maximum extraction of PAHs can basically be assumed in comparison to the other procedures, which, in view of the largely similar methodology, achieves an approximately similar comprehensive extraction of PAHs as the method according to Barrero-Moreno et al. (2018).

8.5.5.1 Determination of PAH migration from test specimens made of ELT materials

8.5.5.1.1 Methods

The migration determination of PAHs from rubber granulate test specimens was performed according to a recently published solvent-based method of the BfR (Bartsch et al., 2016) and based on the experience gained by the BIU during the participation in the round robin test hosted by the Joint Research Centre (JRC) of the EU (Barrero-Moreno et al., 2018) to validate this method. The sample is leached over 24 hours with 20% ethanol in a shaking water bath at 40 °C.

8.5.5.1.2 Materials

In line with the findings of Barrero-Moreno et al. (2018) that the relative migration of PAHs also depends significantly on the matrix and is two to three times lower for coated rubber granulate than for uncoated, migration tests were carried out for a range of potentially relevant matrix materials. The samples examined were always sheet material with a thickness of 2 mm. For their production, material mixtures based on different base materials (matrix) and ELT recyclates (powders and granulates) were first produced and then processed into sheets. Furthermore, a sample without matrix was produced from pure rubber powder, by means of so-called high-pressure high-temperature sintering (HPHTS).

Table 78 Overview of the material composition of the migration samples

Sample	Material composition and production
GM1	Base material: 100% rubber powder - Rubber powder: Truck whole tyre, cryogenically ground, 200-400 µm (MRH Mülsen, K0204) - Sheets produced by HPHTS (150 °C, 20 min, 145 bar) - Density: 1.15 g/cm^3
GM2	Base material: natural rubber (type SVR CV 60) - Mixing ratio: 37% aluminium hydroxide, 36% rubber powder, 16% natural rubber, 5.5% carbon black (SPHERON SO LP), 5.5% cross-linking chemicals and additives - Density: 1.37 g/cm^3
PUR1	Base material: polyurethane (2-component system: isocyanate and polyol) - Polyurethane: aromatic polyether - ELT granulate: Truck whole tyre, size 10-35 mm (MRH Mülsen, W1035) - Mixing ratio: 10% polyurethane, 90% ELT granulate - Density: 1.14 g/cm^3
PUR2	Base material: polyurethane (2-component system: isocyanate and polyol) - Polyurethane: aromatic polyether - Rubber powder: whole truck tyre, cryogenically ground, 200-400 µm (MRH Mülsen, K0204) - Mixing ratio: 38% rubber powder, 32% kaolin, 30% polyurethane - Density: 1.38 g/cm^3
TPU GM 60	Base material: thermoplastic polyurethane (Elastollan 1170 A, polyether). - Rubber powder: Truck whole tyre, cryogenically ground, 200-400 µm (MRH Mülsen, K0204) - 60% rubber powder, 40% TPU - Density: 1.12 g/cm^3

8.5.5.1.3 Results

Table 79 shows the results of the migration measurements. Only the measurement results that were above the determination limit of the measurement method were taken into account.

Table 79 Results of the migration measurements in µg/dm²

Sample	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyren	Total
GM1	0.173	0.030	0.007	0.010	0.053	0.002	0.020	0.040	**0.335**
	0.172	0.040	0.007	0.007	0.035	0.001	0.018	0.057	**0.337**
	<0.052	0.023	<0.007	0.007	0.039	0.002	0.019	0.040	**0.130**
GM2	0.140	0.059	0.008	0.010	0.056	0.002	0.024	0.067	**0.366**
	0.165	0.058	0.008	0.010	0.058	0.002	0.025	0.069	**0.395**
	0.134	0.035	0.008	0.011	0.053	0.002	0.015	0.042	**0.300**
PUR1	0.166	0.035	<0.007	0.007	0.033	0.001	0.018	0.057	**0.317**
	0.173	0.040	0.007	0.007	0.035	0.001	0.018	0.059	**0.340**
	0.122	0.046	0.010	0.013	0.068	0.002	0.033	0.099	**0.393**
PUR2	0.184	0.038	0.009	0.011	0.049	0.001	0.021	0.066	**0.379**
	0.076	0.026	0.013	0.019	0.076	0.002	0.012	0.034	**0.258**
	0.119	0.024	0.010	0.013	0.055	0.002	0.012	0.039	**0.274**
TPU GM 60	0.120	0.022	0.007	0.009	0.043	0.001	0.016	0.049	**0.267**
	0.163	0.016	<0.007	0.006	0.018	0.002	0.006	0.018	**0.229**
	0.052	0.015	<0.007	0.006	0.018	0.001	0.006	0.018	**0.116**

Source: Hoyer et al., 2019

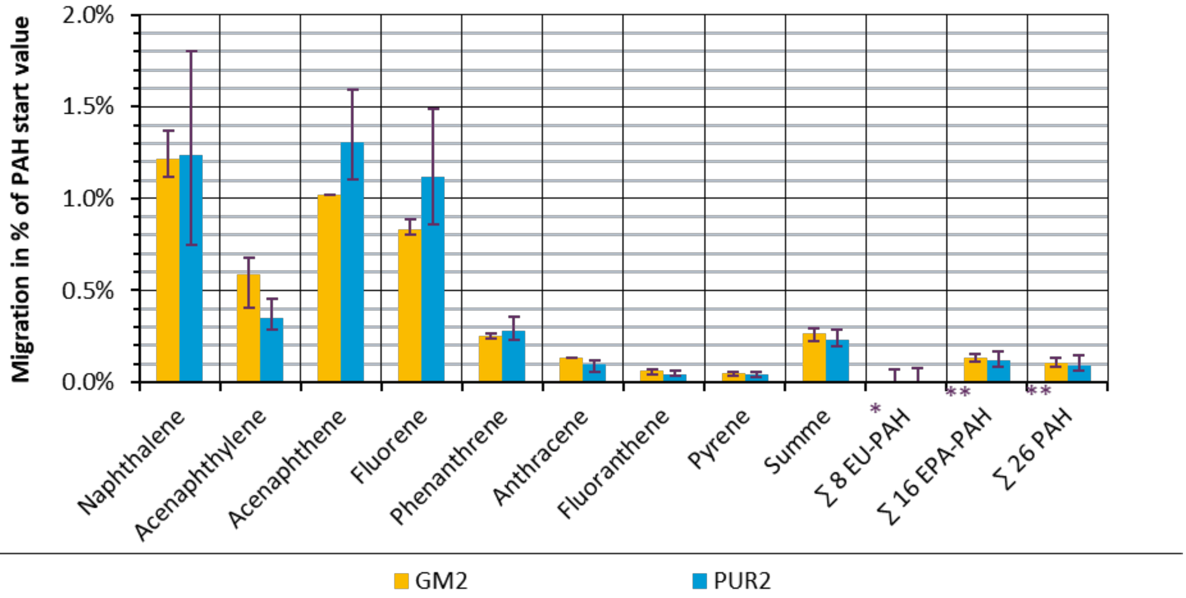
In order to put the amount of migrated PAHs in relation to the amounts of PAHs contained in the samples, a PAH content determination of selected samples was carried out using the Grimmer method (see Table 75). The migration rates of the individual PAH species were calculated relative to the PAH contents determined in this way.

The results for the relative migration rate for the samples "GM2" and "PUR2" are given in Figure 29. The mean values are represented as bars. The minimum and maximum values are shown as the error indicators.

For the calculation of the minimum and mean values of ∑16 EPPA-PAH and ∑8 EU-PAH, only those PAH species were considered which were above the limit of determination (see Table 79). For PAH species that were below the limit of quantification, the maximum values, the respective limit of quantification according to Hoyer et al. (2019) was taken into account.

For the calculation of migration rates of ∑8 EU-PAH, zero was assumed as the minimum value, since all relevant PAH species were below the limit of quantification.

Figure 29 Relative migration of PAH from samples in 20% (aq.) ethanol, based on the analytical PAH content of the sample



Source: Hoyer et al., 2019

8.5.5.2 Test campaign for the determination of the PAH content of ELT granulates

8.5.5.2.1 Introduction

The test results presented below are from a previously unpublished two-year measurement campaign conducted by the Chemnitz University of Technology in the period from 07.2017-07.2019. The measurements were used to determine the total content of PAHs in ELT granulates as defined in Regulation (EU) No 1272/2013, although a significantly more extensive group of 26 different PAH species was analysed.

8.5.5.2.2 Materials and methods

Three different types of tyre recyclates were investigated:

- Truck whole tyre (0.5-2 mm), *Source: Mülsener Rohstoff- und Handelsgesellschaft mbH (MRH)*
- Truck tread (buffed or cryogenically ground < 400 µm), *Source: MRH*
- Passenger car tyres (0.5-2 mm), *Source: PVP Triptis GmbH*

Since both recyclers exclusively process passenger car tyres (PVP Triptis) and truck tyres (MRH Mülsen), the material can be regarded as unmixed with regard to the tyre type (truck or passenger car). The samples were monthly composite samples, which were produced by combining several individual samples. The tested granulates went through several successive crushing and intermediate storage steps. It can therefore be assumed that the material is sufficiently mixed and thus cannot be attributed to a single tyre or even to a single component of a tyre. Therefore, the material is considered quasi-homogeneous and representative of the cross-manufacturer population of ELT granulates typically accumulating in Germany.

The PAH profile analyses in ELT granulates were carried out at the Biochemical Institute for Environmental Carcinogens (BIU) of the Prof. Dr. Gernot Grimmer-Foundation according to the aforementioned Grimmer method (SOP PAK-0397, see chapter 8.5.4.3). PAHs were extracted by hot extraction of a 3g subsample with toluene for 8 h in a Twisselmann extractor. In the case of multiple determinations, a separate sample extraction was always carried out. The Grimmer method was validated for various matrices as part of the BIU's work for the environmental sample bank of the German Environment Agency (UBA) and has been published (Grimmer et al., 1997). Currently, the internal SOP PAH-0397 V16062003 is applied.

8.5.5.2.3 Results of the test campaign

Table 80 and Table 81 show the results of the measurement of five identical monthly samples from PVP Triptis GmbH. In each case, a single measurement of the samples was carried out.

In columns 2 to 4, the PAHs relevant in the respective regulations are marked and the respective applicable limit value is indicated. If a sum symbol is entered, the limit value for the respective sum value can be found in the five lower rows.

The maximum value reflects the highest value measured in an individual measurement across all measurements for each individual PAH or for the respective totals.

Table 80 PAH content of ELT granulate from passenger car and truck tyres

PAH species	Limit values			Passenger car tyre granulate (n=41)						Truck tyre granulate (n=36)					
	Regulation (EU) No 1272/2013	MVV TB 2019/1	AfPS GS 2019:01 PAK (Cat. 3 b.)	Arithmetic mean $\bar{x}$	Absolut error *e*	Standard deviation *s*	Maximum value	*p*-value Anderson-Darling-Test	*p*-value ln(x)	Arithmetic mean $\bar{x}$	Absolut error *e*	Standard deviation *s*	Maximum value	*p*-value Anderson-Darling-Test	*p*-value ln(x)
Acenaphthene		∑		0.13	0.04	0.14	0.87	0.00	0.00	0.21	0.03	0.08	0.46	0.02	0.51
Acenaphthylene		∑		1.15	0.04	0.12	1.35	0.68	0.56	2.34	0.09	0.27	2.82	0.17	0.05
Anthanthrene				3.92	0.22	0.69	4.88	0.00	0.00	2.99	0.22	0.64	4.27	0.01	0.00
Anthracene		∑	∑*	0.31	0.02	0.06	0.54	0.08	0.67	0.39	0.02	0.07	0.56	0.44	0.34
Benzo[a]anthracene	1	∑	1	0.51	0.05	0.15	1.18	0	0.27	0.36	0.02	0.05	0.45	0.10	0.24
Benzo[a]pyrene	1	5/∑	1	1.82	0.06	0.19	2.50	0.02	0.01	1.72	0.05	0.14	2.04	0.81	0.66
Benzo[b]fluoranthene	1	∑	1	0.92	0.05	0.16	1.44	0.34	0.28	0.54	0.02	0.06	0.69	0.05	0.17
Benzo[b]naphtho[2,1-d] thiophen				0.99	0.08	0.26	1.53	0.36	0.02	0.23	0.01	0.04	0.30	0.00	0.00
Benzo[c]phenanthrene				0.21	0.01	0.03	0.29	0.93	0.66	0.17	0.01	0.02	0.21	0.01	0.00
Benzo[e]pyrene	1		1	**2.96**	0.14	0.43	3.74	**0.32**	0.06	**2.10**	0.07	0.20	2.43	**0.07**	0.04
Benzo[ghi]fluoranthene				3.34	0.09	0.29	3.77	0.00	0.00	3.23	0.09	0.26	3.64	0.00	0.00
Benzo[ghi]perylene		∑	1	13.00	0.37	1.16	14.30	0.00	0.00	11.60	0.34	1.01	12.70	0.00	0.00
Benzo[j]fluoranthene	1		1	0.29	0.02	0.07	0.56	0.01	0.19	0.17	0.01	0.02	0.23	0.35	0.63
Benzo[k]fluoranthene	1	∑	1	0.29	0.02	0.06	0.46	0.89	0.46	0.15	0.01	0.03	0.22	0.80	0.37
Chrysene	1	∑	1	1.01	0.06	0.20	1.49	0.63	0.43	0.55	0.02	0.05	0.64	0.07	0.12
Coronene				11.20	0.28	0.87	12.80	0.17	0.05	9.60	0.25	0.74	11.20	0.41	0.61
Cyclopenta[cd]pyrene				4.59	0.20	0.62	5.52	0.02	0.00	4.16	0.22	0.64	5.22	0.56	0.40
Dibenzo[a,h]anthracene	1	∑	1	0.07	0.01	0.03	0.16	0.00	0.31	0.03	0	0.01	0.05	0.09	0.59
Fluoranthene		∑	∑*	8.26	0.22	0.70	9.94	0.54	0.70	9.18	0.21	0.63	10.20	0.00	0.00
Fluorene		∑		0.29	0.03	0.11	0.79	0.00	0.03	0.39	0.04	0.12	0.72	0.01	0.18

PAH species	Limit values			Passenger car tyre granulate (n=41)						Truck tyre granulate (n=36)					
	Regulation (EU) No 1272/2013	MVV TB 2019/1	AfPS GS 2019:01 PAK (Cat. 3 b.)	Arithmetic mean $\bar{x}$	Absolut error *e*	Standard deviation *s*	Maximum value	*p*-value Anderson-Darling-Test	*p*-value ln(x)	Arithmetic mean $\bar{x}$	Absolut error *e*	Standard deviation *s*	Maximum value	*p*-value Anderson-Darling-Test	*p*-value ln(x)
Indeno[1,2,3-cd]pyrene		∑	1	2.30	0.07	0.22	2.69	0.27	0.17	1.90	0.07	0.20	2.32	0.63	0.67
Naphthalin		∑	10	1.62	0.16	0.52	3.39	0.00	0.00	2.36	0.12	0.35	3.64	0.05	0.29
Perylene				0.42	0.02	0.07	0.55	0.36	0.02	0.26	0.01	0.04	0.36	0.25	0.30
Phenanthrene		∑	∑*	4.19	0.18	0.58	6.29	0.00	0.00	5.34	0.15	0.44	6.29	0.57	0.30
Pyrene		∑	∑*	30.40	0.88	2.77	34.10	0.00	0.00	32.90	1.11	3.28	36.10	0.00	0.00
Triphenylene				1.02	0.07	0.23	1.54	0.56	0.24	0.37	0.01	0.04	0.46	0.77	0.43
∑ 4 PAK AfPS GS (∑*)			*50	43.10	1.16	3.69	49.70	0.01	0.00	47.80	1.42	4.19	52.60	0.00	0.00
∑ 8 PAK EU 1272/2013				7.87	0.37	1.16	11.10	0.35	0.09	5.62	0.17	0.51	6.71	0.08	0.06
∑ 15 PAK AfPS GS			50	67.90	1.83	5.80	79.10	0.00	0.00	69.30	1.94	5.75	76.20	0.00	0.00
∑ 16 PAK (EPA)		**50**		**66.20**	**1.76**	**5.57**	**77.10**	**0.00**	**0.00**	**69.90**	**1.95**	**5.78**	**77.00**	**0.00**	**0.00**
∑ all 26 PAK				95.20	2.53	8.02	107.00	0.00	0.00	93.20	2.61	7.70	102.00	0.00	0.00

Source: Hoyer

Table 81 PAH content of two rubber powders from truck tyres

PAH species	Limit values			Truck tyre – fine powder < 400 µm (n=13)						Truck tyre – coarse powder (n=3)			
	Regulation (EU) No 1272/2013	MVV TB 2019/1	AfPS GS 2019:01 PAK (Cat. 3 b.)	Arithmetic mean $\bar{x}$	Absolut error *e*	standard deviation *s*	Maximum value	*p*-value Anderson-Darling-Test	*p*-value ln(x)	Arithmetic mean $\bar{x}$	Absolut error *e*	standard deviation *s*	Maximum value
Acenaphthene		∑		0.21	0.04	0.06	0.36	0.26	0.49	0.10	0.01	0.01	0.11
Acenaphthylene		∑		5.35	0.33	0.54	6.10	0.53	0.44	4.69	1.09	0.44	5.06
Anthanthrene				4.55	0.62	1.02	6.26	0.53	0.55	1.72	0.58	0.23	1.99
Anthracene		∑	∑*	0.58	0.04	0.06	0.67	0.35	0.24	0.41	0.08	0.03	0.44
Benzo[a]anthracene	1	∑	1	0.34	0.03	0.06	0.46	0.87	0.90	0.24	0.10	0.04	0.29
Benzo[a]pyrene	1	5/∑	1	2.68	0.22	0.37	3.38	0.59	0.61	1.85	0.56	0.23	2.10
Benzo[b]fluoranthene	1	∑	1	0.84	0.07	0.11	1.08	0.88	0.95	0.63	0.19	0.07	0.72
Benzo[b]naphtho[2,1-d] thiophen				0.18	0.02	0.03	0.24	0.75	0.90	0.24	0.09	0.04	0.28

PAH species	Limit values			Truck tyre – fine powder < 400 µm (n=13)						Truck tyre – coarse powder (n=3)			
	Regulation (EU) No 1272/2013	MVV TB 2019/1	AfPS GS 2019:01 PAK (Cat. 3 b.)	Arithmetic mean $\bar{x}$	Absolut error *e*	standard deviation *s*	Maximum value	*p*-value Anderson-Darling-Test	*p*-value ln(x)	Arithmetic mean $\bar{x}$	Absolut error *e*	standard deviation *s*	Maximum value
Benzo[c]phenanthrene				0.22	0.02	0.03	0.27	0.28	0.18	0.19	0.01	0.00	0.20
Benzo[e]pyrene	1		1	2.79	0.22	0.36	3.59	0.66	0.77	2.15	0.45	0.18	2.35
Benzo[ghi]fluoranthene				4.56	0.24	0.40	5.21	0.30	0.32	3.45	0.11	0.04	3.49
Benzo[ghi]perylene		∑	1	15.12	1.29	2.14	19.27	0.55	0.57	10.67	2.12	0.86	11.61
Benzo[j]fluoranthene	1		1	0.26	0.03	0.06	0.39	0.33	0.46	0.18	0.05	0.02	0.20
Benzo[k]fluoranthene	1	∑	1	0.24	0.03	0.05	0.32	0.69	0.79	0.16	0.06	0.03	0.19
Chrysene	1	∑	1	0.51	0.05	0.08	0.71	0.04	0.09	0.54	0.26	0.10	0.66
Coronene				12.16	0.76	1.26	14.27	0.50	0.39	8.15	1.28	0.51	8.74
Cyclopenta[cd]pyrene				10.24	1.07	1.77	12.60	0.15	0.13	7.05	2.40	0.96	7.94
Dibenzo[a,h]anthracene	1	∑	1	0.02	0.00	0.01	0.04	0.19	0.53	0.001	0.00	0.00	0.001
Fluoranthene		∑	∑*	14.43	0.83	1.38	15.98	0.12	0.10	11.38	1.29	0.52	11.72
Fluorene		∑		0.40	0.08	0.13	0.63	0.09	0.23	0.25	0.02	0.01	0.26
Indeno[1,2,3-cd]pyrene		∑	1	3.15	0.26	0.43	4.22	0.24	0.43	1.65	0.43	0.18	1.85
Naphthalin		∑	10	7.48	0.57	0.95	8.78	0.47	0.50	6.74	1.11	0.45	7.16
Perylene				0.38	0.05	0.09	0.57	0.39	0.53	0.25	0.06	0.03	0.27
Phenanthrene		∑	∑*	8.09	0.40	0.66	9.00	0.15	0.12	6.96	0.97	0.39	7.40
Pyrene		∑	∑*	42.52	2.65	4.38	47.82	0.04	0.04	32.23	2.17	0.87	32.74
Triphenylene				0.27	0.03	0.05	0.37	0.24	0.54	0.30	0.08	0.03	0.33
∑ 4 PAK AfPS GS (∑*)			*50	71.59	4.18	6.91	79.70	0.05	0.05	56.02	5.35	2.15	57.71
∑ 8 PAK EU 1272/2013				7.69	0.57	0.94	9.57	0.80	0.78	5.76	1.61	0.65	6.51
∑ 15 PAK AfPS GS			50	99.07	6.24	10.33	113.50	0.10	0.09	75.80	8.93	3.60	79.43
∑ 16 PAK (EPA)		**50**		**102.00**	**6.31**	**10.44**	**115.00**	**0.08**	**0.08**	**78.50**	**9.66**	**3.89**	**82.29**
∑ all 26 PAK				137.60	8.89	14.71	157.00	0.08	0.08	102.20	14.24	5.73	108.10

Source: Hoyer

Each measured value of a discrete PAH species as well as the sum values in the five lower rows must be considered on their own, as the values given here did not necessarily exist simultaneously within a discrete measurement. In this respect, the sums of the discrete PAHs here will also not correspond with the respective sum values in the lower five rows. Adding up the individual values of discrete PAH species would lead to incorrect results. The sum values were calculated separately for each individual measurement and then the statistical characteristic values were derived from these discrete individual sums.

The p-value was used to check whether a normal distribution of the measured values could be excluded. The Anderson-Darling test used for this purpose compares the measured values with the theoretical distribution of the values in relation to the normal distribution. If the *p*-value is less than 0.05, the hypothesis that the values correspond to a normal distribution must be rejected. In this case the fields were marked red. In contrast, a *p*-value greater than 0.05 does not necessarily mean that the data are normally distributed. The Anderson-Darling test can be used with a sample size of n=8 or more, which is why an evaluation for the coarse powder from truck tread (n=3) was dispensed with.

8.5.5.2.4 Calculation of the maximum recyclate content for compliance with the PAH limits

In the following, the calculation of a maximum content of PAH species to be assumed is carried out. First, the PAH species that exceeded the limit values of the respective regulations the most are selected. For both truck and car tyres, this was benzo[**e**]pyrene for Regulation (EU)1272/2013 and the sum of the 16 EPA PAHs for the MVV TB 2019/1.

The calculation is based on the assumption of a normal distribution of the measured values of the respective PAH species or sum values although the data basis does not allow any firm conclusions to be drawn about the existence of a normal distribution. The p-value of the Anderson-Darling test for benzo[**e**]pyrene is 0.322 for car tyre and 0.07 truck tyre granulate. A normal distribution is therefore possible. A standard normal distribution of the data for ∑16 PAHs (EPA) can be ruled out for both tyre types (p-value > 0.05).

In the interval of 2.58 times the standard deviation (s) around the expected value, 99% of all measured values are to be found in a normal distribution. The arithmetic mean value ($\bar{x}$) (see Table 80) is assumed as the expected value. Based on these assumptions the limit value w_G can be determined:

$$w_G = \bar{x} + (2{,}575829 \cdot s)$$

Since there is no standard normal distribution for ∑16 PAHs (EPA) for truck tyres ($p = 0.00$), the limit value w_G was estimated based on the distribution of the measured values.

The maximum recyclate content in products is calculated by dividing the applicable limit value w_{max} by the determined limit value w_G.

The results are shown in Table 82. Based on the benzo[**e**]pyrene concentration, products should contain a maximum of 24.6% car ELT recyclate or 38.2% truck ELT recyclate. Granulate-based products, which typically contain more than 90% ELT, would exceed the limit values according to the MVV TB as well as Regulation (EU) 1272/2013, if a similarly aggressive method as the Grimmer method for PAH content determination would be applied.

Table 82 Calculation of the maximum ELT recyclate content in products

Value		Unit	Car (n = 41)		Truck (n = 36)	
			Benzo[e] pyrene	∑ 16 PAK (EPA)	Benzo[e] pyrene	∑ 16 PAK (EPA)
applicable limit value (1)	w_{max}	mg/kg	1.00	50.00	1.00	50.00
Arithmetic mean value	$\bar{x}$	mg/kg	2.96	66,2	2.10	69.90
standard deviation (1)	s	mg/kg	0.43	5.57	0.20	5.78
Absolut error	e	mg/kg	± 0.14	± 1.76	± 0.07	± 1,95
limit value	w_G	mg/kg	4.07	80.56	2.63	80.00 (2)
Maximum recyclate content	w_{max}/w_G	%	24.6%	62.1%	38.2%	62.5%

1) benzo[**e**]pyrene - Regulation (EU)1272/2013; ∑16 EPA PAHs for the MVV TB 2019/1

2) estimated value based on the distribution of the measured values
Source: Hoyer

8.5.5.3 VOC testing of a floor mat with ELT content

For the health assessment of the substances released by a floor mat with a high content of ELT recyclates, Hoyer et al. (2019) tested of such a product according to DIN EN 16516:2018. The product in question was a dimpled floor mat made up off 30% polyurethane and 70% ELT powder from truck tyres.

The sample was tested for emitted volatile and medium volatile organic compounds (VVOC, VOC and SVOC) at ALAB Analyse Labor Berlin in accordance with the approval principles of the German Institute for Building Technology (DIBt) for the health assessment of building products. The test was carried out in accordance with DIN EN 16516:2018-01.

The tests according to the approval principles of the DIBt provides for sampling on Tenax and DNPH cartridges after 3 and after 28 days. The evaluation was carried out according to the AgBB evaluation scheme for emissions of volatile organic compounds (VVOC, VOC and SVOC) from building products. The results are compared with the requirements of the AgBB evaluation scheme for VOCs from building products and the air quality requirements of the Blue Angel for resilient floor coverings (DE-UZ 120).

Table 83 shows the equilibrium concentration in the test chamber after 3 and 28 days. The measured concentrations were below the requirements for all parameters.

Table 83 Results of the emission determination into indoor air according to DIN EN 16516:2018-01 and comparison with relevant requirements

	Parameter [µg/m³]	∑ VOC [1]	TVOC	∑ SVOC	∑ VVOC	R value	∑ Carcinogens
Day 3	**Equilibrium concentration**	**19**	**46**	**0**	**0**	**0.027**	**0**
	Requirements according to AgBB	≤ 50	≤ 300	≤ 30		≤ 500	≤ 1
	Requirements according to DE-UZ 120		≤ 1000				≤ 10 (sum)
Day 28	**Equilibrium concentration**	**17**	**25**	**0**	**0**	**0.008**	**0**
	Requirements according to AgBB	≤ 100	≤ 1000	≤ 100		≤ 1000	≤ 1
	Requirements according to DE-UZ 120	≤ 100	≤ 300	≤ 30		≤ 1	≤ 1 (per single value)

1) without the lowest concentration of interest
VOC - volatile organic compounds; Prefix: S: semi, T: total, V: very
Source: Hoyer et al., 2019

8.5.6 Summary and evaluation

According to the current state of science and research, only very small amounts of potentially harmful substances, such as heavy metals or PAHs, migrate from ELT recyclates into water or the skin. Emissions to air are also very low. The measured concentrations are mostly below relevant limit values and often even below the respective determination limits.

The majority of the investigations focus on infill granules for artificial turf. Embedding recyclates in a material matrix, as is the case with the majority of products based on ELT recyclates, would most likely significantly reduce migration and emission rates even further. In general, the measurement results are not considered to be of concern. However, there are still deficits with regard to the scientific understanding of the correlation between PAH content and migration, which is why a final assessment with regard to an adaptation of the current regulations has not yet been made. According to ECHA, a further risk analysis is needed.

The results of the determination of the PAH content are highly dependent on the selected measurement method. In this context, the PAH content should not be referred to as absolute, but rather as the amount of PAH that can be extracted under test conditions.

From the PAH content determined in accordance with chapter 8.5.5.2, it can therefore not be concluded that products with ELT recyclate would not comply with the limit values according to Regulation (EU) No. 1272/2013, as the companies are currently free, within certain limits, to choose the PAH measurement method.

The JRC has developed an analytical method with which even very low content concentrations of PAHs can be determined (Annex II of Barrero-Moreno et al., 2018). The development of a harmonised method is currently underway at the European Committee for Standardisation (CEN) (European Commission 2017). In view of the current scientific discussion, the introduction of PAH content measurements with sample extraction similar in intensity to the methods according to Grimmer or Barrero-Moreno et al. seems likely (see Table 75). This is likely to be accompanied by significantly higher measured values for the PAH content than is the case, for example, according to the ISO 18287 method (see Table 73). Accordingly, it can be assumed that the limit values of ELT recyclates can potentially no longer be complied with.

With the data of the PAH content measurements according to chapter 8.5.5.2, a very comprehensive and detailed overview of the level and range of variation of the contents of a large number of PAH species in ELT granulates in Germany is available. The Grimmer method used is based on a very intensive sample extraction, so that in principle a very high extraction rate is achieved, especially of the PAHs bound to the carbon black. It can be considered as a similar intensive method as the method according to Barrero-Moreno et al. (2018). Based on the calculated upper limits for the PAH content, maximum recyclate contents in products were calculated (Table 82). This shows that granulate-based products, which typically contain more than 90% ELT, would exceed the limit values of Regulation (EU) 1272/2013, if a similarly aggressive method as the Grimmer method for PAH content determination were to be applied. The immediate consequence would be a significant reduction of the recycled content in the products.

The method developed by Barrero-Moreno et al. (2018) to measure the migration of PAHs using 20% ethanol as the migration medium is considered a safe ("conservative") approach to assess the migration of PAHs from products into the skin as well as into the oral cavity. However, there is not yet a final assessment as to whether a migration limit can be introduced and whether this will replace the PAH content limits.

For the analysis of the migration (chapter 8.5.5.1) and emission behaviour (chapter 8.5.5.3), special mixed materials were produced on the basis of rubber powders and various matrix materials, their PAH content was determined analytically and the migration and emission rates were determined. The chosen method for assessing migration into the skin was in accordance with Barrero-Moreno et al. (2018). The migration measurements of all eight REACH PAHs were below the limit of quantification. With regard to emission, all relevant limit values were met by a good margin. The results thus confirm the findings in the literature that only very small amounts of PAHs leak from the products.

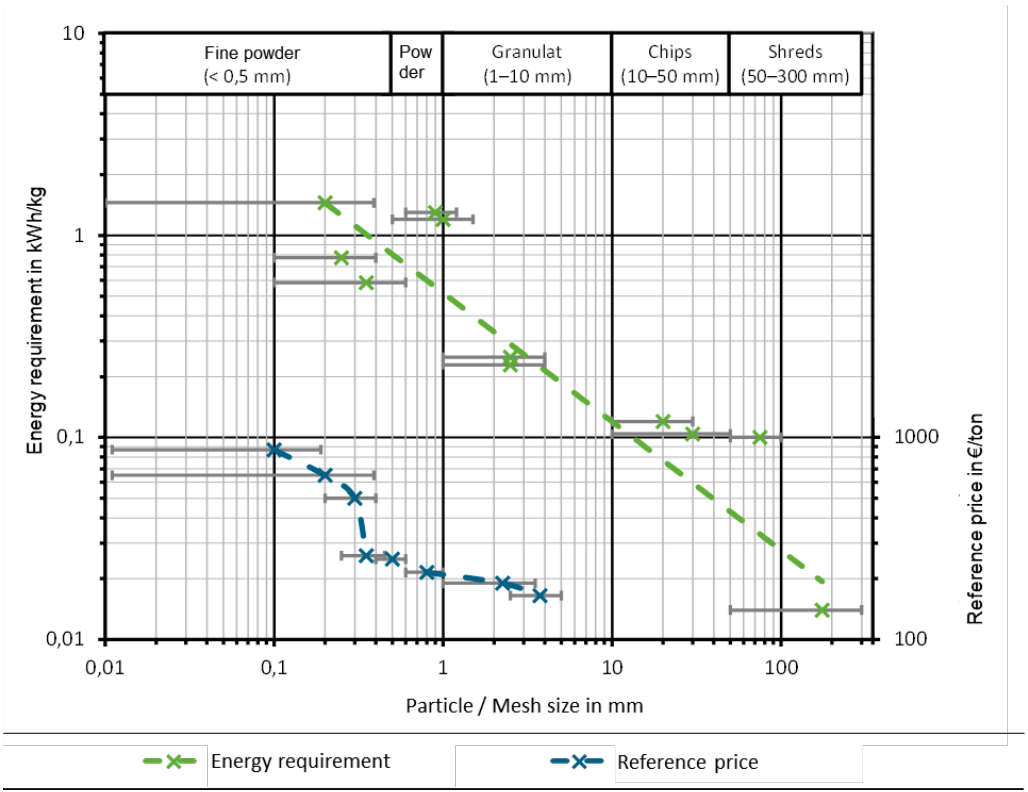
ECHA (2020) is considering the possibility of issuing exemptions for the PAH content limits on the basis of migration measurements. With regard to the determined PAH content of ELTs according to Chapter 8.5.5.2, this appears to be reasonable, as a significant decrease in the maximum admixture of ELT recyclates to new materials is to be expected, especially with the introduction of stricter methods for PAH content determination as well as the sending of the PAH content limits.

8.6 Environmental potential and effort required for ELT recovery

8.6.1 Effort for ELT shredding

Figure 30 compares the specific energy requirements for the production of tyre recyclates of different particle sizes with their market prices. The particle size refers to the mesh size of the screen in mm with which the material was screened. The graph shows the specific energy demand in kilowatt hours (kWh) for the production of one kilogram of recycled material of the particle size distribution. The values refer in each case to the starting product, the whole tyre.

Figure 30 Specific energy requirements for the production of ELT recyclates and standard market prices



x – mean particle size; – – entire particle size spectrum of the respective material

Sources: Faller, 2020; Hoyer et al., 2020b; Pöppel, 2020; Reschner, 2019; Seidel, 1992

Faller (2020) provided guideline values for the specific energy consumption for shredding ELT with the current generation of recycling facilities from the company Eldan Recycling A/S. In Figure 30, the accumulated maximum values were considered in each case.

Table 84 Energy consumption of an ELT recycling facility

Processing steps	Energy consumption	Accumulated energy values
Car/truck tyres to shreds	approx. 13-14 kWh/t	
Shreds to chips	70-90 kWh/t	83-104 kWh/t
Chips to granulates (1-4 mm)	approx. 100-125 kWh/t	183-229 kWh/t

Source: Faller (2020)

Pöppel (2020) puts the energy requirement for the production of granulates with a grain size of 1-4 mm from car tyres at approx. 0.25 kWh/kg. The data comes from a supplier of the REGUPOL BSW GmbH company and refers to an average value derived from the total energy consumption of a year in relation to the quantity of granulate produced. The values largely correspond to the accumulated values of the company Eldan Recycling A/S (Faller 2020).

Madelung (2020) puts the energy requirement for the production of granulates with a grain size of 0.5-3.25 mm from passenger car tyres at 0.304 kWh/kg.

Hoyer et al. (2020b) give values for the energy demand of established processes for the production of fine powder starting from granulates with a grain size of approx. 2.5-5 mm. The value for cryogenic grinding already includes an energy demand of 0.97 kWh for the production of liquid nitrogen. Cryogenic grinding uses 1.75 kg nitrogen per kg of ELT rubber. In Figure 30, only the values for truck tyres were taken into account. Furthermore, a specific energy requirement of 0.25 kWh/kg was added to the representation in Figure 31 in order to take the production of the granulates into account.

- Cryogenic grinding of truck tyres into powder < 400 µm: 1.2 kWh/kg
- Hot grinding of truck tyres into powder < 600 µm / 400 µm: 0.34 / 0.55 kWh/kg
- Hot grinding car tyres into powder < 600 µm / 400 µm: 0.40 / 0.63 kWh/kg

Reschner (2019) gives values for the energy required to shred tyres to various sizes. However, the values are significantly higher than (Pöppel 2020, Faller 2020, Hoyer et al., 2020b) and therefore possibly represent an older state of the art.

- Pre-shredding of whole tyres to chips (50-100 mm): 0.1 kWh/kg
- Shredding of whole tyres to approx. 0.5 to 1.5 mm: 1.2 kWh/kg
- Shredding of whole tyres to fine powder < 400 µm: 2.5 kWh/kg

Seidel (1992, p. 199) gives values for the production of chips with a size smaller than 30 mm. The starting point is a textile tyre that has been removed. The cut-out side parts and protector are pre-cut to approx. 10 cm by means of a chopper and then granulated to a maximum of 30 mm by means of a cutting granulator. The specific total energy demand is given as 0.12 kWh/kg. A grain size range of 10-30 mm was assumed for the consideration of these values in Figure 30.

8.6.2 Costs for the production and processing of primary raw materials

The following is an overview of the energy required to produce different types of raw rubber. Tyres are predominantly made of the rubber types NR (natural rubber) and SBR (styrene butadiene rubber). In parallel, the values for raw materials that typically substitute ELT recyclates (EPDM, PUR) are also given.

Table 85 Energy input for raw material production

Rubber type	Abbreviation	Energy consumption for raw material production	
		GJ/t	kWh/kg
Natural rubber	NR	16	4.44
Styrene-butadiene rubber	SBR	130	36.1
Butadiene rubber	BR	108	30.0
Butyl rubber	IIR	174	48.3
Ethylene-propylene-diene rubber	EPDM	142	39.4
Polyurethane	PUR	174	48.3

Source: Jones (1994)

Table 86 shows the energy requirements for typical raw rubber processing operations.

Table 86 Energy consumption for processing raw rubber

Process step	Energy consumption	
	GJ/t	kWh/kg
Mastication (NR only)	1.2	0.33
Mixing (Banbury)	2.9	0.81
Calendering	6.6	1.83
Extrusion	3.8	1.06
Vulcanisation	6.3	1.75
Typical energy demand for rubber processing	**20 – 30**	**5.6 – 8.3**

Source: Jones (1994)

Based on information on the energy required for the production of a tyre (Continental, 1999), the weight-based energy consumption of tyre production was calculated (Table 87). It is not explicitly stated what the average weight of such a tyre is. From the context of the information, it seemed plausible to assume a weight of 6.5 kg.

Table 87 Energy required to produce a tyre

Process step	Energy consumption		
	MJ/tyre	MJ/kg	kWh/kg
Raw material extraction	211	32.5	9.0
Transport	16	2.5	0.7
Production	104	16.0	4.4
Total	331	51.0	14.1

Source: Continental (1999)

8.7 Ecological evaluation of the different recovery routes

Several life cycle assessments were considered for the ecological evaluation of the different recycling routes of ELT. Life cycle assessments determine and evaluate the environmental impacts of a product or process. The most frequently examined environmental impact category is the Global Warming Potential, which represents the sum of all greenhouse gas emissions as CO_2 equivalents (kg $CO_{2\text{-eq}}$) for a product within the system boundaries and compares them with those of another reference product. A negative global warming potential means that greenhouse gases have been avoided compared to the reference product and that the product is ecologically more advantageous.

Many life cycle assessments are comparative analyses in which ELTs and the products derived from them are compared with primary raw materials or new products. The clients of the analyses are either tyre manufacturers or ELT recyclers.

The studies considered (see Table 88) differ in terms of their system boundaries. Only if several recycling routes are considered simultaneously in a study can the results be compared. As can be seen in Table 88, this is the case in three studies.

Table 88 Overview of the evaluated life cycle assessments on ELT recovery

Life cycle assessments		Prevention	Recovery		
Study	**Client**	**Preparation for reuse**	**Recycling**	**Material recycling**	**Energy recovery**
Boustani et al., 2010		x			
Krömer et al., 1999	Continental	x			
Bakas et al., 2009	Genan		x		x
Kløverpris et al., 2010*					
Merlin und Vogt 2020	Genan		x	x	x
Clauzade et al., 2010	Aliapur		x	x	x
Banar 2015				x	
Johansson 2018	Ragn Sells		x		
Krieg 2017	matteco			x	
ARN Advisory 2011	RecyBEM	x	x		x

*Kløverpris et al. (2010) is an extension of the original study by Bakas et al. (2009).

Merlin and Vogt (2020) compare recycling as granulates in artificial turf, material recycling as cryogenic ELT powder and energy recovery in the cement industry. The study is a successor to the study of the same name by Bakas et al. (2009). Here, a mixture of two material recovery routes was compared with energy recovery in cement production Bakas et al. (2009), or with recycling as a drainage layer Kløverpris et al. (2010).

Clauzade et al. (2010) compare four recycling, one material recycling and four energy recovery options.

On behalf of RecyBEM, the ecotest tool was used to calculate the global warming potential and material savings from recycling, energy recovery and retreading of ELT. The use phase of the respective products was outside the system boundaries. The functional unit was 1 ton of ELT. The tool used the SimaPro software and internal industry data to calculate the two indicators (ARN Advisory, 2011). The underlying data, the exact method, assumptions and system boundaries were not published.

8.7.1 Preparation for reuse

Boustani et al. (2010) prepared a life cycle assessment for the retreading of car and truck tyres in the USA. Only the energy input for the production/retreading and during the use of tyres was examined. In each case, tyres manufactured in 2001 and retreaded in 2004 were compared with new tyres from 2004. The functional unit in each case consists of four tyres. The study is often based on values from 1977, which were transferred to 2004.

Basically, the study finds that significantly more energy is consumed for the production of new tyres than for retreading. During the use phase, energy consumption depends strongly on the rolling resistance of the tyres considered. The higher the resistance, the higher the fuel consumption. Various scenarios were calculated in the study. No clear result on energy consumption can be derived for the use phase. Overall, the study assumes that retreaded tyres have a lower energy consumption than new tyres (Boustani et al., 2010).

The life cycle assessment prepared for Continental (Krömer et al., 1999) comes to a similar conclusion. Retreading has a significantly lower environmental impact than new tyre production. Krömer et al. (1999) assume that the retreaded tyre has a higher rolling resistance and therefore the new tyre performs better in the use phase. Overall, it was concluded that retreaded tyres have a higher environmental impact than new tyres.

According to the ecotest results published by RecyBEM, the retreading of ELTs can save -2,330 kg $CO_{2\,eq}$/t and 85% of the material consumption of new tyre production (ARN Advisory, 2011). The use phase was not taken into account.

The retreading itself therefore appears to be more environmentally beneficial than new tyre production. However, it is unclear whether a retreaded tyre is ecologically more advantageous than a new tyre, as the fuel consumption during the use phase is decisive for this and the available studies are outdated with regard to the input variables.

8.7.2 Recycling

8.7.2.1 Artificial turf systems

The use of ELT granulates as an elastic layer in artificial turf has been considered in various life cycle assessments over the last ten years. The studies compare ELT granulates with granulates made from primary raw materials.

The study by Johansson (2018) commissioned by Ragn Sells, Sweden, compares ELT granulates (SBR) with granulates made from cork, EPDM and TPE. Ragn Sells is the only waste tyre granulator in Sweden and Norway.

Deviating from all other LCAs, a football field with an area of 7,881 m^2, a granulate layer height of 1.5 cm and a lifetime of 10 years was chosen as the functional unit. For the determination of the transport distances, Stockholm was chosen as the location for the football field. The system boundaries for SBR include collection and granulation of the ELT as well as delivery to the football field. The steel wire and textile fibres generated during the recycling of ELT were not considered separately. All environmental impacts of the process were allocated to the granulates.

For the new granulates, the system boundaries extend from the extraction of the raw materials to delivery to the football field. The replenishment of the granulates as part of maintenance measures during the use phase of the artificial turf and the disposal or recycling of the granulates at the end of their life were not considered.

Seven environmental impact categories were examined for the study, with the focus on global warming potential. The results for global warming potential are shown in Table 89.

Table 89 Global warming potential of ELT granulate compared to virgin material

Granulate type	Quantity	GHG emissions		GWP
	[t per field]	[kg $CO_{2\,eq}$ per field]	[kg $CO_{2\,eq}$/t]	[kg $CO_{2\,eq}$/t]
ELT – SBR	52	6,400	123	
Cork	21	9,700	462	-339
EPDM	77	98,000	1,273	-1,150
TPE	65	178,000	2,738	-2,615

GHG – greenhouse gas; GWP – global warming potential
Source: Johansson, 2018 (modified)

According to the results of this LCA, ELT granulate has the lowest environmental impact of all the alternatives studied in all categories, followed by cork. The gap to the two plastic granules is very clear in all categories, with TPE generally having the highest values.

Particularly with regard to the cork granules, the study must be viewed critically, since a service life of only 3-4 years was calculated here, which means that the granules must be completely replaced once during the service life of the artificial turf. The author already points out that the assumed value may be too low.

In Merlin and Vogt (2020), ELT granulate was compared with granulate made from SEBS, a TPE, and from EPDM on behalf of Genan. Cork was not investigated by Merlin and Vogt (2020) because, in their opinion, there is too little experience and publications to date regarding service life.

1 t of ELT was defined as the functional unit. Unlike Johansson (2018), it was assumed that the ELT granulate is exchanged for the same mass of plastic granulate. As a result, the potential environmental benefits of the ELT granulate are lower.

The system boundaries include the reprocessing of the tyres in Genan's facilities, the material recycling of the rubber as artificial turf granulate, and the energy recycling of steel wire and textile fibres. For the calculation of the life cycle assessment, it was assumed that the granulates are energetically recycled at the end of the artificial turf's life. Collection and transport of the ELT are outside the system boundaries and are not included.

Unlike Johansson (2018), in Merlin and Vogt (2020) the EPDM granules have a higher environmental impact than the TPE studied, with a lower difference between the two. In this study, the greenhouse gas savings potential of using ELT granulate instead of EPDM is -972 kg $CO_{2\,eq}$/t and for TPE -838 kg $CO_{2\,eq}$/t.

In the life cycle assessment prepared for Aliapur by Clauzade et al. (2010), 1 t of ELT was also chosen as the functional unit. According to the study, 1 t of ELT replaces 0.5 t of new EPDM and 2 t of lime in the artificial turf. It was also assumed that the useful life of EPDM is only four years. From today's perspective, this value is too low and 10 years is more likely to be assumed.

As in Johansson (2018), the system boundaries also include collection and transport of the ELT for reprocessing. For recycling, the leftover disposal was excluded (Clauzade et al., 2010). The study concluded that the use of ELT granulate instead of EPDM avoids -3,217 kg $CO_{2\,eq}$/t.

For ecotest, a combination of different material recycling routes was chosen to determine the global warming potential and material savings (ARN Advisory, 2011). Similar to the ecotests, the textile lint is recycled for energy. The steel wire replaces primary raw materials, although the field of application is not known. The ELT rubber is granulated and 50% is used as elastic granulate and 5% as elastic base layer in sports field construction. Another 35% is used for the production of rubber mats. In all three cases, EPDM is replaced.10% of the granulate is further ground into powder and used as an additive in asphalt. The tool calculated that recycling in this combination has a global warming potential of -1,050 kg $CO_{2\,eq}$/t and 80% of the material input can be saved (ARN Advisory, 2011).

8.7.2.2 Carbon black

In their life cycle assessment, Merlin and Vogt (2020) assume that the rubber powder produced by Genan replaces new carbon black in a mass ratio of 1:1. The study concludes that the use of the rubber powder is ecologically more advantageous in comparison. The evaluation mentions that the rubber powder also has a lower environmental impact than new carbon black because it contains a high proportion of chalk. It is thus unclear whether the assumed mass ratio is realistic.

The carbon black contained in ELT tyres can be recovered by pyrolysis, although the purity is lower than that of virgin tyres due to ash from other tyre ingredients. To date, there are only a few life cycle assessments of pyrolysis, which mainly rely on laboratory studies rather than values from industrial facilities.

Banar (2015) has prepared a life cycle assessment for a Turkish test facility with a rotary kiln, considering not only the carbon black but also the pyrolysis oil and the steel wire. The study concludes that, overall, the pyrolysis products have a lower environmental impact than the primary products in seven categories. Only in the acidification category did pyrolysis have a higher environmental impact.

The company Scandinavian Enviro Systems AB has announced in a press release that a life cycle assessment has been carried out for their pyrolysis facility. The study itself has not been published. According to the press release, the global warming potential is said to be -1.43 to -2.00 kg $CO_{2\,eq}$ per kg of new carbon black (Scandinavian Enviro Systems AB, 2019). Without knowledge of the functional unit and system limits, the statement cannot be further classified.

8.7.2.3 Synthetic rubber

In 2017, matteco GmbH conducted a study for its new process for rubber mat production by pressing waste tyre powder (Krieg, 2017). Part of the study is a life cycle assessment for the annual production. The greenhouse gas emissions for the replacement of PU granulate, PU powder and new SBR is determined.

Table 90 GWP for the replacement of PU granulate, PU powder and new SBR

Input materials		New products				ELT recyclate	GWP
		PU granulate	PU powder	SBR	total		
Annual production quantity	t/a	173.3	146.3	130.5	450	450	
Annual greenhouse gas emissions	t $CO_{2\,eq}$/a	739	724	3,575	5,038	2,119	**-2,919**
GHG emissions	kg $CO_{2\,eq}$/t				11,196	4,709	**-6,487**

Source: Krieg (2017)

By replacing the input materials, the process can save 2,919 t $CO_{2\,eq}$ per year.

Clauzade et al. (2010) also studied the use of ELT as a substitute for PU in the production of rubber mats and concluded that the global warming potential is -2,703 kg $CO_{2\,eq}$/t of ELTs.

As with carbon black, (Merlin and Vogt 2020) assume that the ELT powder replaces new synthetic rubber in a mass ratio of 1:1. The production of shoe soles and rubber mats are mentioned as possible areas of application. This study also comes to the conclusion that ELT powder is ecologically more advantageous than new material made from primary raw materials.

8.7.3 Energy recovery

The focus of energy recovery is the use of ELT in cement production. Here, the effects of avoiding the use of primary raw materials as fuel and as a source of iron are determined. This was investigated in the studies by Clauzade et al. (2010), Bakas et al. (2009) and Merlin and Vogt (2020).

In addition to material recycling, the energetic recycling of ELT in cement production was also investigated by Merlin and Vogt (2020). The functional unit was 1 t of ELT. In the study, the combustible components of the ELT replace energy carriers amounting to 26 GJ and the non-combustible components (steel, ZnO, etc.) replace 161 kg of iron ore and silica. For the study, it was assumed that the energy carrier mix to be replaced consists of 43% RDF. The system boundaries include the shredding and co-incineration of the ELT. Collection and transport of the ELT were not included. The study concludes that the energy recovery of ELT reduces the ecological impact of cement production. The calculated global warming potential is -197 kg $CO_{2\,eq}$/t ELT.

Clauzade et al. (2010) came to the same result in principle, but it was assumed that the ELTs only replace primary raw materials. As a result, the global warming potential of -1,466 kg $CO_{2\,eq}$/t ELT is around seven times higher than for Merlin and Vogt.

For ecotest, it was also assumed that only primary raw materials are replaced in energy recovery (ARN Advisory, 2011). In addition to the utilisation in cement production, the utilisation in combined heat and power (CHP) plants was considered. It was calculated that the global warming potential of ELT in cement production is -954 kg $CO_{2\,eq}$/t and in the CHP plant -940 kg $CO_{2\,eq}$/t. In both cases, the global warming potential of ELT in cement production is -954 kg $CO_{2\,eq}$/t and -940 kg $CO_{2\,eq}$/t in the CHP plant. In both cases, the calculated material saving is 15%.

8.7.4 Comparison of recycling routes

In the review study by Santiago Gomes et al. (2019), nine LCAs from six countries are examined in more detail. The number of available studies on the disposal routes is considered too low to be able to evaluate the environmental impacts of the individual processes.

As a rule, it is only possible to compare the results of different recycling routes within the same study, as there are differences in the setting of system boundaries between the studies. However, some trends can be observed.

Both Merlin and Vogt (2020) and Clauzade et al. (2010) concluded that material recycling of ELT granulate in artificial turf is the most ecologically beneficial recycling, followed by mechanical recycling in rubber mat production. Energy recovery in the cement industry has a significantly smaller effect, but is still ecologically more sensible than the use of primary raw materials.

With regard to mechanical recycling as carbon black and retreading, the results are difficult to assess. Retreading itself has an indisputably lower resource consumption and lower global warming potential than new tyre production. Whether a retreaded tyre has an ecological advantage over a new tyre during the use phase, on the other hand, is unclear. A broader data basis is needed here to be able to make a statement on how this relates to the other recycling routes.

8.8 Situation overview and summary

The current situation does not allow for an exact accounting of the waste tyre volume. There are currently only register obligations for the waste management companies, which only have to submit the figures to the competent authority upon separate request. Accordingly, all upstream and downstream activities involving ELT are generally unaccounted for. The GAVS (wdk) calculations on the volume of ELTs and dispolar routes appear to be appropriate, given the available data. However, the results are strongly determined by the underlying conversion factors. Based on our own rough calculations, a 35% higher volume is found. Furthermore, it can be assumed that not all material flows are recorded and, to a small extent, that recyclates are recorded twice. In order to improve the accuracy of this calculation model, it should be examined whether the determination of current average ELT weights of different tyre types would be expedient. A comprehensive balancing of the ELT accumulation hardly seems feasible under the given conditions, especially with regard to double counting of quantities in different recycling steps.

The current situation in Germany is characterised by a significant decline in recycling rates in cement production and an extensive discontinuation of recycling in the form of artificial turf infill. In addition, there are regulatory hurdles (PAH) and associated acceptance problems in some sales markets for secondary products from ELT (estimate 10-20% of products), which also extend to unregulated markets and inhibit growth and the willingness to invest in new products and processes overall.

As a result of the amendment to the MVV TB (German Institute for Construction Technology 2021) proposed by the DIBt in January 2021, particle-tight installed products will be exempt from the PAH limits in the future. This will significantly improve the situation in the quantitatively important market of sound insulation and impact sound insulation. However, there are still uncertainties with regard to other products that are not particle-tight. This is overlaid by an overall low level of the prices on the raw material markets and a lack of redistribution of disposal fees from consumers to ELT waste management companies.

Primarily due to the decline in incineration, there is a deficit in the available recycling capacities for ELT in Germany, which can lead to, or has already led to, rising disposal costs, increased illegal dumping and increasing exports. The introduction of measures to prevent illegal dumping would have to include register and verification obligations for the actions from the point of generation to the ELT disposal in order to be effective.

8.8.1 Collection and sorting of ELTs

According to information from the sector, the return of ELTs from end users is working well via workshops and similar points of collection. However, there is a lack of traceability of the amount of ELT generated and their disposal routes. The waste management industry advocates for the introduction of some kind of verification obligation, especially for the actors in the waste management chain upstream of the waste management companies. The objective here is in particular the creation of possibilities to make the illegal dumping of ELT traceable and thus to prevent it. In principle, the aim is to document and further report the type and quantity of ELT as well as the actors involved in all activities upstream of the waste management companies. In a survey (Hoyer et al., 2020a), companies along the ELT waste management chain were asked to which areas of activity or market participants the register or verification obligation should be extended (see Table 91).

Table 91 Approval rates for a register obligation and for a verification obligation

Activity or market participant	Verification obligation	Register obligation
Waste producers	79%	93%
ELT Collectors	93%	93%
Transport	64%	50%
ELT Traders	64%	79%
ELT Broker	57%	71%
Waste management companies	93%	N/A

N/A – no data available

Source: Hoyer et al., 2020a

As a matter of principle, the highest possible sorting level of ELTs should be aimed for. Today, tyres are pre-sorted at the points of collection and tyre dealers with the aim of selling on as many ELTs as possible at a profit. These are primarily tyres that can be reused at home or abroad without further measures. On the other hand, there is a perceived deficit in the sorting of ELTs that are suitable for retreading. Retreading companies often source high proportions of their casings from abroad, which indicates a lack of pre-sorting of tyres in Germany. There does not seem to be sufficient motivation to sort the ELTs accordingly. Finally, however, there is also a demand on the part of the ELT recovery companies not only to receive completely worn tyres. A certain proportion of ELTs with a high residual tread is needed to obtain sufficient quantities of recyclable rubber. If only tyres with a relatively low residual tread are handed in, the treatment costs for the ELT recovery companies usually increase as well.

The ELT disposal industry also criticises a lack of redistribution of disposal cost contributions from end consumers. Only about 24% of the disposal costs to be paid by the consumers actually reach the disposal companies or can be collected by the disposal companies through the acceptance fee for ELTs. Raising the gate fee by ELT recyclers, as has already been done in some cases in the recent past, will further increase the incentives for improper or even illegal disposal of ELT under the existing market conditions.

8.8.2 Waste prevention

Under the given market conditions in Germany, there is a high intrinsic motivation among the points of collection and ELT collectors to maximise waste prevention by pre-sorting and reselling reusable ELT (see chapter 8.2.6). However, this also means that a large number of tyres that no longer meet the requirements of German road traffic approval standards, especially with regard to tread depth, are exported as reusable tyres and thus withdrawn from the established, environmentally friendly recovery routes. The practice of exporting ELTs can result in both road safety problems and environmental consequences during subsequent disposal.

8.8.3 Reuse and retreading

Today, retreading is only important in the truck tyre sector in Germany. In the passenger car sector the share is less than 1%. According to information from the industry, Germany has the capacity to expand retreading of truck tyres from the current 29% to up to 40% of the ELT volume.

Retreaded car and truck tyres are in very strong price competition with inexpensive new tyres, which dampens demand. The situation is particularly pronounced for passenger car tyres. In order to increase demand, it is primarily necessary to improve the cost structure and to reduce the prejudices regarding quality. Here, the automation of the retreading process in particular appears to be of central importance. In addition, further developments in materials technology (silica compounds) and manufacturing technology (multicompound treads) must be accelerated in order to catch up with the performance level of modern passenger car tyres. Finally, the availability of suitable ELTs, especially with regard to the quality of the casing, is a factor that limits the expansion of retreading in the passenger car sector. It would have to be examined in detail whether better sorting of ELTs alone is sufficient or whether the casings of new tyres also need to be modified in order to improve retreading. However, the combination of lack of demand on the one hand and necessary investments in material and product development as well as process automation on the other hand represent a conflict that is difficult to overcome.

Rolling resistance and abrasion during the service life are two factors that significantly influence the life cycle assessment of retreaded tyres. In order to be able to evaluate retreading ecologically, new life cycle assessments should be drawn up, as the existing studies are outdated with regard to the input variables.

In the truck sector, in view of the relatively high retreading rate, it can be concluded that retreading is fundamentally economical here and has no significant losses in terms of fuel consumption and service life. In the passenger car sector, the retreading industry needs to catch up with the know-how of the new tyre industry in terms of compound formulations and production technologies. This could compensate for many deficiencies of retreaded passenger car tyres, which can have an impact on both performance and life cycle assessment.

Accordingly, retreading must be given the greatest importance of all material recycling processes. Retreading should be expanded as far as possible under the given market capacities. However, the hurdles that have to be overcome by retreading companies, especially in the passenger car sector, appear to be limited by regulatory measures. Nevertheless, the aim of any measures should be to support retreading as far as possible, especially in the passenger car sector, particularly in terms of know-how development and market access.

8.8.4 Material recovery/recycling

8.8.4.1 Assessment of the environmental and health risks of ELT recyclates

According to the current state of research, ELT recyclate and products made from it do not appear to pose any significant risk to humans or the environment with regard to migration and emission of substances hazardous to health. Only high application (80 °C) and processing temperatures (from approx. 170 °C) should be avoided, as this results in increased emission of substances.

The future situation in the area of the manufacture of products for use in occupied rooms and for products that regularly come into contact with the skin or oral cavity is not fully foreseeable. The PAH content limits that have existed up to now are being revised in many areas. The introduction of migration- and emission-based measurement methods is being discussed, as is the adaptation of the existing PAH limits and measurement methods. The introduction of binding measurement methods for PAH content determination of ELT recyclates, modelled on the method according to Barrero-Moreno et al. (2018), would result in higher measured PAH contents than is the case according to the currently permissible methods, such as DIN ISO 18287. Accordingly, some applications would be eliminated or would require a significant reduction in the recycled content. Even if the PAH regulations only cover a sub-sector of this market, the general uncertainty also leads to a dampening effect on adjacent areas of application.

The question of the best environmental compatibility of the various mechanical recycling approaches cannot be answered conclusively. In addition to the trivial aspects, such as the saving of primary raw materials, the processing procedures for new products as well as the resulting utility value properties and service life have a serious influence on the overall balance.

The spectrum of processing methods for manufacturing products based on ELT recyclates ranges from relatively simple moulding processes to complex continuous processes from the field of thermoplastic and rubber processing. The differences in the technical effort and specific energy requirements of these highly diverse processing methods are very large and can hardly be estimated across the board. This is especially true since the use of recycled material in an existing product can be associated with an adaptation or even a fundamental change in the processing technology.

In principle, the use of recyclate can greatly reduce the demand for primary raw materials for the manufacture of products. However, the increase in specific energy requirements, for example due to a deterioration in processing properties such as viscosity, can partially offset this advantage. In this respect, a case-by-case consideration of specific products and associated processing technologies is indispensable.

A much more important aspect is also the utility value properties and service life of secondary products based on ELT granulate. Depending on the field of application, there is a wide range of relevant material properties that are often strongly influenced by the use of recycled materials. Accordingly, it is hardly possible to make generally valid statements at this point. This becomes clear when considering closed-loop recycling: For example, the largest share of the cumulative energy expenditure in the life of a tyre is accounted for by the use phase (approx. 96%, see Continental 1999). It is easy to see that even the smallest percentage deterioration, for example in rolling resistance, can seriously impair the overall balance or even make it negative.

Secondary applications that exploit the intrinsic advantages of ELT materials, such as weather resistance, elasticity and damping behaviour, appear to be particularly relevant. This applies in particular to a large number of granulate-based applications. Here, hardly any losses in the utility value properties of ELT recyclates compared to primary raw materials are to be expected. Other applications, which are primarily characterised by wear or dynamic stress, must be assessed on a case-by-case basis.

The use of ELT recyclates in the form of granulates and powders for the manufacture of products generally results in the saving of high proportions of primary raw materials. Based on the findings, there is no reason to prioritise granulate or fine powder. It is true that visually and mechanically much higher-quality products can be manufactured on the basis of fine powder. However, the effects of fine powder on the properties of use cannot be readily assessed, which is why products based on fine powders do not necessarily represent a higher-quality recycling route, taking into account the entire life cycle.

Furthermore, for the production of granulate-based moulded parts, usually only minimal quantities of primary raw materials are needed as binders, which can be seen as a positive aspect. In principle, therefore, both recycling approaches should be regarded as equal and expanded within the framework of ecological and economic sense. In the case of subsidy policy measures, the increased research and development costs of fine-powder-based applications, especially on a rubber basis, should be considered. In view of the higher energy requirement for the production of fine powder (approx. 1.2 kWh), careful consideration should be given as to whether a higher subsidy is expedient. It should be avoided that granulate- and fine-powder-based applications compete with each other and that fine grinding is prioritised without necessity due to better funding conditions.

Truck and car tyres should in principle be recycled separately due to their different material compositions and the sometimes significantly different PAH contents. From the point of view of environmental and health protection, there is no reason to exclude individual mechanical recycling routes, provided that the recyclates are processed according to the state of the art, especially with regard to processing temperatures. Table 92 summarises the main differences between car and truck tyres in this context.

Table 92 Summary of the main differences between truck and passenger car tyres with regard to their material recycling

Truck tyres	Car tyres
Low PAH content, especially for the sum of the 16 EPA PAHs (relevant for applications in occupied rooms).	Trend towards higher PAH content than trucks, especially for the sum of the 16 EPA PAHs
Low textile content, high steel content	High textile content, which can make fine grinding in particular difficult
Good basis for applications in rubber compounds, as there is a high natural rubber content. (Truck treads are even better here).	Poorer characteristic values for recycling in rubber compounds compared to truck tyre recyclates
High relevance of retreading	Hardly any relevance of retreading

Source: Hoyer

For the recycling of ELTs, the objective should be to feed the ELTs into an ecologically meaningful second life cycle. The recyclability of these secondary products should not necessarily be in the foreground, due to the following considerations: Secondary products based on ELTs may in principle be suitable for renewed material recycling, but there is the question of

- to what extent these products can be collected and returned sorted at the end of their life,

- what influence the material composition (mixed material made of ELT recyclates and mostly foreign matrix materials) has on their recyclability, and
- the influence of any ageing phenomena and the introduction of impurities and foreign substances.

In view of the current oversupply of ELT recyclates, the economic and ecological target criteria should primarily be optimised in recycling concepts and the secondary products should be prioritised for energy recovery at the end of their life. The products should therefore be designed in such a way that they can be fed into energy recovery without major additional technical or energetic effort. Furthermore, products with rubber recyclate should be easily identifiable so that they can be easily separated in a later waste stream.

8.8.4.2 Road construction

One of the largest growth markets for the recycling of ELT, which has hardly been tapped so far, is its use in road construction. The rubber modification of bitumen leads to an improvement of individual performance parameters of roads and can also enable the reduction of layer thickness. Based on the current state of knowledge, the use of ELT recyclates therefore appears to make economic sense and can also be carried out without significant risk to people and the environment, thanks to current developments for lowering the laying temperatures of asphalt. What is needed here is primarily the creation of a regulatory basis for the consideration of such modified asphalts in public tenders.

8.8.4.3 Energy recovery

Appropriate capacities for energy recovery should be urgently maintained or additionally created in Germany in order to compensate for the declining demand of ELTs as RDF in cement facilities. The share of energy recovery has already fallen and will presumably continue to fall in the future. A specific basic capacity for the energy recovery of tyres is absolutely necessary, especially for those ELTs that are not suitable for granulation. These are usually seal and silent tyres as well as ELTs that are not suitable for material recycling due to their age, origin or contamination. In this context, the most efficient possible use of the feedstock energy of the ELTs should be aimed for.

The continued use as RDF in cement facilities could be achieved in the future through appropriate pre-shredding of the ELTs, which would allow the ELT recyclates to be used in kilns with calciners. In further work, however, it must be evaluated in detail what degree of comminution is necessary and whether, under these conditions, the use of ELT in cement facilities is economically and ecologically sensible.

Another option would be, for example, highly efficient energy recovery in CHP plants. Pyrolysis only appears relevant if there is secured capacity for the use of its products, especially carbon black.

8.8.4.4 Prognosis of the development of recycling capacities

The ELT generation in 2019 were around 514,000 t (see Table 60). Between 2012 and 2019, the quantity fell by an average of 0.54% per year. If the current trend is maintained, the ELT generation will be 462,000 tons in 2030.

Table 93 compares the current recycling capacities of individual recycling routes with a prognosis of recycling capacities in 2030. It is assumed here that market access for road construction and retreading will be successful in the short term and that recycling and recovery in the cement industry will continue to decline.

The greatest potential for expanding the recycling of ELT lies in granulate- and fine-powder-based applications, in road construction and in retreading, especially of car tyres.

The capacity forecasts are mainly estimates, especially for the recycling and retreading of car tyres. Specific framework conditions are necessary here, under which the markets can develop optimally:

- recycling – in particular, practicable PAH regulations
- retreading - increased demand by consumers for retreaded car tyres
- road construction - the creation of corresponding regulations.

Table 93 Rough prognosis of the capacities of various recycling routes in 2030

Area of application	Current status	Extrapolation or estimation for 2030
Use in road construction	Unknown – estimate: **2,000 t/a**	capacity of maximum **50,000 t/a** *1.67 million t/a bitumen → 25% modified, 12% rubber content*
Recycling to granulate and fine powder	**251,000 t/a** <u>thereof moulded parts:</u> granulate-based: 150,000 t/a fine-powder-based: 21,000 t/a *annual growth rate 2013-2019 average 4.2%*	Unclear capacity of **350,000 t/a** if current trend is maintained (4.2%/a)
Retreading	**26,000 t/a** (according to other calculation 48,000 t/a) Truck tyres: 29% of ELT generation Car tyres: less than 1% *Between 2012 and 2019, average decrease of 5.2% per year*	estimate/d capacity **118,000 t/a** <u>thereof:</u> Truck tyres: increase to 40% of ELT generation (+19,000 t/a) **67,000 t/a** Car and light truck tyres: increase to 10% of ELT generation (+51,000 t/a) **51,000 t/a**
Energy recovery in cement industry	**175,000 t/a** *Exponential decline* *2011-2019: -39% (-111,000 t/a)* *2019 alone -11% (-27,000 t/a)*	**68,000 t/a** *If the current trend is maintained (exponential decline)*
Total	**477,400 t/a**	**512,000 t/a**
ELT generation	**514,000 t/a**	**462,000 t/a**
Recycling capacity	**-36,600 t/a**	**+50.000 t/a**

If the road construction, retreading and recycling markets develop as positively as assumed for the prognosis, then the recycling capacity will exceed the ELT generation in Germany by roughly 50,000 tons in 2030.

If the road construction, retreading and recycling markets stagnate at 2019 levels, this would result in a recycling capacity of 333,400 tons per year in 2030. This would correspond to a deficit of 128,600 t of ELT to the forecast ELT generation in 2030.

8.9 Proposed measures

The aim of the project is to determine the potential for resource conservation and environmental relief through improved collection and recycling of ELT and to identify approaches for tapping resource conservation potential. In the following, various measures for improving the collection and recycling of ELT are described.

Each measure is evaluated on the basis of the eleven criteria mentioned in chapter 1.3.1. Due to its ecological relevance, the criterion "strengthening recycling" is weighted three times. The smaller the result of the evaluation, the better the practical feasibility and impact of a measure.

8.9.1 Introduction of extended producer responsibility or a fee-based system

A number of existing problems in the free market can be remedied by changing the system. As observed in chapter 8.2.7, the illegal disposal of ELTs by commercial participants in the waste management chain is a major ecological problem that entails high costs and effort for public waste management. Furthermore, traceability of the material flows in ELT disposal is hardly given at present.

Alternatives to the free market are the fee-based system, similar to those in Denmark and Croatia, and extended producer responsibility scheme (EPR), as already exists in Germany for several material flows. Depending on the design of the system, there are various advantages over the free market. Table 94 shows the requirements for such a system.

Table 94 Requirements for the design of the measure

Requirement	Necessary	Optional
Clear regulation of responsibility for the disposal of ELTs	x	
Secured financing of collection and recovery	x	
Higher incentives to inspect and sort ELTs for their recyclability	x	
Incentives to prioritise preparation for reuse	x	
Free collection of ELTs for last owners	x	
Statistical recording of material flows in ELT waste management chain	x	
Funding of research, (pilot) projects, public relations work		x

Under an EPR scheme, producers of tyres are legally obliged to organise and finance the collection and recycling of ELT. The term producers refers to both manufacturers and importers of tyres. Depending on the design of the system, producers can fulfil their responsibility either individually or as a group. For joint implementation, they can set up a Producer Responsibility Organisation (PRO) to fulfil their responsibilities.

In both systems, the improved traceability of ELTs and secured financing significantly reduce the incentive to dispose of tyres illegally.

ELTs are taken back free of charge from consumers by retailers and garages. As a rule, ELTs are also collected free of charge from the collection point.

In Germany, the availability of suitable casings is limited, which hinders the expansion of retreading in the passenger car sector. Neither the points of collection nor the ELT collectors currently sort the returned tyres intensively, which is why retreaders often have to rely on imports from other EU countries. Within the framework of the system change, a higher quota of ELTs can be prepared for reuse by specifying appropriate sorting criteria for points of collection and collectors. For this purpose, the criteria for collection and sorting of the BRV for the certification of ELT waste management companies (BRV, 2020) could be included in the requirements for system participants.

Resistance to the change of system is to be expected in particular from the tyre trade and service. In the existing system, these have so far generated income from the financial contributions of the consumers and are then faced with a greatly increased bureaucratic burden. The distributors, tyre manufacturers and importers, would also face increased bureaucracy.

The removal of existing deposits of illegally disposed ELT is not financed by either type of system. After the system change, an industry agreement similar to the one in France should be considered. The removal of the deposits is organised and implemented by the tyre industry. Financing is provided in equal parts by the public sector and the producers (see chapter 8.4.2.1).

Table 95 Evaluation of the measure “Introduction of an EPR system for ELTs”

Criterion	Evaluation	Points
Bureaucratic effort	Additional bureaucratic effort is acceptable, as EPR is implemented in most EU countries	3
Legal aspects	Need for a regulation according to Section 23 para. 4 KrWG	3
Statistical aspects	Collection of statistical data on quantities is ensured due to the reporting obligations of producers and disposers in an EPR system.	1
Organisational effort	Very high; coordination between all stakeholder groups required to improve acceptance	5
Implementation timeline	Long term (more than 5 years)	5
Binding character	Highly binding, as implementation takes place on a statutory basis	1
Contribution to financing the recycling	The financing of collection and recycling can be ensured. By adding the disposal costs to the product price, financing is based on the polluter-pays principle.	1
Improvement of collection	Improves the collection of the waste stream.	1
Strengthening of recycling	Measure affects all tyres sold in Germany; effect depends on legal requirements for collection and recycling	1
Acceptance of relevant actors	Producers, trade: low (high additional effort) Consumers: indifferent (small price increase) Recycling industry: high	3
Public information needs	The measure requires a medium effort for public relations. Consumers must be informed where they can hand in their ELTs free of charge.	3
Weighted result		**2.2**
Key addressees	Federal government, manufacturers, importers, trade, recycling industry, consumers	

Criterion	Evaluation	Points
Summary	A high level of effectiveness in the implementation of ecological, economic and statistical goals is countered by a high level of effort in the implementation as well as a low level of acceptance among manufacturers and trade. Therefore, certain resistance is to be expected, which can lead to a protracted implementation phase.	

The fee-based system

In the fee-based system, the costs of the system are borne by the consumers. A government agency levies a tax on tyres entering the market, which is added to the retail price of the tyres. Compared to EPR, this reduces the possibilities of circumventing the system. The fees collected flow into a fund that is supervised by a central body, which disburses the money to the participating companies in the recycling chain according to defined rules. At the same time, elements of the free market remain in the fee-based system.

In contrast to EPR, in a fee-based system the ELT recycling routes can be directly controlled and monitored by government agencies through the subsidy regulations and approval criteria for ELT collectors and recyclers. The export of ELTs for recycling to non-EU countries, which is attractive for purely financial reasons but ecologically questionable, as is common in many EPR systems, can be significantly reduced through corresponding requirement criteria in the fee-based system.

The European comparison shows that in EPR systems there is a risk that PROs distribute ELTs to the detriment of individual recycling industries in order to serve the interests of their members. This is particularly true of retreading, whose products are in direct competition with new tyres.

The fee-based system allows for a simpler promotion of retreading, which competes with new tyre sales, through a graduated levy on retreadable design or a levy exemption on retreaded tyres while subsidising retreading, analogous to other material recycling processes.

In German law, a fee-based system would require the introduction of a special fee with a financing purpose, which is subject to strict requirements. The courts have developed five legality requirements for these special fees (Wissenschaftliche Dienste, 2020), of which the first three are of special interest here. Firstly, the fee must be imposed on a homogeneous group. This would be the group of tyre buyers, as the fee is added to the price of tyres. The second requirement is a specific proximity between the group of taxpayers and the purpose of the levy. The purpose of the fee is to promote and securely finance the collection and recycling of ELT. There can be a proximity here, as the purchasers of tyres become the owners of waste when they want to get rid of their ELT. According to Section 7 para. 2 and Section 8 para. 2 of the Circular Economy and Recycling Act (KrWG), they are then obliged to dispose of their ELTs in a regulated manner by recycling or disposal. They are therefore dependent on a functioning waste management infrastructure, as is to be ensured by the fee.

Thirdly, the fee revenue must be used for the benefit of the group. The group benefit can be given here, since the tyre buyers, unlike in the free market, do not have to pay a variable price for disposal, but can return their ELT free of charge. The handover also ensures that the buyers can be sure that their ELTs will not be disposed of illegally, but will be recycled or disposed of properly.

In addition to examining whether all the conditions for the introduction of a special fee are fulfilled, the planned subsidisation of the collection and recycling of ELTs must also be examined to determine whether it is permissible under subsidy law.

Table 96 Evaluation of the measure "Introduction of a fee-based system for ELTs"

Criterion	Evaluation	Points
Bureaucratic effort	Additional bureaucratic effort is acceptable	3
Legal aspects	The legal framework for implementing the measure does not exist yet.	5
Statistical aspects	Collection of statistical data on quantities is ensured due to the reporting obligations of producers and disposers in a fee-based system.	1
Organisational effort	Very high organisational effort; coordination between all stakeholder groups required to improve acceptance	5
Implementation timeline	Long term (more than 5 years)	5
Binding character	Highly binding, as implementation takes place on a statutory basis	1
Contribution to financing the recycling	The financing of collection and recycling can be ensured. By adding the disposal costs to the product price, financing is based on the polluter-pays principle.	1
Improvement of collection	The measure improves the collection of the waste stream.	1
Strengthening of recycling	Measure affects all tyres sold in Germany; effect depends on legal requirements for collection and recycling	1
Acceptance of relevant actors	Producers, trade: low (high additional effort) Consumers: indifferent (small price increase) Recycling industry: high	3
Public information needs	The measure requires a medium effort for public relations. Consumers need to be informed about the purpose for which the fee is paid, what it is intended for and where they can hand in their end-of-life tyres.	3
Weighted result		**2.4**
Key addressees	Federal government, producers (manufacturers, importers), trade, recycling industry, consumers	
Summary	A high level of effectiveness in the implementation of ecological, economic and statistical goals is countered by a high level of effort in implementation and low acceptance among producers and retailers, which also results in a long-term implementation period. Higher legal hurdles are attached to the introduction than in the case of extended producer responsibility, but the possibilities for control by government agencies are greater.	

8.9.2 Measures to promote retreading

8.9.2.1 Inclusion of tyres in the EU Ecodesign Directive: implementation of design requirements for retreadability

Currently, many ELTs, especially from passenger cars, are not or only partially suitable for retreading due to their design. Above all, the load-bearing substructure, the casing, should be optimised for retreading in terms of its service life and the load cycles it can withstand. In addition, there are differences in the exact dimensions within a size class between manufacturers and individual models. This variance in the specific geometry of the tyres can only be covered to a limited extent with one vulcanisation mould. Therefore, several vulcanisation moulds usually have to be kept in stock and the tyres have to be pre-sorted in a time-consuming process. In order to significantly reduce the effort involved in retreading, the tyre dimensions in the individual size classes should therefore be standardised.

Table 97 Evaluation of the measure "Inclusion of tyres in the EU Ecodesign Directive: implementation of design requirements for retreadability"

Criterion	Evaluation	Points
Bureaucratic effort	Additional bureaucratic effort is low.	1
Legal aspects	Currently, means of transport for the transport of passengers or goods are excluded from the EU Ecodesign Directive. Whether this exclusion also applies to tyres should be examined. Within the framework of the EU Commission's Action Plan for the Circular Economy, an extension of the Ecodesign Directive to as many product groups as possible is planned.	5
Statistical aspects	No influence on the statistical recording	5
Organisational effort	The organisational effort for the introduction of the measure is high. The necessary agreement of different actors is difficult to achieve.	5
Implementation timeline	Long term (more than 5 years)	5
Binding character	Highly binding, as implementation takes place on a statutory basis	1
Contribution to financing the recycling	The measure has a positive impact on the financing of preparation for reuse, as it reduces effort and costs.	1
Improvement of collection	The measure has no impact on the collection of the waste stream.	3
Strengthening of recycling	Measure affects all new tyres; increases the proportion of ELTs suitable for retreading	2
Acceptance of relevant actors	Producers, trade: low to indifferent (Effort for adaptation of own products) Recycling industry: high (Simplification of work processes, improvement of product quality)	3
Public information needs	No or hardly any additional communication or public relations work is needed to implement the measure.	1
Weighted result		**2.9**
Key addressees	EU, Federal Government, in particular ministry of environment (BMU), manufacturers, industry associations, recycling industry	
Summary	There is no motivation on the part of manufacturers to standardise tyre design in favour of retreading. The specification of a retreadable design in the EU Ecodesign Directive significantly increases the proportion of ELTs that are suitable for preparation for reuse and reduces the effort involved in retreading.	

8.9.2.2 Promoting technology and knowledge transfer between tyre manufacturers and retreading

In new tyre production, so-called silica technology is increasingly being used, in which part of the carbon black in the rubber compound is replaced by silica. Another innovation is the use of multicompound treads, which consist of several rubber compounds lying next to and on top of each other. The retreading sector, which is dominated by small and medium-sized enterprises, does not have the means and possibilities to conduct its own materials research. In order to ensure high quality in retreading in the long term, there must be an exchange of knowledge and technology between the new tyre and ELT sectors. This can be promoted through the establishment of forums, funding and research programmes by the federal government or the states.

Table 98 Evaluation of the measure "Promoting technology and knowledge transfer between tyre manufacturers and retreading"

Criterion	Evaluation	Points
Bureaucratic effort	Additional bureaucratic effort is low.	1
Legal aspects	No legal changes/additions are required for the implementation of the measure.	1
Statistical aspects	No influence on the statistical recording	5
Organisational effort	There is a medium organisational effort for the introduction of the measure. Constructive and targeted communication between several actors is required.	3
Implementation timeline	short term (1-2 years)	1
Binding character	Non-binding; based on voluntary participation of manufacturers and retreaders	5
Contribution to financing the recycling	The measure has a positive impact on the financing of preparation for reuse.	3
Improvement of collection	The measure has no impact on the collection of the waste stream.	3
Strengthening of recycling	The measure creates better conditions for preparation for reuse.	3
Acceptance of relevant actors	Producers, trade: low Recycling industry: high	4
Public information needs	No or hardly any additional public relations work is needed to implement the measure.	1
Weighted result		**2.7**
Key addressees	ministry of environment (BMU), German environment agency (UBA), manufacturers, recycling industry	
Summary	The measure can improve the quality and cost-effectiveness of retreading. However, success depends largely on whether partners from the tyre manufacturing industry can be won over for the measure.	

8.9.2.3 Promotion of facility automation in the retreading industry

Retreaded tyres compete with low-priced new tyres imported mainly from outside Europe. Since November 2018, anti-dumping duties have been provisionally in place for the import of certain truck and bus tyres from China (Regulation (EU) 2018/683). In the passenger car sector, the price difference is currently too small to generate sufficient demand.

Retreading has a relatively low level of automation. Especially the sorting and quality inspection of ELTs in the incoming goods department is very labour- and personnel-intensive. The demand for passenger car tyres is also dampened by the variance in the deformation and damping properties of different casings. Here, solutions have to be found as to how casings with identical construction and thus behaviour can be sorted and paired so that a set of four tyres shows as identical behaviour as possible. In order to increase the competitiveness of retreading in Germany, facility automation must be increased.

To promote facility automation, pilot projects can be carried out or funding and research programmes can be set up. A link to existing funding programmes such as the Environmental Innovation Programme is also conceivable.

Table 99 Evaluation of the measure "Promotion of facility automation in the retreading industry"

Criterion	Evaluation	Points
Bureaucratic effort	Little additional bureaucratic effort is required.	2
Legal aspects	No legal changes/additions are required for the implementation of the measure.	1
Statistical aspects	No influence on the statistical recording	5
Organisational effort	There is a medium organisational effort for the introduction of the measure. Constructive and focused communication between several actors is required.	3
Implementation timeline	Medium term (3-5 years)	3
Binding character	Non-binding; participation in funding programme voluntary	5
Contribution to financing the recycling	The measure has a positive impact on the financing of preparation for reuse.	3
Improvement of collection	The measure has no impact on the collection of the waste stream.	3
Strengthening of recycling	The measure creates better conditions for preparation for reuse.	3
Acceptance of relevant actors	Recycling industry: high	1
Public information needs	The measure requires a medium effort for communication or public relations to make the programme known in the sector.	3
Weighted result		**2.9**
Key addressees	Ministries, retreading industry	

Criterion	Evaluation	Points
Summary	The measure leads to an improvement in the economic efficiency of retreading within a manageable time frame and increases the sales opportunities for retreaded tyres.	

8.9.3 Promotion of recycling

Recycling depends on finding customers for its recyclates. In view of the versatile properties of ELT recyclates, new applications must be sought across sectors in order to compensate for the loss of customers due to the uncertainty regarding the development of PAH limits.

8.9.3.1 Establishment of a material and processing database

Similar to retreading, a transfer of knowledge between production and recycling should be made possible. To this end, a material and processing database could be created to reduce technical hurdles in the complex but very high-quality recycling of ELT recyclates into rubber compounds. This would reduce the research and development effort and facilitate a better pre-estimation of the feasibility of new recycling routes.

Table 100 Evaluation of the measure "Establishment of a material and processing database"

Criterion	Evaluation	Points
Bureaucratic effort	Additional bureaucratic effort is acceptable	3
Legal aspects	No legal changes/additions are required for the implementation of the measure.	1
Statistical aspects	The measure improves the statistical recording of the waste stream.	3
Organisational effort	Very high organisational effort; coordination between all stakeholder groups required to improve acceptance	5
Implementation timeline	Medium term (3-5 years)	3
Binding character	Non-binding; based on voluntary participation of the companies	5
Contribution to financing the recycling	The measure has a positive impact on the financing of preparation for reuse.	3
Improvement of collection	The measure has no impact on the collection of the waste stream.	3
Strengthening of recycling	The measure creates better conditions for preparation for reuse and recycling of ELTs.	3
Acceptance of relevant actors	Producers: low to indifferent Recycling industry: high	3
Public information needs	No or hardly any additional public relations work is needed to implement the measure.	1
Weighted result		**3.0**
Key addressees	Ministries, producers, recycling industry	

Criterion	Evaluation	Points
Summary	The database would reduce the research and development effort for recycling and facilitate a better preliminary assessment of the feasibility of new recycling routes. However, the success of the measure depends heavily on the commitment of the producers.	

8.9.3.2 Codes of practice for the use of rubber-modified asphalt

So far, ELT recyclates are rarely used in rubber-modified asphalts in Germany, as the current codes and standards do not consider rubber-bitumen mixtures. The creation of regulations at the state level for the use of ELT recyclate in road construction, similar to those in Bavaria, can create the necessary basis for tenders.

Table 101 Evaluation of the measure "Codes of practice for the use of rubber-modified asphalt"

Criterion	Evaluation	Points
Bureaucratic effort	No additional bureaucratic effort necessary	1
Legal aspects	The legal framework at federal state level for the preparation of the codes of practice is already in place.	1
Statistical aspects	No impact on the statistical recording of the waste stream.	5
Organisational effort	The organisational effort for the introduction of the measure is low.	1
Implementation timeline	Short term (1-2 years)	1
Binding character	Highly binding, as implementation takes place on a statutory basis	1
Contribution to financing the recycling	The measure has a positive impact on the financing of ELT recycling.	3
Improvement of collection	The measure has no impact on the collection of the waste stream.	3
Strengthening of recycling	The measure creates better conditions for the recycling of ELTs.	3
Acceptance of relevant actors	Federal states: low to indifferent Recycling industry: very high	2
Public information needs	No or hardly any additional public relations work is needed to implement the measure.	1
Weighted result		**2.3**
Key addressees	Ministries of the federal states	
Summary	The regulations form the basis for opening up new sales markets for ELT recyclates and can be introduced with little organisational effort.	

8.9.3.3 Review of PAH limits and detection methods at EU level

In order to assess the health and environmental risk posed by materials containing PAHs, extraction-based content limits have been set as a preventive measure. However, there is no direct correlation between PAH content and bioavailability. For this, the PAHs must migrate or emit. In order to comply with the current state of science, a review and, if necessary, amendment of the PAH limit values was to be carried out by the EU Commission by 27.12.2017 (Regulation (EC) No. 1907/2006; EU Regulation 12872/2013). This has not yet been done. It should therefore be worked towards at EU level that a corresponding review of the limit values is carried out and hazard-related limit values are introduced, which should also be based on new findings on the correlation of PAH content and migration of PAHs.

In this context, it is noted that at national level, when updating the Model Administrative Regulation Technical Building Regulations (MVV TB, 2019), consideration should be given to the extent to which emission-based PAH limits can replace content limits for applications in occupied spaces. In January 2021, it was proposed to exclude particle-tight products from the content limits, but there are still uncertainties regarding the relevance of the content limits for non-particle-tight products without skin contact.

Table 102 Evaluation of the measure "Review of PAH limits and detection methods at EU level"

Criterion	Evaluation	Points
Bureaucratic effort	No additional bureaucratic effort necessary	1
Legal aspects	The legal framework at EU level needs to be updated.	2
Statistical aspects	No impact on the statistical recording of the waste stream.	5
Organisational effort	The organisational effort for the introduction of the measure is low.	1
Implementation timeline	Medium-term (3-5 years)	3
Binding character	Highly binding, as implementation takes place on a statutory basis	1
Contribution to financing the recycling	*Not assessable; depending on the result, positive or negative effect on financing possible*	-
Improvement of collection	The measure has no impact on the collection of the waste stream.	3
Strengthening of recycling	The measure creates better conditions for the recycling of ELTs.	3
Acceptance of relevant actors	Measure accepted by a majority of stakeholders	1
Public information needs	No or hardly any additional public relations work is needed to implement the measure.	1
Weighted result		**2.3**
Key addressees	EU Commission, Federal Government (esp. ministry of environment (BMU))	

Criterion	Evaluation	Points
Summary	Legal certainty with regard to PAH limits is essential for the preservation of the recycling industry. Even though the PAH regulations only cover a sub-sector of the market for ELT recyclate, the general uncertainty due to the current situation leads to a dampening of demand in adjacent areas of application.	

8.9.3.4 Reducing the PAH input in tyre production

PAH content limits exist for most products that can be manufactured from ELT recyclate. To ensure the use of ELT recyclates as a secondary raw material, a low PAH content in tyre rubber is therefore essential.

One of the main sources of PAHs in tyres is the filler and reinforcing material carbon black, whose PAH content is not regulated at EU level. Tyres contain a mixture of different types of carbon black that perform different functions in the rubber. The mixtures of the individual manufacturers sometimes differ significantly and thus the PAH content of the tyres. Some of the carbon black types can be replaced by variants with lower PAH content or alternative substances such as silica. However, functionally equivalent alternatives are not available for all types of carbon black. The extent to which PAH minimisation in tyre production takes place or is technically possible is difficult to estimate, also because of the limited communication of tyre manufacturers. The following two measures help to provide clarity here.

8.9.3.4.1 Study to determine the PAH content in new tyres

To better understand the current status, a study can be conducted to investigate and compare the PAH content of individual tyre models from different manufacturers. This can be used to determine whether there are significant differences in PAH content and thus whether a significant reduction is possible without loss of tyre properties.

Based on the results, a legal restriction of the PAH content in new tyres can be considered. The restriction could be part of future ecodesign requirements for tyres (see chapter 8.9.2.1) or integrated into the requirements of extended producer responsibility (see chapter 8.9.1).

Table 103 Evaluation of the measure "Study to determine the PAH content in new tyres"

Criterion	Evaluation	Points
Bureaucratic effort	No additional bureaucratic effort necessary	1
Legal aspects	No legal changes/additions are required for the implementation of the measure.	1
Statistical aspects	No impact on the statistical recording of the waste stream.	5
Organisational effort	The organisational effort for the introduction of the measure is low.	1
Implementation timeline	Short-term (1-2 years)	1
Binding character	*Not relevant; is a research project*	-
Contribution to financing the recycling	*Not relevant; measure has no financial aspects*	-

Criterion	Evaluation	Points
Improvement of collection	The measure has no impact on the collection of the waste stream.	3
Strengthening of recycling	The measure indirectly creates better conditions for the recycling of ELTs.	4
Acceptance of relevant actors	Manufacturers: low to indifferent (outcome could lead to changes in legal requirements for tyres). Recycling industry: high	3
Public information needs	No or hardly any additional public relations work is needed to implement the measure.	1
Weighted result		**2.5**
Key addressees	ministry of environment (BMU), German environment agency (UBA)	
Summary	The measure can be implemented with little effort and provides the basis for further PAH removal from the ELT waste stream. The results of the study show whether and how high the potential for reducing the PAH content in tyres is. Based on this, appropriate measures can be taken at EU level.	

8.9.3.4.2 Establishment of a database for pollutant content in new tyres

In order to bring about further material developments towards low PAH contents, a certain pressure on the manufacturers is necessary. The establishment of a database on pollutant content with identification of particularly critical tyre types/brands and access for ELT recyclers would be a first step.

Based on EU Directive 2008/98/EC Article 8 (1), an obligation for manufacturers to disclose relevant information on the pollutant content of individual tyre models can be considered within the framework of extended producer responsibility. Of particular interest here would be the total PAH content, as relevant for secondary products, as well as the proportion of other relevant and regulated pollutants and heavy metals, such as zinc compounds.

Manufacturers have been required to report data on the content of substances of very high concern in their products to ECHA's new SCIP database since January 2021 if the content of the substance exceeds 0.1% by mass (ECHA, 2021). At the time of this report, the SCIP database is not yet publicly available. Due to the apparent extensive possibilities for anonymising products, it needs to be monitored whether the information on new tyres provided via the database has sufficient depth to be useful for end-of-life tyre recycling.

Table 104 Evaluation of the measure “Establishment of a database for pollutant content in new tyres”

Criterion	Evaluation	Points
Bureaucratic effort	Additional bureaucratic effort is acceptable	3
Legal aspects	In the case of the introduction of extended producer responsibility, the legal basis can be created based on EU Directive 2008/98/EC Article 8 (1).	4
Statistical aspects	No impact on the statistical recording of the waste stream.	5

Criterion	Evaluation	Points
Organisational effort	There is a medium organisational effort for the introduction of the measure. Constructive and focused communication between several actors is required.	3
Implementation timeline	Medium-term (3-5 years)	1
Binding character	Highly binding, as implementation takes place on a statutory basis	1
Contribution to financing the recycling	The measure has a positive impact on the financing of ELT recycling.	3
Improvement of collection	The measure has no impact on the collection of the waste stream.	3
Strengthening of recycling	The measure creates better conditions for the recycling of ELTs.	3
Acceptance of relevant actors	Manufacturers: low. Recycling industry: high	3
Public information needs	No or hardly any additional public relations work is needed to implement the measure.	1
Weighted result		**2.9**
Key addressees	Federal government (esp. BMU), German environment agency (UBA), manufacturers	
Summary	The measure creates the preconditions for a reduction of the pollutant content in recycled materials and thus a higher acceptance among buyers and consumers.	

8.9.4 Summary

The introduction of an extended producer responsibility or a fee-based system has the greatest positive effects in terms of statistical recording, financing of collection and recovery and reduction of illegal disposal.

Compared to extended producer responsibility, the fee-based system may require less coordination effort and willingness to cooperate on the part of all actors. The promotion of ecologically advantageous recovery routes can be more easily controlled by the responsible government agency. The system also offers fewer opportunities to circumvent participation. When designing a fee-based system, however, it must be checked whether it meets the requirements for special fees and the subsidy regulations in Germany.

It can be assumed that the implementation into a legal regulatory framework will still take several years. The following prioritisation is therefore recommended for the next, timely steps:

1. Review of PAH limit values and detection methods at EU level.

The implementation of this measure has the highest impact on the sales markets for ELT recyclates and thus on the continued existence of recycling. As the procedure for verifying the limit values is extensive, the measure should be started quickly.

2. Study to determine the PAH content in new tyres

Such a study can be implemented in a timely manner and will provide the necessary data for further action when it comes to limiting PAHs in tyres and in tyre recyclates.

3. Regulations for the use of rubber-modified asphalt

As there is already a template in the form of the Technical Terms of Delivery for Rubber Modified Bitumen of Bavaria (Technischen Lieferbedingungen für gummimodifizierte Bitumen), the introduction of corresponding regulations in the other federal states should be pursued with vigour.

9 Used textiles

9.1 General information

For a very long time, the handling of used textiles was characterised by collecting well-preserved clothing, shoes and household textiles such as bed and table linen, towels, bedding, curtains, etc. in order to prepare them for reuse. In particular, humanitarian support by charity organisations has been closely linked to the collection of old textiles for many years. Consequently, the collection of used textiles has received little attention in terms of being a waste management activity. As a result of the amended Circular Economy Act (KrWG) in Germany and the then included obligation to notify any commercial and non-profit waste collection, the extent of used textile collection became apparent in 2012 for the first time. Some public disposal providers also started to engage on the market for used textiles with the result that the collection, sorting and recovery of used textiles was increasingly put out to tender. As there were no technical requirements for the handling of used textiles so far existing, an orientation aid for municipal tenders on the collection, sorting and recovery of used textiles has been drafted in 2016 by the Association of German Counties (Landkreistag) together with the Association of German Cities (Deutscher Städtetag).

Used textiles gained further attention and recognition under the perspective of waste legislation as, among other things, the amendment of the Waste Framework Directive in 2018 (Directive (EU) 2018/851) provides for an obligation to the separate collection of textiles from the year 2025 onwards. These new requirements were implemented in the amended Circular Economy Act (KrWG) in Germany in 2020 in such a way that the obligation to the separate collection was primarily addressed to the public disposal providers. Until to date, a lack of nationwide statistical data on used textiles and detailed knowledge on the quantities handled, their composition and destinations in Germany is observed. A study on the consumption, demand and reuse of clothing and textiles in Germany, commissioned by the private sector association, the Bundesverband Sekundärrohstoffe und Entsorgung e.V. (bvse), and finalized in 2015 provides an assessment for 2013 as the reference year. As part of the study, the members of the bvse were surveyed and their information on the destinations of the collected goods transferred to the total calculated collection volume. The response rate reached 40%. The collection volume was determined on the basis of secondary statistical data (see page 14 of the bvse study on the applied procedure and method). The bvse study estimates an overall collection potential of approx. 1.35 million tons of textiles, shoes and bags/leather goods, of which approx. 1.01 million tons were collected as used textiles. This corresponds to a collection rate of about 75%. According to the study, approx. 93% of the used textiles are sorted in Europe, of which approx. 66% are collected in Germany, shipped to non-European countries for sorting are approx. 7% of the collected quantities.

In 2020, the Textile Study 2020 was published as an update by the bvse (bvse 2020). The new study deals in particular with the changes that occurred on the used textiles market and the factors influencing this, and it shows the domestic availability and collection volume for the reference year 2018. The results have been incorporated in the following assessment.

9.2 Analysis of collected used textiles

The evaluation of the quantities of used textiles was carried out in particular by surveying the collection results in the settlement areas. Hereby must be mentioned that so far there is no legal obligation for competent authorities to report on used textiles.

Therefore, for the purpose of data collection, the authorities responsible in the federal states for notification procedures according to Section18 KrWG were asked to provide the following information via questionnaires:

- Collection quantities, broken down by commercial, non-profit collections and collections within the framework of voluntary take-back pursuant to Section26 KrWG
- Collection systems (bring banks, underfloor containers, civic amenity centres, street collections, collections via waste bins or through shops)
- Legal requirements or inspections within the scope of the verification system
- Final destinations of the collected quantities for subsequent sorting (Germany, EU countries, OECD countries, countries outside the EU/OECD)
- Output from sorting (share of the volumes prepared for reuse and the corresponding sales markets, share of cleaning rags, shredded volumes and those forwarded to energy recovery or other disposal routes with the respective destinations).

In addition, they were able to give their assessment on the following questions:

- Development of collected quantities in Germany
- Development of collected quantities in Europa
- Development of the quality of the collected quantities.

Furthermore, the public disposal providers were asked to provide the following information in a nationwide survey:

- Implementation of separate collection of used textiles in their area of responsibility (through own collection services or commissioning of third parties)
- Collected quantities
- Collection systems (bring banks, underfloor containers, civic amenity centres, street collections, collections via waste bins)
- Legal requirements or inspections within the scope of the verification system
- Final destinations of the quantities collected for subsequent sorting (Germany, EU countries, OECD countries, countries outside the EU/OECD)
- Output from sorting (share of the volumes prepared for reuse and the corresponding sales markets, share of cleaning rags, shredded volumes and those forwarded to energy recovery or other disposal routes with the respective destinations)

These respondents were likewise invited to give their assessment on the following additional questions:

- Development of collected quantities in Germany
- Development of collected quantities in Europa
- Development of the quality of the collected quantities.

The public disposal providers were also able to provide information on the procedures known to them on the subject of illegitimate installed containers for used textile collection.

Feedback provided by the competent authorities at the federal states level

In principle, all respondents were asked to return the questionnaire sent to them even if no information could be provided. The response rate of the competent authorities reached approx. 29% (87 responses). Only 58 questionnaires could be included in the further analyses as 29 authorities reported that they were unable to provide any information. The 58 responses cover a territory inhabited by approx. 20.7 million people (approx. 25% of the German population). It can be noted that the depth of information tends to generally decrease when it comes to the subject of where the collected used textiles go to, i.e. their destinations. For the analysis of the collection volume, the calculation had to be based on the number of 12.8 million inhabitants only (approx. 15% of the German population). Of these, 76% of the returns arrived from two federal states. With regard to the destinations of the collected textiles, only 9 authorities were able to provide feedback, representing approx. 9% of the total population. Regarding the output of the sorting of used textiles, only questionnaires representing a total of approx. 6% of the total population could be finally assessed.

Table 105 Overview of the feedback provided by the competent authorities

Feedback	Number of questionnaires	Number of inhabitants	Share of population
Total feedback	87	-	-
Feedback included in evaluation	**58**	**20,676,660**	**24.9%**
for the collected quantities	29	12,767,010	15.4%
for the collection systems	27	10,164,849	12.2%
for the destinations of the collected quantities	9	7,114,898	8.6%
for sorting output	10	4,615,033	5.6%

Feedback from public disposal providers (örE)

A total of 266 responses to the survey arrived from the public disposal providers (örE), of which 195 questionnaires could be finally included in the analysis, covering a total territory of approx. 37.2 million inhabitants (approx. 45% of the German population).

Of these returns, 97 örE carry out their own collection of used textiles, with 43% of them doing the collection themselves whilst at the remaining 56 örE the collection services are carried out by a commissioned third party. Not all örE were able to provide information on the collected quantities. The evaluation is therefore based on areas that cover a total of approx. 26% of the German population. As far as the final destination of the collected volumes are concerned, only 43 örE representing approx. 16% of the total population were able to provide a feedback. Regarding the output of the sorting of used textiles, only questionnaires representing approx. 10% of the total population could be evaluated. The territorial distribution of the feedback received shows that 62% of the responses are coming from three federal states.

Table 106 Overview of the feedback provided by the örE

Feedback	Number of questionnaires	Number of inhabitants	Share of population
Total feedback	226	-	-
Feedback included in evaluation	**195**	**37,246,266**	**44.90%**
for the collected quantities	97	21,371,424	25.70%
for the collection systems	87	20,859,137	25.10%
for the destinations of the collected quantities	43	13,488,624	16.20%
for sorting output	30	8,272,999	10.00%
for the destination	10	2,634,495	3.20%

With respect to both surveys to address the two different respondent categories, the responses include both rural areas and large cities. Furthermore, information arrived from a total of 15 federal states, with the majority of the responses coming from a total of three federal states.

9.2.1 Collected quantities

All collection actors usually collect the used textiles together in the area of the respective public disposal provider. The share each actor has in the total result and collection area can be quite varying, however.

Collection quantities from the survey of the federal state authorities

The analysis refers to the quantities from commercial and non-profit collection activities as well as quantities shops, i.e. the stationary retail sector collected within the framework of voluntary take-back of used textiles.

According to the authorities' information, the collected quantities from the stationary retail sector amount to 79 tons in 2018, a figure that is derived from the feedback of one federal state. Extrapolating this value to the entire territory of Germany gives a collection quantity of 3,579 tons in total. It is not known how many retailers offer to take back old textiles. The fashion chain H&M has published its collection quantities for Germany on the website Charity Star (Charity Star, n.d.). Since this kind of collection was introduced by her, quantities of approx. 12,600 tons have accumulated, which when considered on an annual basis amounts to approx. 1,800 tons. Other records about such sorting activities are unknown.

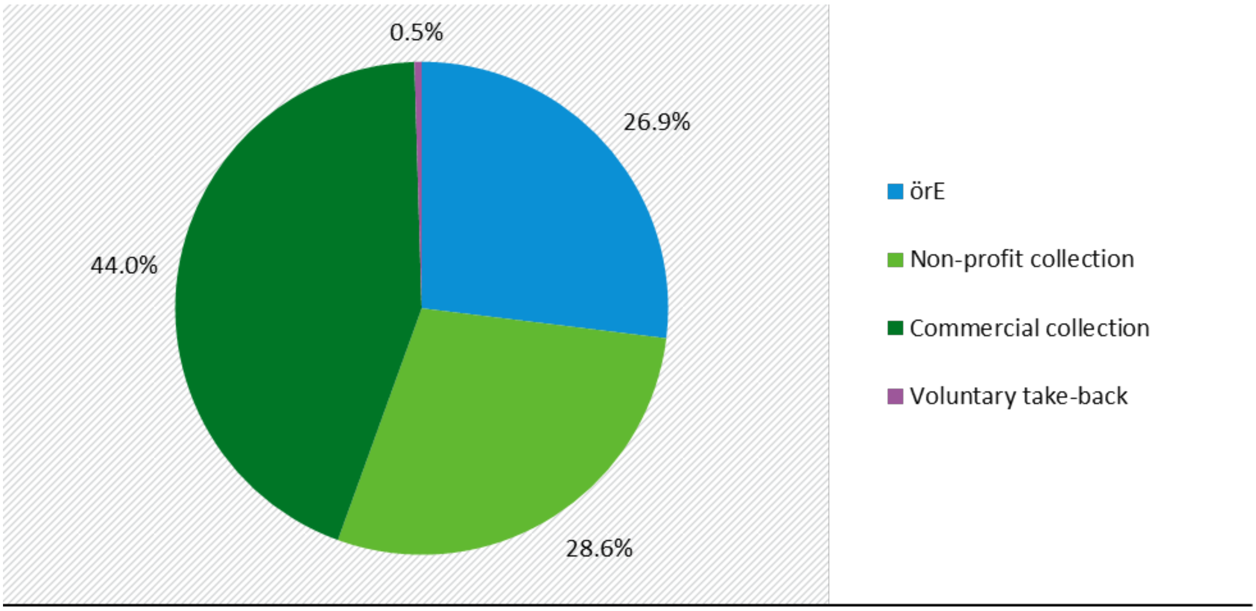
The survey among the competent authorities resulted in a total of 50,923 tons for the area of commercial collections in 2018, whereas 33,080 tons were reported for the area of non-profit collections. Based on these two quantities and including the quantities from the stationary retail sector, this results in a nationwide extrapolated total quantity of about 549,822 tons or 6.6 kg per capita in this reference year.

Collection quantities from the survey of the public disposal providers (örE)

The sum of the quantities of the assessed questionnaires from the örE amounts to a total of 52,205 tons, equivalent to 2.4 kg per capita. Extrapolated to the total population, the collected quantity is 202,794 tons for the year 2018.

Extrapolated across all collection actors, the total of 752,615 tons or 9.1 kg per capita of used textiles have been collected in Germany in 2018.

Figure 31 Shares of the different actors in the collection of used textiles



Source: compilation of INTECUS, Kösegi

9.2.1.1 Evaluation of the results

The determination of the collection quantities is basically based on an extrapolation of the population figures of the total area of the assessed questionnaires in relation to the population figures of the total population. Comparing the collection quantities derived from the örE responses for 2018 with the total 156,700 tons as the statistical data from Destatis (Destatis, n.d.) shows that the quantities extrapolated from the survey exceed those the Federal Statistical Office has published by approx. 29%.

There are no separate statistics on commercial or non-profit collections available. In some cases, quantities from these sources are listed in the waste statistics of the federal states. However, it is often pointed out here that these data are provided without any guarantee. The bvse is the only body that publishes the collection volume of used textiles in Germany on a regular basis. The most recent publication is from 2020 (bvse 2020) for the reference year 2018. In this source, the collected volume is stated to have reached 1,271,242 tons in 2018. This gives a deviation of 518,627 tons (approx. 40%) from the data determined above.

9.2.1.2 Possible weaknesses and missing information in the surveys

The data of the questionnaires were checked for plausibility. Especially where a large deviation and obvious error was seen in the reported data, the figures were discussed with the respective authority and the data was either adjusted or not included in the overall assessment. If one looks at the individual reporting of quantities from comparable settlement structures, there are deviations in the range of +/- 36% in some cases (Zinkler et al., 2019). Clustering therefore does not appear possible. Furthermore, there is hardly any data from all collection activities/actors for an area as a whole available. Some of the returned questionnaires showed that it cannot be ruled out that the quantities across all commercial and non-profit collectors had not been reported in full, as requirements to report quantities annually in conjunction with the notification pursuant to Section18 KrWG were often not followed. Even though the responses include data for both rural and large urban settlements, these areas are largely located in three federal states. Comparing the result of the survey with the collection volumes established from the bvse leads to the conclusion that the data is not sufficient for a representative extrapolation.

9.2.1.3 Other sources for evaluating the data

As mentioned before, various data on used textiles that can be used for an assessment have been published from the bvse in the Textile Study 2020 (bvse 2020).

9.2.1.3.1 Determination of the available collection volume by the bvse

In contrast to the survey addressed to the authorities on material flow data taking the actually collected quantities of used textiles into account, the bvse has determined an available collection quantity on the basis of the following method:

The starting point was set with the domestic availability of those products that are usually collected via the collection systems for used textiles (clothing, household textiles, bags/leather goods and shoes). For the analysis, a usage time of one year was assumed for these items and that the potential collection volume therefore corresponds to the domestic availability (bvse 2020, page 7). The usage time is however strongly dependent on the intensity of wearing a textile good. As part of the study "Valuing Our Clothes: the cost of UK fashion" (WRAP 2017), the organisation WRAP asked consumers how long they are wearing their clothing (underwear excluded). In this case the established average was 3.3 years. In its previous study from 2015 (Korolkow 2015, page 56), the bvse also looked at changes in the usage time of various textile goods. This investigation showed a greatly varying usage time depending on the kind of textile. A comparison of the data from 1998 and 2005 showed that the usage time has decreased during the observation period and reaches about 3 years on average.

9.2.1.3.1.1 Consideration of domestic availability

Domestic availability is determined in the Textile Study 2020 (bvse 2020) using several methods:

- Basic method

  Domestic availability is derived using the domestic production and external trade balance for the calculation, with the latter depicting the difference between exports and imports of the products mentioned before.

  In determining the data, no distinction was made between textiles and footwear produced for households or for commercial purposes (for example, workwear). Workwear or textiles supplied to commercial entities usually have different disposal routes than used textiles from households. The proportion of textiles for commercial purposes is put at approx. 2.7% (Sustainable Global Resources Ltd 2017). In addition to the textiles produced for the German market, illegal imports as well as textiles which households brought along from abroad and dispose in Germany at a later date, must also be considered a potential collection quantity. Statistical data covering the last two phenomena are not available. To determine the quantities in the basic method, the estimated values from the previous study in 2015 (Korolkow 2015) were used.

- Consumption method

  This method determines the per capita consumption of textiles and multiplies it by the number of inhabitants. Basis are estimates made for the fashion consumption in Germany. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety estimates that an average of 60 items of clothing are purchased by a person (BMU, n.d.). To this consumption, which the bvse puts at 18 kg per inhabitant, 3.5 kg per inhabitant were added for household textiles, resulting in a total per capita consumption of 21.5 kg. For the Kearney study "Can circularity save the fashion industry? (Warschun et al., 2020), a total of

8,000 consumers in Germany were asked about their fashion consumption in 2020. The survey showed that on average 17 items of clothing are purchased per year, which would mean a consumption of 5.1 kg per capita if the bvse's reference value for the weight per item of clothing is applied. This figure seems very low. However, no figures regarding the purchase of underwear, swimwear or nightwear were taken into account here. In a European comparison, Germany is one of the countries with above-average consumption. The interim report "Research into circular economy perspectives in the management of textile products and textile waste in the European Union" commissioned by the Joint Research Centre (Köhler et al., 2020) puts the average consumption of textiles in the EU at 12.3 kg per citizen. In this respect, the result of the Kearney survey cannot further be used as a reference value.

In France, manufacturers and importers must report the quantities of clothing, household textiles and footwear placed on the market. This obligation is part of the legal requirements related to the implementation of the extended producer responsibility for textiles (EcoTLC agreement, 2020). For 2019, a total of 2.88 billion products were reported, which corresponds to approximately 44 products per inhabitant of the country. However, this product range does not include leather goods and bags when drawing a relation to the numbers known from Germany. When comparing only the sales of clothing of both countries, Germany has a per capita consumption which is about 42% higher than that of France in 2019 (Statista 2020). If one compares this percentage value with the ratio of the number of clothing purchased in both countries, approximately 37% more items were purchased in Germany than in France. In this respect, the data are not comparable 1:1. However, it should be noted that there exist actual figures for France, which can be used at least approximately for the appraisal of the quantities in Germany. In France, textiles have an average weight of 0.225 kg, for Germany a reference value of 0.3 kg has been established. As already mentioned, France does not include bags and leather goods in the relevant statistics, which account for about 10% of the weight in Germany. Instead, household textiles are taken into account, which are quantified in the study of the bvse with a reference value of 0.1 kg and are also included in the calculations according to the consumption method. A total of 3.5 kg per person is added, which would add another 35 household textiles to the 60 items of clothing accounted for each inhabitant (bvse 2020, page 8). Overall, the per capita consumption seems somewhat too high, which can be adjusted either by correcting the number of products considered or by lowering their average weight.

- Commodity turnover method

  This method adds the percentage difference of consumption expenditure and turnover of the retail of textiles to the result of domestic production and external trade balance. The difference does allow conclusions to be drawn on products bought abroad and imported into Germany. According to the bvse, the difference amounts to approx. 200,000 tons (bvse 2020). As with the basic method, this calculation also includes textiles that cannot be allocated to households.

9.2.1.3.1.2 Evaluation of the different methods

The determination of quantities, in particular on the basis of the data from the Federal Statistical Office, is difficult because these data are published in different ways. For example, there are hardly any data on weight provided, so that the quantities had to be determined on the basis of reference weights and the quantities stated for production. Furthermore, not all producers are obliged to report data to the Federal Statistical Office. Where no updated data could be found, figures from the previous bvse study with 2015 as the reference year were used or own estimates were made.

In this respect, there are different parameters that significantly influence the result. Some relevant points on the calculation of variants for each method are listed below:

- Variant calculation for the basic method

Table 107 Adjusted quantities of the basic method

Parameter	Quantity in tons	Comment
Domestic availability (INLV) bvse	**1,634,731**	
Allowance for wearing time (3 years)	-99,721	Domestic availability 2015: 1,535,010 tons
Deduction of the quantity of workwear	-38,210	Share 2.7%
Allowance for private imports according to consumption method		
Adjusted result	**80,294**	

- Variant calculation for the consumption method

Table 108 Adjusted quantities of the consumption method

Parameter	Weight per piece of clothing
Reference value of bvse	0.3 kg
Weight per item according to quantity declaration in France	0.224 kg
Weighting: bvse 40% / French value 60%	0.254 kg
Adjusted result	**1.575.679 tons**

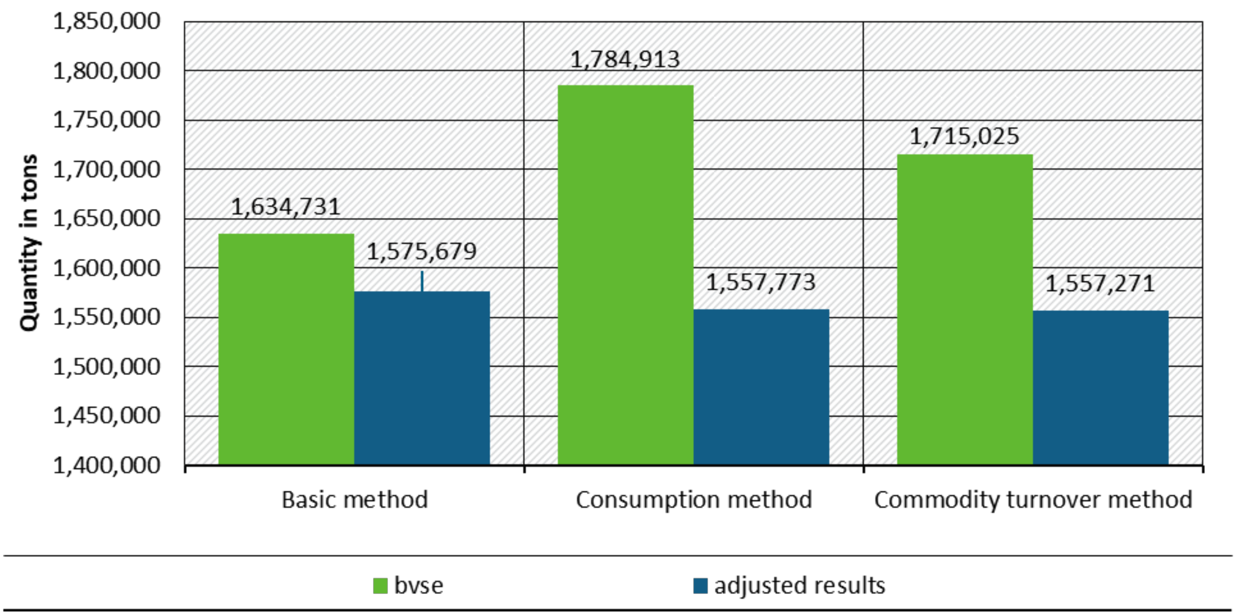
- Variant calculation for the commodity turnover method

Table 109 Adjusted quantities of the commodity turnover method

Parameter	Approach of bvse
Domestic availability (INLV) without private imports	1,375,560 tons
Percentage difference	13.21%
Adjusted result	**1,557,271 tons**

The adjustment of the individual parameters also leads to an alignment of the individual results.

Figure 32 Comparison of domestic availability according to bvse with adjusted results



Source: Graphic of Kösegi

Taking all the above findings into account, the potential collection volume of used textiles for 2018 is estimated to amount to approx. 1.56 million tonnes.

In order to ascertain the actual collection volume, this quantity must be further adjusted. The bvse study has taken the following deductions into account:

- Deduction of a reserve:

In addition to the different usage times, there are many textiles that remain practically unused in the wardrobe for a long time until being disposed of via the used textiles collection. The bvse estimates this reserve at 5% of total consumption. This estimate was carried forward from previous studies, i.e. there exist no current assessment for Germany in this respect. Various surveys such as the Kearney study "Can circularity save the fashion industry?" (Warschun et al., 2020) came to the conclusion that consumers in Germany possess an average of around 100 clothing items. The same conclusion had been made in the Greenpeace survey "Wegwerfware Kleidung" from 2015 (Wahnbaeck, Groth, 2015). Approximately 40% of those items are rarely or almost never worn. In this respect, the deducted reserve seems somewhat too low. Looking at the approach used for other studies that deal with the disposal of used textiles is showing that the reserve for the United Kingdom, for example, is estimated at 14% (Bartlett et al., 2012). The difference in relation to the domestic availability determined by the bvse amounts to 147,126 tons.

- Deduction of a weight loss:

During the usage phase, especially through washing, textiles lose weight due to fibre abrasion. This loss is assessed at a flat rate of 2%. The approach was adopted from previous studies, as there are no new findings on this. In this case, it should also be noted that textiles are not anymore washed as often given that the periods of time they are worn also become shorter. This would reduce the fibre abrasion. A current study analysing the (average) fibre losses during daily use is not known.

- Volume of used textiles not separately collected:

Due to a lack of up to date data, the quantities of used textiles disposed of via the residual waste service were assessed at 3.0 kg per capita in the Textile Study 2020. It has been pointed out already from the study authors that changing quantities are to be assumed (bvse 2020, page 10). The report published in 2020 on the analysis of residual waste in Germany (Dornbusch et al., 2020) puts the quantity of used textiles in the residual waste at 4.5 kg per person. The difference of 1.5 kg accounts for a further quantity deduction of 124,529 tons in total.

If the data were updated with the new findings and assumptions, the actual collection potential as established from the bvse would be reduced by 271,665 tons from 1,271,242 tons to 999,588 tons. Taking further the updated potential collection volume based on above parameters into account would bring the actual collection volume to a level of approx. 930,000 tons. It should be noted in this calculation that the actual collection volume also includes misthrows of waste, which are stated to be in the scale of approx. 5% in the survey response of the different authorities. Likewise, there are other quantities related to the collection system in the material mix, such as non-textile toys but also foil and cardboard packaging.

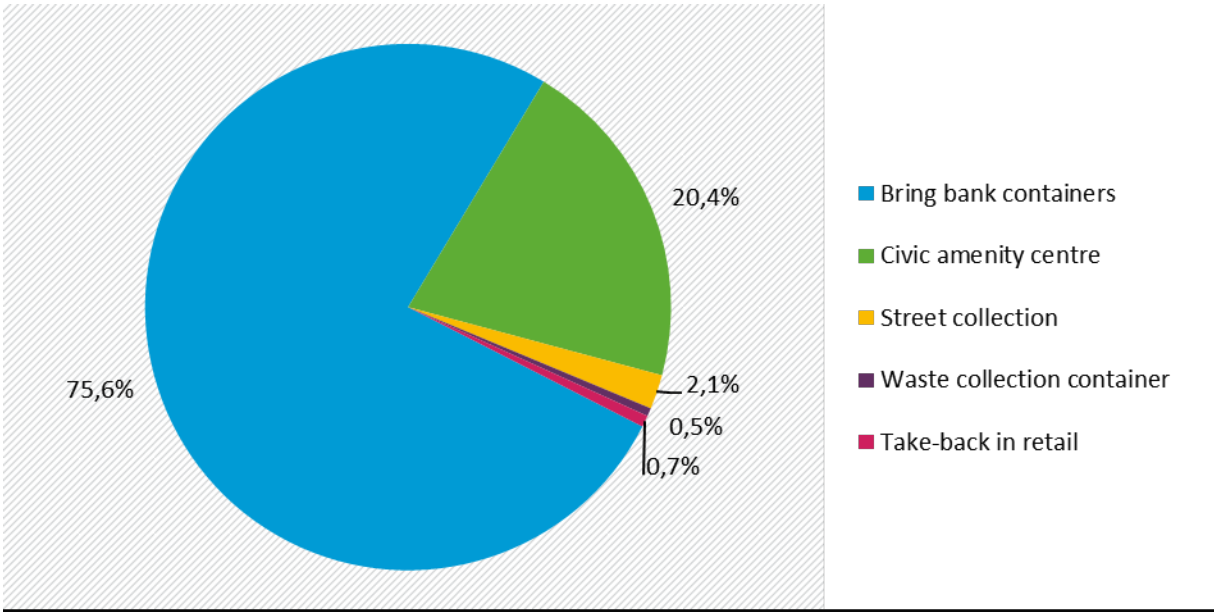
9.2.1.4 Estimation of the actual collection volume in 2018

In summary, it can be stated that there is no reliable data basis available. Considering all data collected as well as findings made and the comparisons undertaken with them, the collected volume of used textiles for 2018 is estimated at approx. 1.0 million tons.

9.2.2 Collection systems

Various systems are used for the collection of used textiles in Germany. Bring bank containers account for the largest share of approx. 75.6%. Second in place with approx. 20.4% is the acceptance of used textiles at civic amenity centres where bring bank containers are usually provided too. Street collections account for approx. 2.1%. Together with collection services using waste bins at the household (0.5%) and take-back at shops and stationary retail outlets (0.7%), these systems play a rather minor role, however.

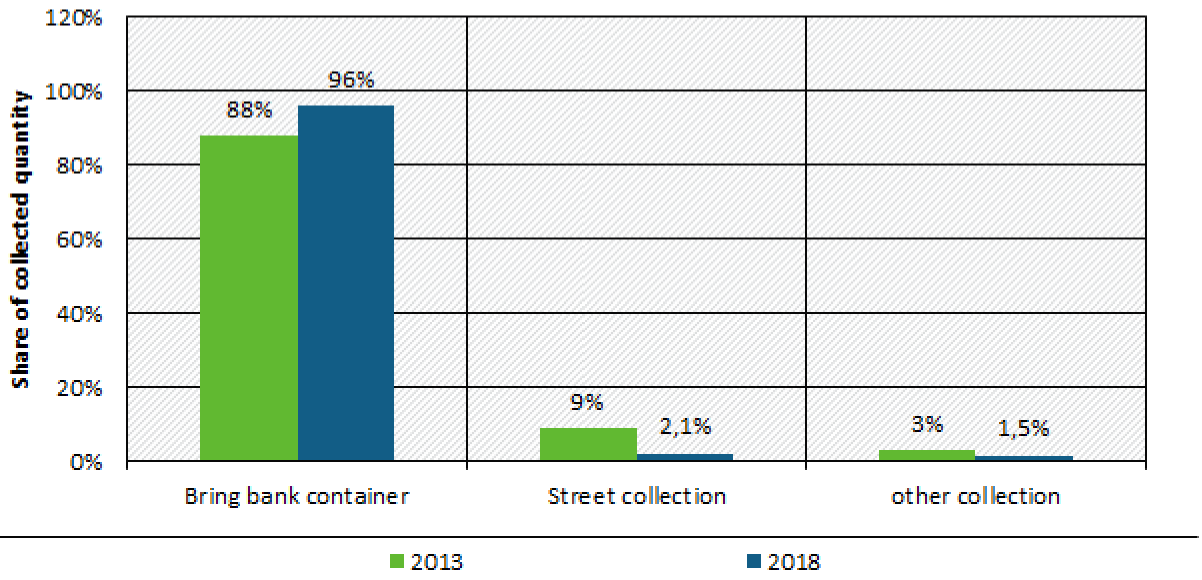
Figure 33 Applied collection systems and their shares



Source: compilation of INTECUS, Kösegi

Compared to the systems implemented for collection in 2013 (Korolkow 2015), street collections have significantly decreased in the meantime. For this comparison, collections at the civic amenity centres were accounted under bring back container collections, as the collection here is mainly carried out with the same sort containers placed across the settlement area. Alternative collection systems, such as online collections or collections organized by the retail sector, did neither in 2013 nor today play a significant role and are therefore summarised in the comparison as other collections.

Figure 34 Comparison of the systems for used textile collection in 2013 and 2018



Source: compilation of INTECUS, Kösegi, including data from bvse 2015 and 2020;

9.2.3 Request for verification

In order to assess the current enforcement practice, competent authorities were asked to provide information on the requirement for evidence. Various information and evidence must be provided when notifying collections.

From commercial collectors following data is requested as part of the examination of notification procedures under Section18 KrWG:

- information on the size and manner of legal organisation of the collection company,
- information on the type, quantity and duration of the collection, in particular on the possible maximum extent and minimum duration,
- information on the type, quantity and destination of the waste to be recovered,
- a description of the envisaged routes of recovery within the notified period, including the measures to ensure the availability of the necessary capacity, and
- a description of how the proper and safe recovery of the collected waste will be ensured within the framework of the designated recovery routes.

The notification of a non-profit collection shall be accompanied by:

- information on the size and manner of legal organisation of the party commissioning the charitable collection and, if applicable, of the party commissioned to carry out the collection,

- information on the type, extent and duration of the collection.

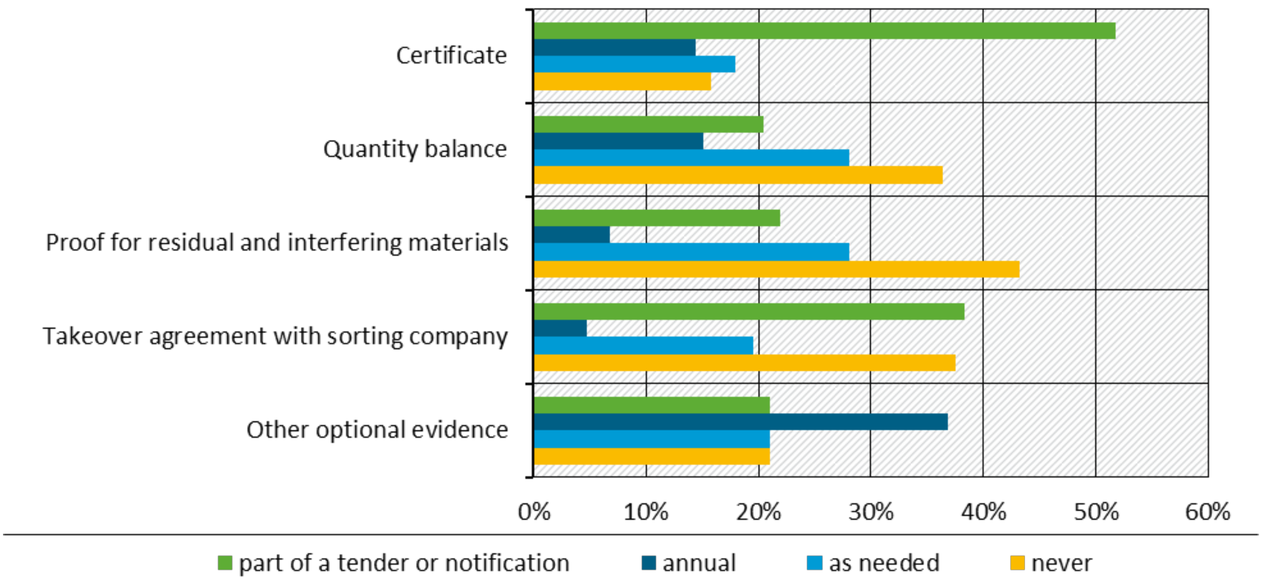
Furthermore, when awarding contracts in municipal tender procedures (on the collection and recovery of used textiles), care must be taken to ensure that the waste hierarchy is observed and that the best possible recovery of the waste stream is achieved.

The authorities were able to indicate the following choices in response to the requested information on the enforcement practice:

- certificates from sorting companies (EfB certificate, TÜV Rheinland or similar),
- balance and list of destinations for the sorted quantities,
- proof for the recovery or disposal of the residual and interfering materials,
- agreement on the takeover of the used textiles by sorting companies
- other optional evidence.

For each type of evidence, a choice could be made as to whether it was requested as part of the invitation to tender or notification, annually, as required or never. Overall, this question was answered in 70% of the returned questionnaires.

Figure 35 Overview of the required evidence



Source: compilation of INTECUS, Kösegi

Nearly half of the questionnaires contained the answer that certificates are requested from sorting companies as part of the tender or notification procedure. The submission of a takeover agreement with sorting companies comes in second place with 38%. All other certificates are requested by less than 23% of the authorities in that course. It also has been established that all other forms of evidence are requested by around a quarter of the authorities, regardless of the point in time. An annual review of further optional evidence is carried out by 37% of the authorities.

In general, it can be summarized that the material stream of used textiles has so far received little attention as far as the request for evidence and verification of performance are concerned.

9.2.3.1 Qualitative criteria in municipal tenders

Proof on the qualification to perform a proper collection is also required in the frame of municipal tenders. On the one hand, the certificates should prove the reliability of the bidder, but also ensure high-quality recycling. To this end, the "Gemeinschaft für textile Zukunft" (GftZ, German Future of Textiles Association) in cooperation with the Association of German Cities and the Association of German Counties, have published a guidance on requirements for the collection, sorting and recycling of used textiles in municipal tenders. It is intended to serve as an aid in the design of the tender dossier, the preparation of the specifications and the determination of the bidder's job qualifications (GftZ 2016).

In order to check whether performance criteria for the collection, sorting and recycling of used textiles are also included in municipal tenders, tender documents were reviewed and evaluated during this research project. Up to December 22, 2020, a total of 29 invitations to tender (either publication of the invitation to tender or notification of the award) had been evaluated. Approximately 24% of the tenders also contained criteria other than the price for the award, whereby the price criterion in these cases has had the greatest weight with >75%. Apart from that, it has been found that various proofs are in general requested, such as the certificate of recognition as specialised waste management company or the proof of equivalent qualification of the service to be provided (e.g. transport permit), a list of job references, self-declarations on the total turnover, presentation of the recovery routes, etc. The tendering procedure altogether is also subject to a number of other criteria.

There was no specific reference in the tenders to the guidance of the Association of German Cities and the Association of German Counties although it is apparent that various references or performance criteria were included in the conditions for tendering.

9.2.4 Illegal collection activities

Illegal collectors neither fulfil their legal obligations to report a commercial collection according to Section18 KrWG, nor do they have permission from the competent authority, local administration or property owner to set up containers for collection. The sales prices for collected used textiles averaged at 0.45 EUR per kg in the period from 2012 to mid of 2014 (Korolkow 2015). With such comparatively high price level it is profitable to set up collection containers illegally, even if there was a risk that the container would be removed again after a short time. In the 2015 study of the bvse, the members of the association put the proportion of illegally placed containers at 33% (Korolkow 2015). It therefore stands to reason that there is a direct correlation to the proceeds which can be made from the sale of the so collected quantities. In 2018, the average price published by EUWID for collected textiles stood at 0.29 EUR per kg, with a downward trend at that time (bvse 2020).

Against this market background, a total of 190 örE answered the question about illegally placed containers. 16% of the respondents were aware of court cases concerning illegally placed containers whilst 84% of the respondents were not aware of any cases. A total of 37 court cases were mentioned, involving 135 container sites. Referring to these results, illegally placed collection containers may hardly play a role in the segment of used textiles anymore.

A similar picture was obtained in a survey involving experts from the bvse, FairWertung and GftZ. The experts noted that there are fewer and fewer illegal collections, lower market prices for collected unsorted amounts result in that the profit from collecting is no longer high, making it no longer worth setting up containers illegally if only for a short period of time. Moreover, the official collection companies have become more sensitive, so that illegitimate containers would be discovered more quickly. Likewise, due to numerous lawsuits, the administrations do have a clear idea how a legal procedure for the removal of illegal containers can be carried out successfully. This means that these containers can be removed much more quickly.

Following the continuing negative changes in textile quality, it can be expected that high market prices for collected quantities will no longer be attainable in future. It can therefore rightly be assumed that the extent of illegal collections will remain low.

9.2.5 Assessment of the future development of collected quantity and quality of used textiles

A total of 156 responses provided an assessment as to how the quantity and quality of the collected used textiles in Germany and the EU will change from 2025 due to the new obligation of separate collection.

62% of the respondents indicated that the collection quantity in Germany will increase. The majority of 82% expects that the quantity in Europe will increase. With regard to the collected quality, 67% agreed that this is going to deteriorate, with a further 18% indicating a significant deterioration in quality to happen. Only 9% think that the quality will increase, 6% estimate that it will remain unchanged.

In addition, 67% of the örE stated that the quality of the collected used textiles has already deteriorated, 2% reported an improvement in quality and 31% could not see any negative developments so far.

9.3 Analysis of sorted used textiles for preparation for reuse and other material recovery

9.3.1 Destination of the quantities collected for preparation for reuse

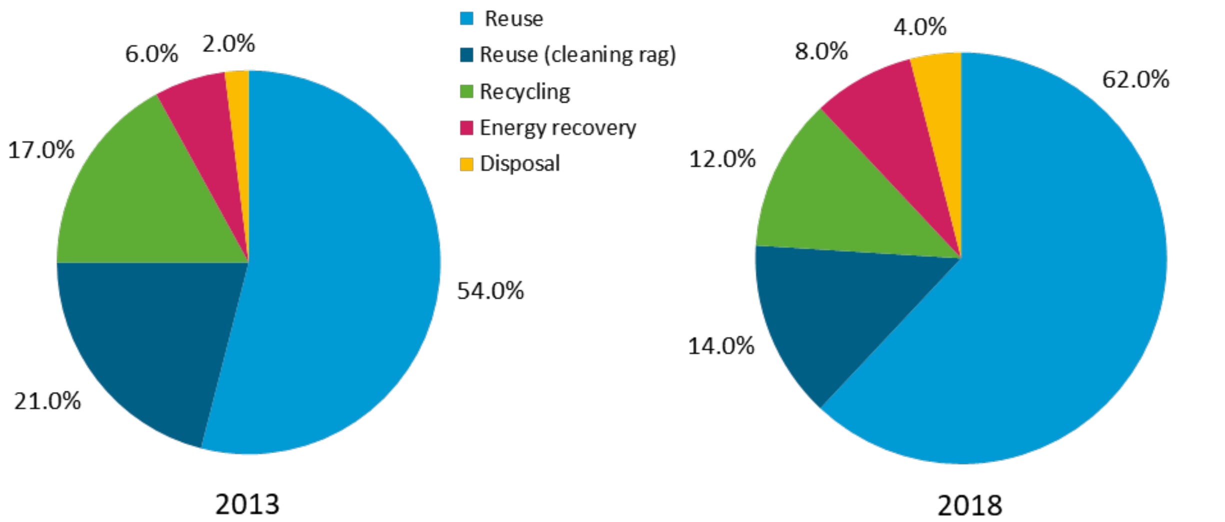
Around 34% of the responses contained information on the destinations of the collected waste. The responses from the federal state authorities and the örE, which represent approx. 17% of the German population, indicate that more than 70% of the collected textiles in Germany are prepared for reuse. The bvse in its current Textile Study 2020 (bvse 2020) has not looked into the destinations of the collected quantities. In the 2015 study, the proportion of collected textiles sorted in Germany was assessed with 61% (Korolkow 2015). According to the statistics on external trade in 2018 (see chapter 9.5), a total of 515,944 tons of waste with the code 63090000 "old goods" was exported. Taking hereby the total value of goods into account shows that these quantities must also be waste or products that have already been sorted. On average, the value of these goods was 0.68 EUR per kg (cf. also market prices for collected materials, chapter 9.2.4). It is assumed that at least 50% of the collected quantities are exported and mostly sorted in Europe. From the experts' point of view, the Netherlands and Poland are those countries that receive the main quantities. The increase in exports also correlates with the development of the minimum wage regulations, considering that sorting is quite a labour-intensive service.

9.3.2 Destinations of the sorted quantities

Nine authorities provided general information on the sorting output. In the survey on the routes of recovery and destination countries, all but four authorities were unable to provide any information. The quality of the data is similar for the survey of örE. 30 örE provided output quantities whilst the destination countries for the different routes of recovery were included in only 26 questionnaires. Thus, the survey response is not sufficiently representative in order to draw up a valid picture on the sorted output.

The bvse has shown the routes of recovery for the years 2015 and 2018 in its two textile studies (Korolkow, 2015, bvse 2020), however without that information for the destination countries were included. The routes are shown below, including the proportion of used textiles that were traded under the second-hand label after preparation for reuse.

Figure 36 Output balance as of bvse textile study 2015 and 2020



Source: bvse, 2020 (modified)

9.3.2.1 Destination countries in relation to the individual routes of recovery

The external trade statistics cannot be used for this assessment, as no distinction is made here between the individual unsorted and sorted used textile streams.

Neither the interviews with the federal state and örE nor the information from the expert survey provided a detailed overview of where the sorted used textiles remain.

As a consequence, only the following general assessment of the experts can be offered:

- Material recovery (cleaning rags): The majority of recovery into cleaning rags takes place in European countries outside Germany.
- Material recovery (shredded fibre): Recovery into shredded fibres is taking place in Germany to a small extent. The majority of this recovery is performed in other European and non-European countries.
- Energy recovery: Energy recovery of sorted quantities (remnants and non-marketable portions that cannot be recycled) takes place in Germany for the used textiles sorted in the country. Corresponding quantities from the original collected textiles sorted in other countries are taken to energy recovery in accordance with the regulations applying in these countries, provided that options for energy recovery are available at all.
- Final disposal: The practice of this option is not proposed in Germany. It is however applied whenever an incineration plant does not hold the status of "recovery" but represents a thermal treatment facility only. No reliable information is available on exported quantities.

In general, it was noted that material recovery is increasingly taking place outside Europe.

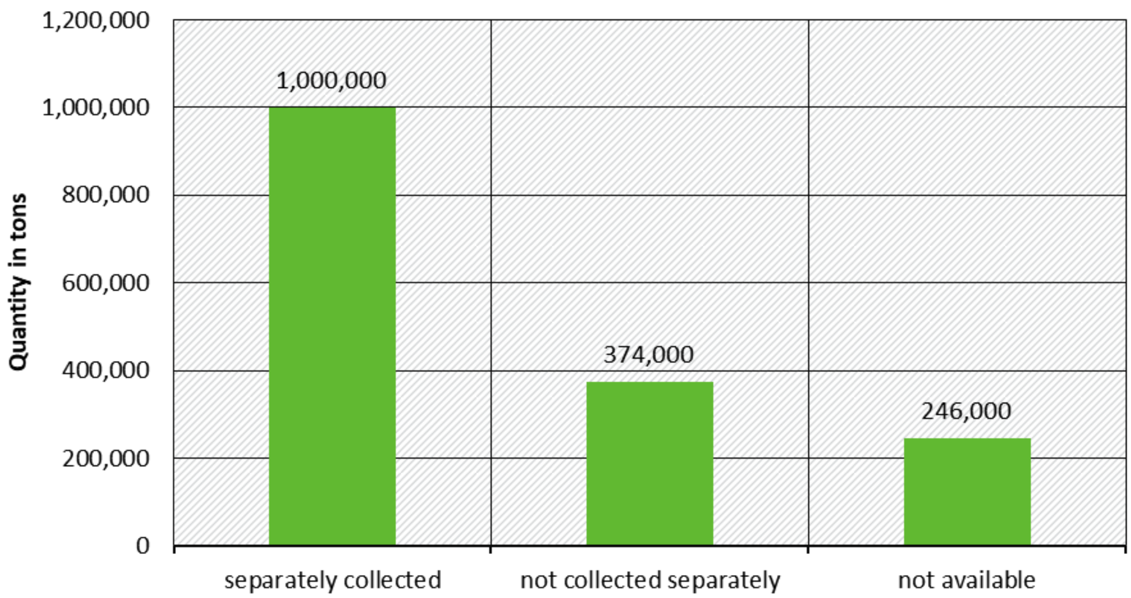
9.4 Determination of the collection rate of used textiles

9.4.1 Method for determining the collection rate

In general, to determine a collection rate, the collected quantity is set in relation to the quantity placed on the market and made available for separate collection. For used textiles, there is currently no specific regulation on how the collection rate is to be determined. The collected quantity of used textiles was estimated at approx. 1.0 million tons for 2018 (see Chapter 9.2.1.4). The potentially available collection quantity was assessed at approx. 1.56 million tons on the basis of the bvse Textile Study 2020 (bvse 2020) and other data sources and comparisons (see Chapter 9.2.1.3.1.2). Both quantities put in relation results in a collection rate of 64% for 2018.

As explained in Chapter 9.2.1.3.1.2, there are several reasons why the potentially available collection volume is not collected separately. One reason is that used textiles are partly disposed of via the collection system for residual waste. This portion is equivalent to a total quantity of 374,000 tons. The remaining share concerns quantities of textiles that are no longer used but nevertheless remain "in the wardrobe" or that are or sold and given away as second-hand goods. This quantity is hence not accessible or subject for waste management measures or only at a later point in time. If only the available quantity is considered and the collected quantity cleared from misthrows and other system-related waste (accounting for approx. 70,500 tons in total), then a technical recycling potential of 71% can be derived.

Figure 37 Breakdown of collection potential (including misthrows and other quantities)



Source: compilation of INTECUS, Kösegi

9.4.2 General evaluation of the result

The currently established collection rate of 64% is above average for a waste stream that is not (yet) subject to mandatory separate collection. Comparisons with other waste material streams can be used here as reference. This rate is, for example, higher than the legally required collection rate for waste electronic and electrical equipment, which is at least 45% according to Section 10 ElektroG. The collection rate for the waste of portable batteries was elevated to 50% by the amendment to the Battery Act from 01.01.2021 (Section 16 BattG2).

The stakeholder survey, in which bvse, FairWertung, GftZ, Gesamtverband textil + mode and BTE Handelsverband Textil took part, revealed that, from the participants' point of view, a collection system with high area coverage is already in place today. It allows consumers in most regions to hand used textiles in a conveniently accessible proximity to collection. It was also assessed in this context that retailers cannot set up points of collection due to limited storage capacities but that this is not also considered necessary as there are already well-functioning collection structures. However, the density of the collection network is largely dependent on the market situation for used textiles.

This statement also gets underlined from the result of the analysis of residual municipal waste in Germany (Dornbusch et al., 2020, page 119). The proportion of used textiles in the residual waste varies in the different settlement structures. Thus, it is assumed that there is a different container density depending on the market situation and that the decision to provide containers is partly determined by efficient logistics. The collection structure today is largely set up by the private sector. Non-profit organisations would also cooperate with private collectors today, as they hardly have their own collection staff. In this context it was also noted that the collection of used textiles still has a social dimension too. The European Commission has explicitly pointed out the importance of non-profit organisations and social enterprises for a circular economy within the framework of the EU Action Plan. From the current point of view of the waste management stakeholders, a legally prescribed collection quota for used textiles is basically not needed. It may become necessary if the area coverage is no longer ensured or if a legal regulation on extended producer responsibility is going to be introduced.

With regard to the establishment of further points of collection, for example in the stationary retail segment, it was emphasized that this kind collection offers continue to play a rather subordinate role and is rather seen as a supplement to the publicly accessible collection sites.

The analysis of municipal waste in Germany showed that 4.5 kg of used textiles are contained in the amount of residual waste generated per capita (Dornbusch et al., 2020). The report states that this would often be damaged, torn or heavily soiled old textiles, the majority of which can still be material recovery. Heavily soiled used textiles are generally not suitable for material recovery, however. The question to what extent such heavily soiled textiles were already present when disposed as waste or whether the pollution occurred during the mixing with other waste, was not addressed.

9.5 Compliance with transboundary waste shipment requirements

For the transboundary shipment of used textiles, the list of goods in the foreign trade statistics contains the code 63090000 with the designation "used goods". This code is assigned to the area "Textiles and textile products", but is not otherwise defined in more detail.

Table 110 Excerpt from the foreign trade statistics 2018 for used goods, commodity code 63090000

Grouping of trade partners	Import		Export		Export surplus
	Quantity in tons	Value in € 1,000	Quantity in tons	Value in € 1,000	Value in € 1,000
EU	28,181	22,469	313,912	164,759	285,731
EFTA	5,693	2,941	2,541	1,279	-3,153
OECD	367	568	24,855	19,599	24,488

Grouping of trade partners	Import		Export		Export surplus
	Quantity in tons	Value in € 1,000	Quantity in tons	Value in € 1,000	Value in € 1,000
Non-OECD countries without control procedure for end-of-life products	224	89	83,517	61,270	83,293
Non-OECD countries with control procedure for end-of-life products	14	13	46,281	65,492	46,267
Non-OECD countries import ban for end-of-life products	97	421	44,838	40,378	44,741
Total	**34,577**	**26,501**	**515,944**	**352,777**	**481,367**

Source: German Environment Agency based on foreign trade statistics

The export of waste to non-OECD countries is regulated in EU Regulation 1418/2007. Depending on how these states have responded to a query by the European Commission, free shipment as between OECD states or the notification procedure according to the Waste Shipment Regulation applies to the export of waste of Basel Code B3030. Otherwise, a ban is to be assumed on exports.

The main export destinations are the Netherlands and Poland with approx. 85,000 tons received from each country, followed by other EU countries. The non-OECD destination with the highest volume of exports is Pakistan with about 22,000 tons.

As the above table shows, an accumulated quantity of approx. 90,000 tons was exported to countries with either bans or control procedures in place. However, control procedures were not carried out in this case. Exports to these countries thus would have been illegal if these had concerned waste. It can therefore be assumed that this code is also used for goods that have undergone sorting and are therefore no longer subject to the waste regime. Affected in particular are the United Arab Emirates with 13,000 tons and numerous African states. Illegal shipments on this scale cannot be assumed since intensive controls are normally carried out in customs procedures. Customs procedures have to be completed both in Germany and in the destination country.

Irrespective of this, transboundary shipments in the used textiles sector account for a significant share of the total volume. Given the overall quantity of about 1.0 million tons, the 516,000 tons of exported used textiles account for a good 51% of that. Since imports are generally low, there is no big change seen on this ratio in the shipping balance.

Due to this high proportion, 27 competent authorities were asked about their practice to enforce compliance with the requirements for transboundary shipments of waste. The response rate to this specific inquiry was 74%.

Basically, it should be mentioned that all authorities pointed out the problem that the Basel Code B3030 does not reflect the collection practice of used textiles in Germany. Usually, in addition to clothing and household textiles such as bed and table linen, towels, down comforters and quilts, also shoes and accessories such as belts, scarves, handbags, but also stuffed animals are counted.

All but one of the Federal States assume that the original collected quantities are a mixture of waste that falls under the "green list" and must be declared under the Basel code B3030. In the concrete examination of individual cases, however, there are differences in the handling of the assessment of interfering components. 50% of the competent authorities addressed do have a rather broad interpretation for the term "used textiles" that corresponds to the above-mentioned collection practice. Interfering components then refer to other wastes that are not listed above.

Two of the interviewed authorities focus on the prior inspection of the original collected quantities. One authority goes very far in this context and concludes that original collected textiles from containers are in principle subject to notification, since the actual content of the bagged and baled textiles are not known and these may be mixed with various wastes.

In four responses it was stated that so far there have been no problems with the classification of original collected textiles being declared as "green listed" waste.

The remaining authorities do have different views with regard to the examination of interfering components. In addition to other waste, non-textile components such as shoes and/or accessories (e.g. belts) from the original collected textile products are considered to be interfering objects also. In each case, a case-by-case examination is carried out and no applicable quota of interfering components has been fixed till to date.

A definition for the quota of interfering components (or impurity rate) is the explicit wish of few authorities, however. Even if most of the interviewed authorities have found a way to implement the waste shipment requirements, some welcome a uniform definition of the term used textiles at European level. This is since the recipient states in turn have their own regulations which, in case of doubt, do not correspond to those of the exporting country. Reference was made in this context to a discussion held between the EU Member States in 2014 on the expansion of Annex III A. It followed the intention to create legality for the shipment of textiles from used textile collections under the general information obligation according to Section 18 VVA. For this purpose, a revision of the entry "used textiles" into "unsorted used textiles from collection containers or from household collection, also mixed with shoes of any material, clothing and bags made of leather or plastic, furs and stuffed animals, but no mattresses and carpets" had been proposed.

9.6 International comparison

The collection, sorting and recovery of used textiles varies widely across Europe. A comparison of the German collection and recovery structure with that in other countries was carried out to show which framework conditions and systems are suitable for enabling high collection volumes that can subsequently be recycled at a high standard.

Belgium, Denmark, France, the Netherlands and Great Britain were selected for this comparison. By means of an interview guide, the experts in the respective countries were asked to describe the collection, sorting and recovery of used textiles and to give their assessment of the future development of the market and the legal framework conditions (see appendix). Interviews were conducted with the Belgian Federation of the Waste and Recycling Sector Denuo (Kristof Bogaert, Dimitri Bohez), the Danish consultancy Planmilijo (David Watson), the French organization EcoTLC (Alan Claudot), the Dutch ministry Rijkswaterstaat Environment (Emile Bruls) and the British textile recycling association TRA (Alan Wheeler).

9.6.1 Organisation of the used textiles collection

What is understood by used textiles?

In all countries except Denmark, the term is defined more broadly and, in addition to clothing and household textiles, also includes

- shoes (in Belgium, the Netherlands, France, Great Britain)

- accessories (in Belgium, Great Britain).

For France it should be mentioned that in connection with the introduction of extended producer responsibility for textiles, products had to be defined that fall under the corresponding regulations. These are clothing, household textiles and footwear. Usually, however, accessories are also included in the collection. Since 2020, household textiles also include textile curtains and interior blinds (EcoTLC 2020).

As part of a voluntary commitment (Green Deal 2012), an attempt was made in the Netherlands to double the collected quantity of used textiles. Against this backdrop, a directive was developed on which textiles should be collected. In addition to the above-mentioned products, broken clothing in particular was to be included; mattresses, bedding, carpets, wet textiles or textiles soiled with paint or oil were explicitly excluded. However, the collection companies did not accept the proposed directive without financial support for non-marketable used textiles.

Is the collection of used textiles legally a waste collection?

In Belgium, France and the Netherlands, the collection of used textiles is considered as waste collection. Denmark and parts of the UK are an exception to this.

In Denmark, if the collector expresses that only clothing in good condition for reuse is wanted, the collection does not fall under the waste regime. Only in the case that, despite sufficient communication, significant amounts of non-wearable clothing are included, then the collection is considered waste collection in individual cases. Typically, however, it is always assumed that approx. 20-30% of the collection quantity is no longer wearable. So far, however, there is no guideline from the Danish Environmental Protection Agency as to how high this proportion may be at the maximum in order for the collection to continue not to be considered a waste collection. If the used textiles come from commercial sources, then it is always a waste collection. Thus, in practice most of the used textiles are collected outside the waste regime.

There is no uniform regulation in the UK. For example, in Northern Ireland, bring bank container collection is a waste collection, but not so in the rest of England, Wales and Scotland. Donated textiles sold in charity shops are generally not waste, however, the remaining used textiles that cannot be sold are then offered to sorting companies.

For some time now, take-back systems have been emerging sporadically in the stationary retail of clothing. In Belgium, Great Britain and the Netherlands there are no special regulations. The collection therefore is taking place outside the scope of the waste legislation. Since the collected quantities are comparatively small, a few local disputes about this take-back arrangement have emerged so far only. However, it is recognised that there exists an unequal treatment compared to other collectors who have to comply with certain requirements under the applying waste legislation.

In Belgium, France and the Netherlands, collection is organised pursuant to the waste legislation. For used textiles from households or businesses that generate household-like waste, municipal responsibility applies in principle, in France this is only for the households.

France introduced an extended producer responsibility for textiles in 2007. Companies importing clothing, household textiles or footwear into the French market are obliged to set up their own collection and recycling program accredited by the French authorities or to pay a contribution to Eco TLC (the only organisation accredited by the French authorities so far).

What end-of-waste criteria are applying?

Since used textiles do not constitute waste in Denmark, this aspect does not play a role here.

In all other countries, sorting in preparation for reuse is a procedure according to which used textiles acquire a product status if they are sold as second-hand goods. The scheme for sorted quantities that cannot be sold as second-hand goods is as follows:

Cleaning rag fractions: In Belgium this is in principle still considered as waste. The Netherlands refers to the general regulations on the end-of-waste status. In the UK, the assessment depends on the respective competent authority. In France, a specification was made in 2018/2019, according to which the end-of-waste for the rag fraction is already reached after the initial sorting.

Fraction of shredded textile (fibres): for this fraction, it is generally assumed by all countries that it is still a waste.

What role does the municipality play?

Basically, the municipality is responsible for the disposal of the waste generated from households, this also applies to used textiles. In this respect, the municipalities in all countries collect used textiles, albeit in a subordinate function. In most cases, the service is awarded to third parties within the framework of a tendering procedure. In the area of bring bank collection, they are also responsible for the allocation of space for the container sites. Even though extended producer responsibility has been implemented in France, municipalities have the possibility, for example, to put the collection of used textiles at civic amenity centres out to tender as part of the implementation of their waste prevention programs.

In Belgium, in contrast to all other countries, there is already an obligation to separate textiles. There exist minimum requirements for this (Uitvoeringsplan huishoudelijk afval). The collection has to take place four times a year or by setting up bring bank containers in a density that one bring bank is available per 1,000 inhabitants.

Who collects used textiles and what collection system is used?

In all countries, used textiles are collected by non-profit organisations, with or by private companies as well as municipal services. Non-profit collections account for the majority (approx. 70%) of the arrangements made (result of the country survey). Fashion brands occasionally take back used textiles in their stores and outlets, although this share is very low. In France, for example, the share is 2.5% (Eco TLC 2018). Municipal authorities currently complete the spectrum of players as lesser influential market participants.

The most employed collection system regardless of the collector is the bring bank collection on public or private premises. In Denmark and the UK, the proportion of used textiles taken directly to charity shops is above average. In Denmark it is about 11%, in the UK even 48% of the used textiles are brought directly to shops (result of the country survey). In the Netherlands, underfloor systems are common practice to collect waste in the bring system. As a result, many cities, especially larger ones, have introduced the collection of used textiles by means of underfloor containers.

During the interviews covering the collection mode, it was asked which collection system is suitable to maintain the quality of the textiles for a further high-quality usage. All interviewed partners agreed that to hand in textiles personally at appropriate points would be most suitable. The psychological barrier to mix in other waste or particularly soiled or wet textiles is much higher in that case than throwing those into a collection container somewhere on public ground. However, it is also seen that the potential to realise used textiles collection via this system is not actually big. Consumers should have the possibility to drop off used textiles at almost any time and a good accessibility (distance and parking) should be ensured as well. Underfloor systems are only used in the Netherlands. Experience has shown that this system is not suitable to maintain the quality of the used textiles thrown into it. The main problem is that the textiles become moist and musty, and thus cannot be reused for the most part. Furthermore, when the containers are emptied, it is not possible to carry out an initial inspection of the collected goods in order to remove any impurities or wet items. Against this backdrop, the Dutch Ministry of the Environment (Rijkswaterstaat Environment), in cooperation with the textile recycling association VHT, the Association of Municipal Waste Management and Cleaning Companies NVRD and VND has developed a guideline to ensure that the collection of used textiles is of high quality and, in particular, to prevent cross-contamination with other waste (VANG 2020).

In the overall, all countries see the bring bank collection as a good compromise to be able to collect large quantities of old textiles with a good quality. The textiles are taken out by hand from these containers and can already be subject to an initial inspection at the container site in order to separate obvious contaminants from the used textiles. The following factors are relevant in order to avoid interfering materials in principle: the choice of location, container condition and labelling, as well as general communication on the collection of used textiles.

How are the statistics und reporting?

In France, the reporting is regulated in very detail. EcoTLC, the accredited system for textiles, is obliged to document a mass flow record annually vis-à-vis the environmental authority. These requirements are transferred to the collectors and sorters in the frame of specific agreements. For example, the locations of the containers or points of collection must be reported. In addition, information must be provided on the quantities collected, reused and recycled. The balances of the sorting plants are checked annually within the scope of an audit.

In the other countries, municipal waste quantities are recorded as part of the nationwide documentation. However, this is often not the case for used textiles, as municipal collections play a subordinate role in all countries. As used textiles are not covered by the waste regime in Denmark, there is also no obligation for documentation. In the Netherlands it was decided to introduce a "mass balance" for household waste, i.e. also for used textiles. The Ministry of the Environment (Rijkswaterstaat Environment) first started in 2014 (with 2012 as reference year) to collect all relevant data related to the consumption, collection, sorting and recycling through surveys. In April 2020, the data for 2018 were published. The response rate to the survey was 70%, so monitoring has further improved. In the UK, there is no requirement for collectors to report quantities. All available data on used textiles is compiled in various studies. The non-profit organisation WRAP (Waste and Resources Action Programme) is mainly responsible. As there is a separate collection obligation for used textiles in Belgium, the quantities also have to be reported. To this end, all collectors have to report their collected quantities monthly to the municipality and once a year to the national authority. Sorting companies have to report the input collected in Belgium as well as the proportion of sorting residues that applies on this quantity.

As the quality of the statistics is concerned it is observed that there are major weaknesses in certain places. Only in France and for the collected quantities in Belgium some detailed specifications for nationwide and uniform documentation exist. In Great Britain and Denmark, there are only data collections performed by research services or scientific institutes. With the data collection taken over from the Dutch environmental authority for this study, it was possible to create broad acceptance among all actors, so that the data basis appears to be precise in the overall.

9.6.2 Consumption and collection of used textiles

With the exception of France, the collected quantities are all derived from estimates. These estimates originate from corresponding studies or assessments by industry associations. With regard to data quality, reference is made to the evaluation in the above paragraph on statistics and reporting. The composition of the used textiles in the individual countries differs in part, so that the values are not 1:1 comparable either. Nevertheless, the information as a whole provides insights as to the collection behaviour and the market share of the different actors.

Table 111 Estimation of consumption, collected quantities and collection rate by country

Country	Consumption		Collected quantity		Collection quota
	t/a	kg/inh*a	t/a	kg/inh*a	
Germany 1	1,560,000	18.8	1,000,000	12.0	64.0%
Belgium 2	175,462	15.0	120,000	10.3	68.4%
Denmark [3,4]	75,000	13.1	36,000	6.3	48.0%
France [4]	624,000	9.3	239,000	3.6	38.0%
Netherlands	305,000	17.7	136,000	7.9	44.6%
Great Britain	1,560,000	18.8	1,000,000	12.0	64.0%

1. including bags and leather goods
2. Data of the Flemish Region: collection quantity 8.1 kg/inh*a and collection quota 54%
3. without shoes
4. without accessories

9.6.3 Sorting and further recovery

The sorting and recovery structure is very different in the surveyed countries. Denmark has only one sorting facility with a capacity of about 1,000 tons per year. Textiles that cannot be marketed on the domestic market are exported together with those that are no longer wearable. In total it is estimated that about 10,000 tons of second-hand clothing remain on the Danish market whereas 21,800 tons go into export. For the exports, some rough sorting takes place, for example to remove soiled textiles or interfering materials. In conjunction with the recovery of textiles, there are very few initiatives that deal with the production of non-woven products (nonwovens), however, in total these only process a few hundred tons per year.

In contrast, there is a strong sorting infrastructure in the Netherlands. A total of 155,000 tons of used textiles were sorted in 2018, with the country's own collection volumes of 57,000 tons accounting for approximately 42%. Another 98,000 tons were imported from Belgium, Germany and France. There exists only a small number of recycling and cleaning rag companies, however. Despite of that, textiles are integrated in the circular economy actions of the government like Dutch Circular Valley (www.dutchcirculartextile.org). Here a large number of projects have been launched dealing with fibre-to-fibre recycling.

In the UK, the quantities that are not dropped at charity shops are largely exported. There is no information on domestic sorting capacity available. The UK generally does not receive foreign collected goods for sorting. In the West Yorkshire region, there are about 20 companies engaging in rag production and shredding operations.

In France, the sorting landscape is characterised by the EcoTLC system. EcoTLC promotes the development of sorting companies, which in particular create jobs in the second labour market.

There is a sorting capacity of about 160,000 tons in France, which corresponds to 50% of the French collection volume. A total of 52 sorting plants are registered with EcoTLC, with an average capacity of 3,000 tons per year. The remaining quantities are exported, with Belgium, the Netherlands, Germany, Portugal, Tunisia and the United Arab Emirates being the main recipient countries here. There are plants for the production of rags in the order of about 5,000 tons and of about 15,000 tons for shredded material.

9.6.4 Strategic and political developments

Are there plans to change the current framework?

According to the Belgian federation Denuo, there are currently discussions in Belgium to transfer voluntary take-back to the waste regime. As separate collection is already implemented in Belgium, the government considers that the requirements of the Waste Framework Directive (Directive (EU) 2018/851) are fulfilled with regard to the separate collection of used textiles. Nevertheless, is believed that too many textiles still end up in residual waste; the first step to improve the collection rate was thus the obligation to label collection containers in such a way that broken textiles are also collected. Against the background of the general development in the recycling of used textiles including the trend that the proportion unsuitable for reuse will continue to increase, it is assessed that measures must be introduced to promote textile recycling.

The Danish Federal Environmental Agency has commissioned a study to evaluate the collection of used textiles in neighbouring regions (Watson et al., 2019). The aim of the study is to create a data basis for transposing the requirements for the separate collection of textiles into national law. Independently of this, it was decided in June 2020 that the addressee of the separate collection of used textiles should be the municipality (Climate Plan 2020). The implementation has to take place as early as 01 January 2022 and thus starts much earlier than required by the Directive 2008/98/EC. Within the scope of the mentioned study, used textiles from public authorities and business sectors, workwear without a special protective function were also considered. The share of these garments amounts to 12% of the total textile consumption. It is estimated that this (often homogeneous) material source will be included in future regulations.

Based on the study findings it is recommended that the political measures be expanded beyond the introduction of separate collection of textiles, on the one hand to reduce consumption but also to ensure the recyclability of textiles. From the perspective of the research participants, there is a need for regulations on eco-design that promote longevity and recyclability, business models that keep textiles in their original state as long as possible, and sustainable consumption.

Extended producer responsibility for textiles is to be introduced in the Netherlands. There exist no detailed plans so far. Among other things, there are considerations to put the definition of used textiles into more concrete terms which eventually could involve the following: Clothing, household textiles and possibly also footwear (both from households and businesses including the public sector). In this context, some strategic measures have already been taken with the aim of building a textile circular economy. In 2017, the government published a roadmap for a circular textile economy in cooperation with Modint, the Dutch clothing and textile association (Dutch Circular Textiles Platform 2017). This has resulted in many initiatives in all areas of the value chain. In addition, there are other initiatives stemming from the European Clothing Action Plan project (ECAP). Most recently, the Ministry of Infrastructure and Water Management published a policy programme for a textile circular economy for the period 2020-2025 in a letter dated 14 April 2020 (government.nl 2020). The document contains measures for design and production, for consumption and the usage phase, as well as measures for subsequent disposal.

A proposal for a model to introduce extended producer responsibility was announced for spring 2021 based on the findings of a commissioned study. There are already concrete targets for the collection and recycling of textiles, these comprise:

2025: the share of recycled fibres or sustainable materials should be at least 25% for textiles placed on the market in the Netherlands, of which at least 30% should be recycled if no longer fit for wear or use.

2030: increasing sustainable materials in textiles placed on the market to 50%, of which at least 30% must be recycled fibres; increase the recycling rate to 50%.

There are no concrete plans made yet in the UK. The government has committed to the EU's Circular Economy Package 2.0, with the consequence that used textiles must be collected separately from 2025. However, the government has put in place a legal framework to introduce extended producer responsibility for various waste streams, including textiles, which have been identified as one of the relevant waste streams. In 2019, a report on clothing consumption and sustainability, titled 'Fixing Fashion', was published by the House of Common's Environmental Audit Committee. The Fixing Fashion report (parliament uk 2019), among other things, assesses the environmental impact, addresses the waste problem due to increasing fashion consumption and recommends that the government sets frameworks for a variety of individual issues. It can be assumed that a strategy for textiles will be developed on the basis of these principles.

On February 10, 2020, a law regarding the implementation of a circular economy and fight against waste was passed in France (Loi n° 2020-105 relative à la lutte contre le gaspillage et à l'économie circulaire). The requirements it contains also affect textiles. In addition to the ban on the destruction of unsaleable products such as clothing and shoes, regulations on the collection and recycling of textiles (see Art. L. 541-10-8) as well as targets for extended producer responsibility (see Art. L. 541-10 ff) are included.

This new orientation also has an impact on the existing organisation that implements the take-back obligations to date. EcoTLC received a further authorisation at the end of 2019 until 31 December 2020. In 2020, the organisation changed its name to Refashion (https://refashion.fr/pro/fr). The name change is also intended to express a new vision. In addition to supporting the development of recycling activities, the organisation also wants to promote the transformation from a linear to a circular circular economy, for example through various programmes, the provision of different information and by networking different actors.

9.6.5 The future of used textile recycling

During the interviews an assessment of the development of textile recycling in the next 5 to 10 years was also asked. The answers were based on the following guiding questions:

- What challenges do you see in the introduction of mandatory separate collection of used textiles?
- What are the technical, economic and regulatory challenges for the reuse and recycling of used textiles?
- What activities are needed at policy level and within the industrial branch to enable high quality recycling?

All country experts agree that increasing overall quantities of used textiles, but also the increasing share of used textiles that are neither sustainable nor marketable, will be a major problem if a recycling industry that is adapted to the collected used textile quantities and qualities is not established soon. The key challenge does not lie in the collection of the old textiles but in the further existence of sales markets for old textiles.

Two of the interviewees also addressed the increasing fashion consumption which, in their views, needs to be reduced by changing fast fashion business models. Business models based on longevity of clothing should be promoted. In particular, the consumer behaviour of always buying (new) clothing must also undergo a change. Consumers in Western Europe should be motivated to buy second-hand fashion. Furthermore, since most second-hand goods are sold outside Europe, it is imperative to keep the sales markets open for European quantities. The influence of Chinese activities in Africa is already huge and has an impact on the marketability of European textile goods.

Everybody was calling for a true circular economy to be created, from ecological product design to the integration of recycled materials in the manufacture of new products. Closing the loop requires a recycling industry that is able to prepare the products and materials to be recycled in such a way that fibre-to-fibre recycling is also possible. The automation of certain processes is essential here and the recycling technologies must be suitable to handle large quantities and implementable on industrial scale.

All respondents see it as important to create legal framework conditions that promote and simplify the use of recycled fibres by encouraging the substitution of virgin material with recycled material in all sectors. At the same time, demand must be increased by setting minimum requirements for the use of recycled fibres. Due to the complex waste stream, chemical recycling should also be promoted.

9.7 Recovery of used textiles

9.7.1 Introduction

The waste stream of used textiles consists of different products that have become waste, such as clothing, household textiles, shoes and accessories. It is a special feature of this waste stream compared to other streams such as paper or plastics waste that a high proportion can be reused through sorting. In order for this potential to be exploited, it is necessary to collect the used items in a way that is gentle on the material so that the textiles can be recycled in a high-quality manner (Führer, 2016).

In the following, different commonly applied systems for the collection of used textiles are considered. In the evaluation qualitative criteria of the individual systems for a material-conserving collection of used textiles will be examined. Furthermore, the collection potential of the collection system is analysed. Assessments from an expert survey, in which bvse, FairWertung and GftZ participated based on a school grading system, are included in the results. The lowest collection potential "very low" was assigned five points, the highest collection potential "very high" one point. For the qualitative evaluation of the collection system, the evaluation is carried out in an analogous manner along the 5-level waste hierarchy.

9.7.2 Collection of used textiles

9.7.2.1 Pickup services

Collection systems that collect used textiles at the household are basically convenient for the waste producer and should have a high collection rate compared to bring systems. The following collection systems are in use for used textiles:

Kerbside collection, traditionally also called “basket” collection is a system that was practised for many years but has lost its importance in the meantime. Today, about 2.1% of the used textiles are collected in this way in Germany. The former habit of "mucking out" worn out clothing no longer takes place seasonally, the collection therefore is carried out twice a year at the maximum due to the high personnel costs. Used textiles must be stored temporarily for a long time because of that. Against this backdrop, the collection potential is rated as medium. Looking at the quality of the so collected textiles, all experts confirm that the share of items that can be prepared for reuse is high and the share of foreign and interfering materials is low. The proportion of textiles that is no longer wearable and/or where there is no sales market and which therefore are sent to energy use or other recovery is considered to be medium.

Another pickup system is the supply of waste containers directly at the household, the collection of which is done door-to-door by compactor trucks. In contrast to kerbside collection, this service usually takes place every 4 weeks. The household does not have a separate additional bin, rather the bin for the collection of paper, cardboard, cardboard packaging (PPK) is alternatingly used (duo bin). The potential collection volume is also considered to be medium in this case. From a qualitative point of view, it was noted that the collection mix is of rather low quality, as the rate of misthrow is estimated to be high, analogous to the collection of light packaging by means of waste bins.

9.7.2.2 Bring system

In the case of collection via stores, a distinction has to be made between clothing shops operated by non-profit organisations (second-hand shops) and take-back points of stationary retailers. Handing in used textiles in “clothing chambers” (e.g. of the Red Cross) or second-hand shops is generally not a waste collection, given that it represents a donation or sale of individual clothing items for immediate further usage. For this reason, the proportion of textiles that are prepared for reuse is considered very high and, conversely, there is only a very small proportion of used textiles that have to be recycled as a sales leftover. In contrast, the collection by stationary retailers is generally classified a waste collection activity (VG Würzburg, verdict W 4 K 13.2015 dated 10.02.2015). In various cases it is also advertised that used textiles are accepted regardless of their condition (H&M: Let's close the loop). The quality or proportion that can be prepared for reuse is rated here as being good, while the proportion of foreign or interfering materials is rated as very low.

For all points of collection, the possibility to drop or hand in waste is limited by the opening hours, moreover a control is taking place at these points, so that the overall collection potential is considered to be very low.

Bring bank collection on public or private property represents the largest share of the collection offers with approx. 77% (see Chapter 9.2.2). According to the experts' assessment, the system is set up over a large area, so that private households have the opportunity to dispose used textiles at any time and in their vicinity. In this respect, the collection potential for this system is estimated to be very high. With regard to the quality of the collected quantity, a distinction is made between manual collection (manual removal of the old textiles from the bring bank container) and the hook lift system (automatic opening of the floor hatch and emptying into a hook lift vehicle). In general, it is estimated that the quality of the used textiles has an average good to medium reuse rate.

This assessment correlates with the high to very high collection potential, as broken clothing that is no longer wearable is also dropped into the containers. In addition, this is an anonymous act (except at the civic amenity centres) resulting in a notable proportion of misthrows. In its Textile Study 2020 (bvse 2020, p. 20), the bvse put the proportion of harmful and interfering materials at 10.8%, these are directly removed when the used textiles are taken from the container on site. The manual removal and initial sorting of the used textiles thus prevents obvious contaminants from entering the material flow for sorting. In addition, used textiles thrown-in loosely can be packed in bags so that they are protected from moisture, but also from cross-contamination while being loaded and transported to the sorting plant. Such handling is not found in systems operated with hook lift devices (e.g. underfloor container). For this reason, the share of used textiles that can be prepared for reuse is estimated to be lower for the hook lift design and the share of used textiles for energy recovery as well as the share of foreign and contaminated materials is assessed to be high.

At civic amenity centres, used textiles collection is usually carried out by means of bring bank containers (with manual emptying) also. Due to the opening hours and sometimes longer travel distances compared to the aforementioned bring bank collection on public or private property, the collection potential is assessed as low to medium. The quality is classified as higher due to on-site inspections, the share of used textiles that suit for energy and other recovery only as well as the share of foreign and contaminated materials is rated to be lower.

Online collection is another novel option and is classified as belonging to the category of bring systems since households usually must bring the parcel with used textiles to one of the online retailer's point of acceptance for handover to the logistics service provider. The effort involved here is estimated to be very high compared to the other collection systems. Moreover, it is assumed that only a smaller quantity can be sent per shipping process than it is the case with other collection systems. The current collection potential for this reason is considered low. However, it was also noted that the increasing e-trade could lead to this collection system becoming more important in the future. In the meantime, some online retailers, such as Zalando (Wardrobe), C&A (we take it back), OTTO (Platz schaffen mit Herz) offer to take back used clothing. The quality of the collected items is rated as good. To what extent these take-back arrangements are classified waste collection is not known. There is also no court decision that has fundamentally clarified this question. Irrespective of this, the question would have to be examined on an individual case-by-case basis as long as there is no general decision on online collections.

9.7.3 Overall assessment of collection systems

The assessment results are listed below in a matrix. All criteria were evaluated with a rating system that includes gradations from very high (1) to very low (5).

9.7.3.1 Quantitative criteria

A collection system should in principle be suitable to enable a high collection volume. Also taken into account in the assessment should be the aspect of the introduction of mandatory separate collection for textiles on 01. January 2025.

The expert-based assessment on the collection potential is giving the following results:

Table 112 Evaluation of collection systems; quantitative criteria

Quantitative criteria	Collection potential
Civic amenity centre	4
Clothing chamber/shops	5
Street collection	3

Quantitative criteria	Collection potential
Bring bank collection – manual collection	1
Bring bank collection – hook lift system	1
"Duo-Tonne" - alternating waste bin use for collection with compaction trucks	3
Online collection	5

9.7.3.2 Qualitative criteria

A collection system should enable the highest possible reuse of textiles after the sorting. Therefore, a weighting was applied to the qualitative system evaluation by weighting the results of the expert survey with the following percentage values in each case:

1. potential preparation for reuse: 60%
2. total recovery potential: 30%
3. share of impurities and interfering components: 10%

Table 113 Evaluation of collection systems; qualitative criteria

Qualitative Criteria Weighting	Preparation for reuse potential 60%	Total recovery potential 30%	Share of foreign matter and impurities 10%	Results 100%
Civic amenity centre	2	3	2	**2.3**
Clothing chamber/shops	1	2	1	**1.3**
Street collection	1	3	1	**1.6**
Bring bank collection – manual collection	2	3	3	**2.4**
Bring bank collection – hook lift system	4	3	5	**3.8**
"Duo-Tonne" - alternating waste bin use for collection with compaction trucks	4	3	4	**3.7**
Online collection	2	2	1	**1.9**

9.7.3.3 Joint evaluation of qualitative and quantitative criteria

In order to evaluate which collection system fulfils both quantitative and qualitative requirements best, the above-mentioned results are to be combined. Here, the result of the quantitative assessment was evaluated with a weight of 40% and the result of the qualitative assessment with 60%.

Two of the analysed collection systems show a rather poor collection potential. Both the clothing chambers and the online-collection were rated with a very low collection rate. In this respect, these systems can only be recommended as a supplement in conjunction with other collection offers. This is also shown by the comparatively low proportion of quantities that are recycled or used for energy recovery. Poorer qualities are therefore collected elsewhere today. If these systems were considered as a stand-alone arrangement, the proportion of used textiles that are no longer reusable or marketable for recycling would increase or, if not accepted (such as in second-hand shops), these used textiles would end up in the residual waste. Against this background, these two systems are not considered further in the overall assessment.

Table 114 Assessment of the collection systems based on quantitative and qualitative criteria

	Quantitative Criteria	Qualitative Criteria	Total
Civic amenity centre	4	2.3	**6.3**
Clothing chamber/shops	5	1.3	**6.3**
Street collection	3	1.6	**4.6**
Bring bank collection – manual collection	1	2.4	**3.4**
Bring bank collection – hook lift system	1	3.8	**4.8**
"Duo-Tonne" - alternating waste bin use for collection with compaction trucks	3	3.7	**6.7**
Online collection	5	1.9	**6.9**

Conclusion

If one compares only the qualitative criteria, clothing champers as well as the online collection of used textiles would receive the highest (best) rating. However, if the collection potential is included as quantitative criteria in the evaluation, the bring bank system with manual emptying and pre-sorting of the container content is the most balanced collection system altogether with the kerbside (or basket) collection, although it should be mentioned that the latter is usually only carried out twice a year. Both these systems with a strong manual component are suitable for handling the collected used textiles in such a way that they are protected from weather and cross-contamination during transportation to the sorting facility (Kietz et al., 2019).

According to the experts, a high collection volume inevitably correlates with a reduction in quality. This makes it all the more important to collect the material in a way that is gentle on the material and to avoid cross-contamination due to misthrows. Furthermore, private households should be informed more about how used textiles should be handled. In general, the awareness of the population for used textiles should be increased and more consumer education take place.

9.7.4 Preparation for reuse of used textiles

There are differences in the sorting processes for used textiles in qualitative terms. Due to the high potential of this waste stream to contain reusable goods, any sorting process that prepares used textiles for reuse to a high degree is generally suitable.

Preparation for reuse in the sense of the German Circular Economy Act (KrWG) is any process of testing, cleaning or repair in which products or product components that have become waste are prepared in such a way that they can be reused for the same purpose for which they were originally intended without further pre-treatment. For used textiles, sorting as preparation for reuse represents the second highest level of the waste hierarchy (Kietz et al., 2019).

In the following, typical sorting processes are evaluated with regard to the aforementioned quality aspect.

9.7.4.1 Negative sorting

In negative sorting, only interfering and foreign waste components including soiled or wet used textiles are removed. This can already take place during the emptying of a collection container or centrally at the point where the collected used textiles are first un-/reloaded. In addition to avoiding cross-contamination during the subsequent transport to the nearest sorting facility, the objective may also be to prepare the collected goods for export and to check compliance with export or import regulations as part of this process. The so cleaned collected mixture of textiles is then packed in bags or big bags in most cases. For this reason, the waste status for the entire (cleaned) collection mixture remains as there is no further sorting step. Hence, the remaining mixed quantities could only be sent to processes for energy recovery or they would have to be disposed of in other ways. Negative sorting is therefore not considered a preparation for reuse.

9.7.4.2 Partial sorting

In contrast to negative sorting, partial sorting explicitly refers to the manual separation of wearable and marketable items that are either sold individually or merged into product groups for second-hand trade. For these items, the waste status ends after this sorting process. In order to keep the expenses for sorting as low as possible, it can be assumed that not all textiles in wearable and marketable state will be discovered and recovered. The remaining portion is therefore still made up from a mixture of products of different quality that have become waste, and can be forwarded to energy recovery or disposal only. In order to enter a process of material recovery, this portion must undergo further downstream sorting tailored to the acceptance criteria of the respective processes.

9.7.4.3 Complete sorting

Complete sorting comprises a rather complex, usually multi-stage sorting process. During pre-sorting, the bags with used textiles are first opened manually and the collected mixture is then sorted on the basis of each items individual state with regard to wearability and the existing markets and sales potential. Used textiles that are no longer marketable are sorted according to the various recovery options. Furthermore, any impurities and unwanted matter are removed. Used textiles that can neither be prepared for reuse nor recycled are also sorted to suit energy recovery or other disposal operations. A total of 40-50 product groups are created in this first sorting process. Product groups containing still wearable and marketable items are then sorted into different qualities in a refined sorting. Each individual item is sorted into the final category based on quality and other requirements of the different markets (considering, for example, the climatic or cultural conditions). Due to the variety of demand, at least 200 sales categories (articles) are finally produced in the sorting process, these are marketed worldwide.

The process of inspecting each individual item for its marketing possibilities cannot be automated with today's state of the art technology. Automated sorting technologies can only be employed for the used textiles portion that is no longer marketable and the result of manual pre-sorting activities (Kietz et al., 2019).

9.7.4.4 Automatic identification and sorting by material type, colour or other characteristics

In a complete sorting process, the no longer wearable and marketable used textiles are manually sorted into various product groups for a recycling process. For certain product categories (such as T-shirts, towels, shirts, etc.), the material used (for example, a high proportion of cotton) is very similar in nature. In this respect, manual sorting into the recycling fractions is done on the basis of the product category. Recycling companies, such as entrepreneurs that process used textiles into cleaning rags or shred textiles for the production of nonwovens, have often been working with sorting facilities for many years and have adjusted themselves to the sorted quality, which, for example, is sufficiently perfect for producing insulation material. For other applications, such as the processing of recycled fibres into yarns for the production of new fabric, a very precise sorting according to material properties, possibly colours and other characteristics is required. A person in charge of manual sorting of textiles cannot fulfil such a requirement by mere tactile and visual skills. The only possibility would be to check the textile label for the material type. Circle Economy (2020) conducted a study "CLOTHING LABELS: ACCURATE OR NOT?" to check the textile labels on proper material information. In the overall it was found that only 59% of the labels contained the correct material composition. Pursuant to the European obligation for textile labelling, the deviation of the material composition may not exceed +/- 3%. The evaluation performed for the study accounted deviations of up to 5% still to the result of correct labelling, so that the legal tolerance was already taken into account. A label check would therefore not also be sufficient, apart from of the enormous personnel costs it incurs.

In this respect, automatic detection techniques can be helpful for sorting used textiles according to material composition so as to generate a homogeneous material-specific material flow. There are a number of projects and (pilot) plants in Europe that use or test these technologies for the identification respectively recognition of the material of used textiles. These are listed hereunder:

Table 115 Near-infrared spectroscopy (NIR) technologies for sorting used textiles

Project	Description	Technology	Publication
FIBERSORT Run time: 2016-2020 Project management: Circle Economy	Development of the FIBERSORT technology including a sorting robot for the mechanical feeding of used textiles. Another goal is to bring together all relevant stakeholders to advance the closing of textile cycles.	NIR + colour sorting (Valvan)	https://www.fibersort.eu/
Telaketju Project management: VTT and LSJH	Teleketju is a grouping of projects and networks to build a textile recycling industry in Finland. One project relates to the development of a hand scanner to support manual sorting. In 2019, a pilot facility was installed in Turku. The aim is to transfer the technology to an automatic sorting system as well.	NIR (Spectral Engines)	https://telaketju.turkuamk.fi/
SIPTex Run time: 2019-2021 Project management: IVL Operator: sysav	Since 2015, work has been underway to develop a sorting solution with the aim of being able to recycle used textiles to a high quality (stage 1+2). As part of the final stage of the project, an automatic sorting facility is being built on an industrial scale with an annual capacity of 8,000 tons per shift. The operational start is planned for 2020.	NIR + colour sorting (TOMRA)	https://www.vinnova.se/en/p/swedish-innovation-platform-for-textile-sorting-siptex/

9.7.4.5 Evaluation of Near-infrared spectroscopy (NIR)

This technology is still in its development phase for the sorting of used textiles but first results look promising. Terra conducted a stakeholder survey as part of the study “Veille sur les technologies de tri optique et de reconnaissance des matières textiles à l'échelle européenne (2020)”, which specifically listed the following challenges for automatic recognition technologies:

- The complexity of used textiles
- Used textiles can be of the most varied material compositions ranging from monofibres to fibre mixtures containing two or more different types of material in different proportions.
- Detection of small proportions of other materials when to sort out used textiles with only 100% of one material (for example 100% cotton) is the actual objective. Often small proportions (2-5%) of elastane are included in most fabrics.
- Technology analysis the surface only:

  In this respect, errors in the recognition and sorting by material can occur where the used textiles consist of several layers of different materials; likewise, the construction of the used textiles or surface coatings can have an influence on the recognition process.
- Colours:

  In the case of dark colours, some pigments (such as carbon black) obstruct the recognition of the material. Compared to plastic sorting in packaging, however, these pigments should be used less in textile production.

In summary, it can be said that the sorting depth depends on the individual recycling processes and the technologies used for sorting must be adapted correspondingly.

In addition to a pure sorting by the type of material such as cotton, polyester, wool, polyacrylic or mixtures thereof, further information with regard to the used materials is relevant for certain recycling processes. The following projects deal with this subject in particular:

Table 116 Radio-frequency identification (RFID) technologies for sorting used textiles

Project	Description	Publication
Tex.IT Run time: 2018-2021 Project management: RI.SE	The project examines the possibility of integrating digital information carriers such as RFID into textiles in order to be able to use end-of-life traceability in addition to increasing transparency. The aim is to gain knowledge in the following areas: Information and data collection systems, standardisation needs, costs, impact of integration.	https://www.ri.se/sv/vad-vi-gor/projekt/informationssystem-framtidens-textilier-rfid
4RFID Run time: 2018-2023 Project management: Decathlon (EcoTLC Projekt)	The intention is to equip garments with an RFID tag containing 2 pieces of information (material composition and colour) to enable error-free sorting.	https://www.ecotlc.fr/ressources/Documents_site/Chemins-Innovation2019_EN_BD.pdf (Seite 8)

9.7.4.6 Evaluation of the RFID technology

Digital information carriers integrated into garments or other textile goods can increase transparency and traceability of textile products throughout the value chain from production to end of life. Some fashion brands such as H&M (Nedap 2017), Inditex (Barrie 2018) or Adidas (RFID store) intend to implement this technology or have already implemented it in terms of logistics optimisation, warehouse/store management and orders for new goods. In this respect, this technology could also be used for other purposes such as sorting used textiles. In addition to information on the material composition, a variety of other information can be included, such as chemical ingredients or dyeing method, which are relevant for certain recycling processes. However, it will also be necessary to examine what impact the tags themselves may have on recycling processes. Similarly, a critical market size of garments and textiles with RFID tags is needed to be able to generate material flows of sufficient size for an efficient introduction and application of this technology. Consumer acceptance with regard to the protection of privacy and data ownership as well as transparency in using this technology is also playing a role here.

9.7.4.7 Overall assessment of automatic sorting technologies

From a waste management point of view, automated sorting technologies are only suitable for already pre-sorted used textile streams or as a support component for manual sorting processes.

Automated textile sorting is yet in the development phase. However, it has gained much in importance in recent years. In order to prepare textile waste for new, high-quality recycling processes, precise sorting is necessary, especially by material type. Additional sorting steps such as sorting by colour or the removal of certain non-textile components or unwanted substances can be possible requirements too and therefore shall be highlighted below. In any case, however, these systems can help manual sorting to achieve the greatest possible added value of the collected used textiles.

9.7.4.8 Overall assessment of sorting systems

In the following, all the aforementioned sorting systems are evaluated in relation to one another using a scoring system based on a rating from very high (1) to very low (5). For this evaluation it is assumed that the respective processes represent a stand-alone practice. Since preparation for reuse is associated with the greatest value-adding potential in the meaning of the waste hierarchy, the individual criteria are weighted as follows:

- Sorting costs: 10%
- Potential for the textiles to be prepared for reuse: 60%
- Further recovery potential: 30%.

Table 117 Assessment of sorting systems

Criteria	Weighting	Negative sorting	Partial sorting	Full sorting	Automated sorting
Sorting costs	10%	1	2	5	5
Preparation for reuse potential	60%	5	3	1	5
Recovery potential	30%	5	5	3	2
Result	**100%**	**4.6**	**3.5**	**2.0**	**4.1**

Resume

‘Complete sorting’ is the only sorting process able to exploit the added value of the collected used textiles in accordance to the waste hierarchy objectives. Negative or partial sorting targets only to a portion of the collected material, so that the remaining quantities must be prepared for the individual recycling options in a further sorting. Mechanical or automated sorting processes can be integrated into the process of ‘complete sorting’ or work as a supplement here in order to sort the material streams particularly along the specifications of high-quality recycling processes.

9.7.4.9 Potentials for resource conservation and environmental relief

Preparation for reuse extends the useful lifetime of clothing, household textiles, shoes and accessories, reliable data about the actual extension or length of the entire life cycle are however not available. In studies evaluating the life cycle of clothing, different assumptions are made in this regard, for example an extension of about 50% (Benton et al., 2014, p. 66) or the clothing being worn for an additional nine months (WRAP 2017). A study on the features of consumption in Germany is not known for this. For each different type of raw material, production technology and also the handling of goods during the usage phase, various environmental factors must be considered with a particular role in the assessment. In the overall, different pattern may apply as the actual consumption and consumers behaviour during usage and at the end of the useful life are concerned, resulting in that studies from other countries cannot be compared one by one with the situation in Germany. However, these analyses do provide a sound basis for demonstrating the effects in relation to the German consumption of clothing. The following is a summary of the most relevant statements derived from various studies:

- Extending the life cycle by 50% reduces a total of 8% of the CO_2 emissions,10% of the water consumption and 4% in the generated waste (WRAP 2017).
- A 70% collection rate of used textiles for (preparation for) reuse reduces the CO_2 emissions by 8% (Benton et al., 2014, p. 124).
- Doubling the wearing time of clothing reduces the ecological footprint by 49% (Sandin et al., 2019).
- If a consumer avoids buying 3 items of clothing, he or she saves 57kg $CO_{2\text{-eq.}}$ (Milieu Centraal).

In Germany, consumers buy an average of sixty items of clothing per year (BMU n.d.). If consumers were to give up 10% of this amount, a total of 9.5 million tons $CO_{2\text{-eq.}}$ could be saved (using a calculation analogous to Milieu Centraal). This shows how big the impact of consumption is on resources and the environment. If it is accounted in addition that about 40% of clothing remains unused in the wardrobe (see chapter 9.2.1.3.1.2), the potential for environmental relief by changing consumer behaviour is very high.

An environmental relief can be achieved, for example, by buying second-hand items. The savings are similar, as the purchase of second-hand clothing offsets the production of new goods. What this presupposes however is that a viable demand for used wearable clothing also exists.

9.7.4.9.1 The second-hand market in Germany

In Germany, the demand for second-hand items is quite low. A representative survey conducted in 2017 by the InNaBe project revealed that the following reservations about wearing second-hand clothing exist:

- too little choice/small spectrum of items (56%)
- uncomfortable to wear (48%)
- inferior quality (40%)
- 'cheap' look - only good for the needy (39%)
- not fashionable enough (36%).

It is estimated that only 1-2% (result from the expert survey) of second-hand items won from old textiles can be practically sold in Germany. Due to the low-budget (cut-price) and fast fashion offers in the market, there is hardly any need for the general population to buy second-hand fashion from a financial point of view. In order to increase the second-hand demand, the stakeholders recommended to focus on the ecological added value and to educate and sensitise consumers as part of the debate on climate protection about the positive effects of wearing second-hand fashion. If necessary, the second-hand trade could also be supported through VAT reductions.

On the other hand, there are meanwhile a large number of online platforms (such as the 'Kleiderkreisel' or 'Mädchenflohmarkt') that organise the private sale of used clothing, shoes or accessories. These products remain within private circulation and do not end up in the collection of used textiles in the first place. According to the bvse, this increasingly poses a problem for the value creation on the side of the sorters (bvse 2020). However, it is not possible to quantify what exact share (amount) of goods is concerned by this.

According to Online Monitor 2020 (Handelsverband Deutschland (HDE) 2020), online trade now accounts for 30% in the fashion and accessories segment, which is an increase of 1.33% compared to 2018. Against the backdrop of a continuous rise of the e-business, it can be assumed that this upward trend will continue in any case. Fashion brands such as H&M (Krisch, 2019), Decathlon (second-use) or Zalando (Wardrobe) have also discovered the second-hand market for themselves. Furthermore, there are numerous fashion brands that have signed the 2020 commitment of the Global Fashion Agenda (Global Fashion Agenda (2017) and have set the sale of second-hand fashion as one of their goals.

Online Monitor 2020 has furthermore published a retail scenario for the year 2030 authored by the Institut für Handelsforschung (Institute for Retail Research) located in Cologne. The authors forecast that conscious action for environmental protection will become more important in consumption. With a 37% quoting, the use of second-hand offers is an essential component of sustainable consumption behaviour. However, such trend in consumption can be considered sustainable in nature only if second-hand purchases are not made in addition to the consumption of new goods but actually in replacement of it.

9.7.4.9.2 Global second-hand trade

The major part of second-hand items obtained from sorting in Germany is exported to Eastern European and non-European countries. With regard to the transport distances and the partly limited possibilities to realize a subsequent recycling, especially outside of Europe, it will be discussed hereunder whether the export of second-hand goods from used textiles is equally ecologically sensible.

The Scandinavian study "Exports of Nordic Used Textiles" (Watson et al., 2016), among others, dealt with the issue of exports in the sphere of second-hand products. Comparable to the quantity sorted in Germany, the majority of used textiles is exported to Africa or other third countries whose population is in need of second-hand items for economic reasons. These countries usually lack an organized separate collection or recycling structures, so that a large portion of the no longer wearable clothing and shoes ends up in landfills.

The transport routes or distances for second-hand products can be considered comparable to those of brandnew goods, as the garment industry has a global supply chain.

Concluding from this it was found that the export of second-hand goods has an overall ecological benefit under the following conditions:

- All non-reusable old textiles and waste components of non-textile nature must be removed during sorting.
- It must be ensured that the imported goods are marketable in the destination country (considering the structural, cultural, climatic conditions). On the one hand, the import regulations of the respective countries must be observed, and in addition, good coordination with the local traders has to take place, which basically requires a longer-term cooperation with them.

Under these conditions, it is assumed that the second-hand trade balances the demand for new textiles. At the end of their useful life, second-hand products are then disposed of like any other goods as local conditions provide.

Resume

Extending the useful life of textiles by preparing them for reuse reduces much of the negative environmental impact of the textile production chain. This requires effective collection and sorting systems to ensure the greatest possible recovery of wearable and marketable textiles, shoes and accessories. In order to be able to supply second-hand markets in an ecologically sound manner, many years of expertise and a long-standing customer base are necessary so that changing conditions and demand (new fashion trends, etc.) can be coordinated.

Today's high share of collected used textiles (for preparation) for reuse contributes to the value creation of the entire used textile sector. Collection systems or sales platforms set up in parallel will have the consequence that certain qualities will disappear in the used textile collection. In its Textile Study 2020, the bvse estimates that this reduces the presence of the high-value qualities in particular whilst these are the basis for having the business model of the used textiles industry financed as a whole (bvse 2020). The new B2C (business to consumer) business models and consequential diversion (draining off) of the items of high quality and value from the used textile collection will be unstoppable, however. The dynamics of this trend should be monitored and reviewed in the long term. If there is a significant change in the composition of the collected quantities, it may be necessary to adjust the current system for collection and sorting.

9.7.5 Used textile recycling

This section is dedicated to the recycling of used textiles as the step following next in the hierarchical perspective. Paying attention to this level of the waste hierarchy is becoming increasingly important as the portion of used textiles that are no longer wearable and marketable is set to rise (Bünemann et al., 2019).

Recycling in the sense of the German Circular Economy Act (KrWG) is any recovery operation by which waste is reprocessed into products, materials or substances either for the original purpose or for other purposes. Less than 1% of waste textiles are recycled respectively converted into a similar or identical product (Ellen Mac Arthur Foundation, 2017). In this respect, the current practices of recycling refer to recycled products outside the clothing and textile industry.

9.7.5.1 Processing into cleaning rags

Used cotton textiles (such as T-shirts, dress shirts, bed linen, towels) are very suitable for the production of industrial cleaning rags. These are sorted again in the receiving facilities according to the type of material (jersey, flannel, bed linen etc.) or even colours and then cut to size. Both the sorting and the cutting are done manually. The manufactured rags can then be used for cleaning or polishing. Sorting is done in particular according to the specific material properties such as absorbency, lint-free performance or tear resistance and also by colours such as white, brightly coloured or dark coloured. These rags are used by a wide variety of commercial and industrial sectors and often replace non-woven fabrics made of paper and plastics. According to a survey of retailers, these rags however are not available for private use (Pokkyarath et al., 2014).

9.7.5.2 Shredded fibres for nonwoven or yarn production

In mechanical recycling processes, the used textiles are first pre-shredded. During that stage, metal and plastic parts such as zippers and buttons are already removed. The small textile particles then enter a mixing chamber, from where they are fed into a comminution process (ripping). The first step is to disintegrate the fabric using a cylinder with coarse tips with the aim of exposing the fibre. The processing line is designed in such a way that the fabric must pass through further cylinders that have increasingly finer tips, so that at the end of the process, in which approx. six cylinders are lined up, the used textiles are torn into fibres. During the disintegration of the fabric, metal parts are mechanically removed by magnetic separators together with buttons.

When the textile is being shredded, the fibre length basically also decreases. The result depends in particular on the material and the structure of the fabric, but also on the handling during the usage phase (e.g. application of dry cleaning). In order to be able to produce the quality of recycled fibre as required for the various applications, different sorted used textiles such as broken jeans or knitwear are used in each case.

Textile fibres do have thermally and acoustically insulating properties, so that use can be made of them in the following areas:

- Automotive industry: processing in the floor of a vehicle, luggage compartment and bonnet, parcel shelves and ceilings
- House insulation as well as interior: roof insulation or ceiling panels
- Other areas: there is a wide range of applications in the manufacturing of mattresses. Material rich in wool of higher quality but also acrylic or synthetic blended knitted fabric are used here. Recycled textile fibres are also used in the production of upholstery or in filtration systems.

For yarn production, it is important that the fibre length remains as long as possible. Used wool textiles have been recycled for many years. For the recovery of this high-priced fibre, the used wool textiles are sorted by colour and all non-textile components or other materials are removed before or during the recycling process. However, according to Textile Network (2019), wool accounts for only 1% of global fibre use.

Cotton recycling is becoming increasingly important. There are already garments on the market that contain 15-20% recycled cotton fibres. Furthermore, several projects have tried to improve the quality of the fibre, for example by adapting the comminution processes, as these are traditionally designed for nonwoven production, or by producing different fibre blends, such as adding production residues from cotton or synthetic fibres such as polyester (Brouw od den, 2019).

In an Interreg project (RETEX n.d.), the recycling of polyester clothing was tested, among other things, with the results being finally presented at a workshop (Verstraete 2019). However, the fibres become so short during the shredding that they can at most be used for the production of nonwovens. However, in combination with a thermal processing, the textiles could be processed into pellets, provided that the material is 100% polyester. In the meantime, many projects have emerged to test fibre-to-fibre recycling and to single out for which used textile streams it is technically and economically worthwhile to build up new recycling capacities (e.g. ECAP n.d.).

It should be mentioned that processes for the mechanical recycling of textiles in principle are not designed to remove colours or other substances which thus remain in the recycled fibre. Depending on the area of application, further steps of processing are hence needed, for example sorting by colour or the sorting out of textiles of certain composition. Furthermore, the pollutant limits that apply to the new product must be complied with. The possible pollutant load of used textiles is discussed in more detail in chapter 9.7.8.

In the overall can be summarized that using recycled fibres reduces the consumption of water, energy and the generation of CO_2 emissions, all which accrue during the extraction of the raw material in particular as well as in part during the production of textiles. The respective material must be considered here to establish the resource conservation potentials (Roos et al., 2019). In the mechanical recycling process the fibre quality is negatively affected while colours and other substances are also retained. This kind recycling, on the other hand, has already been practised for years and on an industrial scale to manage large amounts of used textiles.

9.7.5.3 Chemical recycling methods

Chemical recycling can also be considered for certain used textile streams. As of today, a number of processes are in the development phase. There are only a few that are available on an industrial scale, however. Most processes are in the stage of experimental lab development or do have the status of a pilot installation. At present, the input material used is mostly industrial waste, PET bottles or textile fibres from diverse sources.

There exist different approaches for chemical recycling, such as depolymerisation or solvent-based processes. In depolymerisation, polymers are broken down into monomers or short poly chains in order to subsequently polymerise them again or to build up a new polymer. In the solvent-based process, the desired polymer is separated and retains its structure. In a biochemical recycling process, this component breakdown is carried out by enzymes. These processes make it possible to produce a comparable or in some cases better quality of the original material, colours and other substances are also (largely) removed in that course. In principle, these processes are suitable for all synthetic fibres, but essentially only recycling technologies for PET or polyamide are currently in development (Roos et al., 2019).

Chemical recycling can also work for cellulose fibres such as cotton. Here the chemical process produces a cellulose pulp that can be used for the production of cellulose fibres. As clothing is often made from blended fibres (cotton and polyester), some processes also focus on the recycling of polyester-cotton blended fibres.

Table 118 Overview on the approaches for chemical recycling

Fibre type	Output	Companies
PET	PET	**Ioniqua** (pilot facility), **Tejin** (Eco Circle; commercially available)
PET	PET	**CARBIOS** (plan to build a pilot facility in 2020), biochemical process
Polyamide	Polyamid, ECONYL®	**Aquafil** (industrial waste, fishing nets)

Fibre type	Output	Companies
Cotton	Cellulose pulp	**re:newcell** (pilot facility of 7,000 tons, industrial facility in planning)
Cotton	Cellulose pulp + production of cellulose fibres	**Lenzing** (Refibra™)
Cotton	Cellulose pulp	**VTT** (infinited Fibre Company)
Polyester and cotton	Cellulose pulp + PET	**WornAgain** (pilot facility in planning)
Polyester and cotton	Cellulose pulp	**Södra** (working on further development of decolourisation and use of polyester)
Polyester and cotton	Cellulose pulp + PET	**Hong Kong Research Institute** (pilot facility in cooperation with H&M), hydrothermal chemical process

9.7.6 Energy recovery

Processes for the recovery of energy from used textiles are considered where these are not anymore suitable for recycling. This applies, for example, to heavily soiled or soaked used textiles. For used textiles that are sorted in Germany, this recovery option is generally accessible. As far as the textiles that do not undergo sorting in Germany are concerned, no statement of the general sort can be made as to whether this recovery route is available or whether used textiles must then otherwise be disposed.

9.7.7 Other disposal options

The disposal of used textiles occurs as per definition when these are taken to a treatment process categorized as final disposal. It can be rightly assumed that a disposal of used textiles no longer takes place in Germany, considering that landfilling is not any more a legal option here whilst incineration plants mostly have the status of waste-to-energy installations, thus qualifying/classifying them as recovery rather than disposal facilities. However, disposal is still playing a role as an option for managing waste outside of Germany and thus comes into play this way also for used textiles once these are exported and the no longer wearable and marketable items are sent to landfills or thermally treated in the country of destination.

9.7.8 Pollutant load of used textiles

In the production of textiles, a large number of chemicals are used to support the manufacturing process on the one hand, while on the other hand they are part of the finished product when being introduced as dyes, prints or substances with dirt- and water-repellent effects.

A study by the Swedish Chemicals Agency (2014) identified around 2,400 different substances that are potentially used within the textile production chain. Approximately 5% of these were assessed as a potential environmental risk with a few substances restricted for use under the REACH regulations.

In mechanical recycling processes, these substances are not removed. In chemical recycling processes, they may interfere with the dissolution or depolymerisation process. In any case, recycled products have to comply with certain limits depending on the application, so it is important to know the ingredients or their origin. In 2019, the Swedish Research Institute RI.SE conducted a study to assess the risks of used textiles in relation to mechanical recycling processes.

Used textiles (T-shirts, trousers, jackets, swimwear, bed linen, etc.) manufactured of different materials and with the help of varying processing methods were examined to establish the extent to which hazardous substances of the following sort were still contained in the textiles at the end of their usage phase:

- perfluorinated - and polyfluorine substances (PFC)
- halogenated flame retardants
- toxic plasticisers
- toxic metals
- toxic dyes and pigments
- carcinogenic, mutagenic, reproductive toxicity biocides
- carcinogenic, mutagenic, reproductive toxicity solvents
- Traces of toxic degradation products such as polycyclic hydrocarbons (PAHs), dioxins and dibenzofurans.

In addition to the legal limit values, the results were also compared with the limit values of the STANDARD 100 by OEKO-TEX®. As a result, no textile exceeded the legal limit values, 15 out of 20 items met the OEKO-TEX standard.

Irrespective of the above findings, it was also noted that recycled fibres are not used 100% in new products, rather they are mixed with fibres from the original material or other fibres to attain the desired textile quality. In this respect, the origin of the fibre and transparency of the supply chain play a crucial role for recycled fibre usage. Whenever a newly produced textile fulfils the legal product requirements, it can be concluded that as used textile product which has become a waste it still is compliant to these requirements. In the sphere of packaging recycling for example, EuCertPlast has been developed as a certification system that enables recyclers to comply with the REACH requirements (EuCertPlast n.d.). This system could be transferred to used textile recycling or existing certifications for textiles, such as the Global Recycling Standard, could be expanded correspondingly (Textile Exchange n.d.).

Especially for leather shoes and outdoor clothing, pollutant content in the product seems to be a recurring topic. Perfluorinated and polyfluorinated substances (PFCs) are often used in outdoor clothing to create a water-repellent effect. Greenpeace in a study has looked into how dangerous per- and polyfluorinated chemicals spread (Cobbing et al., 2015). Even though the outdoor industry is increasingly moving away from using these kind chemicals, many of these textiles are still in circulation and end up in recovery or another disposal route once their usage phase has ended. The German Environment Agency in this regard refers to a study by the Danish Environmental Protection Agency from 2015, according to which 50% of the PFCs produced are still used for textile applications (Umweltbundesamt 2020).

In the case of leather products, some tanning processes can produce chromium VI compounds that are harmful to health. According to the European Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH-V), leather products or products containing leather parts that come into contact with the skin beginning from May 2015 are subject to a marketing ban if their content in chromium VI is 3 mg/kg or more. The Niedersächsische Landesamt für Verbraucherschutz und Lebensmittelsicherheit (Lower Saxony State Office for Consumer Protection and Food Safety) tested various leather products for chromium VI content in a project in 2017. As a result, three out of 41 samples had to be rejected due to transgression of the limiting value.

However, as there is no mature technology for the recycling of shoes so far, there is no information on how to deal with this potential pollutant load of used products. (Thomson et al., 2012).

Limit values for energy recovery or disposal processes

Used textiles are also processed for the use as substitute fuel in power plants or other energy-intensive installations. In these facilities, higher quality criteria for the fuel input normally apply (e.g. exclusion of heavy metals, which can potentially occur in used textiles made of leather) compared to those ordinary waste to energy plants usually adopt. Likewise, some used textiles with a certain structure or composition (e.g. outdoor jackets with thick fillings and many non-textile components) are not wanted for substitute fuel production, as they can obstruct or even damage the shredding processes. Generally, however, it should be mentioned that used textiles from sorting comprise a mixture of a wide variety of products that have become waste and where the content of unwanted individual components is found to be negligible.

9.7.9 Overall evaluation of the recovery routes

Used textiles are a complex waste stream for which various options of a further recoveryn exist outside the textile industry. Such a recovery is however not available for all used textiles that are no longer wearable and marketable. Asked for the developments in this sector it is the unanimous opinion of all stakeholders that the total amount of used textiles is going to further increase and this even at an overproportionate rate as the proportion of no longer wearable and marketable textiles is concerned. It is further estimated that the current sorting and recovery capacities will not be sufficient to process the future collection volumes. The GftZ assumes that, due to the obligation to separate textiles in Europe from 2025 onwards, the collected volume will increase by approx. 2.0 million tons per year and approx. 1.3 million tons of new recycling capacities will be needed (Bünemann et al., 2019). This also calls for additional sorting capacities whereby is questionable how the necessary investments are to be financed if the prices are in decline.

From the stakeholders' perspective, the following technical and economic challenges for textile recycling must be observed and addressed:

Technical challenges:

- Lacking information regarding the types of material and substances they contain
- Non-textile product components
- Chemicals in the product
- Fibre mixtures used
- Availability of infrastructure to prepare the input for recycling processes
- Availability of effective and cost-efficient technologies for sorting

Economic challenges:

- Little to no financial support or incentives for doing investments in new technologies
- High sorting and processing expenses

- Lack of investment security
- Recycled fibres are more expensive than virgin materials
- Hardly any demand for recycled fibres

From the stakeholders' point of view, the following measures help to promote recycling:

- Design for recycling
- Specific recycling quota for used textiles, also different recycling quotas for different textile segments (fashion, functional clothing, etc.)
- Re-use quota of fibres from used textiles
- Promotion of research and development: research should be given more freedom so that new things can emerge. Research projects are often not approved because they are too vague as to the benefits and outcome
- Easier permitting procedures for recycling plants; recycling must be wanted by the society
- Development of recovery processes at industrial scale: There are already recycling technologies that are subsidized for a project period by the state. Permanent state support does neither seem sustainable nor useful. Instead, the distributors of textiles should permanently ensure the financing of reuse and recovery as this would provide financial security for investments in new recovery processes.
- More cooperation between all actors ("shared knowledge")
- With regard to public sector procurement: obligation to purchase recycled/recyclable products or long-lasting products
- Uniform monitoring and verification duties that guarantee high-quality recovery
- Clear framework conditions, but no (additional bureaucratic) obstacles
- Better consideration of the non-European influences (due to the high share of imports)
- Introduction of an extended producer responsibility
- Strengthen and establishing markets for recycled fibres and second-hand items at the national level.

Overall, it was remarked that the circular economy requires a systemic change in which all actors must be involved. It should be ensured that new approaches are also incorporated and that the status quo is not solidified, which could be an obstacle to change. The diversity of products and functionalities in textiles should also be taken into account, which means that a variety of strategies must be implemented to realize a circular economy in the textile sector.

Resume

The collection of used textiles in Germany as well as the sorting and recovery of this material stream has been set up by the private sector and is financed today exclusively by the revenues from the sale of the sorted second-hand items. Non-profit organisations also have an important role to play in this area.

Already today there is a noticeable deterioration in the quality of the collected textiles. The high efforts which incur with manual sorting must be financially questioned if the sales revenues can no longer cover the system costs as a result of the declining quality and proceeds derived from the collected material. The anticipated increase in the quantity of used textiles due to the introduction of a mandatory separate collection from 2025 in the EU will intensify this effect even further. Also, the price pressure resulting from a larger second-hand supply on the market is likely to become more pronounced. In addition, the supply of used textiles that are no longer wearable and marketable for recycling will exceed the existing recycling capacities; already today, recycling hardly takes place in Germany and is increasingly being shifted to non-European countries. At the same time, the recyclability of textiles is decreasing due to the way garments are manufactured in the (fast) fashion industry. In order to implement a circular economy for textiles, a systematically driven change requiring a multitude of measures is needed.

9.8 Proposed measures

9.8.1 Introduction

Used textiles are a heterogeneous material flow, the disposal of which is currently mainly performed under the responsibility of private actors who had basically set up the used textiles industry and engage in it. The very diverse collection infrastructure and services established for that yields with approx. 64% a high collection rate of used textiles; the recovery rate even stands at 96%, although the majority of recovery operations isn’t taking place in Germany. From the side of the stakeholders is assumed that the market for used textiles will run into financial problems as a result of further growing volumes and a parallel decline in the collectable quality, while difficulties in sales will also emerge. The obligation to separately collect used textiles starting from 2025 will accelerate this development; an assessment which all international respondents by the way shared unanimously. The EU Action Plan for the Circular Economy includes the development of a textile strategy, the rules it shall set are intended to strengthen competitiveness and innovation in the textile industry and to push sustainable and recyclable textiles production (European Commission 2020b). The package also includes measures to promote sorting, the preparation for reuse and recycling of textiles among others through innovation, support for industrial applications and regulatory instruments such as an extended producer responsibility.

9.8.2 Recommendations for action

In order to develop appropriate recommendations for action, subjects of relevance for a high-quality collection and recovery of used textiles were identified based on the results from the evaluation process. All of that is explained in more detail in the following sections.

9.8.2.1 Promoting the consumption of sustainable products and the implementation of the obligations for information and consultation under the Circular Economy Act

Consumer behaviour has a major influence on resource consumption of primary raw materials, water and the CO_2 emissions. In Germany, the level of emissions is in the scale of over 11.0 tons of $CO_{2\text{-eq.}}$ per capita with the purchase of textiles and clothing accounting for just under 3% of the average greenhouse gas emissions per person and year (Umweltbundesamt, 2019b). In addition to consumption, the handling of textiles during the usage phase is also relevant, as is the disposal route at the end of the useful lifetime. A long use of clothing is an essential factor for sustainability and can be improved through various measures within the entire life cycle. Thus, consumers should be continuously sensitised with regard to:

Purchasing decisions/behaviour:

Textile products are to be given a higher value again, with the aim that consumers should:

- Buy less but higher quality products instead
- Pay attention to sustainable materials when shopping; labels/seals can be helpful here
- Buy second-hand products, rent or exchange clothes for special occasions.

Usage phase:

The handling of textiles plays an equally important role in resource consumption. Unnecessary washing at often too high temperatures damages the textile fibre and contributes to higher energy consumption and water demand. Consumers should be better informed about the correct care of products. Furthermore, repair offers contribute to that textiles can be used longer.

After the usage phase:

With regard to the options for the disposal of used textiles, consumers should have easy access to information about the take back and acceptance points for used textiles or the location of appropriate container sites but also how used textiles should be packaged in order to preserve their state and quality. Further information about the disposal routes for used textiles is also important to enable consumers to understand why the careful handling of used textiles is necessary compared to other waste streams.

Various addressees can be considered for aforementioned recommendations. The amendment to the German Circular Economy Act (KrwG) already contains various regulations in this regard. In Section 46 KrWG, the duties of the public disposal providers (örE) for waste advisory services were extended to waste prevention and preparation for reuse; appropriate measures are to be laid down in particular on the basis of Section 33 subsection 3 no. 2 KrWG and the stipulations of the current waste prevention programme, which also includes textiles. The product responsibility under Section 23 KrWG has been significantly expanded too. In addition to saving resources, which also includes offers in support of reuse and repair (no. 4), producers and distributors are obliged to advise consumers (no. 9), with following subjects deserving a particular attention.

Retailers should mobilise consumers to pay more attention to the symbols displayed on textile care at the textile labels, and to care for clothing according to the manufacturers' recommendations. Expanding the range of repair services on the side of retailers would also help to support the longevity of textiles. Campaigns by fashion brands for durable or recyclable clothing can make consumers proactively aware of quality issues at the point of purchase and support conscious purchasing decisions for sustainable fashion. In this context, companies should also examine which business models lead to more sustainable consumption as part of their sustainability strategy, and change existing concepts if necessary.

9.8.2.2 Mass flow data

There is currently no reliable data on the quantity of used textiles collected nationwide and their disposal routes. The survey of the competent authorities has shown that the activities carried out in the context of commercial and non-profit collection are hardly tracked. Even in the case of collections initiated by the public disposal providers, transparency about the routes used for the disposal of the collected quantities is lacking and the knowledge deficient. Here it has also been noted that the quantity of used textiles may not be correctly recorded by the Federal Statistical Office. For example, the Federal Statistical Office published that a total of 118,400 tons of textile waste was sorted in 46 sorting plants in the year 2017 (Destatis 2019c). Considering the knowledge available on the disposal market and structures, it must be questioned which sorting plants were actually included in this record.

With a view on the predicted developments of the sector, a good database is essential in order to be able to initiate further legal measures to address waste management, if necessary. It is hence recommended to review the data collection procedures the Federal Statistical Office is applying with regard to sorting facilities with the aim of ensuring that all facilities accepting used textiles for sorting are included and the quantities they received are reported correspondingly. This includes in particular the identification of all sorting facilities for used textiles licensed under the Federal Immission Control Act (BImschG) and the inclusion of these facilities in the annual monitoring.

In conjunction with the introduction of separate collection of used textiles from 2025, the public disposal providers should, in their own interest, check at least two to three years before the implementation deadline whether the upcoming obligations are fulfilled by the collection structure already in place. Furthermore, in order to improve data access and availability, the duties of thepublic disposal providers for reporting for the Federal States' waste balances should be extended to commercial and non-profit collections as well as collections within the framework of voluntary take-back. In order to implement these measures, it is recommended that Federal State ministries for the environment agree on regulations to enable data aggregation. The recommendations for improving mass flow information are of a non-binding nature only considering that binding regulations for this measure do not yet exist within existing statutory regulations.

9.8.2.3 Collection volumes and area coverage

The evaluation has revealed that the collection rate for used textiles at approx. 64% is above average and therewith higher than the collection rates legally required for other material flows to be separately collected (see chapter 9.4.2). The nationwide sorting analysis for residual waste (Dornbusch et al. 2020) shows that residual waste still contains about 4.5 kg of old textiles per capita. In many cases can be assumed that this concerns heavily damaged, torn or soiled textiles, the majority of which could still be material rcovered, however. Together with an update of the analysis on residual waste, it is proposed to examine the proportion of used textiles under the aspect of soiled amounts to determine whether these were soiled by being mixed with other waste or they were not collected separately because they were already soiled. Heavily soiled used textiles can only be material recovered to limited extent. Also, for example, used textiles soiled with paint or soaked would lead to a cross-contamination in the used textile collection, which is why these items should not enter the used textile collection but disposed of via the residual waste instead. In addition, the public disposal providers should include in their local analyses of residual waste the determination of the potential for the separate collection of textiles. The findings from such analyses would also serve the purpose to control the implementation of the obligation for separate collection according to Section 20 subsection 1 no. 6 KrWG within their own jurisdiction.

Considering the trend in the general development, it is to be anticipated that the costs for the collection of used textiles can no longer be covered by the sales of the usable portion. Commercial and non-profit collectors who can no longer cover their expenses will gradually give up their collection activities. In this case, the current large-scale private collection infrastructure would fall apart. For this reason, measures are needed to maintain the extensive collection structures, even under different market conditions. Possible solutions are presented in chapter 9.8.3.

9.8.2.4 Recovery routes

Preparation for reuse and recycling account for approx. 92% of the recovery of used textiles (bvse 2020). In this respect, the recommendations for action are rather directed towards maintaining this high level.

Today, the recovery of used textiles takes place to a limited extent in Germany and increasingly also outside of Europe. Restrictions on future imports but also an oversupply due to globally increasing collection volumes pose a risk that not all sorted second-hand items can be marketed or that used textiles can no longer be recycled due to shortages in available capacity.

Looking at preparation for reuse, it must be noted that the overall framework for labour-intensive sorting is more favourable abroad and therefore a further decrease in the sorting of used textiles in Germany can be assumed. Moreover, it has to be noted that individual consumers are increasingly selling well-preserved (branded) clothing themselves on second-hand platforms. According to the retail scenario 2030 (HDE Online Monitor 2020), environmentally conscious consumption is becoming more and more important and will consequently lead to an increase in demand for second-hand products. Clothing that remains in second or third hand use without that a sorting effort is needed depicts a much welcome development from an ecological point of view. However, the trend of private second-hand sales also boosts the collected quality of textiles to further deteriorate, which in turn can cause that the costly complete sorting becomes unaffordable and/or can no longer be financed by private sorters.

In order to be able to cope with the increase in collected volumes, further recovery capacities are also necessary. The recovery infrastructure for used textiles is so far financed by private investments and is basically only realised as long as there is a demand for recycled materials and conditions for their use in new products have been created. The demand for recycled fibres or other secondary materials from used textiles would thus have to be stimulated by the private industry alone, and this despite the fact that even today there is no sufficient level reached and supplementary promoting measures need to be found here. To avoid conflicts with internal market legislation, corresponding stimulations could only be implemented at EU level. Against this background, it is proposed that the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety advocates the introduction of a legal regulation on the use of recycled fibres and secondary materials from used textiles at the EU level.

9.8.3 Statutory and further regulatory options

In the following, measures within the framework of various regulatory options are examined and evaluated on the basis of their impact. In order to draw up concrete recommendations for action in the field of used textiles these are then compared with each other on the basis of the criteria and methodology described in Chapter 1.3.1.

9.8.3.1 Development of LAGA leaflets and further control measures (market monitoring) to support the implementation of the Circular Economy Act

The amendment to the German Circular Economy Act (KrWG) has already led to some provisions that can be supported by the following supplementary measures:

The recommendations for action listed in chapter 9.8.2.1 require comprehensive communication measures. These should be designed in a uniform manner and their realisation should be monitored. For this reason, it is recommended that the Federal States develop a guideline within the framework of the Joint Waste Commission of the Federal States (LAGA) on the implementation of the expanded obligations for waste advisory services by the public disposal providers (örE). In addition, it is proposed that the inspection of the advisory duties of producers and distributors as well as other duties according to Section 23 (2) KrWG be included in the market surveillance for which the local waste authority is responsible. To this end, a law enforcement help could be developed that specifies and harmonises the criteria and measures of the inspections within the framework of the market surveillance activities. In 2016, the state of Saxony-Anhalt published a handbook as a law enforcement help for monitoring under the trademark law, which can serve here as a model (INTECUS 2016).

The amendment to the German Circular Economy Act (KrWG) addresses the obligation for the separate collection of used textiles to the public disposal providers (örE). In this respect, a shift from the free commercial or non-profit collection of used textiles to a municipal collection financed by fees would occur on the market. The örE would have to significantly increase the intensity of their current service offers (their share in this collection segment reached approx. 27% in 2018) in order to maintain the current collection structure and coverage whereby the municipal waste fees would increase as a result.

When compared with the introduction of the separate collection for plastics, except of packaging, since 2015, it can be observed that in most cases the örE have not implemented a further collection offer or an additional bring system for households. Citizens can often only hand in plastic waste at the civic amenity centres. If this model were to be adopted to used textiles, the convenient system of bring bank containers would be converted into a collection system at the civic amenity centres, which by experience will lead to lower quantities of separately collected used textiles. The Corona pandemic in 2020 also showed that a number of örE with own collection activities for used textiles withdrew the collection containers due to certain shortages and only offered a collection at civic amenity centres (e.g. City of Hamburg (euwid 2020b) or District of Pinneberg (GAB 2020). To keep the collection rate also in future at the current high level, the intensity of used textile collection should be maintained. Minimum requirements, for example formulated by LAGA or the Federal States for collection within the existing legal framework, could contribute to this. Here, a minimum density for the collection infrastructure (e.g. required number of points of collection per 1,000 inhabitants) could be defined, which should apply to each service area. The responsibility of the örE would relate in particular to organisational duties, since the points of collection can also be set up by commercial or non-profit collectors themselves. Where the minimum number of collection points is not reached via third parties, the örE would have to set up the difference in collection points on its own. At the same time, minimum standards regarding collection quality should be introduced (see the corresponding working paper submitted from several Federal States as of November 2019). With regard to feasibility, it should be noted that a LAGA leaflet is a non-binding recommendation and can only be enforced if the specifications are integrated into a binding waste legislation of the Federal States. A nationwide implementation would only be feasible when all Federal States agree and provide such binding framework. It can be assumed that the collection infrastructure will be subject to fees when the responsibility for separate collection has shifted to the örE from 2025 onwards. There are already collection volumes which are subject of charging (GFA Lüneburg n.d.), and this development is likely to intensify in coming years. Implementing the mandatory separate collection of used textiles is going to increase the fees, which to politically justify and enforce has quite some difficulties.

The term "textiles" was not defined in more detail in context with the obligation for separate collection as contained in the amendment to the German Circular Economy Act (KrWG). The collection of used textiles at present includes a great variety of products that have become waste, such as clothing, household textiles, shoes, accessories, but also stuffed animals. In case of a rather narrow interpretation of this term, only products, such as textile clothing and household textiles that have become waste, would be subject of the mandatory separate collection. According to the bvse Textile Study 2020 (bvse 2020), however, shoes, bags and leather goods account for a share of about 25% of the potential collection volume. This definition is also important when evaluating the success of separate collection based on the results of the nationwide sorting analysis for residual waste (Dornbusch et al., 2020).

Apart from the obligation to separately collect used textiles, there are no further specifications or specific targets regarding the used textiles to be collected and recycled.

Municipal systems for managing waste are primarily geared towards the collection. The örE ensures that all services in this context are financed through the revenues made from fee collection and that the costs are thus passed on to the actual generators of the waste. The örE can provide incentives for the recyclability of products to a limited extent only. Further specific instruments and steering mechanisms in the sense of promoting a circular economy are not included in this system. Neither can specifications be made for an ecological design, nor for individual forms of recovery routes. Only the need for observing compliance with the waste hierarchy according to Section 8 para. 1 KrWG sets a certain framework, which should have an effect on selecting collection systems with regard to quality aspects also.

Table 119 Evaluation of the measure "Development of LAGA leaflets and implementation of further control measures (market surveillance) to support the KrWG"

Criterion	Evaluation	Points
Bureaucratic effort	medium bureaucratic effort in view to an extension of reporting obligations and also with regard to communication and public relation works	3
Legal aspects	no legal changes are necessary for these supplementary measures	1
Statistical aspects	statistical recording of collection quantities is improved but not with regard to the destinations of the collected quantities	3
Organisational effort	medium; development of minimum standards; political decision as to the public information and collection system as well as preparation of tender or investment; development of enforcement help for monitoring under trademark laws	3
Implementation timeline	medium-term (3-5 years): Development of minimum standards can be implemented in the short term; organisation of separate collection must be implemented by 2025; implementation of other measures on a rather short-term basis (1-2 years)	2
Binding character	non-binding (minimum standards are non-binding, in the current Circular Economy Act (KrWG) no specific goals or targets are set for used textiles; örE have freedom to organise through local self-administration); including textile manufacturers or distributors in market surveillance is also non-binding; binding nature could be strengthened when transposed into federal state law requirements	4
Contribution to financing the recycling	collection and recovery of the entire waste stream is financed from the revenues made via fee collection; it is not possible to set fees based on the principles of pay-as-you-throw in the case of bring bank collection	3
Improvement of collection	no effect on increasing the collection volume	3

Criterion	Evaluation	Points
Strengthening of recycling	recycling is implemented within the framework of the five-step waste hierarchy, additional incentives to promote recycling are not feasible	4
Acceptance of relevant actors	public disposal providers (örE): medium (VKU sees the need for adjusting) waste management industry/non-profit organisations: no acceptance (both call for the introduction of an EPR system) consumers: indifferent (the increase in fees goes rather unnoticed, user-friendliness will suffer if minimum standard is not implemented nationwide) manufacturers/traders: medium (depending on how advisory duties will be put in more concrete terms and eventually monitored)	3
Public information needs	parts of the measures require intensive communication or public information, especially in the area of waste prevention	4
Weighted result		**3.2**
Key addressees	örE, competent federal state authorities, manufacturers and retail sector	
Summary	Municipal systems are primarily focused on collection. Although financing the management of the waste stream is ensured, strengthening recycling is making it necessary that minimum standards are transferred to the waste legislation of the Federal States. Necessary communication measures can be strengthened by implementing minimum standards and control.	

9.8.3.2 Voluntary commitment by the textile industry

The voluntary take-back of used textiles is already addressed in Section 26 KrWG as part of assuming extended producer responsibility. The regulation covers the entire disposal chain with the aim of promoting the circular economy. In this respect, a support could derive from such measure for the municipal collection system, especially for the expansion of sorting and recycling structures. Globally, less than 1% of the waste from used textiles is entering the production of new textiles as recycled fibre today (Ellen MacArthur Foundation 2017). In Germany, too, only a few manufacturers and distributors of textiles are voluntarily assuming this responsibility to date.

In the meantime, however, numerous initiatives have been launched at individual company level but also in the frame of partner alliances with the aim to make the textile industry circular. Various activities which the textile industry undertakes to prepare for change and the ‘textile future’ are for example shown from the Forschungskuratorium Textil e.V. in its study titled "Perspectives 2035" (FKT n.d.). This study addresses, among others, subjects such as the development of new business models, the sustainable and resource-saving production of textiles as well as "Design for Recycling" or "Design for a second/third Usage Phase". It also illustrates the manifold applications textiles have as a material and why different approaches are being pursued in this context. Euratex, the European umbrella organisation of the textile industry, has set itself the goal of establishing five so-called recycling hubs (ReHubs) in Europe, one of them in Germany (Euratex 2020). Here, both textile industrial waste and used textiles are to be recycled in different processes and made available as secondary raw materials for the European industry. The next steps are to fine-tune the ReHubs, coordinate and expand the circle of stakeholders involved, and to evaluate the financial resources needed for techno-economic feasibility studies of the ReHubs with the aim of initiating larger private-public partnerships.

Neither the industry as a whole nor a significant proportion of it so far came up with a voluntary commitment to achieve specific collection and recycling targets, however. Voluntary measures can nevertheless provide a sound basis for such goals and show in the frame of pilot projects "what is possible". One of the advantages is that every company can develop appropriate measures for closing the loop in relation to its own activities, especially against the background of the diverse use of textiles. There exist no reporting obligations towards the authorities, so the administrative effort initially is low. On the other hand, there are no official control instruments with regard to target fulfilment in place and thus no sanctions for non-compliance either. To convert production processes towards circularity goals is oftentimes associated with higher expenses and so there must be a benefit for the operator at least in the long term. A security for the investment can be achieved by voluntary measures only when is ensured that the investment is viable and no competitive disadvantages will be caused as a consequence.

Experiences with other waste streams suggest that a voluntary commitment is particularly successful when the waste stream has a positive market value. Used textiles, however, must be assumed to develop into a material stream that is subject to additional payment. In the case of packaging recycling, which is also a material flow subject to additional payment, it was only a tightening of the legal recycling quotas through the new German Packaging Act that led to an increase in recycling activities in Germany. The Changing Markets Foundation has investigated voluntary measures by large corporations in the packaging industry worldwide and concludes that the initiatives have failed; moreover, as a result of these promises, legislative processes have been delayed (Delemare Tangpuori et al., 2020). Ultimately, it seems difficult to implement a voluntary commitment on a large scale as long as there is no level playing field within a global supply chain. A national supply chain law is now to be introduced for this reason (BMU 2020).

The Global Fashion Agenda, a non-profit organisation that supports the fashion industry in implementing sustainable solutions (GFA n.d.), has initiated the "2020 Circular Fashion System Commitment", which calls on fashion brands and retailers to set (their own) targets for a sustainable business model. The achievement of the targets is reviewed annually. A total of 90 companies have signed the agreement, such as Adidas, Bestseller, Esprit, Inditex, H&M. However, these companies only account for 12.5% of the global fashion market (GFA Circular Actions n.d.). The same organisation furthermore deals with the legal framework conditions for the success of a textile circular economy. Together with the Sustainable Apparel Coalition (SAC) and the Federation of European Sporting Goods Industries (FESI) as other garment and footwear sector representatives, the Policy Hub was founded to develop and jointly promote an effective policy framework for the circular economy within the sector in Europe (Policy Hub n.d.).

Section 26 para. 1 KrWG already provides powers of authorization regarding regulations to set targets for a voluntary take-back of used textiles in Germany. Since only about 5% of the textiles put on the market in Germany are produced by the domestic textile industry, care must be taken to include the retail of clothing and textile in the voluntary commitment when choosing this option.

Table 120 Evaluation of the measure "Voluntary commitment by the textile industry"

Criterion	Evaluation	Points
Bureaucratic effort	low as there is no control by the authorities; if necessary, annual audits may be carried out as part of a self-controlling	2
Legal aspects	a regulation based on Section 26 para. 1 KrWG would also be possible in addition	2
Statistical aspects	the statistical recording of the material flows is going to be improved	3

Criterion	Evaluation	Points
Organisational effort	high as far as the implementation of corresponding measures at the operational level are concerned	4
Implementation timeline	long-term (more than 5 years)	5
Binding character	commitment is meant to represent a binding obligation by the industry itself, however, there is no mechanism for sanctions inherent to it	3
Contribution to financing the recycling	manufacturers and retail sector participate in financing recycling solutions	3
Improvement of collection	hardly any effect can be expected on increasing the collection volume	3
Strengthening of recycling	a material recovery is ensured for a part of the waste stream which improves recycling for this part in the long run	3
Acceptance of relevant actors	voluntary measures are, in principle, widely welcomed although the other, non-involved actors question the broader effects; high among consumers since sustainable actions become more and more important for them	3
Public information needs	requires additional communication or public relations work, incentives should encourage consumers to join and act sustainably as well	4
Weighted result		**3.2**
Key addressees	manufacturers, importers, retail sector	
Summary	The lower bureaucratic effort speaks in favour of this measure but it entails a high effort for getting a workable recycling industry up and running (since this is not part of the voluntary commitment). A voluntary commitment cannot be effectively sanctioned, in this respect it remains uncertain what effectiveness can be achieved. Importers and retailers must be in any case involved, given the high share of imported goods in this product segment.	

9.8.3.3 Textile levy or textile tax

When implementing a levy or tax on textiles, there are various options as to whether the amount to be charged should be based on the product or on the used raw material. For textile manufacturers or distributors such instrument should work as an incentive to produce sustainable textiles, as the levies or taxes they would have to pay are lower in this case. In order to achieve a noticeable effect, the levy or tax would have to make up a clear portion of the product price. However, if the different functional requirements of certain textile products are considered, an unjustified unequal treatment could occur where, for example, using certain materials due to technical requirements would result in higher levies or taxes.

The revenues from a tax would feed the national budget and not be earmarked to a specific purpose. A tax, in this respect, would only serve the steering function in favour of sustainable textile production and consumption. It is not going to provide for the financing of the disposal of used textiles, however. Introducing instead the model of a levy would allow the revenues to be used to cover the costs of disposal. Such product-related levy again would be the responsibility of a national fiscal authority, which would, however, have no direct connection to the generation and disposal of the waste. This in particular raises the question how the revenues were finally distributed and for what purposes, for example will these only go into proper disposal or also finance high-quality recycling. In addition, it is necessary to develop a model for the sustainability criteria along which the levies or taxes will be collected. Further to the administration for product registration, there is also a need for controlling the declaration of the raw materials or the production method used for the textiles.

Table 121 Evaluation of the measure "Textile levy"

Criterion	Evaluation	Points
Bureaucratic effort	high because of the ongoing assessment of levies as well as the administration and disbursement of the collected revenues (use of funds); manufacturers, retailers and importers face a high bureaucratic burden too	4
Legal aspects	any legal framework is lacking so far	5
Statistical aspects	influence on improving the yet deficient transparency of the waste stream is minimal; at least quantities placed on the market should be better known	4
Organisational effort	high since establishment of at least one institution as well as preparation of a catalogue of criteria for calculating and setting the levies and distributing the revenues are required	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding (as implementation is based on legislation)	1
Contribution to financing the recycling	levy must be earmarked for the disposal of used textiles; the extent to which recycling (and not just collection) is financed is determined by the design of the overall concept	3
Improvement of collection	no effect on increasing the collection volume	3
Strengthening of recycling	depending on the concept design, incentives to increase recycling can be created	3
Acceptance of relevant actors	manufacturers/providers of disposal services: low or indifferent consumers: indifferent (possible increase in prices remains rather invisible)	4
Public information needs	a medium effort is required for communication or public relations work in terms of explaining the implementation and effects on product price	3
Weighted result		**3.5**
Key addressees	national government after consultation with stakeholders, manufacturers, retailers and importers	
Summary	Implementing a textile levy entails a high bureaucratic and organisational effort. There exists quite some uncertainty with regard to the use of the revenues. Strengthening of recycling is not guaranteed, as the authority has no direct relation to waste generation.	

Table 122 Evaluation of the measure "Textile tax"

Criterion	Evaluation	Points
Bureaucratic effort	medium in as far as an assessment of the taxes and a certain administration must be ensured; manufacturers, retailers and importers face a high bureaucratic burden	3
Legal aspects	any legal framework is lacking so far	5
Statistical aspects	influence on improving the yet deficient transparency of the waste stream is minimal; at least quantities placed on the market should be better known	4
Organisational effort	high as there must be a catalogue of criteria for calculating and setting taxes compiled	4
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding (as implementation is based on legislation)	1
Contribution to financing the recycling	taxes are not earmarked to waste management purposes	5
Improvement of collection	no effect on increasing the collection volume	3
Strengthening of recycling	depending on the design of the tax, the measure can create incentives with regard to the recyclability of textiles	4
Acceptance of relevant actors	measure is rejected by all principal stakeholders consumers: indifferent (possible increase in prices remains rather invisible)	5
Public information needs	a medium effort is required for communication or public relations work in terms of explaining the implementation and effects on product price	3
Weighted result		**3.8**
Key addressees	national government after consultation with stakeholders, manufacturers, retailers and importers	
Summary	Despite the generally high bureaucratic and organisational efforts it is likely to cause there is a very limited or no influence of this measure on recycling, nor can it contribute to financing the waste disposal. Stakeholders reject the measure unanimously.	

9.8.3.4 Fund model linked to recycled fibre use

The Swedish study "Impact assessment of policies promoting fibre-to-fibre recycling of textiles (Elander M. et al., 2017) evaluated a reimbursement model based on the used raw material. The background for considering such a solution came from that recycled fibres were found to be more expensive than fibres from primary raw materials and that using the more expensive fibre could receive a compensation through the fund.

The fund model consists of a two-tiered approach in which the manufacturers must pay a fee for the use of fibres from primary raw materials. It further involves a subsequent reimbursement to those manufacturers who use a high proportion of recycled fibres in relation to total production. Manufacturers with an above-average share of recycled fibre in production become net recipients under this model, while manufacturers who use little or no recycled fibre are the net payers in this system. In general, this is a useful approach to compensate for the price difference of fibres from primary and secondary raw materials. It can also be assumed that this model has a positive effect on fibre-to-fibre recycling. As problems are perceived the setting of appropriate fees to achieve the desired effect but more particularly the high effort in administering the fund model, the control and the reporting related to the complex and global supply chain. The principal concept for this model is to equalise prices in order for recycled fibres to become more competitive.

Table 123 Evaluation of the measure "Fund model linked to recycled fibre use"

Criterion	Evaluation	Points
Bureaucratic effort	high, in particular with a view on implementing and administering the model at full scale; manufacturers, retailers and importers face a high bureaucratic burden	4
Legal aspects	a regulation based on Section 23 para. 4 KrWG is required	3
Statistical aspects	influence on improving the yet deficient transparency of the waste stream is minimal; at least quantities placed on the market should be better known	4
Organisational effort	high since establishment of at least one institution as well as preparation of a catalogue of criteria for calculating and setting the fees and for managing the payment flows are required	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding (as implementation is based on legislation)	1
Contribution to financing the recycling	only contributes to a price compensation for the use of recycled fibres; partially secures the financing of recycling	3
Improvement of collection	little impact can be expected on the increase of the collection volume	3
Strengthening of recycling	creates better conditions for material recovery	3
Acceptance of relevant actors	manufacturers, waste service providers: low or indifferent; consumers: indifferent (possible increase in prices remains rather invisible)	4
Public information needs	since the fund model only has indirect effects on consumers there is hardly any additional communication or public relations work needed	1
Weighted result		**3.2**
Key addressees	national government after consultation with the stakeholders, manufacturers, retailers and importers	
Summary	The measure addresses and is expected to yield effect on just a partial aspect and therefore has only a medium impact on the economic, ecological and statistical issues associated with textile recycling. This is contrasted by a quite high organisational and bureaucratic effort.	

9.8.3.5 Extended producer responsibility

Extended producer responsibility (EPR) is considered a central instrument for implementing the waste hierarchy. In contrast to the previous measures, EPR represents a holistic approach, as various steering elements can be taken up to promote the circular economy by way of:

- specifications for production and product design
- targets for collection
- targets for preparation for reuse
- targets for the recycling of used textiles that are neither wearable nor marketable
- targets for documentation and record keeping
- monitoring and control mechanisms
- requirements for public information
- requirements on research and development and their promotion.

The way different goals are combined and interact with each other has direct or indirect influence on the entire textile cycle, including waste disposal.

Various EPR models are conceivable here. These models differ above all in the definition of the obligated parties and their identification, the implementation of the obligations, and the auditing and monitoring of compliance.

Based on the experience made in Germany with EPR models for other waste streams, two schemes of full producer responsibility are discussed below. In addition to abovementioned aspects, the EPR models differ in particular with regard to operational implementation and the design of the financial flows.

Section 8 of the EU Waste Framework Directive (Directive 2008/98/EC) leaves it at the discretion to the Member States to introduce EPR systems. In any case, however, some general minimum requirements according to Section 8a must be met. Against this background, a shared producer responsibility is no longer possible.

9.8.3.5.1 Areas of duty (same for all EPR models)

9.8.3.5.1.1 System-relevant products (same for all EPR models)

In general, it must be determined for which system-relevant products an extended producer responsibility shall apply. This is indispensable to achieve a clear delineation with regard to the transfer of obligations but also for the duty of inspection and measuring compliance with the obligations.

As a result of the current collection practice for used textiles, non-textile waste is collected as well and, under a broad interpretation, also allocated and accounted under the term used textiles. This, in particular concerns non-textile shoes, accessories, stuffed animals or leather goods.

The EPR model applied in France, for example, includes shoes of all material types but not clothing or bags made of leather. In the draft submitted in December 2020 for the introduction of an EPR system for textiles in Sweden (Regeringskansliet 2020), only textile products are included. Hence, there should be in any case a catalogue of criteria with examples, including how a differentiation is to be made from other waste streams such as bulky waste (carpet, upholstered furniture, mattresses, etc.).

Furthermore, it should be specified whether the source at which the product is disposed and becoming waste should be considered as a criterion too.

Table 124 Overview on the potential sources

Sources	include
Private households	private households (single-family houses to large apartment complexes)
Waste sources comparable to private households	hotels, catering facilities, hospitals, administration
Commercial sources	industrial facilities (workwear)
Other sources	police, armed forces (uniforms)

9.8.3.5.1.2 Roles and responsibilities

Within an EPR system, roles and responsibilities are assigned to the various actors. These can be different for each model.

Table 125 Overview on the different actor's roles and responsibilities

Actors/roles in the system	Responsibilities
All actors within the supply chain	should benefit from incentives for a sustainable production practice
Obligated companies	take-back obligations or participation in a system to which corresponding responsibilities have been transferred
System (as a legal entity)	organisation and fulfilment of obligations on behalf of the participating companies (design depends on the applied EPR model)
Retailers	take-back obligations or making corresponding offers; banned to sell non-participating products, etc.
Consumers	get motivated to consume sustainably (incl. second-hand purchase and correct disposal of used textiles)
Waste service providers (collectors, sorters, recyclers)	implementation of high-quality collection and recycling; corresponding services are financed via obligated companies or system
Authority/Supervisory body	monitoring the implementation and fulfilment of the obligations, including the part transferred to the system
public disposal providers (örE)	coordination of the collection infrastructure or implementation of collection, provides the link to consumers (information/public relations work)

9.8.3.5.1.3 Official/neutral body or clearing house

The official or neutral body is of particular importance when it comes to control the implementation of the obligations under an EPR system. As a minimum, it identifies the obligated parties and operates a register on them. Considering the fact that the authorities have performed any tasks in the area of monitoring used textiles disposal so far to very limited extent only, it is proposed that such neutral body should also assume the control on compliance with the law, including for example the check of the mass flow reports for plausibility and examination as to the fulfilment of the obligations. In addition, this body should also develop criteria and specifications for the certification/expert audits as well as on record keeping. The uniform implementation is particularly relevant where there are several systems involved and in competition to each other as well as for a possible setting up of individual take-back solutions by the manufacturers.

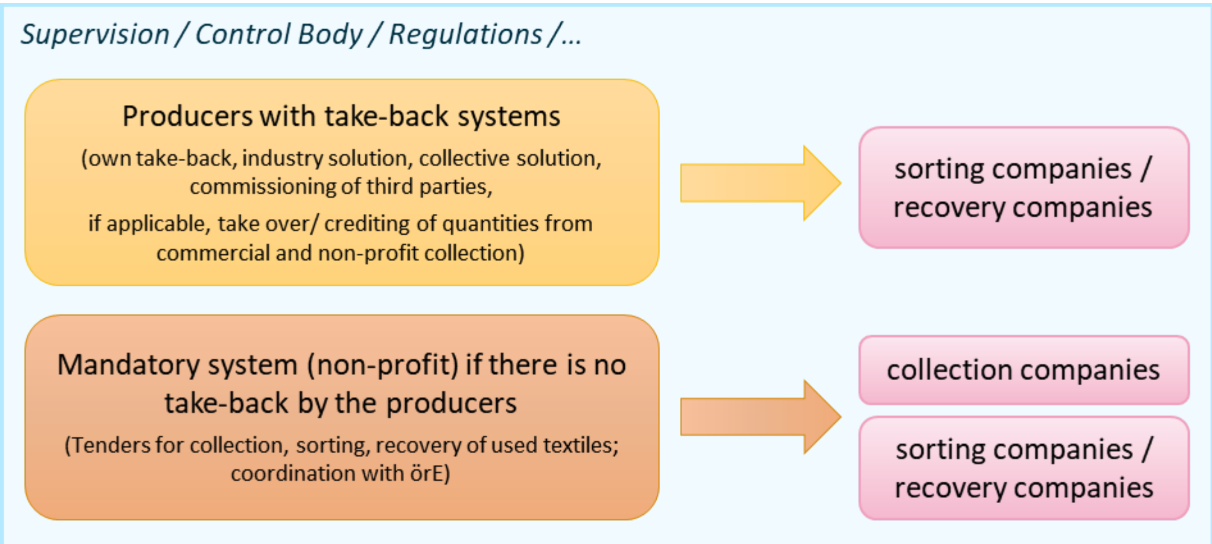
Depending on the EPR design, the aforementioned tasks can also be incorporated into a joint (non-profit) system, which assumes the obligations for all manufacturers and importers, insofar as no individual take-back solutions are established by them. If several systems operate in competition, a neutral body is a must to work as a clearing house.

9.8.3.5.2 Complete producer responsibility model, variant I

This model puts the implementation of the obligations entirely into the hands of the private sector. The örE assumes the role of a partner for the coordination of the collection infrastructure and to undertake the public information tasks for which it is remunerated. Where it wishes to take part in the collection services, it has to apply in the same way within the frame of the calls to tender.

Obligated parties can fulfil their duties themselves (also in a joint venture) or must participate in a system. In the latter case, the system is responsible for organising nationwide the take-back for all other obligated parties and for this purpose concludes contracts with collection, sorting and recycling companies that are awarded in a competitive procedure. Furthermore, the system coordinates with the örE the use of collection sites and public information.

Figure 38 Roles and responsibilities in the producer responsibility model, variant I

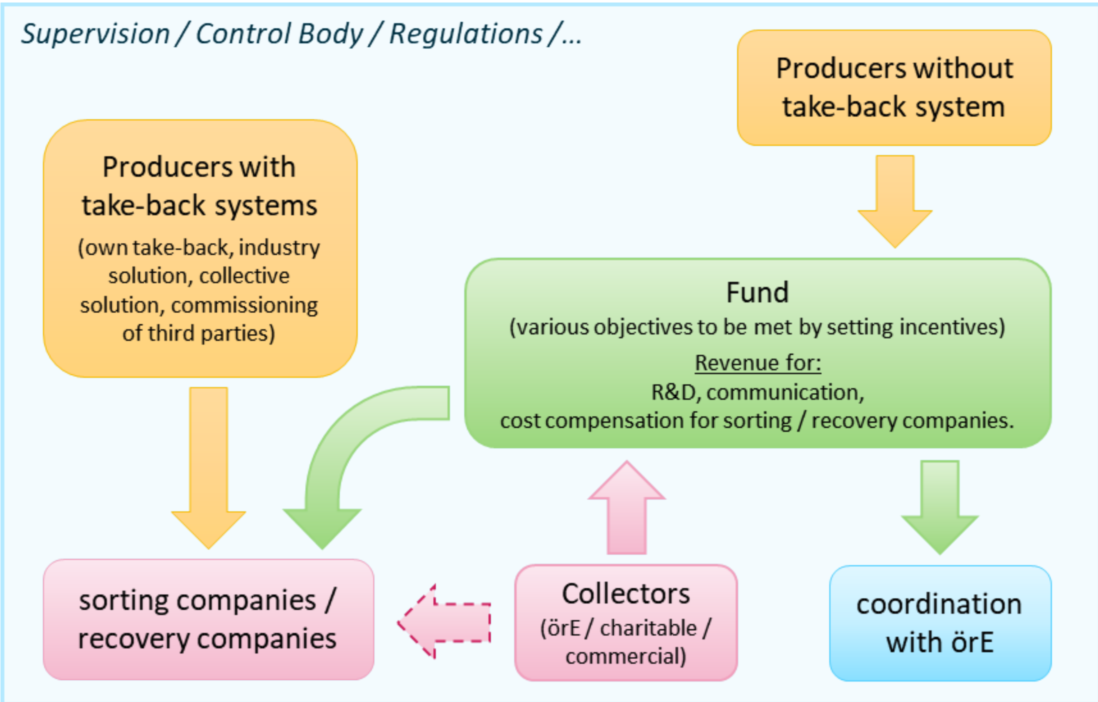


Source: Graphic of Kösegi

9.8.3.5.3 Complete producer responsibility model, variant II (fund model)

In the fund model, the obligated parties also have the possibility of fulfilling all obligations themselves. The fund takes over the task for all other obligated parties. The fund is to provide support in particular where there is a (financial) need. Like the obligated parties, the fund itself has to meet all objectives in accordance with the legal requirements. To this end, the fund must set incentives by way of contractual regulations with the waste service providers in order to achieve that. All (current) actors in collection (commercial and non-profit collectors, örE) as well as the sorters and recyclers can join the fund model which means that in this model all regulations on collection would remain in place in their current form. However, collectors, sorters and recyclers must be registered and fulfil certain requirements in order to benefit from the fund (e.g. for sorters: certain quotas, mass flow certification, etc.). The coordination with the örE comprises in particular public information and support in setting up sufficient collection sites (taking all actors in the area into account). As with the other variants, the obligated party can also implement its own take-back solution.

Figure 39 Participants and their roles in variant II for the complete producer responsibility



Source: Graphic of Kösegi

Generally, is to be noted for both the two variants of complete producer responsibility that a multitude of coordination and contractual issues are to be tackled due to the various actors interacting in this model. The administrative effort for the obligated parties will increase in any case, also with regard to the registration duty and reporting of data. Even if the obligations are assumed by the obligated parties themselves, compliance must be proven, which entails an additional control and reporting effort. In all variants, it is possible to assume the obligations oneself. Thus, the model is suitable for both large but also the smaller sized companies which may transfer their obligations to a system.

It must be noted also that the amended German Circular Economy Act (KrWG) provides for the örE as addressees for the obligation to implement a separate collection of used textiles from January 01, 2025. Given their current participation rate with approx. 27% in the nationwide collection of used textiles, the örE would first have to establish the necessary collection infrastructures or undertake the organisation of a separate collection, both at a nationwide scale. This effort and the established structures would become obsolete however if the complete producer responsibility is introduced, which could lead to conflicts if the system change were initiated (immediately) after 2025.

9.8.3.5.4 Evaluation of the extended producer responsibility

Table 126 Evaluation of the measure "Extended producer responsibility"

Criterion	Evaluation	Points
Bureaucratic effort	high, considering in particular the control of the obligations as well as operational implementation; manufacturers, retailers, importers and the waste service providers face a high bureaucratic burden	4
Legal aspects	a regulation based on Section 23 para. 4 KrWG is required	3
Statistical aspects	collection of statistical data on mass flows is ensured due to the reporting obligation of producers and waste service providers in a system of extended producer responsibility	1
Organisational effort	high since the establishment of at least one institution is required; manufacturers, retailers, importers and the waste service providers face a high organisational burden	5
Implementation timeline	long-term (more than 5 years)	5
Binding character	highly binding (since implementation is based on legislation)	1
Contribution to financing the recycling	financing of collection and recycling can be ensured; by adding the costs for the disposal to the product price, financing is based on the principle of pay-as-you-throw	1
Improvement of collection	legal requirements regarding the to be collected quantities are suitable for increasing the collection quantity	2
Strengthening of recycling	depending on the legal requirements (e.g. quotas) that will be imposed for collection and recycling and the implementation of incentives leading to a sustainable product design (e.g. modulated fees), the recycling is going to be strengthened	1
Acceptance of relevant actors	manufacturers, retailers: low (high additional effort) waste management industry/non-profit organisations: high municipalities: medium consumers: high (sustainability becomes increasingly important as topic)	3
Public information needs	requires intensive communication or public relations work; incentives should encourage consumers to act sustainably	5
Weighted result		**2.5**
Key addressees	National government after consultation with the stakeholders, manufacturers, retailers, importers	
Summary	A high level of effectiveness in implementing ecological, economic and statistical requirements is countered by a high level of implementation efforts and burdens for organisation and administration. Various stakeholder groups are calling for the introduction of an EPR system whereas the acceptance among manufacturers and the retail sector tends to be low (due to the high additional effort expected).	

9.8.4 Summary

In the overall can be said that introducing an extended producer responsibility has the greatest positive effects with regard to the relevant criteria for promoting the textile circular economy beside offering also solutions for all identified subjects of criticality. The requirements anchored in the amended German Circular Economy Act are not sufficient as the municipal systems are primarily focused on collection. The other legal regulations only cover parts of the relevant aspects. Considering the experience from other areas, a voluntary commitment is not sufficient to bring about systemic change. For this reason, the introduction of extended producer responsibility is recommended.

It can be assumed that creating a legal regulatory framework will take several more years. Thus, the following is recommended in terms of a priorisation for the next steps that are to be undertaken in a timely manner:

1. Decision by the government on the introduction of extended producer responsibility for textiles

A timely decision is particularly relevant for the örE, as they have to deal with the implementation of the obligation to separately collect used textiles two to three years prior to its introduction. In this respect, existing implementation deadlines must be observed for all further measures.

2. Promoting the sustainable consumption of textile products and implementation of information and consultation duties under the German Circular Economy Act

The measures outlined should be realised immediately at all levels. Their implementation is compatible with the introduction of other legal regulations and could be continued in a new set of regulations, if necessary.

3. Stakeholder dialogue

The evaluation has shown that almost all stakeholder groups are already intensively concerned with the future of used textiles. Together with the ongoing discussion in Germany, the publication of the EU strategy for textiles is expected in 2021, which, as announced, will also contain regulatory measures. In this respect, it can be assumed that the European Commission will also consider the introduction of an EPR system. In view of this, it is however not recommended to wait for the publication and next steps of the EU Commission but to initiate a stakeholder dialogue in parallel, which deals with the takeover of product responsibility according to the German Circular Economy Act and the introduction of an extended producer responsibility.

In this study, different basic models for an EPR system were analysed, whereby each EPR model can be modified in parts. Furthermore, there are current examples of EPR systems for textiles, such as from France, Sweden (draft published) and the Netherlands (draft expected to be available in the first half of 2021) whose implementation can be compared to the initial situation in Germany. The Stakeholder dialogue could assess the implications for different aspects such as transparency, controllability, competition, effects on the production of textiles, effects on the disposal management as well as economic impacts of the different models, for example within the framework of a simulation exercise. The expected elements of the EU strategy can also be included here.

10 Priorisation of the waste streams

In conclusion to the previous chapters, the waste streams are evaluated with regard to the urgency of improving recycling according to defined criteria (quantitative relevance, technology availability, economic viability and ecology), which are briefly presented below. The evaluation was carried out per waste stream and criterion with the evaluation points 1 to 5. The smaller the result, the more urgently measures should be implemented for the waste stream.

10.1 Criteria

10.1.1 Quantitative relevance

The criterion of quantitative relevance describes the annual quantity of waste streams. The larger the volume of a particular waste stream, the more ecological, economic and social impacts can be achieved through specific measures. Large waste streams offer better conditions for the utilisation of large-scale recycling facilities.

Table 127 Classification matrix of the criterion "Quantitative relevance"

Points	Annual quantity
1	> 2 million tons
2	1-2 million tons
3	0.5-1 million tons
4	100,000-500,000 tons
5	< 100.000 tons

10.1.1.1 Technology availability

The criterion of technology availability consists of the availability of recycling facilities and the degree of establishment of recyclable product design. The existing wealth of experience and the availability of best practice examples for the respective product or waste stream are taken into account.

Table 128 Classification matrix of the criteria "Recycling facilities" and "Product design"

Points	Recycling facilities	Product design
1	Functioning facilities in Germany	wide range of products recyclable
2	Functioning facilities outside Germany	some products are recyclable and established on the market
3	Demonstration facilities and promising concepts in Germany or abroad; experience from failed recycling processes available in Germany	some products are already recyclable, but not the norm
4	Pilot projects planned; individual patents available	recyclable products are in development
5	No promising technology available so far	Recyclable product design is a challenge

10.1.1.2 Economic viability

The criterion of economic viability examines the costs and revenues of recycling processes and the collection effort required to recycle a waste stream. The higher the effort for the recycling-oriented collection of a waste stream and the higher the investment and operating costs for a recycling facility, the greater the burden on the market participants addressed by the respective policy measures. The goal must always be to achieve the greatest possible ecological benefits with the least burdensome and most efficient measures.

Table 129 Classification matrix of the criteria “Recycling processes” and “Collection”

Points	Recycling processes	Collection
1	Economically viable; costs equal to or lower than energy recovery	Well-functioning system in place
2	Can compete with energy recovery, costs are somewhat higher	Adaptation of existing collection systems possible with reasonable effort
3	More expensive than energy recovery, conditionally competitive, depending on subsidies	Modification of existing systems necessary and associated with additional costs
4	More than twice as expensive as energy recovery; long-term viability unclear	Complex to implement and associated with significant additional costs
5	No economically viable recycling available	Collection would be disproportionately expensive

10.1.1.3 Ecology

Recycling must not be an end in itself. The prerequisite for measures that entail a financial or bureaucratic burden for the economy and society is that a relevant ecological benefit can be achieved through the recovery of the highest possible quality resources.

The Ecology criterion deals on the one hand with the finite or critical resources bound in the waste stream and on the other hand with the potential for recycling of the waste stream.

Table 130 Classification matrix of the criteria “Recycling rate” and “Resources”

Points	Recycling rate	Resources
1	Very high recycling rate possible; use in production of equivalent products	Product consists largely of finite or critical resources; positive effects for recycling processes identified in life cycle assessments
2	High recycling rate possible; use in the production of new products	Product consists largely of finite or critical resources; predominantly positive effects for recycling processes identified in life cycle assessments
3	Medium recycling rate possible; use in the production of lower value products	Product partly consists of finite or critical resources; predominantly positive effects for recycling processes identified in life cycle assessments
4	Only low recycling rate possible	Product consists largely of renewable raw materials; no positive effects for recycling processes determined in life cycle assessments

Points	Recycling rate	Resources
5	No reasonably usable secondary materials obtainable through recycling processes	Product consists largely of renewable raw materials; negative effects for recycling processes determined in life cycle assessments

10.1.1.4 Weighting of the criteria

Criteria		Weighting	
		Individual rating	Total
Quantitative relevance		25%	**25%**
Technology availability	Recycling facilities	10%	
	Product design	5%	**15%**
Economic viability	Recycling processes	10%	
	Collection	10%	**20%**
Ecology	Recycling quota	20%	
	Resources	20%	**40%**

10.2 Evaluation of the waste streams

The previously examined waste streams were classified according to the above criteria in order to enable a comparison and recommendation for which of the waste streams measures should be implemented as a priority. The criteria were weighted differently, as the individual criteria have different relevance for policy measures. The weighting, as well as the classification and the result calculated for each waste stream are shown in the following table.

Table 131 Evaluation results and ranking of the waste streams

Criteria		Weighting	Bulky waste	Mattresses	Furniture	Carpets	Artificial turf	Diapers	End-of-life tyres	Used textiles
Quantitative relevance		25%	1	4	1	4	5	2	3	2
Technology availability	Recycling facilities	10%	1	3	2	3	2	2	1	2
	Product design	5%	4	2	3	3	2	3	5	2
Economic viability	Recycling processes	10%	5	3	5	4	2	2	2	2
	Collection	10%	4	2	4	3	2	4	2	1
Ecology	Recycling quota	20%	4	2	4	2	2	2	2	2
	Resources	20%	4	2	4	2	2	2	1	2
Weighted results			**3.1**	**2.7**	**3.1**	**3.0**	**2.8**	**2.3**	**2.1**	**1.9**
Ranking			7	4	8	6	5	3	2	1

As a result, it is recommended that measures be taken primarily for the waste streams of used textiles and end-of-life tyres (ELT). In the case of used textiles, the economic viability is currently changing acutely, so that it is to be feared that the collection systems and the possibilities for recycling in Germany will disappear. Theoretically, high recycling rates are possible in ELT recycling, but due to the economic viability and legal uncertainties regarding PAH limits, the potential is currently not being exploited.

Secondarily, measures should be implemented for nappies, mattresses, artificial turf and carpets, as these products are partly made from petroleum-based materials and it would be possible to recover secondary raw materials through changes in product design or in the collection system as well as by setting up recycling facilities. Although bulky waste and furniture have the highest volume relevance, they consist for the most part of wood-based materials that currently cannot be recovered for recycling in any economically and ecologically suitable quality. Accordingly, bulky waste sorting facilities in Germany currently achieve recycling rates in the single-digit percentage range. Instead of measures in the area of material recovery, measures for prevention and reuse are primarily recommended for furniture or bulky waste.

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