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Promoting the high-quality recycling of plastics from demolition waste and enhancing the use of recycled materials in construction products in accordance with the European Plastics Strategy

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Final report

Promoting the high-quality recycling of plastics from demolition waste and enhancing the use of recycled materials in construction products in accordance with the European Plastics Strategy

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Abstract: Promoting the high-quality recycling of plastics from demolition waste and enhancing the use of recycled materials in construction products in accordance with the European Plastics Strategy

This report highlights the key aspects of a circular economy for plastics in the context of their second largest application, namely construction products. It covers the production, take-back and recycling of construction products made of plastics, as well as the use of plastic recyclates therein. In addition, the plastic packaging of construction products is addressed. The current production of construction plastics is presented and delineated by quantities, grades and products, as well as the resulting contributions to the anthropogenic plastic stockpile. The plastic types relevant in terms of quantity are polyvinyl chloride (PVC), polyethylene (PE), expanded polystyrene (EPS), and polyurethane (PUR). These are primarily used in pipes, profiles and insulation products. The various take-back systems in place for construction plastics are also compared and their contribution to recycling evaluated; some of these take-back schemes enable high-quality recycling. Recycling technologies for construction products are presented and the issue of additives as barriers to high-quality recycling is analyzed. Opportunities and barriers to the use of recycled plastics in construction products are derived from the intersection of available technologies, recyclate supply, and technical requirements for construction products. Depending on some factors, such as recycled material sources, degradation or product requirements, it is necessary to weigh up each individual case with respect to whether, or how much, recycled material can be used. In principle, however, the potential exists for expanding the use of recyclates. Furthermore, the use of plastics as packaging material for construction products is presented and the possibility of using recycled plastics in this packaging highlighted. The report concludes with recommendations to various stakeholders on how to promote the use of recyclates in construction products and their packaging. Important considerations here include the introduction of a recyclate quota for films as construction product packaging and a description of recycling potential and recyclate content in the technical documentation for construction products.

Kurzbeschreibung: Promoting the high-quality recycling of plastics from demolition waste and enhancing the use of recycled materials in construction products in accordance with the European Plastics Strategy

Dieser Bericht beleuchtet die Kreislaufführung von Kunststoffen in ihrem zweitgrößten Anwendungsbereich, den Bauprodukten. Er untersucht Produktion, Rücknahme und Recycling von Bauprodukten aus Kunststoff, sowie den Einsatz von Kunststoffrezyklaten in Bauprodukten. Zusätzlich werden Kunststoffverpackungen von Bauprodukten behandelt. Die aktuelle Produktion von Baukunststoffen wird nach Mengen, Sorten und Produkten differenziert dargestellt, ebenso wie das sich entwickelnde anthropogene Kunststofflager. Die mengenmäßig relevanten Kunststoffsorten sind Polyvinylchlroid (PVC), Polyethylen (PE), expandiertes Polystyrol (EPS) und Polyurethan (PUR). Sie sind vor allem in Rohren, Profilen und Dämmungen verbaut. Die verschiedenen Rücknahmesysteme für Baukunststoffe werden vergleichend dargestellt und ihr Beitrag zum Recycling bewertet. Einzelne dieser Rücknahmesysteme ermöglichen ein hochwertiges Recycling. Die Recyclingtechnologien für Bauprodukte werden vorgestellt und die Thematik von Additiven als Hürden für ein hochwertiges Recycling behandelt. Die Chancen und Hindernisse des Rezyklateinsatzes in Bauprodukten werden aus der Schnittmenge der verfügbaren Technologien, des Rezyklatangebotes und der Anforderungen an Bauprodukte aus Kunststoff abgeleitet. In Abhängigkeit einiger Faktoren, wie z. B. Rezyklatquellen, Degradation oder Produktanforderungen, muss im Einzelfall abgewogen werden, ob bzw. wie viel Recyclingmaterial eingesetzt werden kann. Grundsätzlich besteht aber Potenzial für die Steigerung des Rezyklateinsatzes. Der Einsatz von Kunststoffen als

Verpackungsmaterial für Bauprodukte wird dargestellt und die Möglichkeit des Rezyklateinsatzes in diesen Verpackungen beleuchtet. Der Bericht schließt mit Empfehlungen an unterschiedliche Akteure, wie der Rezyklateinsatz in Bauprodukten und deren Verpackungen gefördert werden kann. Wichtige Punkte sind hierbei die Einführung einer Rezyklatquote für Folien als Bauproduktverpackungen und die Beschreibung von Recyclingmöglichkeiten und Rezyklatgehalt in der technischen Dokumentation von Bauprodukten.

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List of abbreviations

Abbreviation	Long form
€	Euro
%	Percent
°C	Degrees Celsius
a	Year
Ω	Surface resistance
ABS	Acrylonitrile butadiene styrene
u.o.a	Unless otherwise stated
AGP	Working Group on PVC and Environment e. V.
AGPE	Working Group on Packaging + Environment
REWD	Regulation on the European Waste Directive
BauPVO	REGULATION (EU) No. 305/2011, setting out harmonized conditions for the marketing of construction products (EU Construction Products Regulation)
BBSR	Federal Institute for Research on Building, Urban Affairs and Spatial Development
BGBl	Federal Law Gazette
BMBF	Federal Ministry of Education and Research
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BNB System	Sustainable Building Rating System
BOPP	Biaxially-oriented polypropylene
bzw	Respectively
cm	Centimeter, 10^{-2} m
CMEPD	Circularity module for environmental product declarations
CEN	European Committee for Standardization; French: Comité Européen de Normalisation
Destatis	Federal Statistical Office, Wiesbaden
DIN	German Institute for Standardization
EAD	European Assessment Documents
EBS	Substitute fuel
ElektroG	Law on the market placement, recovery and environmentally-sound disposal of electrical equipment waste
EN	European norm
EPAL	European Pallet Association
EPD	Environmental Product Declaration
EPDM	Ethylene propylene diene rubber
EPS	Expanded polystyrene; also PS-E
ERDE	Initiative for Crop Plastic Recycling Germany

Abbreviation	Long form
EU	European Union
e. V.	eingetragener Verein (registered association)
EVOH	Ethylene-vinyl alcohol copolymer
FIBC	Flexible Intermediate Bulk Container
g	Gram
GewAbfV	Ordinance on the Management of Commercial Municipal Waste and Certain Construction and Demolition Waste
GFRP	Glass fiber-reinforced plastic
GVM	Society for Packaging Market Research
h	Hour
HBCD	1,2,5,6,9,10-hexabromocyclododecane
hEN	Harmonized European standards
IBC	Intermediate Bulk Container
IK	Industrial Association for Plastic Packaging e. V.
ISO	International Standardization Organization
KDP	Plastic pallets Düsseldorf
kg	Kilogram
CI	Carcinogenicity index
kN	Kilonewton
KRV	Trade association of the plastic pipe industry
KrWG	Act to Promote the Circular Economy and Ensure Environmentally-Compatible Waste Management
kt	Kilotonnes, Gg, 10^9 g
K-Value	Constant, independent of the concentration of the polymer solution and characteristic of the polymer under investigation, which is a measure of the average degree of polymerization
LCA	Life cycle analysis
SBC	State building code
m	Meter
MBC	Model building code
MFR	Melt mass flow rate)
mg	Milligram, 10^{-3} kg
Min	Minute
Mil.	Million
mm	Millimeter, 10^{-3} m
MOP	Maximum operating pressure
MPa	Megapascal, 10^6 Pa
RTP	Reusable transport packaging
MARTBR	Model Administrative Regulation of Technical Building Regulations

Abbreviation	Long form
ABR	Acrylonitrile butadiene rubber
NIR	Near-infrared
OIT	Oxidation induction time
PWD	Public waste disposal
Pa	Pascal
PA	Polyamide
PA6	Polycaprolactam
PA66	Poly[imino(1,6-dioxohexamethylene) iminohexamethylene]
PBDE	Polybrominated diphenyl ether
p_c	Critical pressure
PE	Polyethylene
PE-HD	High-density polyethylene
PE-LD	Low-density polyethylene
PE-LLD	Linear low-density polyethylene
PET	Polyethylene terephthalate
PET-A	Amorphous polyethylene terephthalate
PET-G	Polyethylene terephthalate glycol
PM	Quantity produced
PMMA	Polymethyl methacrylate
POM	Polyoxymethylene
PO	Polyolefin
POP	Persistent organic pollutants
POP Regulation	Regulation (EU) 2019/1021 on persistent organic pollutants
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinyl chloride
PVC-C	Post-chlorinated PVC, polyvinyl chloride chlorinated
PVC-U	Soft PVC, polyvinyl chloride unplasticized
PVC-P	Rigid PVC, polyvinyl chloride plasticized
REACH	Regulation (EU) No. 1907/2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) and establishing a European Chemicals Agency
RoHS	Restriction of Hazardous Substances; European Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical Equipment
SAN	Styrene acrylonitrile
SBR	Styrene-butadiene rubber
SDR	Standard dimension ratio

Abbreviation	Long form
SN	Nominal ring stiffness
t	Tonne
TIR	True impact rate
TPU	Thermoplastic polyurethane
TRHS	Technical rules for hazardous substances
TGC	Technical guideline concentration
UBA	Federal Environmental Agency, Dessau
VDE	Association for Electrical, Electronic & Information Technologies, e. V.
VerpackG	Law on the market placement, take-back and high-quality recycling of packaging
Cf.	Compare
VIS	Visible, here in the sense of visible light
VM	Installed quantity
VST	Vicat softening temperature
XML	Extensible markup language
XPS	Extruded polystyrene

Executive Summary

The construction sector is the second-largest consumer of plastics after the packaging sector. The amount of plastics used in construction products is increasing annually and exceeds the amount of construction products disposed of. Thus, the anthropogenic stockpile of plastics is continually growing. This report analyzes the aspects of construction plastic production and recovery necessary to promote high-quality recycling.

The basis for high-quality plastic recycling is knowledge of the quantities and types of plastics being used. Data on this were collected for this project, and are presented in Chapter 2. Waste streams are another foundation of high-quality recycling and should be as pure as possible in order to facilitate recycling. One way of achieving this is to reclaim plastic products following their use phase as part of a manufacturer-supported take-back system. Chapter 3 therefore presents some basic considerations regarding take-back systems for construction products and outlines existing systems. Chapter 4 provides an overview of the technical processes used in recycling, as well as the handling of plastic waste pollutants. In the interests of high-quality recycling, plastic waste from building products should be recycled as much as possible and reused in the same applications. With respect to this, Chapter 5 describes the possibilities and limits of the use of recyclates. Plastic is also used in the packaging of construction products. Chapter 6 presents an overview of the products, types of plastic, and quantities used for this purpose, in addition to the possibility of utilizing recyclates in packaging. Finally, Chapter 7 builds on the previous chapters to advance recommendations for the promotion of high-quality recycling.

Chapter 2 – Market research on plastic construction products

Chapter 2 presents a comprehensive list of construction products that are primarily made of plastics. The list is based on the harmonized specifications (hEN and EAD) of European Construction Products Regulation (EU) No. 305/2011, as well as the administrative regulation template for technical building regulations (especially parts B, C and D). In addition, reference is made to both technical literature and manufacturer and dealer information. The list, which is attached as a supplement in xls format, consists of more than 240 construction products and is divided into four different levels. Level 1, the highest level of aggregation, differentiates between *pipes, window profiles, insulation materials*, and *others*, and these applications are subsequently broken down into increasingly finer detail, with specific building products listed up to level 4, in addition to further information on relevant standards and types of plastic used.

The market volumes of currently-manufactured and utilized construction products are presented, with corresponding association and industry statistics and data from the technical literature and German Federal Statistical Office serving as the sources. The production volume of plastic building products calculated for Germany in 2017 totaled around 3.3 million tonnes, whereas the volume used was around 2.6 million. If one breaks down the percentages of these quantities, 30% can be attributed to the application areas of *pipes* and *others*, 22% to *profiles*, and around 18% to *insulation materials*. In the domain of pipes, polyethylene (PE) and polyvinyl chloride unplasticized (PVC-U), known as rigid PVC, are the most widely-used types. In profiles, too, PVC-U is by far the most prominent plastic, followed by PE. For insulation materials, expanded polystyrene (EPS) is the most widely used, followed by polyurethane (PUR), and extruded polystyrene (XPS). The predominant types of plastic used in the other application areas are PVC and bitumen. If all four of these application areas are combined, PVC constitutes the most frequently-used plastic in construction products.

In addition to determining the market volumes and their breakdown by application and plastic types, the anthropogenic plastic stockpile accounted for by the construction sector is estimated. The calculations for this utilize data from the Conversio study and the waste statistics of the German Federal Statistical Office. Overall, a total input into the anthropogenic stockpile of around 30.3 million t of plastics was assumed for the period between 2005 and 2017. The output quantity for the same period, on the other hand, amounted to approximately 7.9 million t. Thus, in this timeframe, the anthropogenic stockpile can be estimated to have grown by around 22.4 million t, corresponding to an average annual increase of 1.7 million t of plastics. Projections indicate that the output quantity from this anthropogenic stockpile will roughly double by 2030 compared to that from 2005.

The comparatively long service lives of construction products mean that waste streams currently being recycled contain plastics that are decades old, while currently-utilized (plastic) materials will not be found in the waste stream for several decades. This state of affairs, and in particular the presence of unknown or hazardous ingredients contained in old products, makes the mechanical recycling of plastic construction products more difficult. In individual cases, therefore, a well-founded analysis of the viability of recycling or reclaiming these plastics is necessary.

Chapter 3 – Take-back schemes

Chapter 3 addresses existing take-back schemes for plastic construction products. Through these systems, products are recovered following their use phases and recycled. Ideally, recyclates obtained in this way are also recycled, but downcycling to products with lower material requirements is also possible. Take-back schemes are investigated in more detail as part of this project, as they offer the potential for highly pure material flows. These in turn will form the basis for processing into high-quality recyclates.

The following criteria for the successful operation of a take-back system were obtained from expert interviews: Sufficiently high and locally-concentrated quantities of material, with the possibility of selective deconstruction of the recovered products; no contamination of the materials, e.g., by additives hazardous to health or quality-reducing impurities; and an economically-operable recycling process. Additionally, the experts noted the following hurdles for the establishment of recycling systems: the technical difficulties and economic feasibility of removing pollutants; the often poorly-defined properties of recyclates compared to virgin material; the insufficient qualifications of employees; and the legal jurisdiction handling the pollutants.

The relevant standards, especially for the use of recyclates, are outlined in the context of take-back schemes. It is concluded that in legal terms, there are no acute, substantial obstacles to the operation of take-back-systems.

Twelve existing take-back schemes are analyzed. They mainly correspond to the areas of floor coverings, pipes and PVC products. With the exception of agricultural films, the quantities taken back are in the single-digit percentage range of the total production quantities. The take-back schemes are characterized individually on the basis of the products and materials processed, the quantities taken back, and the recycling and logistics processes entailed. Especially for the area of PVC recycling, various take-back schemes with high-quality recycling protocols have been established.
While the recycling of floor coverings is demanding, it is shown that it can be made possible via take-back schemes. However, existing take-back solutions are manufacturer-specific. A multi-manufacturer, industry-wide solution would therefore be advantageous; especially in

combination with recycling-friendly product design (designed for recycling). Such a take-back system would offer hitherto untapped potential.

In the pipe sector, the technological foundations for high-quality recycling have been laid, and a functioning take-back system also operates. However, dismantling following the use phase usually proves to be economically difficult. Meanwhile, insulation materials are not recovered, apart from construction site waste.

Chapter 4 – Recycling technology

Chapter 4 provides an overview of the processing and recycling technologies used in the construction sector. The recycling options available are mechanical- and chemical-based. In accordance with the definition of recycling contained in the Circular Economy Act (KrWG), thermal energy recovery is not considered a viable recycling option. The focus of this chapter is on mechanical recycling by means of sorting and recompounding. Solvent-based processes are shown if they are relevant to the specific context, e.g., PA6 from carpet fibers. The individual steps of waste collection and pre-treatment for waste generated in the construction sector are explained. This includes the shredding, cleaning and sorting of the waste and is followed by one of the central process steps, namely recompounding. Its individual sub-steps, such as plasticizing, melt-filtering or granulating, as well as their importance in the recycling of construction plastics are outlined.

Mechanical recycling is presented for the plastic types identified as the most relevant in terms of volume, and the specific features of construction product plastics are discussed. In addition, the mechanical recycling of the most important product groups is described. Glass-fiber reinforced plastic (GRP) is an especially demanding material for recycling. The options for mechanical recycling, use as an aggregate, and chemical recycling are explained. Use as an aggregate would be possible but also involves risks and is energy-intensive, as the GRP must be ground down to fine particles.
Possible applications as a substitute fuel are considered possible with respect to the calorific value of the GRP, but can only be used successfully in special cases due to the composition of glass and its influence on, e.g., cement quality.

Chapter 5 – The use of recycled material in plastic construction products

In Chapter 5, the potential use of recycled materials in plastic construction products is considered. For this purpose, an evaluation is first carried out with respect to the quality and quantity of plastic waste produced, as the quality of recyclates is largely determined by the quality of the secondary raw materials used. Purity of type, the reduction of impurities, and the integrity of the polymer chains are important parameters for assessing input quality. The application of design-for-recycling concepts in product development also favors recycling and establishes a good starting point for the production of high-quality recyclates.

The quantitative recording of the plastic waste generated in 2017 amounts to 6,154 kt, of which around 5,201 kt can be allocated to the post-consumer sector and around 953 kt to the post-industrial one (i.e., waste generated by producers and processors). 52.7 % of this plastic waste was recycled for energy and thus removed from the material cycle, whereas 46.7% was sent for material recycling.

The compiled figures show an imbalance of existing waste and the required qualities or types of plastics in the construction industry for different materials. In principle, it can be assumed that plastic waste from the post-industrial sector can be classified as being of higher quality than that from the post-consumer sector. Whether a transfer of secondary plastics from non-construction areas of application can be viable must be questioned on a case-by-case basis against the backdrop of the additional additives required and the conservation of quantities in the respective system. In principle, a genuine closed-loop system should be sought. Ideally, this would mean using take-back schemes to keep the respective material and product cycle closed, which already works well in the case of PVC. The PVC recycling loop leads to relatively high construction sector-specific recyclate use rates, even if demand cannot yet be fully met. The supply of qualitatively suitable recyclates must therefore be increased to meet specific demand. This also applies to other types of plastics.

Furthermore, the prerequisites for the use of recyclates in the manufacturing of construction products are presented. On the one hand, the use of recycled materials must correspond to the basic requirements of the European Construction Products Regulation (CPR), and on the other, standards and customer requirements must be met. The CPR requires, among other things, that the use of natural resources be sustainable. In concrete terms, this means that the structure or raw materials it contains must be reused or recycled following demolition. The structure must also be durable and environmentally-friendly raw and secondary materials must be used for its construction. Durability, recyclability and the use of recycled materials are properties that are generally taken into account by legislators, but normative and product-specific concretization is often lacking. In principle, many standards already permit the use of recycled material, but the use of such is often still viewed critically by plastic processors and customers. In the following, the potential for the use of recycled material in the four areas of application examined – *pipes, profiles, insulation* and *others* – is shown.

Pipes

The variety of pipe and tube systems is large, which is why corresponding quality requirements must be met, depending on the application. These include, for instance, mechanical properties or color. Current standards already provide good indications with respect to the use of recycled materials. In the case of pressurized pipes, the standards do not permit the use of recyclates or recovered materials, whereas up to 20% is permitted for non-pressurized pipes. Of course, this only applies under the condition that all requirements such as mechanics or optics are sufficiently fulfilled. The type of plastic used also has a limiting effect on the possibilities of using recycled material. The subsequent stabilization of PVC is relatively easy to carry out, which is why it is possible to reuse it as a recyclate. This is more difficult with polyolefins. For this reason, the standards only permit return material and recyclates from pipes and pipe fittings. Totaling more than one million tonnes, pipes and pipe systems represent the largest share of the construction products examined in terms of volume. The supply of recyclates cannot currently meet demand from companies, which is why the potential for using recyclates in this context has not yet been exhausted.

Window profiles

Currently, 18% of recycled materials are used in the production of window profiles, and a well-functioning material cycle has already been established. According to experts, however, there is a potential for using up to 50–70% recycled material. The reasons for this still-unused potential are complex. On the one hand, there are economic factors. The development and application of suitable technologies are highly cost-intensive. The high prices for recyclates also reduce their increased use. Moreover, current standards also limit the use of recyclates. In principle, high demands are made on window profiles with respect to weathering and UV stability. Recyclates may be used in the profile core, but the corresponding standard does not permit this in the outer wall. The trend towards composite systems also reduces the good recyclability of old windows.

As with pipes, the demand for recycled material in window profiles cannot be met by the existing supply.

Insulation materials

Compared to pipes and window profiles, the current situation for insulation materials with regard to the use of recyclates is profoundly worse. Appropriate take-back schemes have not yet been established because the quantities of recycled material are currently too small. The use of recycled material also leads to significant quality losses. Mechanical recycling is therefore not ideal for insulation materials, which is why feedstock recycling appear to be more promising in this instance.

Others

The areas of application for the use of plastic recyclates in other construction products are highly diverse. Many applications in road construction and garden and landscape development have already been established and are possible. Products corresponding to *Part D of the Model Administrative Regulation on Technical Building Regulations* are also suitable in principle, as no proof of usability must be provided here, and there are no recognized rules of technology for this. Another advantage is that due to the relatively small product quantities, the available recyclate quantities do not have a limiting effect, as is the case with pipes and window profiles. The application area *others* thus proves to be promising as far as the use of recyclate in construction products is concerned.

Chapter – 6 Plastic packaging for construction products

Chapter 6 describes the plastic packaging used for construction products and identifies possibilities for more circular usage, such as avoidance and increased use of recycled materials. PE films make up a large share here. First, the packaging volume is estimated on the basis of the three domains of packaging production, packaging use, and packaging consumption. The use of plastics for construction product packaging amounts to approximately 170 kt/a and the production of construction product packaging made of plastics to an estimated 368 kt/a. On the one hand, the difference is due to the export surplus; on the other, these figures can only be interpreted as rough estimates due to the sparse data available.

Both the approaches of eliminating packaging and improving packaging design can be used to reduce the amount of packaging plastic. The use of reusable solutions also offers options for waste avoidance. The ecological benefit of a reusable solution strongly depends on its design.

The recyclability of packaging also depends on both the separation of waste and a design that is suitable for recycling. Some of the packaging is disposed of via the German dual systems and recycled accordingly. However, the majority is covered by the law on commercial waste. According to this law, there is a basic obligation to separately collect and transport plastics from other waste fractions. However, existing exemptions are often used. Material recycling takes place for sufficiently separated and uncontaminated fractions of construction packaging. For many construction packaging materials, recyclates can also be used for production. Examples of products using recycled material are given for the various product categories and plastics. Due to the lower requirements compared to food packaging, recycled material can be used comparatively well in the area of films for packaging of construction material. A recyclate use of 30% seems to be technically-feasible and should be mandatory in the medium-term through the use of a corresponding recyclate quota.

Chapter 7 – Recommendations

In chapter 7, recommendations are provided on how to increase plastic recycling in the construction sector. An important and easy-to-implement approach is to document recyclability and recyclate content. This can be performed in the technical documentation of the products in the separate section, "Recyclability."

Moreover, recyclates can be used in films used as construction product packaging. This should also be determined within a recycled material quota. The demand thus created will enable and accelerate the transformation to further closed-loop recycling.

In addition, it is recommended to include design-for-recycling in the product design and to consistently implement the separation of waste in order to create pure, recyclable waste streams.

Zusammenfassung

Nach den Verpackungen sind Bauprodukte das zweitgrößte Einsatzgebiet von Kunststoffen. Die Menge an Kunststoff, die in Bauprodukten verwendet wird, steigt jährlich an und übertrifft die Menge an entsorgten Bauprodukten, sodass das anthropogene Lager an Kunststoffen wächst. Diese Kunststoffe werden erst in der Zukunft als Abfall anfallen und müssen dann einer ressourceneffizienten Verwertung zugeführt werden. Dieser Bericht betrachtet die zur Förderung einer hochwertigen Verwertung notwendigen Aspekte der Produktion und des Recyclings von Baukunststoffen.

Grundlage für ein hochwertiges Recycling der Kunststoffe ist das Wissen über Mengen und Kunststofftypen der derzeit verbauten Produkte. Die Daten wurden in diesem Vorhaben erhoben, die Ergebnisse hierzu sind in Kapitel 2 dargestellt. Eine weitere Grundlage für ein hochwertiges Recycling sind möglichst reine Abfallströme, die das Recycling erleichtern. Eine Möglichkeit, dies zu erreichen, ist die Rücknahme der Kunststoffprodukte nach Ihrer Nutzungsphase durch ein herstellergestütztes Rücknahmesystem. Kapitel 3 erläutert daher grundlegende Erwägungen zu Rücknahmesystemen für Bauprodukte und stellt vorhandene Systeme vor. Kapitel 4 gibt eine Übersicht über die beim Recycling verwendeten technischen Prozesse, sowie über den Umgang mit Schadstoffen in Kunststoffabfällen. Im Sinne einer hochwertigen Verwertung sollen die Kunststoffabfälle aus Bauprodukten möglichst recycelt und in einer gleichwertigen Anwendung wiedereingesetzt werden. Hierzu beschreibt Kapitel 5 die Möglichkeiten und Grenzen des Rezyklateinsatzes. Auch für Verpackungen von Bauprodukten wird Kunststoff eingesetzt. Kapitel 6 gibt eine Übersicht über die hier verwendeten Produkte, Kunststoffsorten und Mengen sowie über die Möglichkeit des Rezyklateinsatzes in diesen Verpackungen. Abschließend werden aus den vorangegangenen Kapiteln abzuleitende Empfehlungen für eine Förderung der hochwertigen Verwertung in Kapitel 7 vorgestellt.

Kapitel 2 - Marktrecherche für Bauprodukte aus Kunststoff

In Kapitel 2 wird eine umfassende Produktliste mit überwiegend aus Kunststoffen gefertigten Bauprodukten dargestellt. Als Grundlage dient die Liste der harmonisierten Spezifikationen (hEN und EAD) nach europäischer Bauproduktenverordnung (EU) Nr. 305/2011, sowie die Musterverwaltungsvorschrift für Technische Baubestimmungen (speziell die Teile B, C und D). Zudem wird auf Fachliteratur sowie Hersteller- und Händlerangaben zurückgegriffen. Die im xls-Format als Supplement beigefügte Liste umfasst mehr als 240 Bauprodukte und untergliedert sich in vier unterschiedliche Ebenen. Während Ebene 1 als höchste Aggregationsebene in *Rohre*, *Fensterprofile*, *Dämmmaterialien* und *Sonstiges* unterscheidet, werden diese Anwendungsbereiche unter Auflistung spezifischer Bauprodukte bis hin zu Ebene 4 immer feiner aufgeschlüsselt und weiterführende Informationen, wie relevante Normen und verwendete Kunststoffsorten aufgeführt.

Es werden die aktuell produzierten, sowie verbauten Marktmengen der betrachteten Bauprodukte dargestellt. Als Quellen dienten entsprechende Verbands- und Branchenstatistiken, Daten aus der Fachliteratur sowie des Statistischen Bundesamtes. Die für Deutschland ermittelte Produktionsmenge an Bauprodukten aus Kunststoff beträgt für das Jahr 2017 rund 3,3 Mio. t., die verbaute Menge hingegen beträgt circa 2,6 Mio. t. Betrachtet man die prozentuale Aufteilung der verbauten Mengen, so sind jeweils 30 % auf die Anwendungsbereiche *Rohre* sowie *Sonstiges* zurückzuführen, 22 % auf *Profile* und rund 18 % auf *Dämmmaterialien*. In Rohren kommen überwiegend Polyethylen (PE) und Polyvinylchlorid unplasticized (PVC-U), unter der Bezeichnung Hart-PVC bekannt, zum Einsatz. Auch bei Profilen ist PVC-U mit Abstand der am meisten verwendete Kunststoff, gefolgt von Polyethylen (PE). Als Dämmstoff kommt vor allem expandiertes Polystyrol (EPS) zum Einsatz, gefolgt von

Polyurethan (PUR) und extruidertes Polystyrol (XPS). Die dominierenden Kunststoffsorten des Anwendungsbereichs Sonstiges sind PVC und Bitumen. Fasst man alle vier genannten Anwendungsbereiche zusammen ist PVC der am häufigsten eingesetzte Kunststoff in Bauprodukten.

Neben der Ermittlung der Marktmengen und deren Aufteilung nach Anwendungsart sowie Kunststoffsorte, erfolgt die Abschätzung des anthropogenen Kunststofflagers im Bausektor. Die Berechnungen hierfür basieren auf Daten der Conversio-Studie sowie der Abfallstatistik des Statistischen Bundesamtes. Insgesamt wird für den Zeitraum zwischen 2005 und 2017 von einer Inputmenge in das anthropogene Lager von rund 30,3 Mio. t an Kunststoffen ausgegangen. Die Outputmenge beläuft sich hingegen für den gleichen Zeitraum auf etwa 7,9 Mio. t. Für den Zeitraum von 2005 bis 2017 kann der Zuwachs des anthropogenen Lagers somit auf rund 22,4 Mio. t geschätzt werden, was einem durchschnittlichen jährlichen Zuwachs von 1,7 Mio. t Kunststoffen entspricht. Hochrechnungen zeigen, dass sich die Outputmenge des anthropogenen Lagers bis 2030, gegenüber der Menge des Outputs im Jahr 2005, in etwa verdoppeln wird.

Die vergleichsweise langen Nutzungsdauern von Bauprodukten führen dazu, dass derzeit rücklaufende Abfallströme Kunststoffe enthalten, die Jahrzehnte alt sind, während gegenwärtig verbaute (Kunststoff-)Materialien erst in mehreren Jahrzehnten im Abfallstrom wiederzufinden sein werden. Diese Tatsache und insbesondere die in alten Produkten enthaltenen unbekannten oder gefährlichen Inhaltsstoffe erschweren das werkstoffliche Recycling von Bauprodukten aus Kunststoff. Im Einzelfall ist daher eine fundierte Überprüfung der Sinnhaftigkeit eines Recyclings bzw. der Rückführung dieser Kunststoffe erforderlich.

Kapitel 3 - Rücknahmesysteme

Kapitel 3 behandelt Rücknahmesysteme für Bauprodukte aus Kunststoffen. Durch diese Systeme werden Produkte nach der Nutzungsphase zurückgenommen und dem Recycling zugeführt. Idealerweise wird das so gewonnene Rezyklat im Kreis geführt, aber auch ein Downcycling zu Produkten mit geringeren Anforderungen an das Material ist möglich. Rücknahmesysteme werden in diesem Vorhaben genauer untersucht, da hier das Potenzial für sehr reine Stoffströme besteht. Diese bilden die Grundlage für eine Verarbeitung zu hochwertigen Rezyklaten.

Folgende Kriterien für den erfolgreichen Betrieb eines Rücknahmesystems wurden aus Experteninterviews abgeleitet: Ausreichend hohe und örtlich konzentrierte Mengen an Material, Möglichkeit des selektiven Rückbaus für die zurückgenommenen Produkte, keine Kontamination der Materialien z. B. mit gesundheitsgefährdenden Additiven oder qualitätsmindernden Verunreinigungen, sowie ein wirtschaftlich betreibbares Recyclingverfahren. Außerdem wurden von den Experten folgende Hürden für die Etablierung der Recyclingsysteme genannt: schwierige technische und ökonomische Realisierbarkeit der Schadstoffentfrachtung, die oft schwankend dargestellten Eigenschaften des Rezyklats im Vergleich zu Neuware, die schlechte Qualifikation der Mitarbeitenden, die Rechtsprechung zum Umgang mit Schadstoffen.

Die relevanten Normen, besonders für den Rezyklateinsatz, werden im Kontext der Rücknahmesysteme vorgestellt. Rechtlich bestehen keine akuten, substantiellen Hindernisse für den Betrieb von Rücknahmesystemen.

Es werden zwölf verschiedene Rücknahmesysteme dargestellt. Sie sind vor allem den Bereichen Bodenbeläge, Rohre und PVC-Produkte zuzurechnen. Mit Ausnahme der Agrarfolien bewegen sich die rückgenommen Mengen im einstelligen Prozentbereich der Produktionsmengen. Die Rücknahmesysteme werden anhand der verarbeiteten Produkte und Materialien, der zurückgenommenen Mengen und anhand des Recycling- und Logistikprozesses einzeln

charakterisiert. Besonders für den Bereich des PVC-Recyclings sind verschiedene Rücknahmesysteme mit hochwertigem Recycling etabliert.
Das Recycling von Bodenbelägen ist anspruchsvoll, kann aber durch Rücknahmesysteme ermöglicht werden. Die hierfür existierenden Rücknahmelösungen sind allerdings herstellerspezifisch. Eine herstellerübergreifende, branchenweite Lösung wäre vorteilhaft. Gerade in Kombination mit einer recyclinggerechten Produktgestaltung (Design-for-Recycling) böte ein solches Rücknahmesystem noch ungehobenes Potenzial.
Im Rohrbereich sind die technologischen Grundlagen für ein hochwertiges Recycling gelegt, auch ein funktionierendes Rücknahmesystem existiert. Allerdings stellt sich hier der Rückbau nach der Nutzungsphase meist als wirtschaftlich schwer darstellbar heraus. Die Rücknahme von Dämmmaterialien findet, abgesehen von Baustellenabfällen, nicht statt.

Kapitel 4 - Verwertungstechniken

Kapitel 4 gibt einen Überblick über die im Baubereich angewendeten Aufbereitungs- und Verwertungstechniken. Als Verwertungsoptionen werden in diesem Bericht das werkstoffliche und das chemische Recycling behandelt. Die energetische Verwertung zählt entsprechend der Recyclingdefinition des Kreislaufwirtschaftsgesetzes (KrWG) nicht zum Recycling. Der Fokus dieses Kapitels liegt auf dem werkstofflichen Recycling durch Sortieren und Recompoundieren. Lösungsmittelbasierte Verfahren werden aufgezeigt, falls Sie im spezifischen Kontext relevant sind, wie z. B. für Polycaprolactam (PA6, Polyamid 6) aus Teppich-Fasern. Die einzelnen Schritte der Abfallerfassung und Vorbehandlung für im Baubereich anfallende Abfälle werden erläutert. Hierzu zählen die Zerkleinerung, Reinigung und Sortierung der Abfälle. Darauf folgt einer der zentralen Prozessschritte, das Recompoundieren. Dessen einzelne Teilschritte, wie z. B. Plastifizieren, Schmelzfiltrieren oder Granulieren, sowie ihre Bedeutung im Recycling von Baukunststoffen werden erläutert.

Für die in Kapitel 2 als mengenmäßig am relevantesten identifizierten Kunststoffsorten wird das werkstoffliche Recycling vorgestellt und auf die für Baukunststoffe spezifischen Besonderheiten eingegangen. Ergänzend wird das werkstoffliche Recycling der wichtigsten Produktgruppen beschrieben. Glasfaserverstärkter Kunststoff (GFK) ist ein für das Recycling besonders anspruchsvoller Werkstoff. Die Recyclingoptionen des werkstofflichen Recyclings, der Verwendung als Zuschlagstoff und des chemischen Recyclings werden beschrieben. Eine Verwendung als Zuschlagstoff wäre möglich, birgt allerdings auch Risiken und das Aufbereitungsverfahren ist angesichts der Zerkleinerung bis auf sehr geringe Korngrößen energieaufwendig.
Die Möglichkeit der Verwendung als Ersatzbrennstoff wird zwar hinsichtlich des Brennwertes der GFK als möglich angesehen, kann aber aufgrund der Glaszusammensetzung und deren Einfluss auf die Zementqualität nur in speziellen Fällen erfolgreich eingesetzt werden.

Kapitel 5 - Rezyklateinsatz in Bauprodukten aus Kunststoff

Im Kapitel 5 erfolgt die Ermittlung des Einsatzpotentials von Rezyklaten in Bauprodukten aus Kunststoff. Hierfür wird zunächst eine Bewertung hinsichtlich Qualität und Quantität der anfallenden Kunststoffabfälle durchgeführt, denn die Qualität von Rezyklaten wird maßgeblich von der Beschaffenheit der aufzubereitenden Abfälle bestimmt. Sortenreinheit, die Reduktion von Störstoffen und Verunreinigungen, sowie Unversehrtheit der Polymerketten sind wichtige Parameter zur Beurteilung der Inputqualität. Auch die Anwendung von Design-for-Recycling-Konzepten bei der Produktentwicklung begünstigt die Wiederverwertung und schafft eine gute Ausgangsbasis für die Herstellung hochwertiger Rezyklate. Prinzipiell kann davon ausgegangen werden, dass Kunststoffabfälle aus dem Post-Industrial-Bereich (d.h. bei Produzenten und Verarbeitern angefallener Abfall) als qualitativ hochwertiger einzustufen sind als aus dem Post-

Consumer-Bereich. Die quantitative Erfassung der im Jahr 2017 insgesamt aus allen Anwendungsbereichen angefallenen Kunststoffabfälle beläuft sich auf 6.154 kt, wovon rund 5.201 kt dem Post-Consumer-Bereich und rund 953 kt dem Post-Industrial-Bereich zugeordnet werden können. 52,7 % dieser Kunststoffabfälle wurden energetisch verwertet und somit dem Materialkreislauf entzogen, 46,7 % wurden der stofflichen Verwertung zugeführt (Lindner und Schmidt 2018).

Die recherchierten Zahlen zeigen für unterschiedliche Werkstoffe ein Ungleichgewicht vorhandener Abfälle und benötigter Qualitäten bzw. Kunststoffsorten im Bauwesen auf. Ob ein Transfer von Rezyklaten aus baufremden Anwendungsbereichen sinnvoll sein kann, ist vor dem Hintergrund des zusätzlich nötigen Additiveinsatzes sowie der Mengenerhaltung im jeweiligen System im Einzelfall zu hinterfragen. Grundsätzlich sollte eine echte Kreislaufführung angestrebt werden. Dies bedeutet im Idealfall über Rücknahmesysteme den jeweiligen Material- und Produktkreislauf geschlossen zu halten, wie es bei PVC bereits gut funktioniert. Der PVC-Recyclingkreislauf führt zu relativ hohen baubranchenspezifischen Rezyklateinsatzquoten, wenn auch hier die Nachfrage noch nicht völlig bedient werden kann. Das Angebot an qualitativ passendem Rezyklat muss daher der spezifischen Nachfrage entsprechend vergrößert werden. Dies gilt auch für andere Kunststoffsorten.

Ferner werden die Voraussetzungen für den Einsatz von Rezyklaten zur Herstellung von Bauprodukten dargestellt. Dazu müssen die aktuellen chemikalienrechtlichen Anforderungen erfüllt werden. Der Rezyklateinsatz muss den Grundanforderungen der europäischen Bauproduktenverordnung (BauPVO) sowie den Vorgaben der harmonisierten Spezifikationen genügen. Zugleich sind Kundenwünsche zu erfüllen. Die BauPVO fordert u. a., dass eine nachhaltige Nutzung der natürlichen Ressourcen gegeben ist. Konkret bedeutet dies, dass das Bauwerk bzw. die enthaltenen Rohstoffe nach dem Abriss wiederverwendet oder recycelt werden müssen. Auch muss das Bauwerk dauerhaft sein und für dessen Errichtung umweltverträgliche Roh- und Sekundärstoffe verwendet werden. Dauerhaftigkeit, Recyclingfähigkeit und Rezyklateinsatz sind Eigenschaften, die durch den Gesetzgeber zwar grundsätzlich Berücksichtigung finden, die normative und produktspezifische Konkretisierung bleibt jedoch oftmals aus. Prinzipiell erlauben bereits viele Normen den Rezyklateinsatz, jedoch wird der Einsatz von derartigem Sekundärmaterial von Verarbeiter- und Kundenseite häufig noch kritisch gesehen. Nachfolgend wird das Rezyklateinsatzpotential der vier untersuchten Anwendungsbereiche *Rohre, Profile, Dämmung* und *Sonstiges* aufgezeigt.

Rohre

Die Vielfalt an Rohren- und Rohrsystemen ist groß, weshalb je nach Anwendungsfall entsprechende Qualitätsanforderungen erfüllt werden müssen. Diese umfassen beispielsweise mechanische Eigenschaften oder auch die Farbe. Die aktuellen Normen geben hier bereits sehr gute Anhaltspunkte hinsichtlich der Möglichkeiten des Rezyklateinsatzes. Bei druckbelasteten Rohren lassen die Normen keinen Einsatz von Rezyklat oder Rücklaufmaterial zu, bei drucklosen Rohren hingegen sind bis zu 20 % gestattet. Dies gilt natürlich nur unter der Voraussetzung, dass alle Anforderungen wie beispielsweise Mechanik oder Optik hinreichend erfüllt werden. Auch die verwendete Kunststoffsorte wirkt sich limitierend auf die Möglichkeiten des Rezyklateinsatzes aus. Eine nachträgliche Stabilisierung von PVC ist relativ einfach durchzuführen, weshalb ein erneuter Einsatz als Rezyklat gut möglich ist. Bei Polyolefinen (PO) gestaltet sich dies schwieriger. Aus diesem Grund lassen die Normen hier nur Rücklaufmaterial und Rezyklate aus Rohren und Rohrformteilen zu. Mit über 1 Mio. t stellen Rohre und Rohrsysteme mengenmäßig den größten Anteil an den untersuchten Bauprodukten dar. Das Angebot an Rezyklaten kann aktuell nicht die Nachfrage der Unternehmen decken, weshalb das Rezyklateinsatzpotential hier noch nicht ausgeschöpft ist.

Fensterprofile

Bei der Fensterprofilproduktion kommen aktuell 18 % Rezyklate zum Einsatz, zudem hat sich bereits ein gut funktionierender Materialkreislauf etabliert. Laut Experten ist das Rezyklateinsatzpotential mit 50–70 % jedoch weitaus höher. Die Gründe für das noch ungenutzte Potenzial sind vielschichtig. Zum einen sind hier wirtschaftliche Ursachen zu nennen. So sind die Entwicklung und Anwendung von geeigneten Technologien sehr kostenintensiv. Auch die hohen Preise für Rezyklate mindern deren verstärkten Einsatz. Zum anderen limitieren auch die aktuellen Normen den Rezyklateinsatz. Prinzipiell werden hohe Anforderungen bzgl. Bewitterung und UV-Stabilität an Fensterprofile gestellt. Im Profilkern dürfen Rezyklate eingesetzt werden, in der Außenwandung gestatten es die Vorgaben nicht. Auch der Trend in Richtung Verbundsysteme schmälert die gute Recyclingfähigkeit von Altfenstern. Analog zu den Rohren kann auch bei den Fensterprofilen die Nachfrage nach Rezyklaten nicht durch das bestehende Angebot abgedeckt werden.

Dämmmaterialien

Im Vergleich zu Rohren und Fensterprofilen ist die aktuelle Situation bei Dämmmaterialien hinsichtlich Rezyklateinsatz grundsätzlich als schlechter zu bewerten. Entsprechende Rücknahmesysteme sind noch nicht etabliert, da die Rückbaumengen gegenwärtig zu gering sind. Auch kommt es beim Einsatz von Rezyklat zu signifikanten Qualitätseinbußen. Ein werkstoffliches Recycling ist daher bei Dämmmaterialien nicht ideal, weshalb rohstoffliche Verfahren aussichtsreicher erscheinen.

Sonstiges

Die Anwendungsbereiche für den Einsatz von Kunststoffrezyklaten bei den sonstigen Bauprodukten sind sehr divers. Viele Anwendungen im Straßen- sowie Garten- und Landschaftsbau sind bereits etabliert und gut möglich. Auch Produkte entsprechend *Teil D der Musterverwaltungsvorschrift Technische Baubestimmungen* sind prinzipiell gut geeignet, da hier keine Verwendbarkeitsnachweise erbracht werden müssen und es hierfür keine anerkannten Regeln der Technik gibt. Ein weiterer Vorteil ist, dass aufgrund der relativ geringen Produktmengen die verfügbaren Rezyklatmengen nicht limitierend wirken, wie dies bei den Rohren und Fensterprofilen der Fall ist. Der Anwendungsbereich *Sonstiges* erweist sich demnach als aussichtsreich, was den Einsatz von Rezyklat in Bauprodukten anbelangt.

Kapitel 6 - Kunststoffverpackung für Bauprodukte

Kapitel 6 beschreibt die für Bauprodukte verwendeten Kunststoffverpackungen und ermittelt Möglichkeiten zur Kreislaufführung wie Vermeidung und verstärktem Rezyklateinsatz. Einen großen Anteil haben hier PE-Folien. Zunächst wird das Verpackungsaufkommen anhand der drei Ebenen Verpackungsmittelproduktion, Verpackungseinsatz und Verpackungsverbrauch abgeschätzt. Der Einsatz von Kunstoffen für Bauproduktverpackungen beträgt ca. 170 kt/a, die Produktion von Bauproduktverpackungen aus Kunststoff schätzungsweise 368 kt/a. Der Unterschied kommt einerseits durch den Exportüberhang zustande andererseits sind diese Zahlen aufgrund der spärlichen Datenlage nur als grobe Schätzungen zu interpretieren.

Sowohl Ansätze des Verpackungsverzichtes als auch eine Verbesserung des Verpackungsdesigns lassen sich für die Reduktion des Verpackungseinsatzes nutzen. Auch der Einsatz von Mehrweglösungen bietet Optionen für die Abfallvermeidung. Der ökologische Nutzen einer Mehrweglösung hängt dabei stark von ihrer Ausgestaltung ab.

Für die Recyclingfähigkeit der Verpackungen ist sowohl die Getrennthaltung der Abfälle als auch ein recyclinggerechtes Design notwendig. Teile des Verpackungsaufkommens werden über die Dualen Systeme entsorgt und dementsprechend recycelt. Der Großteil fällt hingegen unter die

Gewerbeabfallverordnung. Nach dieser besteht grundsätzlich die Pflicht, Kunststoffe von anderen Abfallfraktionen getrennt zu sammeln und zu befördern. Es wird allerdings häufig von den vorhandenen Ausnahmeregelungen Gebrauch gemacht. Für ausreichend getrennte und unverschmutzte Fraktionen der Bauverpackungen findet ein werkstoffliches Recycling statt. Für viele der Baustoffverpackungen kann auch Rezyklat zur Produktion verwendet werden. Zu den verschiedenen Produktkategorien und Kunststoffen werden Beispiele für Produkte mit Rezyklateinsatz genannt. Aufgrund der, im Vergleich zu Lebensmitteln, geringeren Anforderungen lässt sich im Bereich der Folien für Baustoffverpackungen vergleichsweise gut Rezyklat einsetzen. Ein Rezyklateinsatz von 30 % erscheint technisch machbar und sollte mittelfristig durch eine entsprechende Rezyklatquote festgelegt werden.

Kapitel 7 - Empfehlungen

In Kapitel 7 werden Empfehlungen zur Steigerung des Kunststoffrecyclings im Baubereich gegeben. Ein wichtiger und einfach umzusetzender Ansatz ist die Dokumentation der Recyclingfähigkeit und des Rezyklatgehaltes. Dies kann in der technischen Dokumentation der Produkte unter einem gesonderten Abschnitt „Nachhaltige Nutzung der natürlichen Ressourcen” erfolgen.
Des Weiteren kann in den als Bauproduktverpackung verwendeten Folien Rezyklat eingesetzt werden. Dies sollte als Rezyklatquote auch festgeschrieben werden. Durch die so entstehende Nachfrage wird die Transformation zu mehr Kreislaufführung ermöglicht und beschleunigt. Zudem wird empfohlen, Design-for-Recyclingin das Produktdesign einzubeziehen und die Getrennthaltung der Abfälle konsequent umzusetzen, um reine, recyclingfähige Abfallströme zu schaffen.

1 Introduction

The construction sector is the second-largest consumer of plastics after the packaging sector. The amount of plastics used in construction products is increasing annually and exceeds the amount of construction products disposed of. Thus, an anthropogenic stockpile of plastics is continually growing. These plastics will in turn become waste in the coming decades, and must then be recycled in a resource-efficient manner. This report analyzes the aspects of construction plastic production and recovery necessary for promoting high-quality recycling.

The high-quality recycling of plastic requires knowledge of the quantities and types of plastics currently being used. Data on this were collected for this project, and are presented in Chapter 2. Waste streams are another foundation of high-quality recycling and should be as pure as possible in order to facilitate it. One way of achieving this is to reclaim plastic products following their use phase as part of an appropriate take-back system. Chapter 3 therefore presents some basic considerations regarding take-back systems for construction products, and outlines existing schemes. Chapter 4 provides an overview of the technical processes used in recycling, as well as the handling of plastic waste pollutants. In the interests of high-quality recycling, plastic waste from building products should be recycled as much as possible and reused in the same applications. With respect to this, Chapter 5 describes the possibilities and limits of the use of recyclates. Plastic is also used in the packaging of construction products and Chapter 6 presents an overview of the products, types of plastic, and quantities used for this purpose, in addition to the possibility of utilizing recyclates in packaging. Finally, Chapter 7 builds on the previous chapters to advance recommendations for promoting high-quality recycling.

2 Market research on plastic building products in Germany

The basis of this report is a comprehensive product list of construction products that are primarily – or oftentimes – made of plastics. In order to compile this list, extensive literature and internet research was conducted, in addition to interviews with experts, associations, manufacturers, and other stakeholders. The construction products investigated were divided into thermoplastics, thermosetting plastics, elastomers, and composites. The determination of the current market volumes, waste volumes and growth rates of the plastic products associated with the construction sector also enables conclusions to be drawn regarding developments in the anthropogenic stockpile over the last few years. The product list compiled in this manner is very extensive (see the Appendix). The results of this investigation were also fully collated in a data table in the form of an .xlsx file, which is published as a supplement to this report. A detailed description of the contents and functionalities of this supplement is also provided. The results of Chapter 2 form the basis for the subsequent procedures undertaken for this study.

2.1 Methodology

2.1.1 Procedure for compiling the product list of plastic construction products

The lists of harmonized specifications (hEN and EAD) derived from European Construction Products Regulation (EU) No. 305/2011, as well as the administrative regulation template for technical building regulations (especially parts B, C and D), initially served as the basis for the compilation of the comprehensive product list of plastic construction products used herein (German Institute for Construction Technology (DIBt) 2017; European Commission 2018b).

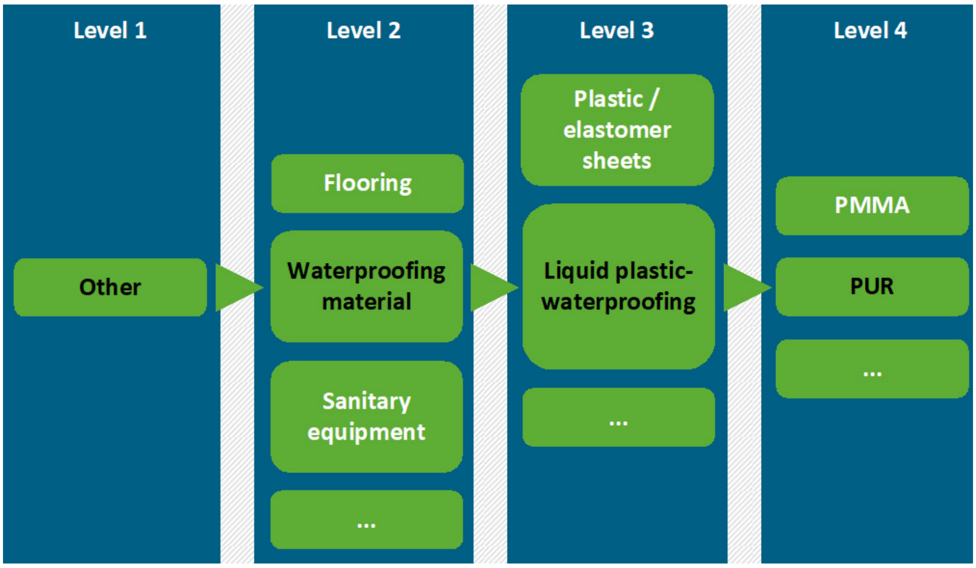
The aforementioned lists and ordinances were reviewed with respect to construction products predominantly plastic- or bitumen-based, and the relevant construction products were noted and included in the product list. The level of detail of the listed construction products varied considerably, especially in relation to the specification of the types of plastics used to manufacture the corresponding construction products.

In the case of plastic piping systems, for instance, the administrative regulation for technical building regulations template has a high level of detail regarding the types of plastic commonly used (e.g., polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), etc.), and the data could be directly transposed to product ranges (German Institute for Construction Technology (DIBt) 2017). However, for the majority of the construction products considered, such a level of detail in terms of the plastics used was not possible within the harmonized lists, regulations and standards. If no detailed information on the material normally used was available for a plastic construction product, a supplementary literature and Internet review was undertaken. The data collected in this manner was collected almost exclusively from the technical literature or corresponded to information provided by manufacturers and distributors.

In order to ensure the clarity of the compiled product list, the construction products being evaluated were classified into four levels. The level structure – starting with the lowest level 4 – is briefly outlined below.

Level 4 contains over 240 analyzed plastic construction products (these were not manufacturer-specific units) for which both the type of application and plastic used in their manufacturing were determined. This level was the highest in terms of detail. These construction products were initially classified into more than 50 parent product categories at level 3, which were subsequently further subdivided into 14 parent product categories at level 2. Finally, the 14 product categories were divided into the four existing areas of *pipes, insulation, profiles,* and *others* at level 1. Figure 1, below, depicts the structure of the compiled product list of plastic construction products made in Germany using the example of liquid plastic sealant, comprised of polyurethane (PUR).

Figure 1. Structure of the product list with the example of liquid plastic seals made of PUR.



Source: Own representation SKZ – Das Kunststoff-Zentrum.

In addition to fostering clarity, the adopted structure has further advantages. For many of the detailed, material-specific products at level 4 (e.g., shower trays made from polymethyl methacrylate (PMMA)), we have no separate information on current market volumes, unlike general product types on parent level 3 (e.g., for bathtubs and shower trays in general). Furthermore, the breakdown into the four sub-sectors of *pipes, insulation, profiles*, and *others* enables a comparison of the quantities determined in the Conversio study, "Material flow picture plastics in Germany 2017," in which construction products made of plastics were divided up in a similar manner (Lindner and Schmidt 2018). Thereby, a comparison of the data collected for the present study with that from the Conversio one will be possible later.

2.1.2 Procedure for estimating current market quantities

After identifying the various plastic construction products, an assessment of current market volumes (in terms of quantities produced and installed) was conducted. For the time being, data from the production statistics of the German Federal Statistical Office according to the list of goods (nine-digit data) were used as the basis for the production quantities (Destatis and Genesis-Online 2020b). The nine-digit data are collected and published quarterly, and provide information on the quantities of selected goods produced in Germany. Division 22 of the index of goods contains information on annually-produced quantities of rubber and plastic goods. Products that can be assigned to the construction sector are to be found in goods class 2223 (plastic construction materials), as well as in class 2221 (plastic sheets, foils, hoses, and profiles).

However, a review and assessment quickly indicated that the data from the Federal Statistical Office alone is insufficient for clearly allocating the varying production volumes to the respective construction products researched. Although the Federal Statistical Office can provide initial production quantities for various construction products, the structure of the data used is problematic. As a general rule, the nine-digit numbering and product designations include a number of sometimes greatly differing construction products made of plastics. For instance, floor, wall and ceiling coverings made from plastics are not separately listed, but as a common category, without any conclusion possible regarding distribution to the respective, individual construction products. Upon inquiry with the Federal Statistical Office, it was confirmed that no additional information is available in such instances, despite the fact that it would permit the more precise allocation of quantity data among the individual construction products. In addition, it is not always clear from the production statistics data which types of goods and products are exclusively used in the construction sector.

Additionally, the quantity analyses were further complicated by the different units applied to the production statistics. Although a large proportion of the data is already available in the requisite units of kilograms and tonnes, the figures for plastic construction materials in particular (e.g., floor, wall and ceiling coverings) or quantities (e.g., for bathtubs, showers and washbasins) are often given in square meters. Data of this type often require the elaborate creation of conversion factors to allow existing data to be presented in terms of weight, thus enabling subsequent comparisons among the various construction products. In additional literature research, it was found that the structuring of data from the Federal Statistical Office had already posed a problem in other studies that dealt with similar research questions, and so other quantity data were used (Deilmann et al. 2014).

Therefore, in addition to the nine-digit data, industry and association statistics, as well as existing technical literature, were used to calculate the different production volumes. The quality of the data varied and ranged from detailed data collected annually by the associations, to individual volume data published in trade journals or as press releases for the selected years.

In order to infer the installed volumes from the production volumes, a simplified assumption was made that adjusted the production volumes for imports and exports to represent domestically-utilized stocks. In order to be able to draw conclusions regarding imports and exports, data on foreign trade statistics, corresponding to the list of goods of the Federal Statistical Office (Destatis and Genesis-Online 2020a), were used and again supplemented with data from the associations and the specialist literature. It should be noted here that the data on foreign trade statistics only enables the allocation of import and export volumes to eight-digit data, whereas the production volumes obtained from the production statistics are based on more detailed nine-digit data. In some instances, therefore, the import and export volumes had to be simplified and allocated to the respective product types on a pro rata basis, in accordance with the production volumes of individual products.

By using the various association and industry statistics, along with data from specialist literature and the Federal Statistical Office, it was possible to make an initial determination of the quantities currently produced and installed. In interviews with industry experts, manufacturers or associations, the quantities determined in this manner could be confirmed or supplemented.

2.1.3 Procedure concerning the evaluation of the anthropogenic stockpile

A few studies have already been published (e.g., Deilmann et al. (2014) or Schiller et al. (2015)), that address the size and composition of the domestic anthropogenic plastic stockpile. In the following, we will briefly outline which findings could be derived from these publications and the extent to which they could be used in the study presented here. It should be noted that plastics were not the only material covered in these two studies, and were not considered in the same degree of detail, as is the case herein. At the same time, the areas of consideration in those studies differed significantly from the one focused on in this paper.

The size of the anthropogenic stockpile composed of plastic materials was estimated by Schiller et al. (2015) for the year 2010 as totaling around 254 million t. In that study, the material stock was subdivided into the subsectors of technical infrastructures, building structures, building services, and consumer durables. Around 226 million t could be attributed to the building construction sub-sector, whereas only 12 million t can be allocated to the technical infrastructure sector, 1 million t to the building services sector, and 15 million t to the durable goods sector. Of the approximately 226 million t of plastics in the building construction sub-sector, 64 million t were attributed to the roofing and sealing membranes application; 79 million t to windows and doors; and 83 million t to insulation materials. One problem with using this data herein is that no separate value of a similar magnitude was given for plastic piping systems, despite these accounting for a large proportion of the plastics used in construction. At the same time, it was not possible to determine the different plastic types (e.g., PVC, PE, glass fiber-reinforced plastics (GFRPs), etc.) that make up the application-related volumes calculated (Schiller et al. 2015).

In another study on the circular economy potential in building construction, Deilmann et al. (2014) estimated the material stock of the sector for 2010 as totaling 15,256 million t, of which plastics accounted for 181 million t, or around 1.2%. In this study, plastics in the anthropogenic stock of building construction were divided into three application types, namely: *insulation materials*, *windows and doors*, and *others* (including pipes and floor coverings). Around 30 million t were allocated to the insulation category, 83 million to the windows and doors one, and 68 million t to the application type *others*. With respect to the types of plastics making up the anthropogenic stockpile, only guidance values were given for PVC (around 120 million t) and PE (26 million t) which, however, could not be assigned to any application type. Another difference, that makes it difficult to use the data from this study in the one presented here is that areas of application in the construction industry outside of building construction (e.g., civil engineering, gardening and landscaping) have not been discussed in greater detail (Deilmann et al. 2014).

As there was not enough reliable data available for an analysis of the current anthropogenic stockpile in the domain of plastics in the construction industry, an analysis of the stockpile's dynamics over the period from 2003 (input side) and 2005 (output side) to 2017 was provisionally conducted. In order to obtain an initial estimate of the stockpile's annual growth, the volumes of plastics that have entered the anthropogenic stockpile in recent years (input volume) and those removed from it (output volume) were calculated.

In order to be able to take annual fluctuations in input volumes into account, the quantity installed in 2017 was offset against data on the growth of plastic processing in the construction sector. These data were drawn from the biennial survey of the plastics market conducted by Consultic Marketing & Industrieberatung GmbH and, since 2018, by Conversio Marketing & Strategy GmbH (Lindner and Schmidt 2018). The input-side development of the anthropogenic stock could therefore be based on the specifically-determined amount consumed in 2017, and could be calculated retroactively back to 2003.

Data from the waste statistics (Technical Series 19) of the Federal Statistical Office were used for the output-side analysis of the stock list (Destatis 2020). The following waste types associated with construction and demolition waste were considered relevant: Plastics (waste code: 170203), mixed construction and demolition waste (waste code: 170904), insulation materials (waste codes: 170603 and 170604), cable waste (waste code: 170411), and plastic waste (excluding packaging) from the gardening and landscaping sector (waste code: 020104). Although it can be assumed that the wastes listed under codes 170203 and 020104 are exclusively plastics, the corresponding proportion of plastics was estimated for the other waste types on the basis of different statements from experts and plausible assumptions. For the mixed construction and demolition waste category (waste code: 170904), the plastic content was estimated to be 15% following an evaluation of suitable specialist literature and the conducting of an expert interview. In addition to insulation materials made from plastic, mineral-based insulation materials or those manufactured from renewable raw materials are also disposed of under waste codes 170603 and 170604. Therefore, the simplifying assumption was made that the ratio of the production volume between mineral, synthetic and insulation materials manufactured from renewable raw materials roughly corresponds to that of the composition of the corresponding waste fraction. The proportion of plastics corresponding to the two waste code numbers was thus estimated to be around 12%. For cable material waste, the share of plastics could finally be estimated to be around 30% according to an expert who was interviewed. The output-side analysis of the stock list could thus be carried out for the period between 2005 and 2017 (Dehne et al. 2015; Destatis 2020).

An estimate of future developments was made for both the input- and output-side considerations in order to be able to draw conclusions regarding the future development of return flows from the stock list, among other things.

2.2 Preparation of the product list for plastic construction products

The result of this analysis of construction products is a product list of plastic construction products, which is published alongside this report as a supplement. This approach was chosen, as it allows both clarity and the full scope of the results to be appropriately outlined. However, a brief overview of the compiled product list is provided below. The researched construction products were assigned to four application areas, namely:

- Pipes
- Insulation
- Profiles
- Others

The application area of pipes includes non-flexible and flexible pipe performance systems, as well as manholes. There are 25 different products at level 4. Insulation materials include 15 construction products that utilize thermal and acoustic insulation at level 4, 80% of which are of the thermal type. The section of profiles is mainly composed of building profiles, shutters, doors and windows, and includes 12 construction products. Also included is the large grouping of other construction products, which consists of approximately 38 additional examples.

The created product list is also presented in a table in reduced form in the appendix through level 4, including the associated construction standards. Moreover, the precise plastic type is assigned to each building product. The full results can be found in the supplement.

2.2.1 Navigation of the supplement

The goal of this chapter is to provide potential users with an overview of the supplement's content and functionality. The supplement is presented in an .xlsx-based file format and consists of six spreadsheets, which are listed – and briefly described – below:

- Complete list of construction products (spreadsheet 1)
- Level 1 (spreadsheet 2)

- Level 2 (spreadsheet 3)
- Level 3 (spreadsheet 4)
- Level 4 (spreadsheet 5)
- EAD, hEN, MVVBT – DIN-Title (spreadsheet 6)

Spreadsheet 1 – "Total list of construction products," displays the identified construction products and their subdivision into levels 1, 2, 3, and 4. The spreadsheet shows the standards and technical rules to which these products are subject. At the same time, the types of plastic commonly used for construction products are specified and assigned to the respective plastic type (i.e., thermoplastic, thermoset, elastomer, composite). With the help of the filter function, it is possible to search the selected application areas, plastic types or grades and easily select and customize the desired presentation.

Based on information from the subordinate spreadsheets, **Spreadsheet 2 – "Level 1"** shows the quantities of domestically produced and installed of plastic construction products in aggregated form. With respect to application, a distinction can be drawn between the four selected areas of *pipes*, *insulation*, *profiles*, and *others*. As well as an application-related breakdown of the determined quantities, the spreadsheet also presents a breakdown by plastic type (i.e., PVC, GRP, PE, PP, etc.).

Spreadsheet 3 – "Level 2" displays 14 different, superordinate product types that are classified according to the application areas *pipes*, *insulation*, *profiles*, and *others*. The total produced and installed quantities, based on information from the "Level 3" subordinate spreadsheet, are also shown for the respective superordinated product types. At the same time, their allocation to spreadsheet "Level 1" can be traced.

Spreadsheet 4 – "Level 3" shows 52 subordinate product types, which serve to further break down the 14 product types specified in the "Level 2" spreadsheet. For the various subordinate product types, the calculated produced and consumed quantities, which correspond to information from the "Level 4" subordinate spreadsheet, are also shown. In addition, the products' allocation to higher-level product types can be traced to the "Level 2" spreadsheet.

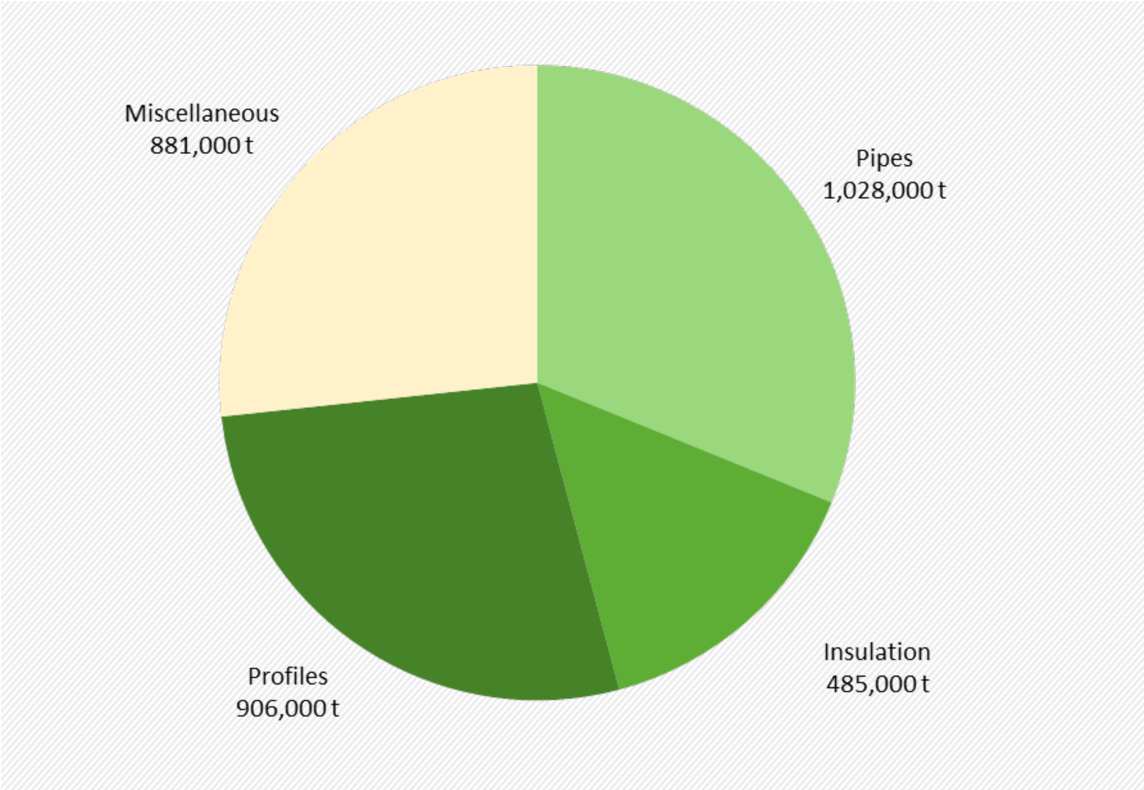
Spreadsheet 5 – "Level 4" presents a detailed overview of all of the construction products made from plastics that were identified in this project. As well as detailed information on the quantities produced and installed, the various plastics used are also specified here. Moreover, it is possible to identify which of the listed products are subordinate to which corresponding products in the "Level 3" spreadsheet.

In **Spreadsheet 6 – "Sources: EAD, hEN, MVVBT – DIN titles,"** the stated technical rules and standards of the lists of harmonized specifications (hEN and EAD) according to European Construction Products Regulation (EU) No. 305/2011 and the Model Administrative Regulation on Technical Building Regulations (MVVTB), both of which relate to plastic construction products, can be separately identified. The lists of hEN and EAD are continuously revised, and for this reason it is important to always make reference to the most recent version.

2.3 Assessment of current market volumes

This chapter presents the results of the evaluation of current market quantities, with 2017 taken as the reference year. The total quantity of plastic construction products produced in Germany in 2017 is calculated to have been around 3.30 million t, a breakdown of which into the four aggregated application areas (Level 1) is shown in Figure 2, below:

Figure 2. Calculated production volumes of the four aggregated application areas in 2017 in tonnes.

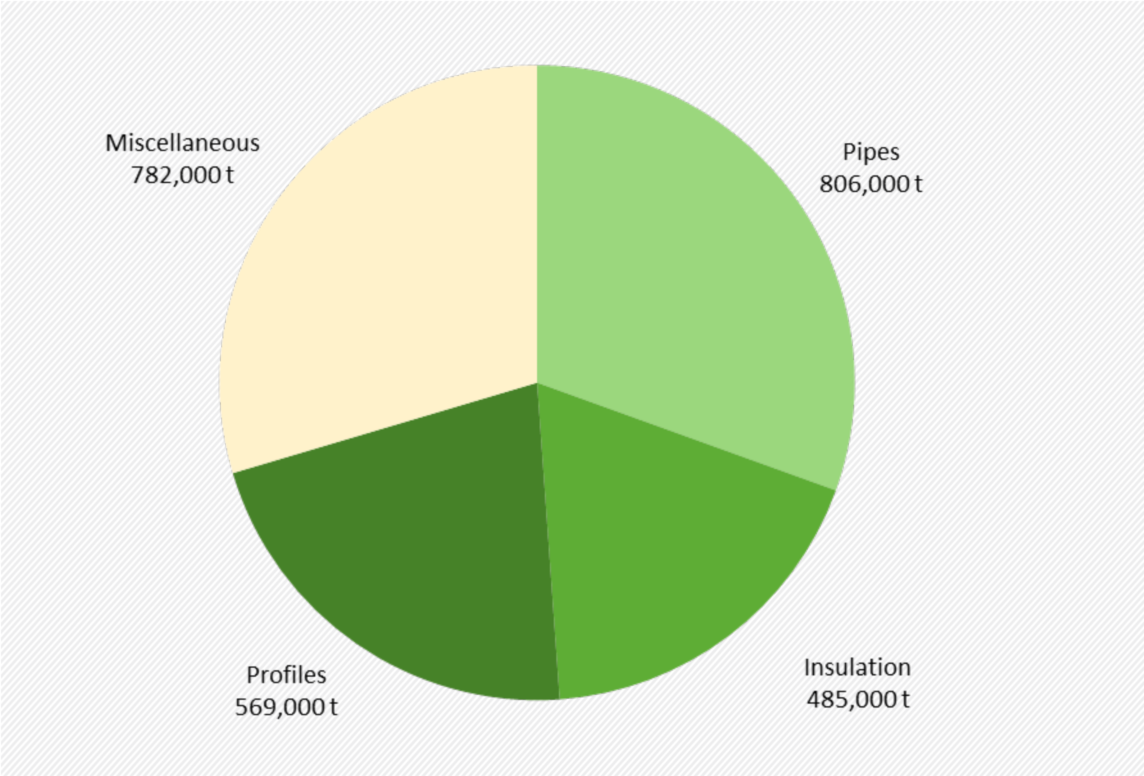


Source: Own research SKZ – Das Kunststoff-Zentrum (the basis of the calculations can be found in the supplement).

The percentage breakdown is as follows: the pipes sub-segment accounts for the largest share of production volume at 31%, followed by the profiles and others sub-segments, at 27% each. Insulating materials accounted for around 15% of the total production volume.

The utilized volume results from the quantity produced minus the determined export surplus of around 0.66 million t, and amounted to approximately 2.64 million t for 2017. The breakdown into the aggregated application areas is shown in Figure 3, below.

Figure 3. Calculated installed volumes for the four aggregated application areas in 2017 in tonnes.



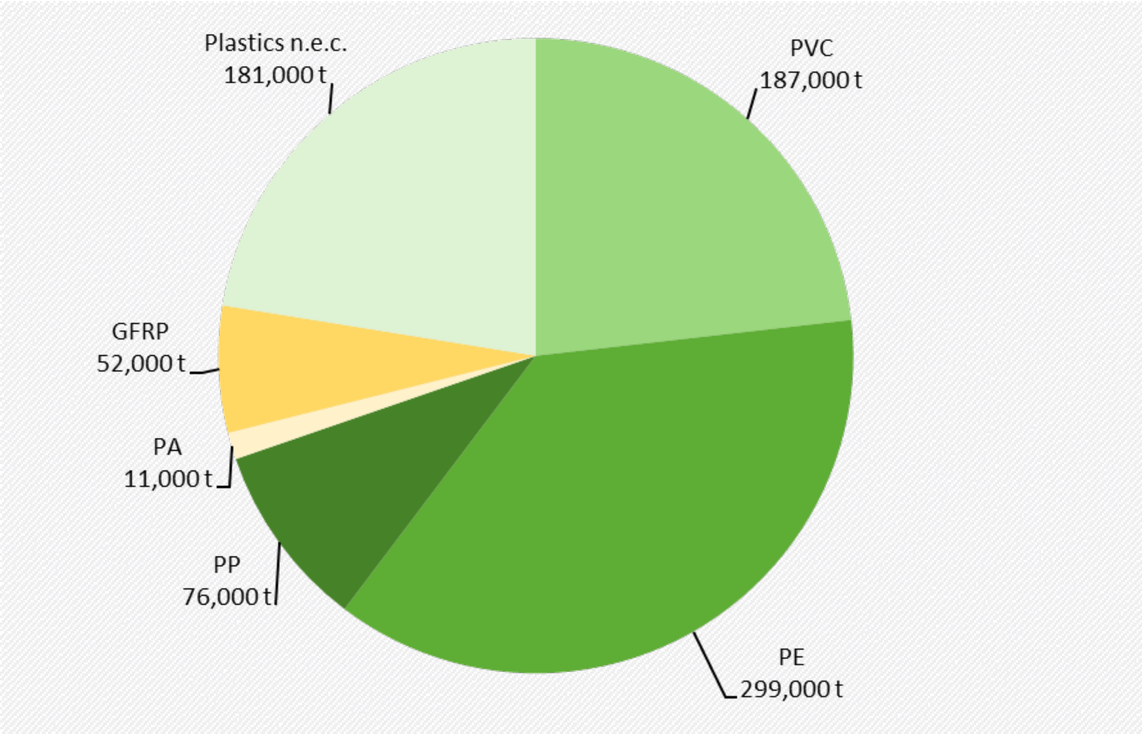
Source: Own research SKZ – Das Kunststoff-Zentrum (the basis of the calculations can be found in the supplement).

If we consider the percentage breakdown of the installed volumes, 30% each can be attributed to the subsectors of *pipes* and *others*, 22% to *profiles*, and around 18% to *insulation* materials.

Later sections of this chapter will present a more detailed look at the individual aggregated application areas of *pipes*, *insulation*, *profiles*, and *others*.

In the *pipes* sub-segment, the data situation is mostly satisfactory. In addition to the data from the production statistics, the statistics of the Trade Association of the Plastic Pipe Industry were used as a supplement to determine current market volumes. A review and evaluation of the data indicated an annual production volume of around 1.03 million t of plastic piping, with pipes made of polyethylene and polyvinyl chloride accounting for the largest share in terms of overall volume. The installed volume was estimated to be around 0.81 million t per year (of which around 0.30 million t comprised PE, 0.19 million t PVC, 0.08 million t PP, 0.05 million t GRP, and 0.19 million t of plastics that could not be precisely identified), which is depicted in Figure 4 (Trade Association of the Plastic Pipe Industry e.V. (KRV) 2018; Destatis and Genesis-Online 2020a, 2020b).

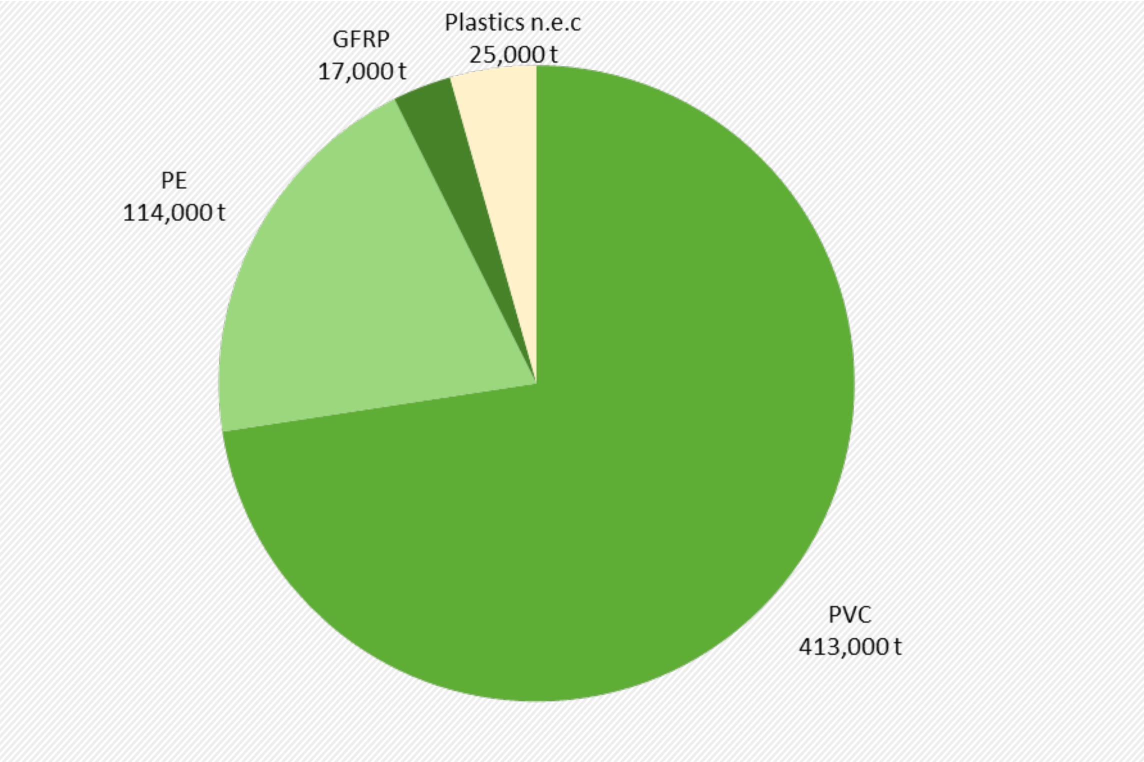
Figure 4. Volume of plastics used in the *piping* subsegment in 2017 in tonnes.



Source: Own research SKZ – Das Kunststoff-Zentrum (the basis of the calculations can be found in the supplement).

For the *profiles* sub-segment, the production volume in 2017 was around 0.91 million tons. The material most often used here was PVC. Due to a very high export surplus within this sub-segment, the volume was estimated to be around 0.57 million t (of which around 0.41 million t comprised PVC, 0.02 million t GRP, 0.11 million t PE, and 0.03 million t of plastics that could not be precisely defined) (Destatis and Genesis-Online 2020a, 2020b). The results are depicted in Figure 5.

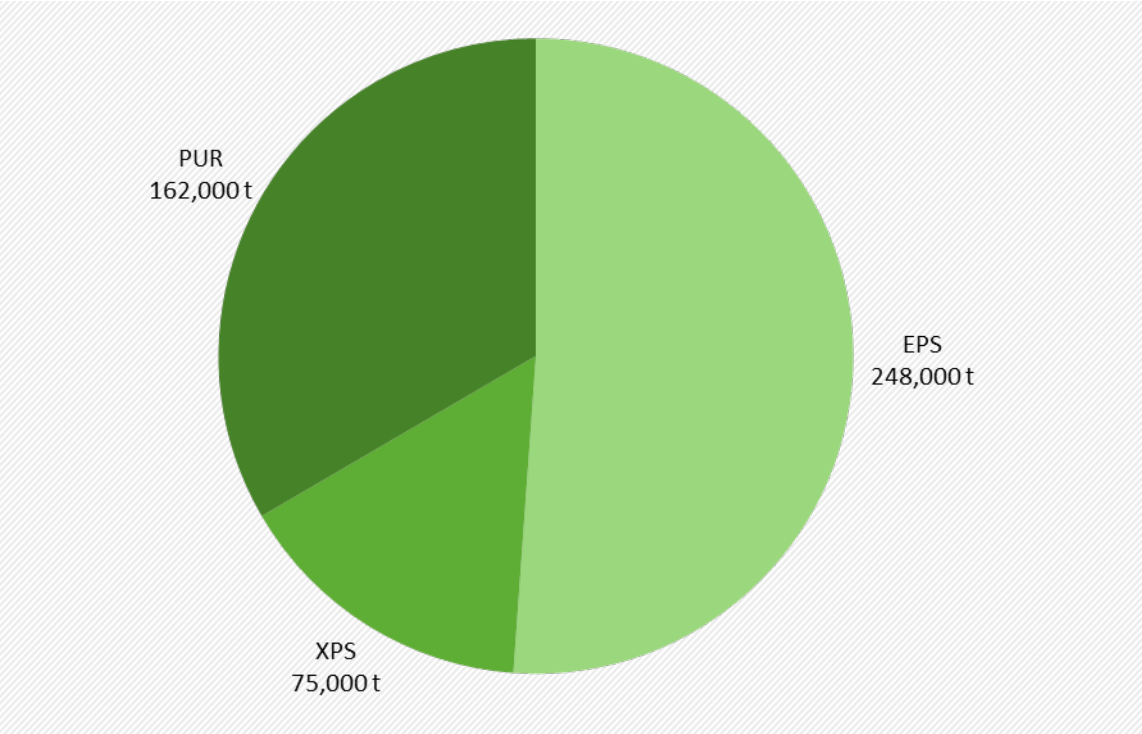
Figure 5. Volume of plastics used in the *profiles* sub-segment in 2017 in tonnes.



Source: Own research SKZ – Das Kunststoff-Zentrum (the basis of the calculations can be found in the supplement).

In the *insulation* sub-segment, data from technical literature and associations (e.g., from interviews with experts) were mostly used (Building Center Munich 2017; Bürger et al. 2017; Sprengard et al. 2014). It should be noted here that the obtained information mostly refers to the three insulation material types of expanded polystyrene (EPS), extruded polystyrene (XPS), and polyisocyanurate (PIR). No information was available on the market volumes of other insulation materials (e.g., those made of phenolic resin rigid or polyethylene foams), although it was confirmed during the expert interviews that these make up a negligible proportion in terms of the total quantity of insulation materials installed. As data on the quantities of insulation materials were only available in the unit of m^3, corresponding conversion factors (based on the bulk densities of the individual insulation material types, drawn from the relevant technical literature) were used to affect conversions into tonnes. The total production volume for insulation materials in 2017 could thus be determined to be 0.49 million tons. As no detailed data on imports and exports were available, it was assumed, based on information obtained from an interview with an expert, that imports and exports roughly balanced each other out. Thus, the quantity used was also estimated to be 0.49 million t (around 0.25 million t of EPS, 0.08 million t XPS, and 0.16 million t of PIR), as shown in Figure 6.

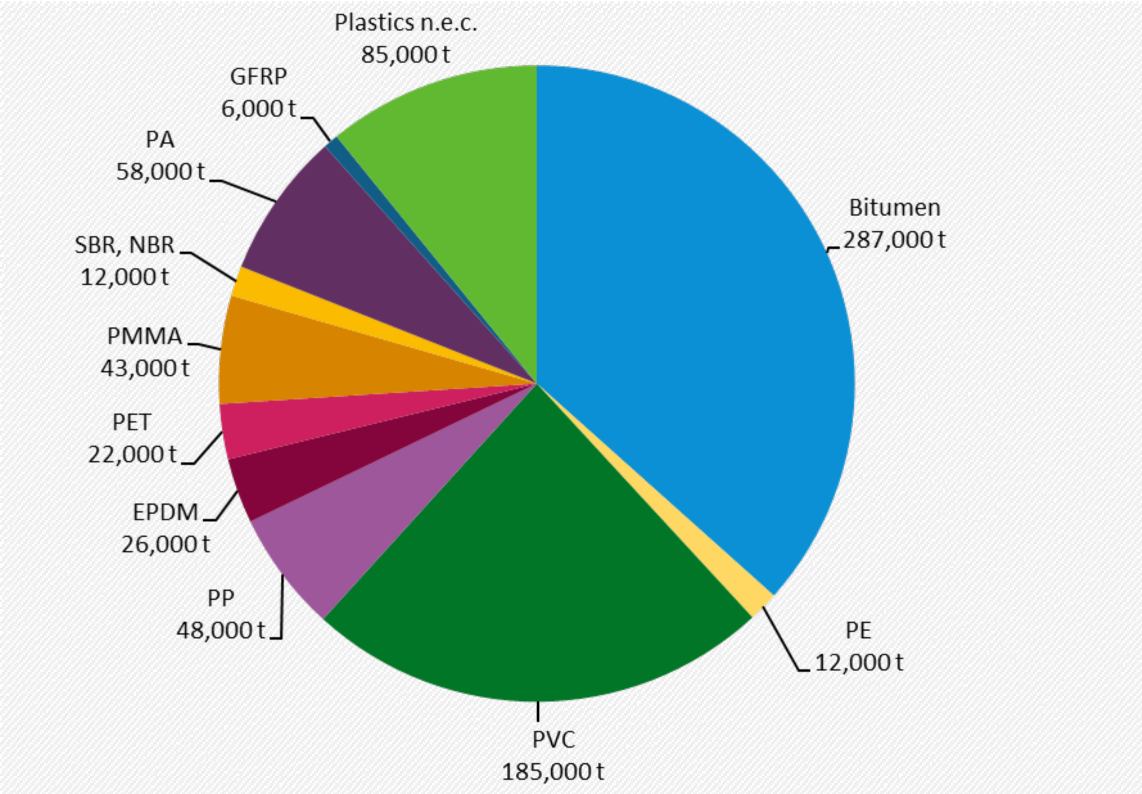
Figure 6. Volume of plastics used in the insulation sub-segment in 2017 in metric tons.



Source: Own research SKZ – Das Kunststoff-Zentrum (the basis of the calculations can be found in the supplement).

For the last sub-segment, *others*, the production volumes of waterproofing materials, floor coverings, and cables are especially relevant. Due to their versatility and the large number of different products in the sub-segment, the availability of data on the current market volumes of the different construction products turned out to be highly heterogeneous. Therefore, in order to estimate the quantities of waterproofing membranes, floor coverings, and cables, data from the technical literature or corresponding association statistics was utilized. For data on other products belonging to the *others* sub-segment, production statistics weas employed (Destatis and Genesis-Online 2020b). The production volume for the other sub-segment was estimated to be approximately 0.88 million t, of which bitumen-based roofing and waterproofing membranes accounted for around 0.29 million t. The remaining production volume could mainly be attributed to floor coverings (around 0.20 million t) (German Environmental Help e.V. (DUH) 2017; Wecobis Ecological Building Materials Information System 2018), plastic roofing and waterproofing membranes (0.14 million t) (Ernst 2017; Eurobitume 2019) and cable materials (0.07 million t) (Lindner 2014). The total volume of the sub-segment was estimated to be about 0.78 million tons, although it should be noted that no import and export figures were identified for waterproofing materials and floor coverings. Bitumen-based roofing and waterproofing membranes accounted for a large portion of the installed volume, at around 0.29 million tons. The 0.19 million t of PVC used could primarily be attributed to the three application types of roofing and waterproofing membranes, floor coverings, and cable materials. Although polyamide (PA) (0.06 million t), PP (0.05 million t) and PMMA (0.04 million t) accounted for other large shares of the sub-segment, just under 0.09 million t could not be allocated to any specific plastic. The data are visually presented in Figure 7, below.

Figure 7. Volume of plastics used in the *others* sub-segment in 2017 in tonnes.

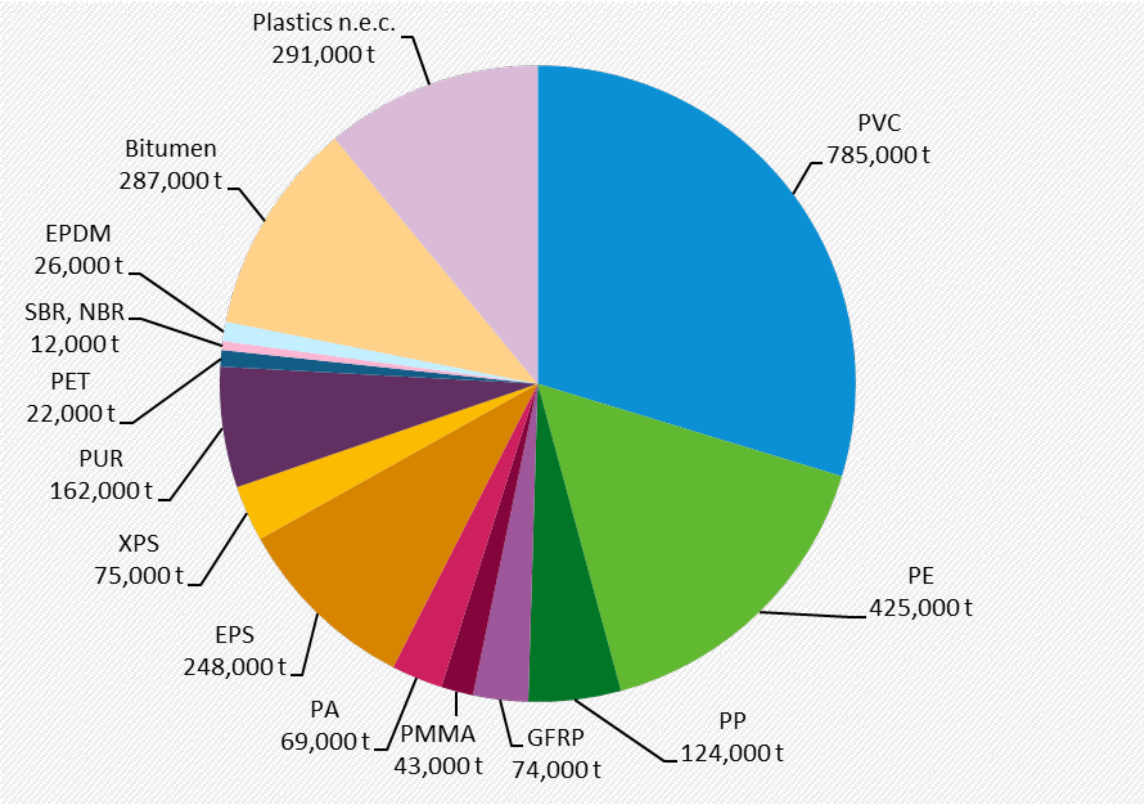


Source: Own research SKZ – Das Kunststoff-Zentrum (the basis of the calculations can be found in the supplement).

In principle, it can be assumed that agricultural or mulch films are also produced and used domestically in gardening and landscaping in thoroughly relevant quantities every year. However, since no reliable data could be found to determine the quantity produced and used, market quantities can only be estimated. For example, the initiative Erntekunststoffe Recycling Deutschland (ERDE) states that it collected and recycled around 20,500 t of harvest plastics in 2019. At the same time, the initiative states that it currently already collects around 35% of the silage and stretch films put into circulation. Assuming for the purposes of a rough estimate that the 20,500 t correspond to around 35% of the crop plastics put into circulation, a total quantity of around 58,500 t can be assumed to be put into circulation each year (Initiative for Crop Plastics Recycling Germany (ERDE) 2020). However, it should be noted that the 20,500 t figure primarily relates to silage and stretch films. Thus far, not all agricultural films have been taken back, which is why they cannot be recycled. For instance, the take-back of films used for asparagus crops is only in the initial stages, whereas no mulch films have been taken back yet.

After aggregation of the sub-segments of *pipes*, *profiles*, *insulation*, and *others*, the following breakdown by plastic type corresponds to the installed volumes (2.64 million t) in 2017, as shown in Figure 8, below:

Figure 8. Determined installed volume by type of plastic in 2017 in tonnes.



Source: Own research SKZ – Das Kunststoff-Zentrum (the basis of the calculations can be found in the supplement).

Around 30% of the installed volume could be attributed to PVC plastic, and around 16% to PE. Other plastics of particular relevance in terms of volume include EPS (share of PM: 8%, of VM: 9%), PUR (PM: 5%, VM: 6%), PP (PM: 4%, VM: 5%), and GFRP (PM: 3%, VM: 3%).

2.3.1 Construction products made of GRP

As products made of glass fiber-reinforced plastics are common, but often still pose a major challenge in terms of the highest possible quality of recycling being achievable, and these will be briefly outlined separately below. The total volume produced in Europe in 2019 is stated to have been around 1.14 million t. About 36% of this can be attributed to the *construction/infrastructure* application area (other areas are transportation: 34%; electrical/electronics: 15%; sports/leisure: 14%; and other: 1%) (Witten and Mathes 2019).

Piping systems and profiles in particular were identified as construction products of particular relevance for GFRP in terms of volume; at the same time, GFRP is also used in smaller quantities in the construction sector in a number of different construction products in the *others* sub-sector (e.g., containers, tanks, wall cladding, and fittings). Although the total GRP production volume in Germany in the years 2016–2019 was, according to Witten and Mathes (2019), between 220,000 and 229,000 t, the total amount of GRP-based construction products consumed domestically in the construction sector in 2017 was estimated in this study to be about 75,000 t. This estimate is based, among other factors, on an expert interview conducted with a representative of the Industry Association for Reinforced Plastics e.V. (AVK). This can be considered plausible, as the shares of the construction and infrastructure sector in Germany are estimated to be lower than in the aforementioned Europe-wide comparison (AVK 2020). At the same time, however, it should be noted that GRP products are often manufactured as one-offs or in small quantities (e.g., to construct bridges, water slides, playground slides, or large silos) and it is unclear as to whether, and to which extent, corresponding quantities are reflected in the production statistics of the German Federal Statistical Office.

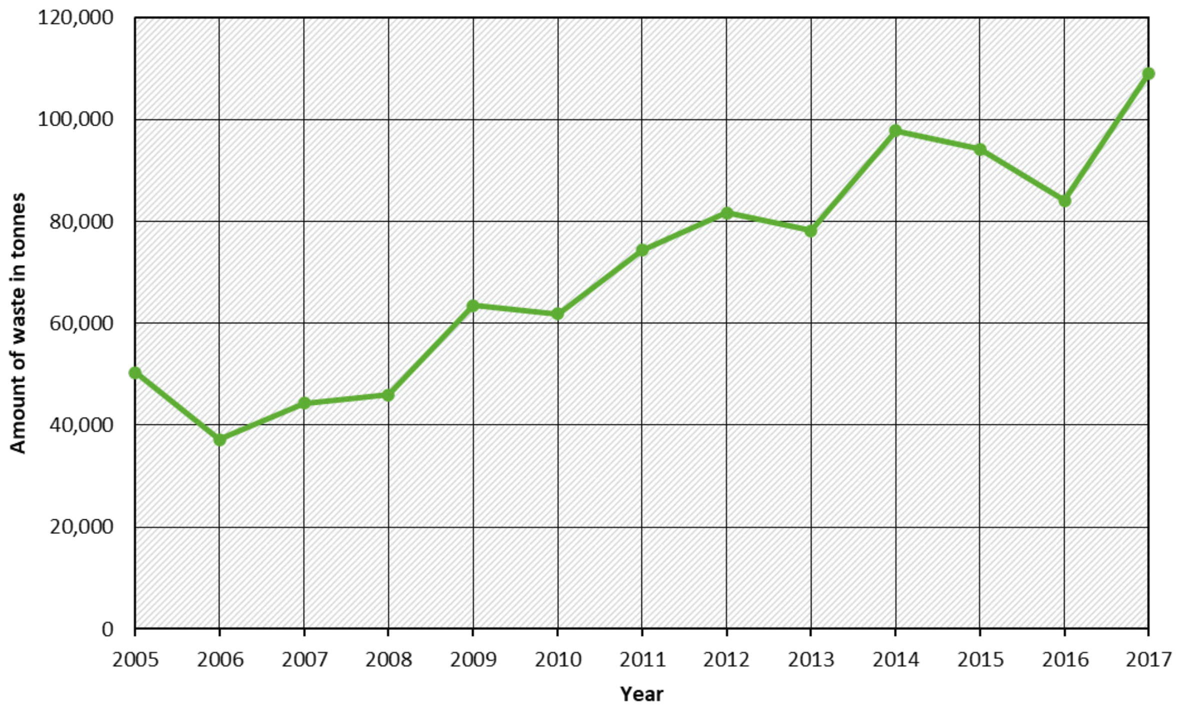
All areas of the GRP market, including the construction sector, are expected to grow in the future. Substantial additional potential for the increased use of GRP can be identified in the context of pipeline systems (especially in the areas of new construction projects or sewer redevelopment). GRP has also been increasingly used in the area of bridge restoration and construction for a number of years (Witten and Mathes 2019). The existing advantages of GRP compared to the materials commonly used in bridge construction include, for instance, its lower weight (and the greatly simplified and more rapid bridge installation that results) and its high resistance to corrosion. At the same time, bridges made of GRP are typically more expensive than alternatives made of the materials often used in bridge construction, but viewed across the entire lifecycle, they are also characterized by a significantly lower maintenance requirement and correspondingly lower associated costs (Mottram and Henderson 2018).

2.4 Considerations regarding the anthropogenic stockpile

In total, an input quantity of around 30.3 million t of plastics is assumed for the period between 2005 and 2017 (bituminous roofing and sealing membranes are neglected for the moment). The input quantity is subject to certain fluctuations, and increases by around 12% between 2005 and 2007, and then falls by a total of about 17% in 2008 and 2009. By 2011, the volume again increased by about 7%, before falling by a total of just over 1% by 2015, and finally rising by 4% by 2017. Especially relevant volumes here are PVC (around 10.1 million t) and PE (5.5 million t). Furthermore, considerable quantities can also be attributed to the plastics PP (1.6 million t), EPS (3.2 million t), and PUR (2.1 million t). Once again, a volume of some 3.7 million t could not be ascribed to any specific plastics.

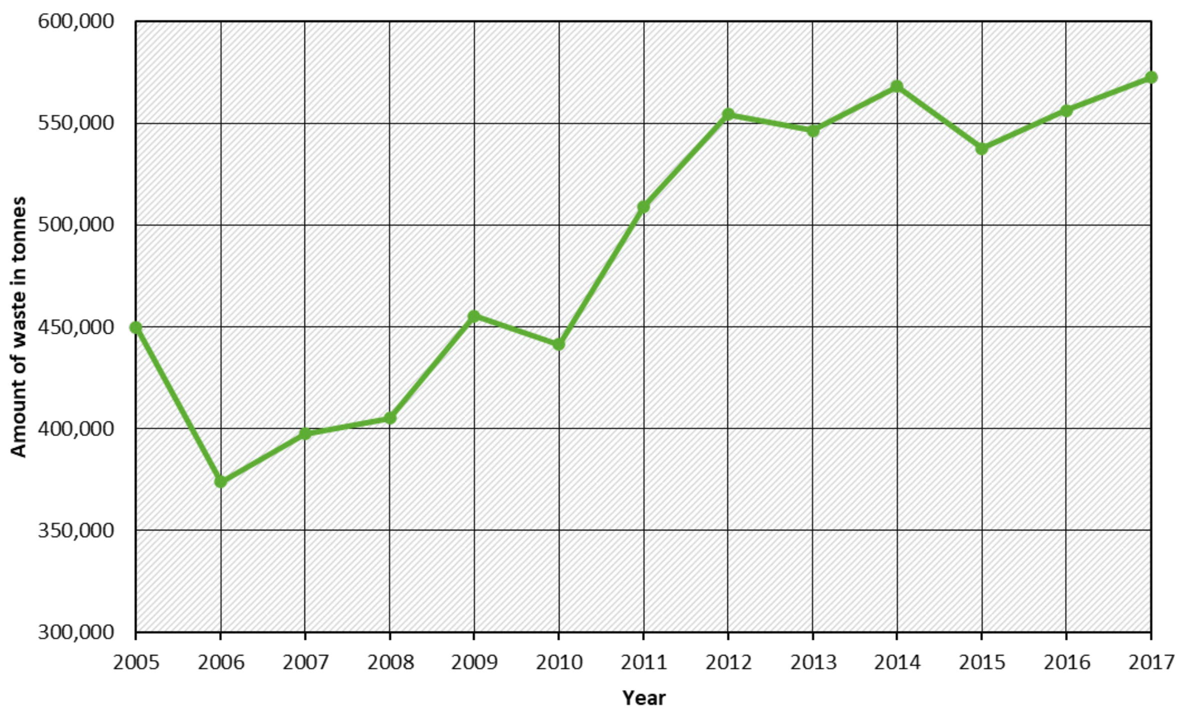
On the output or waste side, it can be seen that for all waste types considered, despite minor decreases in the intervening period, a growing trend in the volume of waste could be observed in the period between 2005 and 2017. Although it was possible to separately calculate the proportion relevant to this work for plastic waste collected in the course of demolition work (waste code: 170203, mixed construction and demolition waste; cf. Figure 9 and waste code: 170904; cf. Figure 10), insulation material waste (waste codes: 170603 and 170604; cf. Figure 11) and cable material waste (waste code: 170411, Figure 12), it proved far more difficult to estimate the proportion of waste relevant to this work listed under waste code 020104. Although it can be assumed that a certain proportion of this waste type can be attributed to plastic waste from gardening and landscaping, it also includes, for instance, plastic waste from pond management, forestry, or hunting and fishing activities. Due to a lack of information provided in the specialist literature, it was not possible to make a corresponding assessment of which proportion of the waste type was to be regarded as relevant for this study. Nevertheless, the development of the corresponding waste type is shown below, in Figure 13, and exhibits – like the other waste types – a similarly increasing trend.

Figure 9. Trend of plastic waste collected separately from construction and demolition waste (waste code: 170203) generated in Germany between 2005 and 2017.



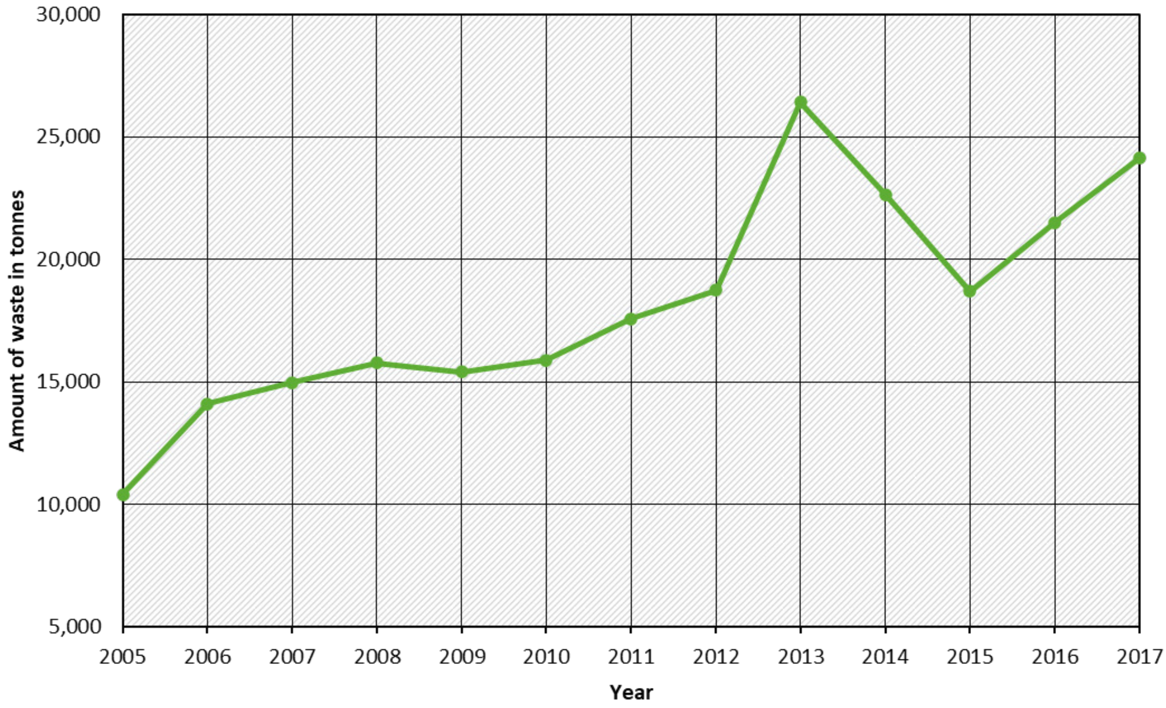
Source: Own illustration according to Destatis (2020) SKZ – Das Kunststoff-Zentrum.

Figure 10. Trend of mixed construction waste generated in the course of construction and demolition work (waste code: 170904, estimated plastic content: 15%) in Germany between 2005 and 2017.



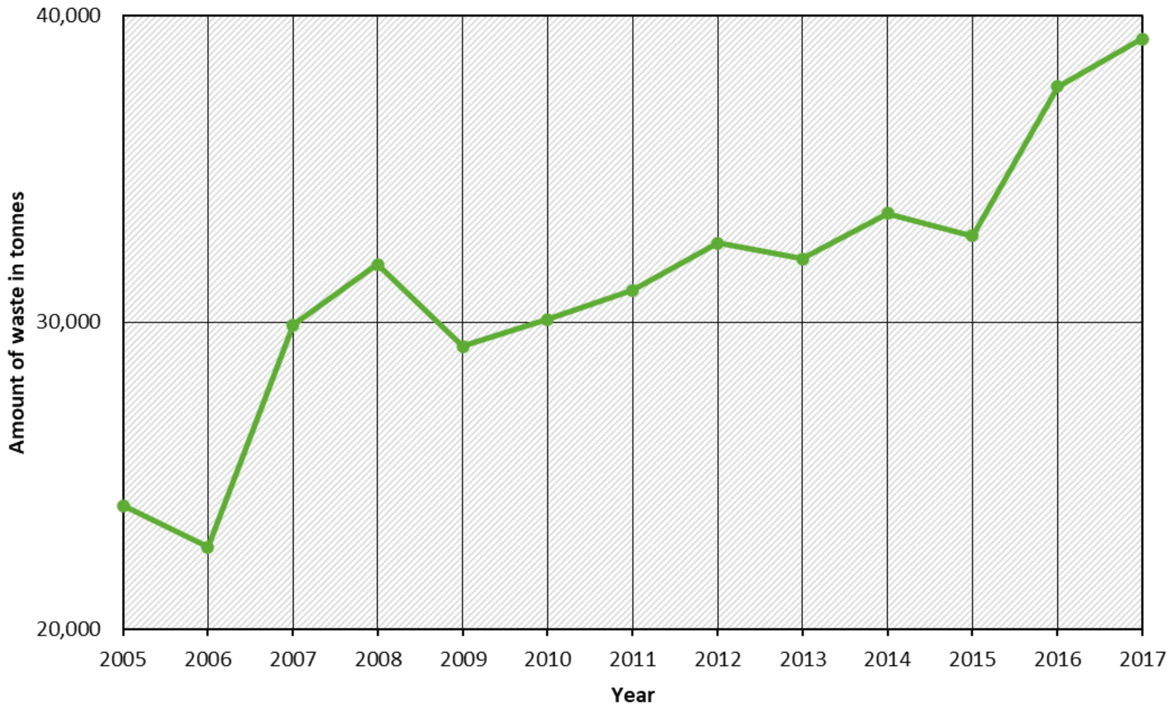
Source: Own illustration according to Destatis (2020) SKZ – Das Kunststoff-Zentrum.

Figure 11. Trend of insulation material waste (waste codes: 170603 and 170604, estimated plastic content: 12%) generated in the course of construction and demolition work in Germany between 2005 and 2017.



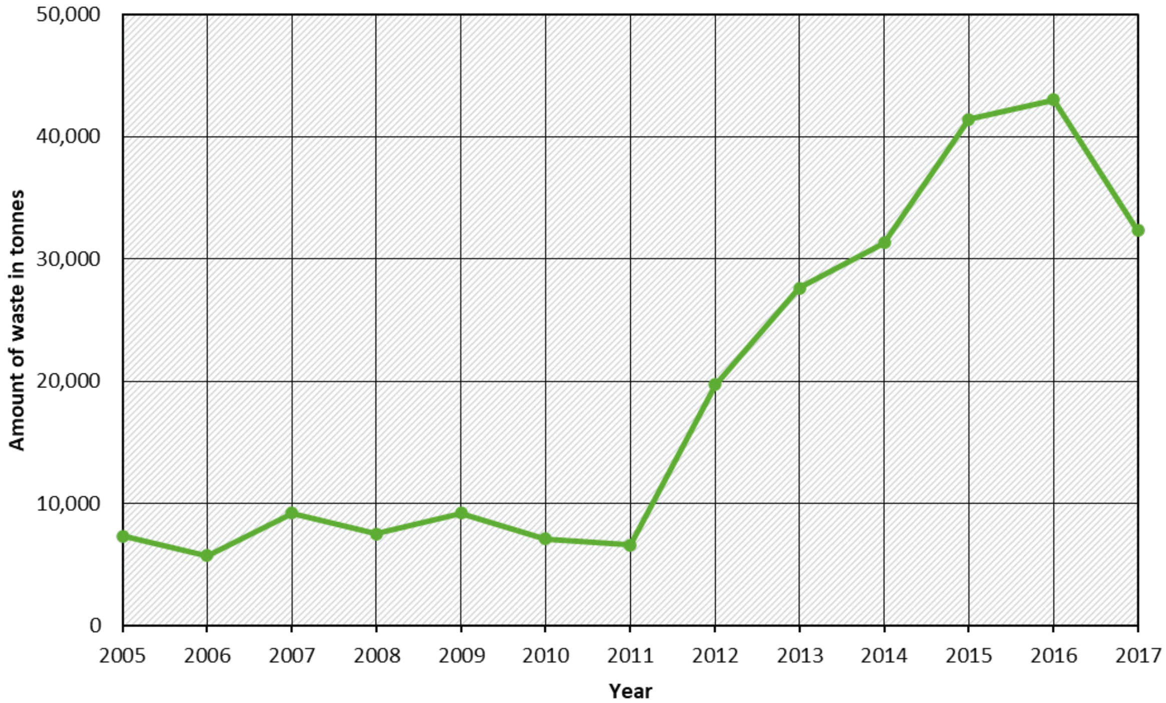
Source: Own illustration according to Destatis (2020d) SKZ – Das Kunststoff-Zentrum.

Figure 12. Development of cable waste generated in the course of construction and demolition work (waste code: 170411, estimated plastic content: 30%) in Germany between 2005 and 2017.



Source: Own illustration according to Destatis (2020) SKZ – Das Kunststoff-Zentrum.

Figure 13. Development of plastic waste generated in agriculture, horticulture, pond management, forestry, hunting, and fishing (waste key: 020104, excluding packaging), generated domestically between 2005 and 2017.



Source: Own illustration according to Destatis (2020) SKZ – Das Kunststoff-Zentrum.

The total waste volume for the period between 2005 and 2017 was around 7.94 million t (provisionally ignoring bituminous roofing and sealing membranes, as well as the waste falling under waste code: 020104). At 6.4 million t, the plastics contained in mixed construction and demolition waste (waste code: 170904) were responsible for the largest share of waste mass. Only 0.9 million t of plastics were collected separately (waste code: 170203). Around 0.4 million t of cable waste (waste code: 170411) and around 0.2 million t of insulation materials (waste codes: 170603 and 170604) could be placed in this category.

The net input (i.e., growth) of the anthropogenic stockpile in the period between 2005 and 2017 can thus be estimated to have been roughly 22.4 million t, corresponding to an average annual increase of 1.7 million t.

The large difference between the volumes of plastics consumed and those generated as waste in the construction sector is primarily a function of the industry-specific service lives of the various product types and the increased use of the material in the construction sector in recent decades. Compared to plastic products from other sectors, such as packaging (typical service lives of a few days or weeks), plastic-based construction products are characterized by significantly longer service lives and, in some cases, remain in dedicated storage for several decades (see Table 1, in which the service lives specified by the BBSR for selected plastic construction products for the preparation of lifecycle calculations are shown). A large part of the waste currently generated during dismantling was therefore first installed many decades ago. Plastic products currently being used will, in turn, not emerge in the waste stream for several decades.

This state of affairs represents a major obstacle to holding manufacturers responsible under the ‘polluter pays’ principle, or implementing manufacturer-supported take-back and recycling systems for currently returning streams. The utility of the mechanical recycling of current and, from today's point of view, partially-contaminated post-consumer waste, must also be examined on a case-by-case basis and, depending on the ingredients that were initially used. On the other hand, longevity as such already offers ecological advantages over the use of plastics in products with short service lives. The empirical values for the service lives of selected plastic construction products are displayed in Table 1.

Table 1. Service lives of construction components and products made from plastic.

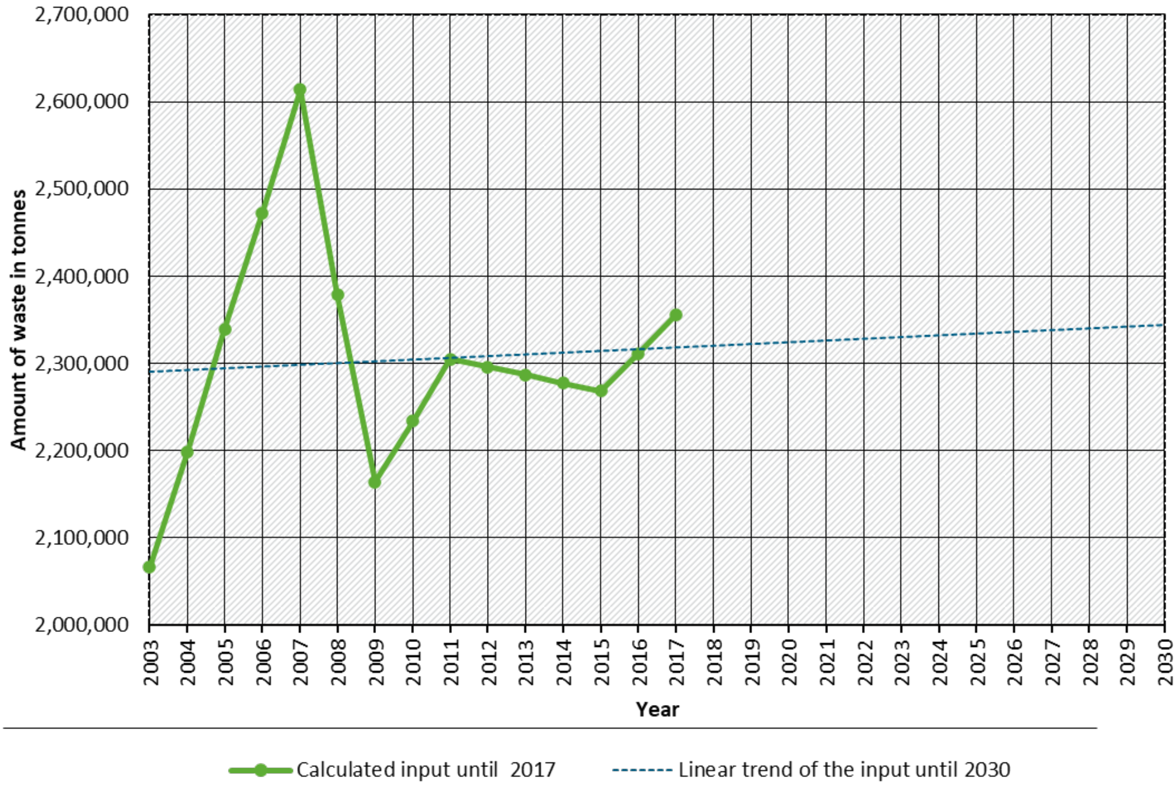
Product	Service life [years]
Sealing against non-pressurized water	35
Standard exterior door (plastic)	40
Exterior windows (aluminum–plastic composite)	>50
Exterior windows (plastic)	40
Exterior fittings	25–30
Rolling shutters	40
Exterior sealing profiles (windows, doors)	20
Exterior sealants (windows, doors)	12
Waterproofing membranes against pressurized water, in contact with the ground	>50
Bitumen membranes against non-pressurized water, in contact with the ground	40
Waterproofing, in contact with the ground, made of rigid foam battens, polystyrene, dimpled membranes (PP, PE), and corrugated sheets	40
Thermal insulation, in contact with the ground, extruded PS	40
Insulation layer as core insulation, PUR boards, PS	>50
External thermal insulation composite system: PS and PUR boards	40
Acrylic sheets (exterior wall cladding)	40
Polycarbonate sheets (exterior wall cladding)	30
Wall cladding (systems): plastic	40
Blinds	25
Parapet cladding: plastic panels	40
Interior doors (plastic)	>50
Interior windows (frames and sashes)	>50
Interior fittings	30 - >50
Interior sealing profiles (windows, doors)	30
Interior sealants (windows, doors)	20
Wallpapers (interior wall, ceiling)	10

Product	Service life [years]
Footfall sound insulation	>50
Floor insulation, insulation of highest floor ceiling	>50
Textile floor coverings	10
PVC, sports, and rubber floors	20
Ceiling coverings (plastic)	>50
Grids and grates (plastic)	40
Roof windows (frames), plastic	>50
Roof windows (frames), plastic–aluminum composite	35
Light bands	20
Skylight domes	25
Roof vents and hatches	30
Waterproofing membrane (flat roof): elastomeric membranes, plastic membranes, under insulation	40
Waterproofing membranes (flat roof): bitumen membranes under insulation	30
Waterproofing membranes (flat roof): bitumen membranes, elastomeric membranes, plastic membranes, above insulation with heavy protective layers	30
Waterproofing membranes (flat roof): bitumen membranes, elastomeric membranes, plastic membranes, above insulation with light protective layers	20
Roof coverings: bitumen shingles, corrugated sheets	25
Inter-rafter insulation (XPS, EPS, and PUR)	>50
Drainage (gutters, downpipes, roof drains): plastic	20
Roof cladding: vapor-diffusion-open plastic foils	30
Inter-, above- and below-rafter insulation (PS, PUR)	>50

Source: Own representation according to the Federal Office for Building and Regional Planning (BBSR) (2017).

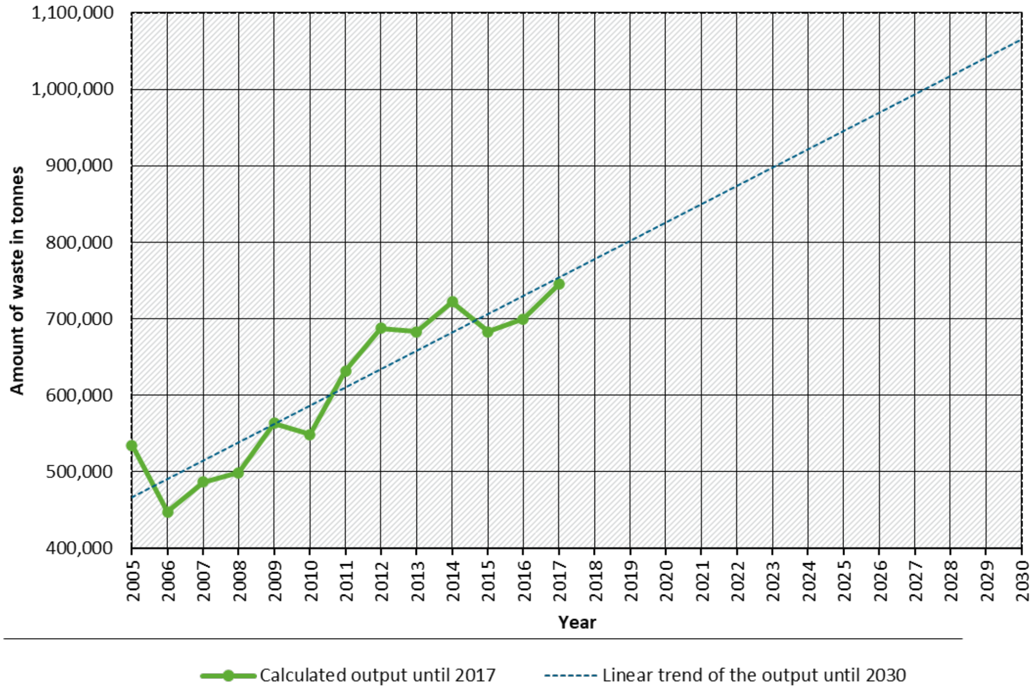
In addition to the already determined trends of the input and output flows of the anthropogenic stock in the past, the figures below (Figure 14 and Figure 15) also depict the estimated future developments of the anthropogenic stockpile. A clear estimation of input side developments turned out to be difficult in some instances given that the plastics market sometimes underwent substantial periods of development (for instance, between 2003 and 2009), which are difficult to predict, and these can have a notable impact on the annual input volume. In the case of the stockpile output, on the other hand, a clear upward trend in the volume of plastic waste can be observed. Therefore, it is assumed that the output volume will roughly double by 2030 against that from 2005. The calculation approach implemented to estimate the future developments of the input and output volumes of the anthropogenic stockpile was linear regression.

Figure 14. Annual volume of installed plastic construction products (input) for the period 2003 to 2017, including estimated development of the input with respect to the anthropogenic stockpile through the year 2030.



Source: Own illustration, SKZ – Das Kunststoff-Zentrum.

Figure 15. Determined waste volume of discarded plastic construction products (output) for the period from 2005 to 2017, including estimated development of the output with respect to the anthropogenic stockpile through the year 2030.



Source: Own illustration, SKZ – Das Kunststoff-Zentrum.

2.5 Summary

- This chapter compiled a comprehensive product list of construction products made primarily of plastics. The list comprises more than 240 construction products and is also published in the form of an .xlsx file supplement. Furthermore, current market volumes, as well as developments of the anthropogenic stockpile of construction products made of plastics, were researched and compiled.
- It was calculated that the volume of plastic construction products produced in 2017 totaled around 3.3 million t, whereas the installed volume that year was around 2.6 million. The most commonly used plastic was PVC, which is also the most frequently used plastic.
- Overall, an input volume of around 30.3 million t of plastics into the anthropogenic stockpile was assumed for the period between 2005 and 2017. The output quantity for the same period, on the other hand, amounted to approximately 7.9 million t.
- The net input (i.e., stockpile growth) of the anthropogenic stockpile in the period between 2005 and 2017 was estimated to be about 22.4 million t, which corresponds to an average annual increase of 1.7 million t.
- Projections indicate that the output volume of the anthropogenic stockpile will roughly double by 2030 against that from 2005.

- Due to relatively long service lives of construction products current waste streams containing plastics are decades old, and that currently used (plastic) materials will not be emerge again in the waste stream for several decades.
- The fact that current waste streams are decades old and contain unknown substances or substances now classified as hazardous is a major obstacle to the imposition of producer responsibility in accordance with the 'polluter pays' principle, or the implementation of manufacturer-supported take-back and recycling systems, given that products placed into circulation today will not be collected for several decades – a situation that currently makes the mechanical recycling of plastic construction products more difficult and requires an analysis of the advantages of recycling or the return of these plastics in individual cases.

3 Take-back systems: An overview

In take-back systems, products are recovered following their use phase. Take-back schemes can take different organizational forms, such as deposit systems, loan models, or simple take-back. Most of the take-back systems for plastic products from the construction sector presented in this chapter are of the simple type and do not make use of deposit or loan mechanisms. The long service lives of many of the plastic products installed in this sector favors normal product take-back rather than deposit- or loan-based models. It should be noted, however, that plastic products are indeed used in the logistics of the construction industry via deposit and lending, or pooling systems. These include plastic pallets made of high-density polyethylene (PE-HD), as well as intermediate bulk containers (IBCs) and flexible intermediate bulk containers (FIBCs), also known as 'big bags.' However, due to their low costs the latter are mostly used in disposable packaging. All of the extant take-back systems presented here are operated on a voluntary basis.

From a recycling point of view, take-back systems offer the advantage that the materials taken back can offer high-purity material streams. This is the case, for instance, for the recycling of bottles made of polyethylene terephthalate (PET) on which small deposits are made at purchase. The secondary raw materials obtained via take-back systems are therefore of high quality and can be partially reused for the same applications. A further advantage of such a closed-loop system is that returned products can be reprocessed into equivalent new products. In many cases, product manufacturers have no incentive to optimize their products for subsequent recycling because they, as manufacturers, bear the costs of so doing, whereas other actors in the value chain benefit. This circumstance often poses a significant hurdle to so-called "design-for-recycling" schemes. However, if manufacturers use the material returned from take-back systems in their own production processes, there is an incentive to optimize the products to enable high-quality recycling. The RAUFIPRO material produced by the REHAU company can be cited as an example of this. In this instance, glass fiber-reinforced PVC-U is used (REHAU AG 2019). In order to be able to separate the material streams of the reinforced and non-reinforced materials, tracer materials are added that facilitate subsequent separation (Fahr 2018). PVC windows are also collected and recycled as part of the Rewindo take-back system, and the recyclate is then used in the production of new window profiles.

The legal basis for construction products is regulated by the Circular Economy Act, more details of which can be found in Section 3.4. In some instances, the costs of operating take-back systems are covered by disposal fees, whereas in others they are cross-financed by the product manufacturers; some are also self-financed via the sale of the recyclates obtained. In most cases, there is no direct financial incentive to reclaim products, recycle them and use their recyclates in the production of new products. However, these activities are viewed positively by society and can therefore be presented to the public in order to give a material or product a unique selling point.

3.1 Methodology

The information listed here was collected by means of a literature review, an Internet search, and through semi-structured expert interviews.

3.1.1 Literature and internet research

A literature review of relevant scientific and technical publications was conducted. On the one hand, this served to identify existing take-back systems and, on the other, to provide in-depth insights into how they function, their economic and legal foundations, and other important factors. The focus of the Internet research was the identification of various take-back systems and the collection of related information. In addition, general information on take-back systems, recovered product groups, association structures, and legal considerations were also explored. The internet research was conducted in German, English and Spanish. The search engines Ecosia (= Bing), DuckDuckGo, and Google were used, with keywords that included the following: "Take-back," "take-back system," "take-back systems plastic," etc.

In the course of the research process, only a small number of currently-operating take-back systems could be identified. There are two possible reasons for this:

1. There are only a small number of existing take-back systems and the search was able to cover a large number of them – or:
2. The search did not provide a comprehensive overview of take-back systems.

In order to be able to falsify number two, relevant industry associations, interest groups, and other stakeholders were investigated and information requested from them.

Requests were submitted to:

- 16 German industry associations
- 23 European trade associations
- 7 hardware store companies/building materials wholesalers

These stakeholders also only named a handful take-back systems, which proved to correspond to those already found during the Internet search.

3.1.2 Expert interviews

Interviews were conducted with representatives of take-back systems, the recycling and disposal industry, manufacturers' associations, manufacturers, and the construction industry. One focus of the interviews was on the viability of take-back systems and obstacles and challenges they face – from a technological as well as legal and economic perspective. Another focal point was on political support for take-back systems in the context of the circular economy through the design of framework conditions, regulations and direct support measures.

3.2 Literature review

Take-back systems constitute a tool for fulfilling the product responsibility stipulated in the Circular Economy Act. They are financed by either the value of the products taken back or with their operating costs subsumed in the product price. The literature primarily discusses issues of logistical implementation, as well as the economical design of take-back systems, and also evaluates the ecological benefits. It should be noted that the literature review was not limited to take-back systems for specific materials or industries.

Various factors are cited as incentives for the introduction of take-back systems:

- Resource protection/scarcity/improved recycling (Weiland and Urban 2014), (Thierry et al. 1995), (OECD 2014), (Hallmann and Jäger 2010)
- Environmental protection (Weiland and Urban 2014), (Klausner and Hendrickson 2000), (Hischier et al. 2005)
- Cleaner material flows (Weiland and Urban 2014)

- Better product design with respect to disposal (Klausner and Hendrickson 2000)
- Less waste (Klausner and Hendrickson 2000) (Thierry et al. 1995)
- Internalization of waste disposal costs (Klausner and Hendrickson 2000)
- Retention of environmentally-conscious customers and employees (Thierry et al. 1995) (OECD 2014)
- Avoidance of excessive inventory among distributors (Hallmann and Jäger 2010)
- Accommodation of reclaimed goods and warranty parts (Hallmann and Jäger 2010)

The literature reveals that if products are taken back at a profit, corresponding take-back systems are typically implemented and a market for used products or waste is established. If there are 'only' the aforementioned incentives for society as a whole, either the manufacturers can be legally obligated by the governing authorities to take back products or the manufacturers can be compelled to act voluntarily (Weiland and Urban 2014).

According to Thierry et al. (1995), the following categories of information are important for planning a take-back system:

- Information regarding the composition of products
- Information on the extent and uncertainty of recoverables
- Information on markets for remanufactured products, components, and materials
- Information on actual product recovery and the implementation of waste disposal

Furthermore, Thierry et al. (1995) distinguish the use of returned products on the basis of: a) the firm itself; b) other firms; or c) firms external to the original value chain. The following possibilities of reuse are mentioned: repair, refurbishment, remanufacturing, cannibalization, and recycling, all of which are comparatively presented in Table 2, below.

Table 2. Comparison of the possibilities of recycling after take-back has taken place according to Thierry et al. (1995).

	Degree of disassembly	Quality requirements	Resulting product
Repair	Product	Restore functionality	Individual parts replaced
Overhaul (refurbishment)	Modules	Inspection of critical parts and restoration of specified quality	Individual modules replaced or repaired, upgrade possible
Remanufacturing	Parts	Restore to new quality or better	Used and new parts combined into new product, upgrade possible
Cannibalization	Removal of selected parts	Dependent on later use of the parts	Reuse of individual parts, for the remainder disposal or recycling

	Degree of disassembly	Quality requirements	Resulting product
Recycling	Materials	High for the restoration of original parts, lower when used in other parts	Reuse of the material for new parts

Wallau (2000) addressed financing models for take-back schemes in the course of discussions on end-of-life vehicle disposal. These results assume that the take-back of a product is not covered by the material value of the parts and recyclates thus obtained, and that this must therefore be financed in another way. The system designed can also be applied to other products to a certain degree. Wallau (2000) poses the following key questions:

- Who pays the disposal fee and when (e.g., manufacturer or importer, first purchaser, all purchasers as an ongoing charge)?
- Which disposal fee is paid (e.g., lump sum, amount differentiated by product criteria)?
- Who administers the deposited funds (the manufacturers alone or jointly, external private or state actors, or some mixture thereof)?
- According to which principle is the fund managed (the capital or capital contribution methods)?
- How is it paid out (lump sum or differentiated)?
- To whom are payments made (actors in the utilization chain)?

The combinations of the various options yield a range of possibilities in which the take-back system can be mapped. For its construction, Wallau also distinguishes between material, information and payment flows.

Klausner und Hendrickson (2000) also examine the cost aspect, specifically the example of the cost of taking back power tools. They propose a built-in device for storing usage data that would make it possible to track loads in machines used. In this manner, they argue, the suitability of some mostly wear-free components for recycling can be assessed. The authors also present a model for estimating costs as a function of equipment returned.

An important financial factor for consumers using deposit systems is the negative interest effects that arise from the capital tied up as deposits (Weiland and Urban 2014). Especially for building plastics, with their typically long product lifetimes and large volumes, this effect is not insignificant and therefore another disadvantage of transferring the concept to construction products.

Witek (2015) compare various publications regarding the predictability of the amount of equipment returned. Being able to calculate, estimate or, even better, control this variable is an important factor in the planning of take-back systems. Active return management should already be considered in the planning phase. This would enable a means of implementing reverse logistics – another key aspect of take-back systems.

This is also considered by Hallmann und Jäger (2010) from the perspective of a company that maps reverse logistics networks via service providers. In addition to a functioning take-back scheme, they also focus on the efficient utilization of its component systems. In Table 3, the special features of reverse logistics are outlined in a comparison with conventional logistics.

Table 3. Comparison of take-back systems used for reverse logistics alongside regular forward logistics according to Hallmann and Jäger (2010).

	Forward logistics	Reverse logistics
Forecasting	Relatively simple	Difficult
Material flows	Diverging	Converging
Product quality	Uniform	Variable
Product condition	Uniform	Variable
Packaging	Uniform	Variable
Delivery speed	Important	Unimportant

3.3 Results of the expert interviews

The following were stated as criteria for the establishment and operation of take-back systems:

- Availability of the materials as a sufficiently large mass flow, so that economic efficiency can be achieved. Sometimes, the bundling of different wastes is necessary, e.g., combining PU from insulation materials with PU material streams from other industries.
- The concentration of plastics in the total waste volume so that collection is logistically-feasible and rational, e.g., the separate collection of windows during a renovation project.
- The existence and feasibility of selective deconstruction processes with which materials can be technically recovered for recycling.
- The economic feasibility of these deconstruction processes, two aspects of which should be noted here:
  - The preparation of selective dismantling during the planning and construction phase – in the view of the experts, economic and knowledge aspects in particular play a role here. Systems that enable selective deconstruction are normally considered more expensive than those that do not. According to one expert, for instance, the use of a curtain wall for insulation can be easily deconstructed, but is more than twice as expensive as alternative solutions. The major cost pressure in the construction industry, which has intensified in recent years, makes the implementation of these solutions highly unlikely. On the other hand, deconstruction-friendly construction is not an anchored principle in the approach of architects and engineering firms, and cannot be provided by many of them. In this case, it would be necessary to resort to providers that specialize in sustainable construction.
  - The separation of materials during the demolition and dismantling phase – the economical separation of the materials to be separated would be hampered by several factors. On the one hand, there would be no financial incentive to separate plastics, as the proceeds from secondary plastic recovered would not cover the costs of the additional effort entailed in dismantling or demolition; this would be different for copper cables, for

instance. The economical separation of plastics would also be hampered by the cumbersome-to-impossible removal of many plastic products. Pipes or geotextiles laid underground, for example, cannot be dismantled. Similarly, the dismantling of bonded insulation materials is not economically viable. An exception to this is built-in components, such as doors, windows, and floor coverings, which can be separated with relatively little effort. Another factor that hinders separation is that the plastic can and is simply disposed of together with normal construction waste.[1]

- Possible additives – can materials from demolition waste be used, or do they contain additives, pollutants or contaminants, making recycling difficult or not a form of harmless recovery? Experts' views differ on this – whereas some believe that we are currently "building tomorrow's legacy," others point to the extensive regulation, testing, and recycling processes which they believe ensure that much plastic can be recycled.
- The challenging economics of reprocessing processes – the price competition of the recyclate with virgin material was declared an obstacle by a large proportion of the experts. The take-back systems surveyed and presented in Chapter 3.5.1 are partially self-financing through the disposal fees charged and the sale of their recyclates, but in some cases the take-back system would also be subsidized by the manufacturers of the virgin material, which would not cover its costs. The costs of take-back and recycling also scale to a certain extent with the quantity being processed.
- The political will to implement take-back and recycling – in the opinion of the experts, take-back and recycling schemes supplementing existing ones could only be created through regulation by policymakers. If the current conditions remained the same, they would not arise on the basis of the economic interests of manufacturers.

The following factors were cited as technical hurdles for the recycling of construction plastics from take-back systems:

- The technical and economic feasibility of the removal of hazardous substances, especially in light of the price competition between recyclates and virgin material. However, for selected material streams, pollutant removal is not necessary, or can be implemented by means of simple processing technology.
- Poorer performance properties of recycled materials, in contrast to virgin ones. For instance, the use of recycled material in pressurized pipes is neither technically feasible nor legally permissible. Even recycled materials, i.e., recyclates from a company's own unused products, do not always meet the required quality standards.

[1] Indeed, according to GewAbfV §8, the producers of construction and demolition waste are obliged to collect plastic separately from other waste. However, according to §8 (2), this obligation does not apply "[...] insofar as the separate collection of the respective waste fraction is technically impossible or economically unreasonable."

- The poor qualifications of the employees of some recycling and disposal companies contribute to suboptimal recyclate quality.
- Inefficiency and technical hurdles facing chemical recycling.

The legal and regulatory hurdles noted were:

- The jurisdiction(s) handling chemical pollutants and waste legislation (e.g., various flame retardants and lead- and cadmium-based additives). Sometimes poor planning with respect to political regulation was also cited here. A current example is the discussion regarding titanium dioxide and the lack of clarity as to whether, or to what extent, it should be banned.
- The waste status of offcuts during the installation of virgin material. If offcuts generated during construction are to be transported from construction sites to recycling facilities, these installation offcuts are considered waste and thus require the appropriate documentation during transport. This cannot be performed by the installing companies though and so makes the recycling of these leftovers impossible.
- The permissible content of plastics in construction waste – with plastics accounting for up to 2% of construction waste and the enormous mass thereof, a lot of plastic could be legally disposed alongside construction waste.[2]
- Electrification of products such as shutters. Products of this type come under the scope of the ElektroG when they are electrified and must be recycled as waste as part of WEEE processing activities. With respect to the use of recyclates in these products, the European RoHS Directive and the national Electrical and Electronic Equipment Ordinance are authoritative and specify pollutant limit values.

The following wishes were expressed to policymakers:

- That the recycling of products should be made possible and simplified by regulating the product itself, e.g., through "design-for-recycling" principles.
- That pollutant issues should not be decided upon via non-scientific discussions in civil society, but on the basis of scientific findings.
- Strategic planning should be reflected policies designed for the long term.
- That policy forces the use of recyclates. Corresponding technical solutions would then emerge as a result of this.

[2] According to "DAfStb Beton, recycled aggregates," depending on the type, it may contain 1%w or 2%w of glass and other materials, including plastics. For unbound materials, a maximum content of 0.1%w of other materials is permissible according to "TL Gestein-StB – Technical delivery conditions for aggregates used in road construction." A precise quantity of these types is not stated for Germany, but according to the Federal Environment Agency (UBA), the total quantity of construction waste in 2018 was 58,500 kt.

- That recycled plastics are taken into account as a criterion in tenders and not excluded on principle, as is still the case in some municipalities.

Stakeholders other than those interviewed are of the view:

- That recycling should be pursued as a goal across the entire value chain in order to be successful, and not only by recyclers at the end thereof.

3.4 Legal situation regarding the voluntary take-back of waste

The take-back of waste is legally regulated in Germany by the Circular Economy Act (KrWG), among other provisions. Accordingly, the extended producer responsibility dealt with in § 23 KrWG includes the "taking back of products and remaining waste after use and their subsequent environmentally-compatible recycling or disposal." If this requirement from § 23 KrWG results in an obligation to take back or return products, the details of such a precept can be determined by the Federal Government by means of a statutory order in accordance with § 25 KrWG. A labeling obligation can also be established by the government according to § 24 KrWG. For voluntary take-back systems, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) can set targets through legal ordinances.

For private waste, there is normally an obligation to turn over waste in accordance with § 17 KrWG, i.e., producers or owners of waste must surrender it to public waste disposal companies. However, this obligation does not apply to waste that is voluntarily taken back (§ 26 KrWG) in compliance with extended producer responsibility (§ 23 KrWG). Especially for potentially valuable waste such as old textiles, the question therefore arises of the extent to which manufacturers may also take back products from other manufacturers as part of a take-back scheme; this was the subject of a recent court battle between fashion houses and municipal companies. According to the rulings to date, however, such a take-back approach by other manufacturers is also possible (Oexle and Lammers 2019; Wenzel 2015)

Take-back schemes for construction plastics often offer take-back options for both commercial and residential wastes.

3.5 Analysis of existing take-back systems

12 take-back systems for products in the domain of construction plastics in Europe could be identified. These include local and Europe-wide take-back systems with take-back volumes ranging from a few t to 33,000 t per year. Such take-back systems are primarily operated for PVC, as well as for pipes and flooring.

For the purposes of this report, the take-back systems were converted into a standardized description so as to enable comparisons and overviews. This standardized description includes the following points:

- Name of the take-back system.
- Brief description: The essential features of the take-back system are summarized in a block of text with a maximum of three sentences.
- Contact: Contact information, including address, email, phone number, and website address.
- Recycled materials: Recycled plastic types and other materials are listed.

- Quantities: Provides information on the total quantities recycled by the take-back system.
- Waste: Specifies the products collected and recycled by the take-back system.
- Recycling process: Describes the procedural steps for the preparation or recycling of the materials.
- Acceptance logistics and catchment area: Provides an overview of the logistical organization of the product take-back and of the area in which the system operates.
- Use of recyclates: Provides an assessment of the quality of recycling. This ranges from recycling into equivalent virgin material, to the use of the returned plastics as substitute fuel.

The standardized descriptions are listed below. An assessment of the take-back systems can be found in the Chapter 3.5.2, which follows. The sources used are indicated at the base of each table. Much of the information was also gathered through personal contact with representatives of the respective schemes. Due to the anonymity assured to the interviewed experts, these sources are not shown separately here.

3.5.1 Descriptions of the take-back systems

Rewindo	
Rewindo organizes the return and recycling of windows, shutters and doors made using PVC. After dismantling, the material is processed, regranulated and recycled for re-use in PVC profiles. Rewindo is a member of the European voluntary commitment association, VinylPlus®.	
Contact	
Am Hofgarten 1–2 53113 Bonn	info@rewindow.de +49 228.921283-0 www.rewindo.de
Recycled materials	Collected products
▪ PVC-U	▪ PVC Windows ▪ PVC Doors ▪ PVC Shutters
Volumes	
▪ 33.3 kt/a of mechanical recycling (2019) ▪ 2.7 kt/a of secondary use (2018)	
Recycling process	Receiving logistics and catchment area
▪ Rough pre-sorting and shredding ▪ Separation of glass and metal ▪ Cutting mill for size reduction to granular sizes < 20 mm ▪ Washing, drying, and purification ▪ Extrusion using melt filtration to regranulate	▪ Self-delivery to one of 36 collection points ▪ Self-delivery directly to one of the eight recyclers ▪ Collection by recycler ▪ Germany-wide
	Recycled material use
	▪ Recyclates are reused by manufacturers for the production of new PVC profiles, demand is currently greater than supply

Sources: Rewindo (2019, 2020c)

Roof Collect

The Roof Collect take-back system recovers plastic-based waterproofing membranes. Take-back is possible in most European countries and part of the PVC industry's VinylPlus® initiative. The waterproofing membranes are then dismantled and processed into protective mats.

Contact

Avenue de Cortenbergh, 71
B-1000 Brussels
+32 (0) 2/739 63 83

info@roofcollect.com
+32 (0) 2/739 63 83
www.roofcollect.com

Recycled materials

- Soft PVC
- EVA/PVC
- Other PVC-containing blends
- PVC-coated textiles

Volumes

- 3.5 kt/a (2018)

Products collected

- Plastic roofing and waterproofing membranes
- The PVC content must be > 90%
- It must not contain any metals
- It must not contain loose fibers
- It must not contain water as an impurity

Recycling process

- Cleaning and cutting of films during disassembly into 1 m-wide sheets
- For transport, films are rolled up and put in large bags or containers
- Dissolving, purification by filtering, precipitation in water, solvent-recovery
- Downcycling to protective mats, e.g., for greenhouses and equestrian sports

Receiving logistics and catchment area

- No information available on receiving logistics
- DACH countries, France, Benelux, and Spain

Recycled material application

- The recycle is used in protective mats

Sources: VinylPlus (2019) and RoofCollect (2020)

Plastic Pipe Association

The Plastic Pipe Association e.V. takes back and recycles plastic pipes in collaboration with the recycling company PreZero. The plastic types PE, PP and PVC are processed. Some of the recyclates generated are then reused in plastic pipe applications.

Contact

Plastic Pipe Association e.V. (KRV)
Kennedy Avenue 1–5
D-53175 Bonn

info@krv.de
+49 228. 914 77-0
www.krv.de

Recycled materials

- PE
- PP
- PVC

Volumes

- ca. 5 kt/a

Products collected

- Plastic pipes
  - No pipes made of cross-linked PE
  - No mineral fiber-reinforced pipes
  - No multilayer or composite pipes
- Mainly offcuts from new installations

Recycling process

- Sorting according to materials
- Manual preparation
- Grinding in large mills/rotor cutters to produce mixed material comprising PE/PP/PVC with particle sizes of 8–12 mm
- Cleaning in an air classifier to remove impurities
- Recompounding

Receiving logistics and catchment area

- Worldwide acceptance with the help of recycling partners from the waste disposal industry

Recycled material application

- Can be used for new products, but not in pressurized, drinking water, or gas pipes.

Source: KRV Impulse (2019)

The Austrian Working Group for Plastic Pipe Recycling (ÖAKR)

The ÖAKR organizes the take-back of various plastic pipes in Austria. The recovered plastic is then materially recycled and reused for the manufacture of construction products.

Contact

Arsenal Obj. 213
Franz-Grill-St 5
A-1030 Vienna

info@oeakr.at
+43 1 798 16 01-150
www.oeakr.at

Recycled materials

- PE
- PP
- PCV
- PB
- Alu-PEX
- PEX

Volumes

- 1,3 kt/a (2017)

Collected products

- Plastic pipes
- Multilayer pipes
- Composite pipes
- Pressurized pipes
- Sewer pipes
- Drainpipes
- Drainage pipes
- Gas pipes
- Heating and sanitary pipes
- Cable protection pipes
- Electrical and installation pipes

Recycling process

- Day-to-day operation is carried out by Reststofftechnik GmbH on behalf of the ÖAKR.
- Fully automatic sorting by plastic types – 99.9 % purity, daily throughput of 5 t at 8 h/day
- Subsequent recycling

Receiving logistics and catchment area

- 67 collection points in the regional branches of ÖAKR members, as well as collaboration with the company, Reststofftechnik GmbH of Henndorf am Wallersee
- Only pipes of certain colors and free of residues or impurities are accepted

Recyclate utilization

- Recycling and reuse of recyclate for construction products (pipes, boards, recyclate compounds)

Sources: ÖAKR (2018, 2020), Reststofftechnik GmbH (2020)

Working Group on the Recycling of PVC Floor Covering (AGPR)

The AGPR organizes the take-back and recycling of PVC-P flooring. Recovered floor coverings are cleaned and materially recycled.

Contact

Bau 1136/PB 16
Paul-Baumann-St 1
D-45772 Marl

info@agpr.de
+ 49 23 65-50 92 133
www.agpr.de

Recycled materials

- Plasticised PVC

Volumes

- 2.5 kt/a mechanical recycling (2016)

Collected products

- Homogeneous coverings (single-layer coverings, patterned throughout)
- Heterogeneous coverings (PVC wear layer on a PVC carrier layer)
- System flooring (thicker PVC wear layer on PVC foam)
- CV coverings (thinner PVC wear layer on PVC foam)
- PVC wall coverings (PVC wear layer on PVC foam)
- PVC welding cords

Recycling process

- Manual sorting of non-PVC coverings and foreign materials
- Coarse shredding
- Magnetic metal separation
- Hammer milling to knock off screed residues
- Sieving
- Fine grinding at -40 °C to a particle size of 400 µm, separation of coarse particles and PET fiber balls
- Filling of the powder

Receiving logistics and catchment area

- 159 receiving points
- Network of receiving points and logistics centers in neighboring European countries

Recyclate utilization

- Recycled material can be reused in the production of floor coverings (with the exception of lounges)

Sources: AGPR (2020), Recylingportal.eu (2017)

ReStart

The Tarkett company takes back parts of its flooring product range as used goods and installation offcuts and recycles them, along with production scraps. The latter are used to produce recyclates and carpet backing.

Contact	
Tarkett Holding GmbH Germany Nachtweideweg 1–7 D-67227 Frankenthal	info.de@tarkett.com +49 6233 81 0 www.tarkett.de
Recycled materials	**Collected products**
▪ Vinyl ▪ Linoleum ▪ PA6 **Volumes** ▪ 3.3 kt /a (2018)	▪ Take-back and recycling of offcuts: Homogeneous and heterogeneous flooring, linoleum ▪ Take-back and recycling of used flooring ▪ All DESSO carpet tiles (PA6 and country-specific PA6.6 yarn) with bitumen and EcoBase backing, depending on composition ▪ Post-material testing also competitive products
Recycling process	**Receiving logistics and catchment area**
For post-consumer carpet tiles: ▪ Pick-up of carpet tiles (fixed, not glued) by the installation company ▪ Transport to Carpet Recycling Center in Waalwijk (Netherlands) ▪ Separation of yarn from carpet backing ▪ Closed loop recycling of PA6 yarn to new white yarn (by the Aquafil Group) ▪ Closed-loop recycling of carpet backing from Tarkett ▪ Bitumen, fillers, and PA6.6 as substitute fuel Specific processing methods for offcuts depending on the material	▪ Virgin material is delivered in grid boxes through the deposit system, which can then be filled with recycled material and returned ▪ Acceptance of loose debris from demolition work ▪ Cooperation with various waste disposal companies ▪ Germany, France, the Netherlands, Belgium, Luxembourg, Sweden, Norway, Denmark, North America, and Brazil **Recyclate utilization** ▪ For Ecobase carpet tiles, 76 % closed loop recycling

Source: Tarkett (2019)

Interface

The Interface company offers flooring made of various materials, which it also takes back. In addition to its take-back system and recycling, Interface attempts to minimize the environmental impact of its products and was an early adopter of innovations such as adhesive-free installation and the use of recycled materials.

Contact

Interface Germany GmbH
Mies van der Rohe Business Park
Girmesgath 5
47803 Krefeld

info-de@interface.com
+49 2151-37180
www.interface.com

Recycled materials

- PA
- PVC
- Natural rubber
- PVB
- Soft PVC

Collected products

- Modular textile flooring
- "Luxury vinyl tiles"
- Rubber flooring

Volumes

- No information

Recycling process

- Collection of carpet tiles, installed without adhesives
- Evaluation of the condition and composition of used products, then reuse, recycling, or thermal recovery

Receiving logistics and catchment area

- No information

Recyclate utilization

- Depending on material condition, recycling or thermal utilization performed

Source: Interface n.d.

Greenstream

Greenstream collects used carpet tiles and, if possible, recycles or uses them as filling material. The company also takes the social aspects of the reprocessing of carpet tiles into account, e.g., providing low-cost flooring to low-income households.

Contact	
No information	info@gsflooring.org.uk +44 2151 371 80 www.findcarpettiles.co.uk
Recycled materials	**Collected products**
▪ Diverse	▪ Carpet tiles
Volumes	
▪ No information	
Recycling process	**Receiving logistics and catchment area**
▪ Preparation and cleaning for reuse ▪ Use for social purposes ▪ Giving away of used carpet tiles	▪ Collection of palletized carpet tiles or carpet offcuts in large bags ▪ Performed by partner logistics companies ▪ England-wide
	Recyclate utilization
	▪ Reuse

Source: Greenstream (2020)

Anglo Recycling

Anglo Recycling collects commercial carpet installation scraps and edge trimmings from the carpet manufacturing process and uses them to produce carpet-backing layers.

Contact

Tong Lane,
Whitworth, Rochdale, Lancashire,
OL12 8BG,
United Kingdom

info@anglorecycling.com
+44 1706 853-513
www.anglorecycling.com

Recycled materials

- PP
- Wool
- Soft PVC

Collected products

- Edge trim professional carpet installers
- Offcuts produced during the manufacturing process

Volumes

- 1 kt/a

Recycling process

- Shredding
- Sorting
- Preparation into fibers
- Production of carpet backing

Receiving logistics and catchment area

- Collaboration with commercial carpet installers, as well as producers
- England-wide

Recyclate utilization

- Downcycling to carpet backing layers

Source: Anglo Recycling (2020)

Crop Plastics Recycling Germany (ERDE)

As part of the various take-back schemes grouped under RIGK, the ERDE take-back system organizes the take-back of plastic films from agricultural applications. These are regranulated and reused in plastic products.

Contact

Friedrichstr. 6
D-65185 Wiesbaden

erde@kunststoffverpackungen.de

+49 611 308600-0

www.erde-recycling.de

Recycled materials

- PE-LD
- PE-LLD

Volumes

- 13.4 kt/a (2018)

Collected products

- Flat silo films
- Silo tubes
- Underdraw films
- Silage stretch films
- Net replacement films
- Round bale nets

Recycling process

- Acceptance of compressed films
- Shredding and washing
- Regranulation

Receiving logistics and catchment area

- Approx. 500 collection points across 90 retail partners in Germany
- Container logistics at the collection points
- Farm collection

Recyclate utilization

- Plastic products, also films and sacks

Sources: RIGK (2019), Peters (2019)

3.5.2 Assessment of the voluntary take-back systems

3.5.2.1 Take-back of PVC waste

Many of the take-back systems for construction plastics established in Germany and outlined here engage in the take-back of PVC products. There are several reasons for this. On the one hand, it reflects the fact that PVC is the most widely-used plastic type in the construction sector and thus generates a material flow that is relevant in terms of volume. However, it is also due to the technical viability of its recovery and recycling. The thermoplastic material can be processed into recycled material by means of recompounding, unlike thermosets such as PU. The requisite technologies and industrial experience also exist to process these recyclates in a useful manner. The collection of many PVC-based products can also be readily carried out. The separation of PVC contained in windows, doors or shutters can be accomplished without excessive effort during selective deconstruction, and the removal of flooring or roofing membranes can also be performed with reasonable ease. However, the reuse of pipes installed under plaster or buried belowground is unlikely due to the difficulty of deconstruction, and is rarely carried out. The current PVC recycling systems came into being because of the formerly negative image of PVC in society and the resulting pressure on the PVC industry to demonstrate the material's potential environmental compatibility, which drove their implementation.

According to our analysis, take-back systems for PVC can be divided into two main streams. One is the PVC-U, which is taken back by Rewindo and the Plastic Pipe Association. The collection logistics for separated products are established here, and high-quality recycling is both possible and well-developed. Technologies exist to allow the recyclates received via take-back systems to be used again in the same product category, thus facilitating a material cycle. The following standards or draft standards are relevant for the use of recyclate in these products:

- Regulated process for the recycling of used PVC-U windows and doors; prEN 17410:2020:
  - Based on the Life Cycle Analysis (LCA) method, represents the life cycle of PVC and defines its material flow for different approaches to reuse
  - Defines test procedures for the material, which explicitly refer to different stages in the life cycle, such as recycling input and output
  - Describes how recyclable products can be designed and how quality assurance implemented
- Plastic piping and fittings – Characteristics for the use of return material and recyclate from PVC-U, PP and PE materials; CEN/TS 14541:2013:
  - Specifies test methods for assessing recycled materials, including PVC
- Plastic recyclates – Characterization of PVC recyclates; German version EN 15346:2014:
  - Specifies both mandatory and optional methods for the testing of PVC recyclates
  - Describes test methods for testing PVC recyclate quality and determining the suitability of PVC recyclates for processing
- Plastic recyclates – Characterization of plastic waste; EN 15347:2007:
  - Specifies both mandatory and optional characterization data on plastic wastes

The second relevant PVC material stream is PVC-P, which is taken back by AGPR and RoofCollect. Here, too, separation is possible during dismantling or renovation work. The pollutant issue of PVC-P is outlined in Chapter 4.2.1.2. As in the case of PVC-U, collection and recycling is conducted by manufacturers. The collection of materials and their recycling is well-established, but downcycling to lower-value products also occurs in this area.

3.5.2.2 The take-back of floor coverings

Take-back systems for the recycling of flooring theoretically have much potential, as separation during selective deconstruction is readily possible. Recyclates are also already used in production on a large scale. One hurdle, however, is the diversity of materials contained in the products. The existing systems therefore offer the following options:

- Reconditioning and reuse of used flooring, such as that conducted by Greenstream. Here, however, the product’s service life is only extended and subsequent recycling is still not possible.
- A product designed with subsequent recycling in mind can make the recycling of individual products or product groups possible. Take-back and recycling is then carried out on a manufacturer-specific basis. This model is utilized in the Interface and Restart take-back systems for EcoBase carpet tiles.

- Downcycling of the type conducted by Anglo Recycling.

3.5.2.3 The take-back of pipes

The take-back systems for pipes reflect the multifaceted challenges that beset the successful recycling of plastics in the construction sector. Recycling is technically feasible and a low level of downcycling due to high-quality requirements, such as for pressure pipes, is acceptable. Relevant standards or draft standards are as follows:

- Plastic piping and fittings – Characteristics for the use of recovered materials and recyclates from PVC-U, PP and PE materials; CEN/TS 14541:2013.
- Plastic recyclates – Characterization of PP recyclates; EN 15345:2007:
  - Specifies test methods for the characterization of PP recyclates and test reports
  - Describes a test method for the characterization of PP recyclates
- Plastic recyclates – Characterization of PE recyclates; prEN 15344:2020:
  - Specifies mandatory and optional test methods for testing PE recyclates and a test report
  - Describes several test methods for the characterization of PE recyclates
- Plastic recyclates – Characterization of plastic waste; EN 15347:2007

A major hurdle in pipe recycling is separation during deconstruction. The recovery of pipes installed under plaster or buried belowground is not currently economical.

3.5.2.4 The take-back of agricultural films

The ERDE recycling system for agricultural films demonstrates that take-back systems can also be established in the agricultural sector. The product spectrum here is still limited, but can and should be expanded. Collection focuses on the fractions of low-density polyethylene (PE-LD) and linear low-density polyethylene (PE-LLD). For PE recycling, the standard, "Plastic recyclates – The characterization of PE recyclates; prEN 15344:2020" is relevant.

3.5.2.5 The take-back of insulation materials

Plastics are also used in large quantities in the construction sector in insulation materials. Here – in contrast to rock and glass wool – no take-back systems are currently in operation. For thermoset materials such as PUR, mechanical recycling is not currently possible. According to an expert interviewed, the recycling of PUR insulation materials takes place as an aggregate in pressed boards; cf. Chapter 4.3.4.6. Here, the demand for PUR foam residues is currently greater than the supply. Polystyrene as a thermoplastic material, on the other hand, could theoretically be materially recycled; cf. Chapter 4.3.4.4.

Flame retardants are a potential source of pollutants in all combustible insulation materials. The time lag between production and dismantling due to the long service life of these products further complicates recycling. This can be well-illustrated by the example of 1,2,5,6,9,10-hexabromocyclododecane (HBCD). The low density and thus relatively low masses of insulation materials also obstruct the economical collection and recycling of insulation materials. In addition, insulation materials are collected according to the Waste Catalogue Ordinance (AVV) and no separation is made between plastic-based and other insulation materials. Here, a further split or a classification into plastic waste should be carried out.

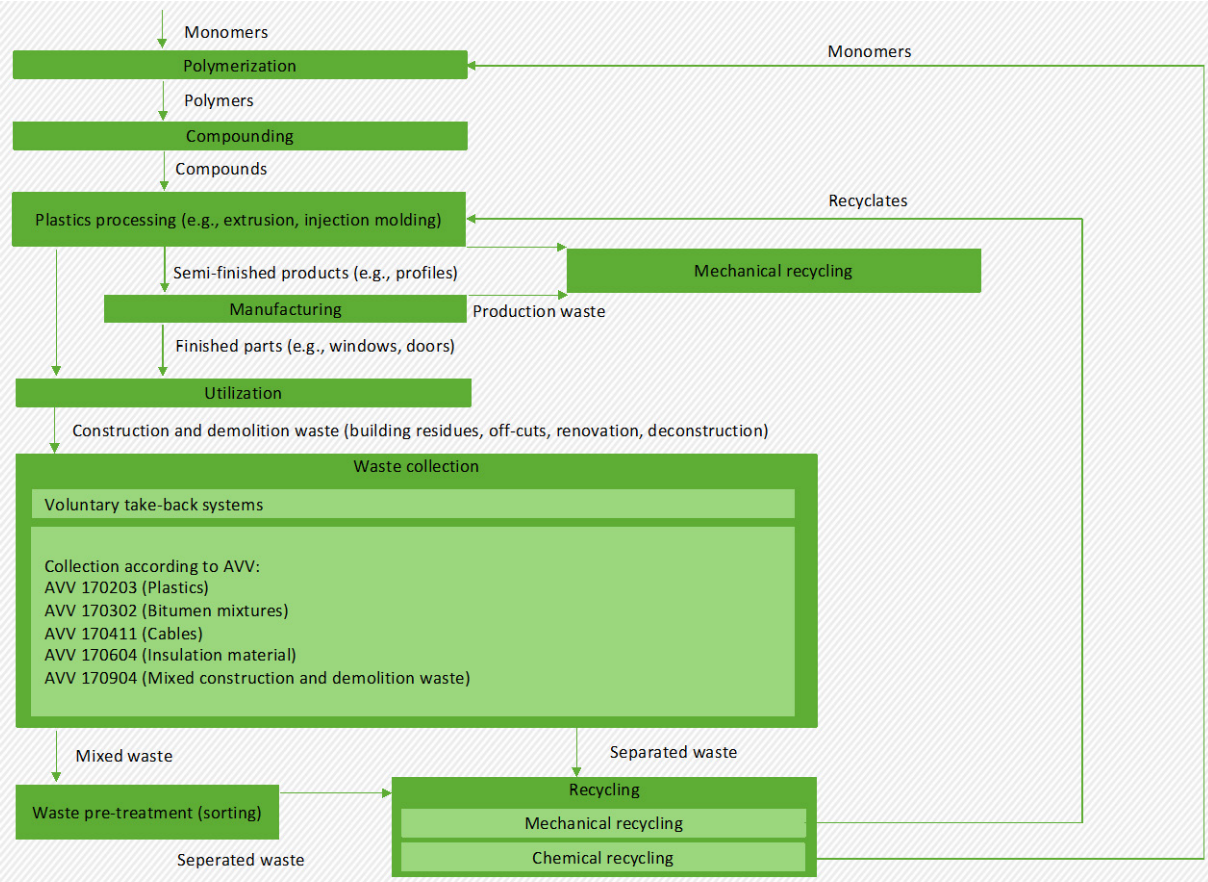
4 Recycling techniques

This chapter describes the plastic processing and recycling techniques currently available for construction products. Section 4.1 first provides an overview of the plastic cycle in the construction industry, the types of plastics used, and their areas of application. Section 4.2 then describes the expected pollutant loads and presents some methods for their removal. The description of the mechanical and feedstock recycling processes of the materials used follows, in Section 4.3 and the construction of product-specific processes are described in Section 4.4. The recycling options for glass fiber-reinforced plastics are presented separately, in Section 4.5. The chapter concludes with a summary and recommendations.

4.1 The plastic cycle in the construction industry

The plastics cycle in the construction industry is visually depicted in Figure 16. It begins with the polymerization of monomers, such as vinyl chloride into polyvinyl chloride. The plastic obtained is then compounded, i.e., additives are added to modulate its properties. Plastic processors are then made use of to manufacture products. This is performed by either injection molding or extrusion into semi-finished products, such as films or profiles, which are then further processed into construction products. Production waste from the manufacturing process can be recycled to a high standard and is then returned to plastics processors as recyclate or reprocessed in-house and fed back into production. Construction products become waste following use. Plastic from mixed waste is either thermally-recycled or recycled after pretreatment and sorting, whereas unmixed waste can be recycled directly. If the material is recycled without changing its chemical structure, the process is referred to as mechanical recycling, and usually consists of cleaning, sorting and recompounding (see Chapter 4.3). Solvent-based processes are also included another recycling process that does not change chemical structure. In niche applications such as the recycling of PA6 fibers, chemical (=raw material) recycling is also useful. Here, the plastic is depolymerized, purified and then repolymerized back into plastic. Chemical recycling is also used when the plastic is thermally-decomposed into products similar to petroleum and monomers are synthesized therefrom again (Martens and Goldmann 2016).

Figure 16. Plastic cycle in the construction industry.



Source: Own representation, Wuppertal Institute for Climate, Environment, and Energy.

4.1.1 Volume-relevant plastic types

Table 4 shows the most widely-used plastic grades (including bitumen) in terms of volume and their areas of application from Chapter 2. Together, these account for around 85% of construction products manufactured using mostly plastics. In view of the relevance of volume with respect to recycling, the processing and recovery technologies described in the following focus on this selection of materials and the stated areas of application.

Table 4. By volume, the most widely-used types of plastic in construction products mainly made of plastic in 2017, as well as their key areas of application. Source: Chapter 2.

Plastic type	Installed volume (2017)		Important areas of application
	t	Portion	
PVC	785,000	30%	Window, door, shutter, and building profiles, pipes, waterproofing membranes, flooring, and cable insulation
PE	425,000	16%	Pipes, building profiles
Bitumen	287,000	11%	Waterproofing membranes
EPS	248,000	9%	Insulation materials
PUR	162,000	6%	Insulation materials

Plastic type	Installed volume (2017)		Important areas of application
	t	Portion	
PP	124,000	5%	Pipes, textile flooring
XPS	75,000	3%	Insulating materials
GFPR	74,000	3%	Pipes, profiles, skylight domes, and strips
PA	69,000	3%	Textile floors, fittings
PMMA	43,000	2%	Skylight domes and bands, plumbing

4.2 Pollutant loads and removal

Building plastics can be contaminated in very different ways, making recycling difficult or impossible. The contamination can have various causes. Relevant are foreign substances (other plastics, metals, etc.), but also fillers or impurities, e.g. from product residues in packaging. These contaminants can make recycling more difficult or prevent it, as they deteriorate the properties of the secondary plastics. In addition, there are contaminants that should not be contained in the recyclate because of their concern for human health. These include, in particular, additives that were used in the past but are no longer permitted today. These additives were deliberately introduced into the plastic in order to positively change its properties. In addition, contaminants can also be introduced during assembly, use or disassembly. These include contamination by paints and varnishes, adhesives and mortar adhesions. The aim must be to select connections that are as detachable as possible, to dismantle them cleanly and to sort them well.

4.2.1 Additives in plastics processing

Additives often significantly contribute to the specific properties of plastics. The use of additives therefore cannot be avoided per se. However, many formerly common additives have had their use restricted by chemical legislation, in particular the REACH Regulation (*Regulation (EC) Nr. 1907/2006*). For the substances evaluated and restricted under this regulation, as well as the suspect list of substances for which a final evaluation has yet to be made, there is suspicion of their considerable potential for harm. Furthermore, the POP Regulation (*Regulation (EU) 2019/1021*) is relevant and restricts or prohibits the use of certain substances. This creates problems during recycling, some of which are considerable, because in many cases pollutants cannot simply be separated but remain in secondary plastics. This problem is naturally more likely to occur with long-lived products, such as construction products, than with short-lived ones, such as packaging. It is also important to note that this is not a closed process, and that substances will always be banned.

The additives used in plastic processing can be divided into various groupings. Of the many substances used overall, however, only some are relevant for restrictions on recycling. Harmful substances in construction plastics are typical for individual plastics, as their additives were and are also used in certain plastics. In the case of PVC-U, stabilizers and pigments in particular can pose a problem for recycling. In contrast to PVC-U, PVC-P contains plasticizers, which may pose health hazards but also problems for recycling and the use of recyclates. In the case of polystyrene insulation materials (EPS and XPS), the flame retardants used are especially critical in this respect.

Problems arise in the recycling process if additives are incompatible with one another. This can occur in particular when plastics and their additives derive from different sources and are mixed together during recycling.

4.2.1.1 **Stabilizers**

Stabilizers are of great importance for PVC for reducing the damage caused by thermal stress and friction (Diemert et al. 2008). Lead stabilizers could be used in PVC in the EU until the end of 2015. Even before that, they were often voluntarily replaced by calcium–zinc systems in Germany on the basis of the voluntary commitment, "Vinyl 2010" (The European Council of Vinyl Manufacturers et al. 2001). Before the advent of lead stabilizers, cadmium stabilizers were no longer being used in the EU. With a voluntary commitment, barium–cadmium stabilizers were phased out in the EU-15 by 2001 (Diemert et al. 2008). This commitment was extended to the EU-27 and implemented in 2007 (Rohde 2014). Barium–cadmium stabilizers were replaced by barium–zinc stabilizers (Maier und Schiller 2016, 498). However, lead stabilizers in particular can still be found today in old, durable PVC products, such as windows, doors, shutters, or pipes. Imported PVC products can also contain them. Thus, recyclates made from them may also contain lead stabilizers.

Despite the ban on cadmium and lead stabilizers, it has thus far been possible to use PVC recyclate in construction products (*Regulation (EU) Nr. 494/2011*) if the lead or cadmium it contains is obtained from recycled material. However, there is resistance to this exemption (European Parliament 2020). The European Parliament has vetoed a Commission proposal that would have continued to allow lead content in certain PVC products made from PVC recyclates with low exposure potential. The proposal had envisaged allowing higher limits (2% for PVC-U and 1% for PVC-P) for recycled PVC as an exception to the general limit of 0.1% lead content in PVC (European Parliament 2020). According to the ECHA, the final decision of the European Commission on the regulation of lead in recycled PVC is still pending (European Chemicals Agency 2021b).

The recycling of PVC-U from windows has already been well-established and exhibits continuously increasing quantities of manufactured recyclate (Rewindo 2020a); cf. chapters 3.5 and 5.3.4. Should the general limit value also apply to recycled PVC in the future, this would make the mechanical recycling of PVC from the construction sector considerably more difficult or even impossible. However, the energy recovery of PVC is also not very profitable due to its low heating value. In principle, it is also possible to recover chlorine in the form of hydrogen chloride during the recycling of feedstocks (VinylPlus 2015).

4.2.1.2 **Plasticizers**

In the construction industry, PVC-U is especially widely used, and is generally produced without the use of plasticizers. However, they are found in PVC-P, which is mostly used in cables and floor coverings.

Phthalates constitute the most important class of plasticizers and account for around three-quarters of the market (Bonnet 2014). In particular, plasticizers include short-chain phthalates diethylhexyl phthalate (DEHP), benzyl butyl phthalate (BBP), dibutyl phthalate (DBP), and diisobutyl phthalate (DIBP), which are subject to REACH restrictions and have been placed on the list of substances of very high concern by the European Chemicals Agency (ECHA). DEHP, BBP, DBP, and DIBP are classified as toxic to human reproduction (Repr. 1B), BBP and DBP are classified as hazardous to the aquatic environment (Aquatic Acute 1), as is BBP (Aquatic Chronic 1) (European Chemicals Agency 2019). With few exceptions, the use of these phthalates was banned in the EU as of 07 July 2020 (European Chemicals Agency n.d.). The higher molecular weight phthalates such as diisononyl phthalate (DINP), diisodecyl phthalate (DIDP). and di-n-octyl phthalate (DNOP) are subject to less stringent regulations, although they may no longer be used in children's toys (European Chemicals Agency n.d.).

The short-chain phthalates in particular are therefore virtually no longer used and have been replaced by other plasticizers, but they may still be present in end-of-life PVC. Removal of the phthalates hardly seems practicable during recycling. For instance, the recycling plant in Ferrara, Italy, which practiced the solvent-based Vinyloop process, was also shut down in 2018 because its products contained excessive amounts of phthalates that could not be economically separated (KunststoffWeb 2018).

4.2.1.3 **Pigments**

Pigments are also often used in construction plastics. Of particular relevance at present is the use of titanium dioxide (TiO_2), e.g., in plastic windows. In October 2019, TiO_2 was classified by the European Commission as a category 2 carcinogenic substance due to the risks associated with inhalation of it. However, this only applies to powdered TiO_2 with an aerodynamic diameter of ≤ 10 µm and products in which its concentration is at least 1%. For solid and liquid mixtures containing 1% TiO_2, the classification does not apply, but a warning label is required (Merz 2019). This means that in the future, products such as plastics that contain TiO_2 will require warning labels.

It can be problematic during recycling if used PVC contains cadmium pigments and lead stabilizers. As different types of PVC flow together during recycling, discoloration can occur when cadmium pigments, which contain sulfide, come into contact with PVC lead stabilizers and these react with each other. A dark lead sulfide is thereby formed. This can also occur when sulfur-containing tin stabilizers react with lead-containing pigments (Maier and Schiller 2016, 789).

4.2.1.4 **Biocides**

Various biocides were formerly used in PVC and are no longer in use today, having been replaced by other biocides. One reason for this replacement initiative was that the biocide copper-8-hydroxyquinoline caused discoloration. The other reason was toxicity, as in the case of phenyl-mercury compounds and OBPA (10,10'-oxybisphenoxarsine), which were especially used in PVC-P, as well as in polyolefins (Maier and Schiller 2016: 1160).

4.2.1.5 **Flame retardants**

The flame retardant hexabromocyclododecane (HBCD), which was previously used in polystyrene foam (EPS and XPS), has been banned since August 15, 2015, as it is listed as a substance of very high concern in Annex XIV of the REACH Regulation (European Chemicals Agency 2021a). As early as 2013, HBCD had been classified as a persistent organic pollutant (POP) under the Stockholm Convention on Persistent Organic Pollutants. It is bioaccumulative, toxic and suspected of being a reproductive hazard. HBCD can be replaced by block copolymers of polystyrene and brominated polybutadiene (BrPBPS) (Maier and Schiller 2016: 1027; Wurbs et al. 2017). As HBCD is not destroyed during recycling, this means that end-of-life plastics containing it cannot be recycled without its removal and must be disposed of. Thus, there is a significant recycling barrier for one of the largest building material streams (see, e.g., Wurbs et al. 2017). A rapid flame retardant test can be used to determine relatively quickly, and with fault tolerance, whether HBCD or BrPBPS has been used in EPS. For this purpose, EPS or XPS waste material is extracted with acetone, and the bromine content in the extract is established by means of an X-ray fluorescence analysis (XRF). As bromine can be dissolved from HBCD, but bromine from polymers remain in the residual gel and are not dissolved, it is relatively easy to verify whether or not the waste contains HBCD by determining the bromine content of the extract (Schlummer et al. 2017; Schlummer et al. 2015).

Processes are now available for the removal of HBCD (Creacycle n.d.), whereby plastic waste is shredded and dissolved. Insoluble impurities can also be separated. The plastics can then be re-precipitated, the solvent regenerated, and the soluble impurities, including the HBCD, disposed of or recycled. As the solvent is recycled, the amount of solvent used is small in relation to the plastic processed, at less than 1%.

Chlorinated parrafin waxes are also found as flame retardants in PVC, polystyrene, and polyolefins. Since 2014, the use of short-chain chlorinated parrafin waxes has been prohibited (*Regulation (EU) 2019/1021*). Furthermore, as a result of the POP Regulation (*Regulation (EU) 2019/1021*), the brominated flame retardants (decabromodiphenyl ether (DecaBDE)) and polybrominated diphenyl ether (PBDE) tetra-, penta-, hexa- and heptabromodiphenyl ether, may no longer be contained in plastics above a cumulative limit of 1000 mg/kg if they are to be recycled. In this case, the plastic must be treated in accordance with Art. 7, Para. 2 and 3 of the EU POP Regulation in such a way that the PBDEs are destroyed in the process. Recycling processes are also prohibited unless PBDEs are first separated and then destroyed. Primarily affected by this are electronic products, as well as textiles, plastics used in vehicles under certain circumstances, and also products in the construction sector, such as electrical insulation, sealants, coatings, paints, and pipes, etc. (Neumann 2019).

4.2.2 Glass fibers and GFRP

The resins and hardeners used in the processing of GFRP are especially problematic (BG BAU 2020), but this does not cause any problems in terms of their disposal or recycling, which is hardly possible in any case.

The individual glass fibers have a diameter of 7–13 µm (Hornbogen et al. 2019). Thus, the glass fibers themselves, with the following characteristics, are not respirable:

- Fiber diameters of < 3 µm
- Fiber lengths of > 5 µm
- Length-to-diameter ratios > 3

However, such particles can be released, for example, when grinding GFRP components. A technical reference concentration (TRK) value of 250,000 fibers/m^3 applies to them. Even though no information has been made available on this subject to date, it seems possible, in principle, that such fiber particle-containing dusts can also be released during the recycling of GFRP. This therefore also applies to the exposure of workers during recycling.

The fiber dust issue has been intensively discussed in relation to mineral fiber insulation materials, and has led to regulatory measures, such as TRGS 905 (Committee on Hazardous Substances 2020). An application of TRGS 905 to textile glass fibers is not planned, however. Nevertheless, it can at least be used to assess whether any respirable fibers that may be produced during the disposal, recycling or processing of GRP can pose a health risk. In the assessment, not only is the shape taken into account but also the chemical composition in order to assess the biosolubility and formulate a so-called carcinogenicity index. For this purpose, the following formula is used (Committee on Hazardous Substances 2020):

$$KI = \left(\sum Na, K, B, Ca, Mg, Ba - Oxide\right)[\%] - (2 \times Al - Oxide)[\%]$$

- KI ≥ 40: non-carcinogenic
- KI > 30: up to < 40, possibly carcinogenic (category 2)
- KI ≤ 30: carcinogenic (category 1b)

For the glasses listed in Table 6, this results in values for KI of 0.2–7.5 for the E glasses, 19.4–23 for the C glasses, and -40 for the S glass. Thus, all glass fibers used in relevant quantities exhibit high bio-resistance. However, the method is not considered very reliable, as significantly different compositions have also been investigated that show proven low biostability at high KI and Al_2O_3 contents (Diederich et al. 2017; Ritthoff 1997). In contrast to fiber insulation materials, the amount of released respirable fibers should be low, as the fiber diameter is typically too large. Measurements by the Wood Trade Association have thus far found that neither the permissible concentration of fine dust nor the permissible concentration of fibers was exceeded during the manufacturing of GFRP components. Concentrations of a maximum of 110,000 fibers/m^3 have been measured when grinding GRP parts, as have much lower concentrations when cutting fabric mats (Wood Trade Association 2000). However, the situation in the context of recycling should be individually considered if necessary.

4.2.3 Conclusions

A number of pollutants occur in building materials that are prohibited from being used today and represent a considerable obstacle to recycling. This applies in particular to stabilizers, flame retardants, and plasticizers. As a rule, these pollutants cannot be removed or can only be removed at great (i.e., uneconomical) expense.

The regulation of many substances has changed in recent years. It can therefore be assumed that further substances will also be regulated in the future, and may come to hinder recycling.

In the case of glass fibers used for reinforcement, there has to date been no critical classification. However, in the event that reinforced GFRP is recycled, it cannot be ruled out that restrictions may also be imposed in this instance.

4.3 Processing and recovery techniques

4.3.1 Waste collection and pre-treatment

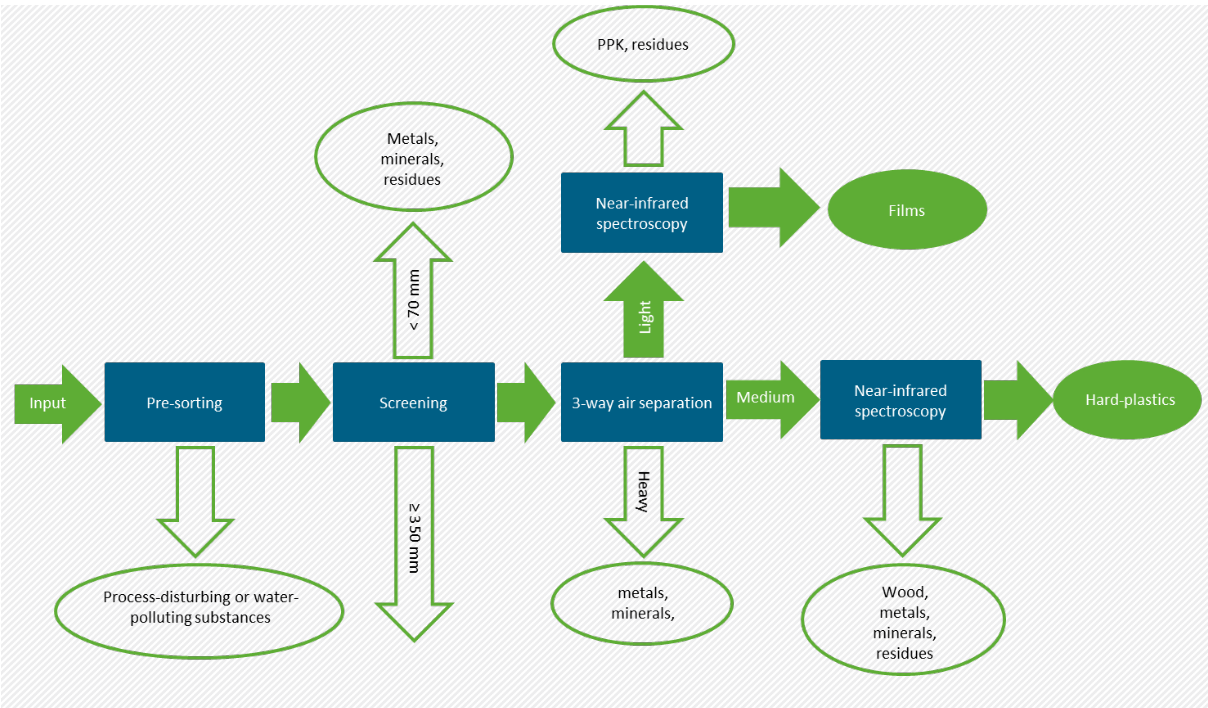
According to § 8 of the Industrial Waste Ordinance (GewAbfV), the producers and owners of construction and demolition waste are obliged to separately collect and transport plastics (waste code: 17 02 03), bitumen mixtures (waste code: 17 03 02), cables (waste code: 17 04 11), and insulating materials (waste code: 17 06 04) and assign them priority of preparation for reuse or recycling. It should be noted that plastic-based insulating materials (i.e., EPS, XPS, and PUR) are collected alongside other insulating materials, such as rock or glass wool, under a common waste code, resulting in a mixture that is detrimental to material processing.

In practice, separate waste containers (e.g., containers or big bags) and appropriate collection logistics are required to keep the plastic waste stream separate. In the case of materials resulting from demolition or selective deconstruction, sort-specific collection is also required (BMI and BMVg 2018; Krauss and Werner 2014). However, in the course of current demolition practices, plastics rarely present themselves in a clean and sorted manner (Deilmann et al. 2017). In addition, there are logistical challenges, such as those arising from a large volumes with low weights in the case of insulation materials, or from comparatively small quantities per accumulation point in the case of roofing membranes, pipes, door, and window profiles (ibid.).

The obligation to keep the afore-mentioned waste streams separate in accordance with GewAbfV does not apply if separate collection is technically impossible or economically-unreasonable. In such cases, the mixtures that mostly contain plastic, as with mixed construction and demolition waste (waste code: 17 09 04), must be sent to a pretreatment facility in accordance with § 9 GewAbfV. However, this obligation also does not apply if pretreatment is technically impossible or economically-unreasonable.

The pretreatment of mixed construction and demolition waste is graphically depicted in Figure 17: First, the mixed waste is delivered, and consists of mineral building materials, wood, glass, metal, roofing felt, insulation materials, cables, foils, and wallpaper residues, amongst other materials. During pre-sorting, valuable, interfering, or otherwise process-disturbing materials, as well as water-polluting substances, are removed. Process-disturbing materials are in particular those which, due to their size, should not be fed into the plant, such as scrap parts, wooden beams, large sheets, concrete parts and stones, cordage and strapping, plasterboard, and insulation wool. In the sorting plant, following pre-screening to yield sizes of < 350 mm, the material is first classified into two particle size fractions (< 70 mm and ≥ 70 mm) in a screening drum. Only metals and minerals are separately discharged from the fine fraction. The coarse fraction is then separated into heavy, medium and light stock streams by means of a three-way air separation system, with the medium and light stock streams being relevant for plastics. Near infrared spectroscopy (NIR) is then used to sort films from the light fraction and hard plastics from the medium one (Nehlsen AG n.d.; Nehlsen AG n.d.).

Figure 17. Typical waste pretreatment process for mixed construction and demolition waste.



Source: Own representation Wuppertal Institute for Climate, Environment, and Energy according to Nehlsen AG, n.d.-a, n.d.-b.

According to the German Association for Secondary Raw Materials and Waste Disposal (BVSE), this sorting technology represents an environmentally-friendly and economical solution for the treatment of mixed construction and commercial waste, the separation of which is not possible on site (BVSE 2020). Up until now, however, these technical options have generally not been used for the mechanical recycling of the recovered plastic fractions, but have mostly focused on thermal recycling, as well as that of other combustible materials (Deilmann et al. 2017; DUH 2020).

Significantly better conditions for recycling are created by the voluntary take-back systems that exist for construction products (see Chapter 3). Separate collection at the point of generation and bundling of waste streams can also achieve the required quantities and purities.

4.3.2 Sorting and cleaning

The following section describes the sorting and purification of separately-collected plastic waste. Depending on the plant, different process technologies are used, with the most important steps being presented below.

4.3.2.1 Shredding

Incoming waste is reduced to a size compatible with the subsequent sorting, cleaning and transporting technology. A first step, if necessary, is so-called de-baling, in which waste compressed to bales is broken down into its individual components. Shredders for coarser regrinding and granulators for fine regrinding are then utilized to affect further size reductions.

4.3.2.2 Cleaning

Plastics are often contaminated by adhering foreign materials, such as adhesives, labels, or mortar residues. In order to remove these contaminants, one or more cleaning steps are necessary. A distinction is made between dry and wet cleaning. In the case of dry cleaning, impurities are separated from plastic by friction to then be removed in a subsequent sorting step. In the course of wet cleaning, water is used to separate the plastic from the contaminant, possibly also with the aid of surfactants or caustic soda. High product purities can thus be achieved, but the effort involved is high. In addition to water and cleaning agents, power is also consumed in the subsequent drying process.

4.3.2.3 Sorting

Various techniques are used for the sorting of plastics, which sort items in the material stream according to certain properties. The most important of these are listed in Table 5, below.

Table 5. List of sorting steps for construction waste sorting.

Sorting method	Separation criteria	Application in plastics recycling	Designs	Source
Screening	Particle size	Separation of fractions that are too small / large, separation into fractions of different sizes	Drum screen, linear vibrating screen, circular vibrating screen, trash screen	(1)
Wind sifting	Mass, shape, and size	Separation of impurities or dust	Counterflow sifter, e.g., zigzag, pipe, or crossflow sifter	(2)
Paddle / Ballistic sifting	Shape and density	Separation of round, rolling, heavy materials like pipes from flat, light materials like films	Normally with integrated sieve	
Magnetic separation	Ferromagnetism	Separation of ferromagnetic materials such as iron, tinplate, and steel	Magnetic drum, magnetic tape roll, overband magnetic separator	(3)
Eddy current separation	Electrical conductivity	Separation of aluminum, stainless steel, and copper	Electromagnetic with permanent magnet	(3)
NIR spectroscopy	IR absorption spectrum	Sorting according to plastic types	-	(4)
VIS spectroscopy	Color	Sorting by colors	-	(4)
Camera	Shape, size, and color	Sorting by shape, color, size; object recognition for negative sorting	-	(4)
Manual picking	Color, shape, and size	Quality control, pre-sorting	-	(3)

Sources listed in the table: (1) - (Feil and Pretz 2020), (2) - (Pallman 2007; Venti Oelde n.d.), (3) - (O A 2004), (4) - (Martens and Goldmann 2016).

4.3.3 Recompounding of thermoplastics

In order to prepare thermoplastic waste for reuse in production, it is recompounded. The shredded, sorted, and cleaned waste plastics are melted in an extruder, mixed with various additives and/or fillers, and then granulated. During the melting process, the plastics, which have already been homogenized at the particle level, are further homogenized at the molecular one. However, excessive energy input during melting or mixing can lead to thermal degradation reactions in the plastics, which has a detrimental effect on their material properties. It is also possible to remove pollutants during the extrusion process; cf. Section 4.2. The material properties of the obtained recyclates can be adjusted within certain limits by adding additives and fillers, and by selectively mixing different waste streams, in order to achieve the requirements for subsequent components, even under the condition of varying input quality.

The individual process steps entailed in recompounding are presented below. For a given application, depending on the input material, not all of these must necessarily occur.

Recompounding process steps

- Shredding – the starting materials can come in a wide variety of forms. If their size makes them unsuitable for direct feeding into the extruder, as is the case with films, for instance, upstream size reduction is performed. Typically, the material is broken up in a granulator and reduced to a particle size at which it can then be drawn in by the extruder.
- Compacting – materials with a low bulk density, such as fibers or foams, must first be compacted prior to processing. In this step, the material is mechanically-heated, compressed, and thus compacted.
- Prehomogenization – depending on the heterogeneity of the input material, it is prudent to homogenize it again following shredding and prior to feeding it into the extruder in order to be able to guarantee consistent material properties in the recycled plastic. This is achieved by using a mixer.
- Drying – excessive residual moisture in the material has a detrimental effect on the extrusion process. To prevent this, the material is mechanically dried in centrifugal dryers and/or thermally in hot-air dryers.
- Plasticizing – the material is heated and melted in the extruder by the energy introduced with the screw rotation or through a heating device. Here, as in the subsequent process steps, it is important that the plastic not be subjected to excessive heat or shear in order to minimize degradation of the polymer structure.
- Homogenization – within the extruder, further homogenization of the now liquid material occurs. This is achieved by the extruder screw(s) having a suitable geometry.
- Degassing – if volatile impurities or degradation products formed during processing must be removed from the material, this can be achieved by degassing. For this purpose, the melt is subjected to a vacuum of down to a few mbar within the extruder, thus extracting the volatile components. Another approach is entraining agent degassing, in which comparatively volatile substances, such as supercritical CO_2, are added. If these entraining agents are then removed from the melt, other highly volatile substances are also “entrained” in the process. Degassing is especially widely used for the removal of odors.
- Melt filtration – in order to remove non-volatile, non-meltable impurities, such as metals, elastomers or mineral particles, the melt is filtered within the extruder. In this process, it is pressed through a screen with mesh sizes in the range of a few hundred µm. The filtered-off impurities are then discarded and disposed of. This step improves the processability of the recycled plastic and reduces the process fluctuations induced by contamination.
- Metering – in order to specifically influence the property profile of the recycled plastic, additives or fillers are inserted. As is common in polymer technology, the substances that can be added include liquids, solids and masterbatch. Stabilizers, plasticizers or colorants, for example, are also used.
- Pelletizing – after the material has passed through the extruder, it is extruded and the strand cut into pellets by the pelletizer. Depending on the plastic type and the required pellet properties, different processes are used at this point. If pelletizing is carried out with the aid of water, the pellets must be dried as part of a downstream process step.

4.3.4 Material recycling of the most important plastics for the construction industry

In mechanical recycling, secondary plastics are obtained from the waste via physical processes without destroying the polymer structure. The mechanical recycling of thermoplastics will be described first. Mechanical recycling is similar for all thermoplastic materials. The already-outlined sorting and cleaning and recompounding processes are followed by processing into new components. The purer the material stream obtained from sorting, the easier and more reliably the desired material properties can be achieved. Not all technically-possible sorting and cleaning steps are also economically-feasible, however. Thus, the cost of sorting is largely determined by the value of the plastic fractions derived as a result.

The recycling processes for the most relevant plastics in terms of volume in the construction sector, from pre-sorted material to re-granulation, are outlined below.

4.3.4.1 Recycling of polyvinyl chloride

PVC-U and PVC-P are recycled separately. Their recycling process is largely carried out by the industry association, the AGPU. In the construction sector, product-specific take-back systems also play a key role here (see Chapter 3). PVC-U from pipes and profiles is recycled to a high standard, with these products accounting for approximately 75% of the volume of PVC used. For this purpose, the shredded, sorted, cleaned, and ground waste is recompounded, as described in Section 4.3.3. PVC-U regranulates can be reused for pipes, profiles, and other applications. Various standards also exist for the production of products from PVC-U recyclates (European Committee for Standardization 2013, 2019) The characterization of PVC-U and PVC-P recyclates is standardized in EN 15346 (European Committee for Standardization 2015).

PVC-P can be materially recycled in the same manner. Due to the elastic deformation of PVC-P, it is more difficult to grind, and so the material is partially cold-ground, which also facilitates the separation of composites. PVC-P can be recycled to a high standard on an industrial scale. A different approach is taken in the VinyLoop process, in which PVC-P is purified with a butanone-based solvent mixture. However, the process is not used in Europe due to the residual quantities of DEHP in the recycled material, which is toxic to reproduction (European Commission 2011a; Plastech 2018).

4.3.4.2 Recycling of polyethylene

The rubric ‘polyethylene’ groups together several types of plastic that are chemically similar but significantly differ in terms of their material properties. These are primarily: PE-HD, PE-LD, PE-LLD, and ultra-high molecular weight polyethylene (PE-UHMW). The macromolecules differ, on the one hand, in terms of the length of the polymer chains, and on the other, in their branching. These two parameters, in turn, influence the crystallization behavior, which leads to variable material properties, such as tensile strength and elongation at break or impact resistance. Relevant to the construction sector are PE-HD for use in pipes, profiles and containers, and PE-LD and PE-LLD for films. Due to their different material properties, it is illogical to recycle the different PE types together. PE-HD waste, as well as that from PE-LD and PE-LLD, are generated in large quantities by the packaging sector. As thermoplastic materials, they are technically easy to recycle, and the processes for doing so have been established on a large scale. However, recycled plastics must compete with comparatively inexpensive virgin materials.

Pure-grade and purified PE is typically supplied as regrind, flakes or pellets and should be free of macroscopic impurities, such as metal pieces or paper. The feedstock is then recompounded (see section 4.3.3) and supplied to plastic processors as regranulate. Mixtures of PE and PP are also offered as recycled plastics as polyolefin polymer. The methods for characterizing the recyclate properties are specified in DIN prEN 15344:2020 (European Committee for Standardization n.d.), and there are also standard requirements for its use in pipes (European Committee for Standardization 2013).

4.3.4.3 Recycling of polypropylene

Polypropylene can be polymerized in different tacticities and as a PE copolymer. Of particular relevance to the construction industry is the isotactic polypropylene homopolymer, which is primarily used to produce pipes and fibers but is also utilized for blown film extrusion with the appropriate melt flow rate. Polypropylene is readily recyclable by means of the standard thermoplastic process. Accordingly, large quantities are recycled to a high standard in the Dual System for packaging recycling. In the area of construction waste, PP from pipes is collected and recycled separately; other PP waste enters the material streams of the disposal firms. With appropriate purity, the recyclates come close to the quality level of virgin material. Here, too, the characterization of recyclates and their use in pipes has been standardized (European Committee for Standardization 2007, 2013).

4.3.4.4 Recycling of polystyrene

In terms of volume, foam polystyrene in the form of insulation materials is the most relevant to the construction industry, with a distinction being made between expanded polystyrene (EPS) and extruded polystyrene (XPS) depending on the manufacturing process used. For EPS production purposes, pentane is used as a blowing agent, the granules are foamed by increasing the temperature, and the resulting beads are fused together with steam as part of a second temperature step. The material is then cut into insulation boards, for example (Plastics Processors 2020). XPS is extruded into sheets through a wide-slot die using CO_2 as the blowing agent and is then cut to size. Other polystyrene copolymers are also used in the construction sector, although for recycling purposes they are not relevant in terms of quantity. For instance, the elastomeric styrene-butadiene rubber (SBR) is used in floor coverings, whereas the thermoplastic PS copolymers acrylonitrile-butadiene-styrene (ABS) and styrene-acrylonitrile (SAN) are used in a variety of products.

As a thermoplastic material, polystyrene is in principle easy to recycle (Maharana et al. 2007) and the use of shredded polystyrene foam, e.g., as cavity insulation or lightweight aggregate in screeds, is also possible in the context of material recycling (Rygol Insulation 2020). High-quality recycling is therefore technically feasible, with the characterization of recyclates defined in EN 15342 (European Committee for Standardization 2008). However, high-quality recycling does not yet take place separately from the recycling of production residues, as well as building site waste in the construction industry. The uneconomical deconstruction, pollution and long product service life of insulation materials are the biggest hurdles in this regard.

4.3.4.5 Recycling of polyamide

Polyamides refer to an entire class of polymers that feature amide bonds in the main chain. However, the term is typically used for the plastics polycaprolactam (PA6), which is also used as a building material, or the condensation product of hexamethylenediamine and adipic acid (PA66), often used as a fiber-reinforced material. Both are similar in their properties (Lanxess 2009). PA is used in large quantities in the construction sector, primarily for textile floor coverings. It is also used in fittings and various small-scale applications subject to high mechanical stress such as dowels. In terms of volume, only waste from textile floor coverings can be considered for recycling. Large-scale, high-quality, albeit chemical, recycling is carried out as an industrial process for PA6 from textile floor coverings.

4.3.4.6 Recycling of polyurethane

Although PUR is a plastic designation, it is highly heterogeneous chemically and in terms of its properties. PUR is manufactured from a polyol component and isocyanate. The isocyanate serves as a bridge between the polyols. The polyol itself can consist of a wide variety of polymers, such as synthetic polyether polyols, polyether polyols or, in certain instances, natural or bio-based polyols, such as castor oil. The properties of these largely determine those of the PUR produced. In terms of volume, the most relevant material flow in the construction sector is the production of closed-cell rigid foam for use as an insulating material. Other sectoral applications include cable insulation and pipes. Additionally, though irrelevant for recycling, it is used in coatings, as cast flooring, and as a protective or elastic layer in multilayer flooring.

Polyurethanes can also be used as thermoplastic elastomeric materials – so-called thermoplastic polyurethane (TPU). PUR, which is used for cable insulation in the construction sector, belongs to this group. However, with the exception of production waste, there is no known means of materially recycling it.

As a thermoset, the PUR used in insulating materials cannot be recycled in a closed-loop process to produce the same product. The typical recycling route in this case is thus grinding and use in press plates.

4.3.4.7 Recycling of bitumen

Bitumen is produced as a non-volatile residue during the distillation of certain types of petroleum. It consists of hydrocarbons of different molecular weights, which give it its hydrophobic character (European Committee for Standardization 2014). Bitumen is used in the construction sector in waterproofing materials, such as roofing membranes, and also in combination with polymers. Construction and demolition waste containing bitumen is mostly thermally-recycled. However, initial attempts at material recycling have already been made, such as bituminous roofing felt used in road construction (DD/H – The Roofing Trade 2019; Deilmann et al. 2017).

4.4 Construction product-specific recycling processes

4.4.1 Pipes

Plastic pipes made of PE, PP, or PVC can be materially-recycled. Production waste is shredded, extruded and processed into regranulate, which is then fed back into production (Heinzlreiter 2016). A voluntary take-back system is currently in operation for construction site waste and pipe systems deconstructed following use (cf. Chapter 3.3).

The raw waste is first sorted by material and processed by hand. During this process, foreign materials and contaminants, such as sealing and fastening materials, connectors, labels, and dirt, are removed (Seki and Yoshioka 2017). The pipes are then crushed into regrind 8–12 mm in size and impurities are removed by means of wind sifting. The recyclates obtained by recompounding (see Section 4.3.3) are again used to produce pipes, but at a lower requirement level, e.g., the recyclates are used in sewage, cable protection, and drainage pipes (KRV 2015).

Material properties and test methods for the use of recyclates in pipes are specified by the European Committee for Standardization (2013). Chemical recycling processes are currently under development, but are not yet marketable (KRV 2015).

4.4.2 Window, roller shutters and door profiles

As already noted in Chapter 3.3, window, shutter and door profiles can be easily recycled. The reason for this is that, amongst other factors, the pure material flow their collection offers, as well as their easy dismantling. The collected end-of-life products are roughly pre-sorted and then shredded as a whole, with FE and NFE metals, as well as glass and mortar residues being separated. The resulting plastic fraction is crushed in a granulator to particle sizes of ≤ 20 mm and then washed. After drying, the ground material is color-sorted and any sealing residues are sorted out. Finally, the material is regranulated by means of extrusion with melt filtration (see 4.3.3– Recompounding) (Rewindo 2020b). The recycled material is then used as a core in the non-visible area of new profiles (cf. Chapter 5).

4.4.3 Insulation materials

The prerequisites for the mechanical recycling of insulation waste differ greatly according to the point in the value chain at which it is generated. The waste generated during production is unmixed, uncontaminated, of known and homogeneous additivation, and can be temporarily stored and reintroduced into production without substantial logistical efforts. Therefore, recycling is achievable and has already been well-established. Unpolluted, unmixed construction site cuttings are partly recovered by the manufacturers, provided that an appropriate logistics concept is in place, whereby recycling is also possible. Insulation waste from renovation and demolition work is usually heavily contaminated with adhesives, mortar, plaster, paints, and fastening materials, and is not sorted by type. In trials, selective deconstruction processes that enable the separation of material composites directly at the point of generation have proven to be technically feasible. However, material recycling is uneconomical due to its high logistical and cleaning costs, and therefore waste is usually thermally-recycled (Albrecht 2019).

The types of plastic primarily used in insulation materials are EPS, XPS and PUR. Production waste, as well as unmixed and clean EPS offcuts, can be reused for production with recycled content ranging from 5% for facade insulation boards, to 30% for floor or flat roof insulation boards. For this purpose, the waste is ground, dedusted, and released foam beads are welded together with beads of virgin material using steam. Construction site waste can be recycled using the same process, having undergone previous cleaning of coarse impurities. Recyclate contents of up to 100% can be achieved here, but the qualities required for facade insulation have not yet been attained, and so downcycling is currently practiced (Albrecht 2019)

Production waste from XPS insulation materials can also be recycled to a high standard. Recyclate percentages in the double-digit range are possible with output of equivalent quality. The waste is shredded, screened, dedusted, and fed back into the extruder. Construction site waste can theoretically be recycled in the same manner, but this does not happen in practice due to heavy contamination and a lack of collection logistics. In the case of renovation and demolition waste, low volume flows currently present a further obstacle, such that in this case as well, thermal recycling predominates (Albrecht 2019).

For both EPS and XPS, the content of the flame-retardant HBCD, which is now classified as teratogenic, is problematic in used materials; see also Chapter 4.2. Processes for removing pollutants exist, but are significantly more expensive than normal recycling; the solvent-based CreaSolv® process could play a role here (Creacycle 2020).

Insulation materials made of PUR cannot be recycled in a closed cycle due to their inherent thermosetting properties. However, production waste can be recycled and reused as insulation material, albeit of lower quality. A common recycling option for this is compression into recycled panels with the addition of adhesives. It can also be shredded into flakes that are used as blown-in insulation. Renovation and demolition waste is usually thermally-recycled due to contamination (Albrecht 2019).

The quantities of insulation materials obtained from demolition remain relatively low, but are projected to increase in the coming decades (Deilmann et al. 2017), as will the importance of high-quality recycling. Likewise, it can be assumed that economies of scale will make the construction and operation of suitable recycling infrastructures more economically attractive. With respect to contamination with pollutants and impurities, the further development of alternative recycling processes, such as the solvent-based CreaSolv® process for EPS and XPS insulation materials, which is currently in the trial phase, or new processes for dissolving material composites, may also be of significance (ibid.).

4.4.4 PVC floor coverings

Due to the voluntary take-back system in place for PVC flooring (see Chapter 3), conditions for mechanical recycling are good. However, as recycling is only possible if both the wear and the backing layers consist exclusively of PVC, the waste must be sorted accordingly (Krauss und Werner 2014).

The pre-sorted PVC floor coverings are first crushed into chips up to 30 mm in width. Following magnetic separation, screed and adhesive residues are removed using a hammer mill and subsequent screening. At a temperature of -40 °C, the chips are again finely ground to grain sizes of 400 µm. PVC floor coverings covered in plastic films or fabrics made of other types of plastic require additional process steps (AGPR n.d.; Krauss und Werner 2014).

The recyclates obtained are primarily used for the production of new PVC flooring, as they contain specific additives and fillers (Krauss und Werner 2014) and it is not often necessary to add plasticizers again (Yarahmadi et al. 2003). Due to reduced color quality, the recyclates are only used in layers that are invisible from the outside (Deilmann et al. 2017).

With respect to the recyclability of PVC floor coverings, bonding to fresh concrete is not recommended, as it leads to the undesirable degradation of the plasticizers present (Yarahmadi et al. 2003). The applicability of solvent-based processes is currently being researched for recycling floor coverings contaminated with plasticizers that are no longer legally permitted (Recycling Magazine 2019).

4.4.5 Cable insulation

The most frequently used plastic for cable insulation is PVC, with a market share of 53% (AGPU 2019) but, depending on the application, various other thermoplastics, thermoplastic elastomers, or crosslinked thermoplastics, are also used. Cables are labeled according to DIN EN 60445 or VDE 0197, which also specifies the plastics used in insulator and sheathing materials. Cables are listed under waste code 170411, provided that they do not contain any hazardous substances. The subcategory 1704 stands for waste-containing metal, under which fiber optic cables also fall, although they do not contain metal. In principle, cables are mostly recycled on the basis of the metals they contain (e.g., copper or aluminum). However, they are also collected separately because of this, which has potential for plastic recycling processes. The recycling of production waste is quite feasible, and even fractions from the peeling of thicker cables can be collected by type and then reprocessed. Plastic residues from the automated recycling process, on the other hand, accumulate as mixed fractions. This recycling process begins with the coarse shredding of the cables. Then, FE metal armor is separated via metal separators, which is followed by breaking up using granulators and, if necessary, impact mills to break up fine strands. The obtained regrind is then delineated on a separation table (Hosokawa Alpine 2016;

Recovery 2020). The PVC regrind extracted in this manner can then be recompounded and recycled in the next step. However, the recyclates are only used for low-grade applications such as beacon bases, guardrails, or turf elements (Plasticker 2010). The process, which is geared towards the recycling of metals, does not apparently yield plastic fractions that are sufficiently pure for high-quality recycling.

An attempt at solvent-based recycling, the so-called VinylLoop process, failed to gain widespread acceptance and the facility practicing it shut down (Plastech 2018).

4.4.6 Textile floor coverings

Carpets consist of several layers in which different materials are used. The wear layer is mostly made of synthetic fibers, predominantly comprised of PA (40%), PP (25%), and PET (15%) (EU Recycling 2019). This is attached with an adhesive layer and an intermediate layer to a back layer, which is in turn coated. The largest weight shares are made up of the wear and adhesive layers, each totaling around 45% (Sotayo et al. 2015). A wide variety of thermoplastic or elastomeric plastics are used in these various layers (German Environmental Aid 2017).

The complexity of the carpet structure and the variety of materials used constitute difficult initial conditions for recycling. This is exacerbated in part by cross-linked or poorly-separable adhesive bonds. When mixed fibers are used, downcycling is often the only option. Additionally, the quality of the recycled fibers is affected by pollution and contamination, for instance adhesive residues and wear. On a logistical level, Germany also lacks a nationwide collection systems or an industry-wide take-back system (see Chapter 3), as well as large recycling plants for used carpets. Accordingly, the majority of these are currently incinerated or thermally-recycled (German Environmental Aid 2017).

The recycling of carpet fibers made of PA6, PA66, PET, and PP is technically possible, but currently only feasible in a cost-neutral manner for PA6 (German Environmental Aid 2017). The recyclates obtained by means of chemical processes can be reprocessed into carpet fibers (Sotayo et al. 2015). In addition, mechanical recycling is possible through the shredding and extruding of carpet waste, but this leads to poor mechanical properties due to the mixing of different, sometimes incompatible, plastic types (ibid.). Thus, only downcycling, into carpet backing or technical plastics, for instance, is possible (German Environmental Aid 2017).

In the view of the authors of this report, a consistent design-for-recycling in this case would facilitate mechanical recycling in this sector, especially given that the simple deconstruction and separate collection of the products are possible.

4.5 Recycling of GFRP

4.5.1 Features of GFRP

Fiber-reinforced plastics are increasingly widely-used today. The most commonly-used fibers are glass, carbon, basalt, aramid, and natural ones. In the context of this project, however, only GFRPs are considered due to their relevance to the construction domain; plastics that feature other reinforcing fiber types are not considered.

Individual glass fibers have a diameter of 7–13 µm and are combined into spun yarns. They are then used to produce the strands, fabrics, or mats (from irregularly-cut and arranged fibers) for reinforcement (Hornbogen et al. 2019). In addition, cut or milled short fibers are also utilized.

Glass fiber-reinforced plastics are used in large and increasing quantities in the construction, transportation, and automotive sectors due to their specific properties (and adaptation of properties with respect to loading, high tensile strength, high stiffness, low creep, etc.) and the capacity to specifically adapt their properties. At the same time, GFRPs are considered non-recyclable, due to the fact that many are manufactured with thermosetting resins, which are not thermoplastically-deformable but also because the material composites are complex, clear identification is difficult and the material quantity accumulation of the individual GFRPs is low and discontinuous. The problems inherent to the recycling of GFRPs are therefore both material and organizational in nature. Therefore, incineration is the standard procedure for the treatment of these sporadically-occurring forms of construction and demolition waste (Rybicka et al. 2016).

The majority of GFRPs are made from thermoset plastics. In particular, unsaturated polyester and epoxy resins are used in casting (Maier/Schiller 2016). In these, strands, fabrics and mats are used to increase strength and heat resistance and reduce linear expansion (Hornbogen et al. 2019).

Increasingly, however, thermoplastics are also used. Due to processing in extruders and injection molding machines, very short fibers are used here. In so-called pultrusion processes, long fibers or fabrics are now also processed together, along with extruded thermoplastic, in a continuous process.

Glass fibers are not a uniform material; they feature considerable differences in terms of both the resins and fibers used. Their manner of use also differs. Both aspects have an influence on the properties of the GFRP but also on possible recycling. The glass from which the reinforcing fibers are made also affects the properties of the composite. Therefore, reinforcing fibers with different qualities are available (Flemming et al. 1995; Chokri 2011). The various glass fibers differ in terms of their mechanical properties, but especially with respect to their chemical resistance. A distinction is made between the following relevant glass fibers (Illig et al. 1983):

- A-glass is an alkali-rich (> 8%) alkali-lime glass. It does not have a high chemical resistance and is (or was) especially used in cases where there are no high quality requirements. It is only of minor importance now, but may be found in older products.
- E-glass (E = Electric) is an aluminum borosilicate glass that usually contains less than 1% alkali oxides. It is considered the standard glass for fiber for general plastic reinforcements, as well as for electrical applications, due to its low conductivity. However, it is attacked in basic and acidic environments. It makes up about 90% of the market.
- S-glass (S = Strength) is aluminum silicate glass with added magnesium oxide. It is a special glass with a high modulus of elasticity (Young’s modulus) and high strength for the high-quality reinforcement of GFRP.
- R-Glass (R = Résistance) is an aluminum silicate glass with additives of calcium and magnesium oxide. It is a special glass for conditions with high mechanical requirements and temperatures.
- M-glass (M = Modulus) is a glass containing beryllium. Its fibers have an increased modulus of elasticity. It is used for applications with the highest mechanical requirements and increased stiffness.
- C-glass (C = Chemical) is a low-alkali glass with increased chemical resistance.
- ECR glass (E-Glass Corrosion Resistant) is an E-glass fiber with especially high corrosion resistance.

- D-Glass (D = Dielectric) is a glass with a low dielectric loss factor, e.g., for the radomes used in radar systems.

Even across the respective types of glasses, there can still be considerable differences in composition. Some typical compositions are shown in Table 6. In addition to the composition of the glass fibers, they can also be delineated into filaments and staple fibers (Pfaender 1989).

Table 6. Composition of glasses for glass fibers (v. Kamptz 1991).

Glass type	SiO_2 [%]	Al_2O_3 [%]	Fe_2O_3 [%]	CaO [%]	Na_2O [%]	MgO [%]	K_2O [%]	B_2O_3 [%]
E-glass	55.2	14.8	0.3	18.7	0.3	3.3	0.2	7.3
E-glass	52–56	12–16	Traces	16–25	Traces	0–5	Traces	5–10
E-glass (De Jong et al. 2007)	54	14		20	<0.5	4.5	<0.5	<10
C-glass	72	2.5	0.5	9	12.5	0.9	1.5	0.5
C-glass	65	4		14	8	3	0.5	5.5
S-glass	65	25				10		

4.5.2 Recycling

Although GFRPs have been long manufactured and used, the recycling of these materials continues to cause substantial problems. The main reason for this is the poor separability of the glass fibers from the plastics used and the fact that mostly thermoset plastics are used in them. Material recycling of the complete material has therefore been virtually impossible for reinforced thermosets up until now. In the case of reinforced thermoplastics, on the other hand, mechanical recycling is possible in principle and already practiced, such as for manufacturing waste (Ribeiro et al. 2011). This applies in particular if the thermoplastics have been reinforced with very short glass fibers. In principle, these can be re-extruded. However, in addition to the thermal stress placed on the thermoplastics, which can cause degeneration, i.e., shortening of the polymer chains of these plastics, this can also result in damage to the reinforcing fibers. As a result, the mechanical properties of these materials can significantly change.

The chemical recycling of GFRPs also has limitations. A wide variety of processes have already been analyzed, but implementation has yet to take place. Studies on the use of pyrolysis to recover glass fibers were also carried out in the early 2000s. In addition to glass fibers, oils and gases can also be produced and recovered as fuel or as raw materials for the chemical industry. However, the developed concepts have not been put into practice (Job 2013). Thus far, chemical recycling processes have been in competition with thermal utilization in particular, both economically and ecologically. Up until now, the high energy consumption necessitated by such processes, as well as process control, has been problematic. Due to the quantities of the glass fibers they contain, GFRP introduce considerable amounts of inert material into the chemical recycling processes and reduce their efficiency. This has a negative impact in terms of both energy efficiency and the quantities of organic compounds that can be recovered. Recycling strategies for GFRPs generally therefore take other paths.

4.5.2.1 Mechanical recycling of GFRPs

The recycling of glass fibers poses a considerable challenge, as mechanical treatment does not enable clean separation from the plastic matrix, and thermal treatment usually causes severe damage to the fibers. Therefore, attempts have been made to apply alternative pyrolysis processes. One of these is microwave pyrolysis. In tests on shredded rotor blade material from wind turbines, it was possible to recover glass fibers with significantly less strength than the original ones. New nonwovens could thereby be produced containing 25% recycled fibers.

Use of recycled material in new plastics

Repeated attempts have also been made to use old GFRP following mechanical reprocessing, which has various possible fields of application. For instance, it has been shown that it is possible to reinforce only slightly reprocessed mixed plastics with recycled glass fibers and thus create substitutes for wood and concrete products, such as railroad sleepers or poles and masts (Turner et al. 2018). Ultimately, this is an attempt to recycle two problematic fractions (mixed plastics and waste glass fibers) in order to achieve better product quality in a simple manner. The main advantage of the process lies in its simplicity of preparation. However, this is probably also associated with low uniformity and reproducibility of the product properties, which is generally required for even supposedly simple applications.

However, examples can also be cited in which it has been demonstrated that the use of short-fiber-reinforced PET recyclates is even possible for the production of safety-critical components in automotive engineering. For this, however, it is necessary to consider the interactions between the modified material properties of component development, material and component specifications, and the production process itself. Simply replacing primary material with secondary is typically not possible.

From a technical point of view, the use of other processing methods can, under certain conditions, be suitable for significantly improving the preparation and obtaining significantly purer fractions of resin and fiber. For instance, it has been shown that a high-voltage shredder originally designed for rock crushing could recover fibers with less resin adhesion and a greater length compared to conventional mechanical processing. However, the necessary energy input was at least 2.6 times higher than in the case of mechanical recycling (Mativenga et al. 2016).

Use as aggregate

Several studies have been conducted on the use of crushed or ground recycled GFRP as an aggregate or filler in concrete, mortar and plaster.

The use of glass fibers in conventional concrete and mortar, based on Portland cement, is limited because an alkali–silica reaction (cf., e.g., Henning et al., 1989) can occur between glass fibers and a cementitious binder matrix, resulting in the formation of swellable alkali–silica gel, which can lead to the destruction of concrete and mortar. Nevertheless, tests were also carried out to utilize small quantities of fine-grained waste from GFRP production in conventional concrete. It was found that only small quantities could be used without significant deterioration in the properties, especially the compressive strength. The quality of the concrete products depends on the properties of the GFRP waste, the particle size distribution, the grinding process used, the degree of grinding, the proportion of aggregate mixture, and concentrations of other additives (Osmani and Pappu 2011).

However, it is also possible to use crushed GFRP waste in polymer mortars. It has been found that polymer mortars filled with processed FRP waste exhibit improved flexural and compressive behavior compared to unmodified polyester-based polymer mortars. This confirms the fundamental viability of reusing GFRP waste to produce concrete-polymer composites (Ribeiro et al. 2011).

However, given the intense debates surrounding the ubiquitous use of plastics and their associated releases into the environment, it is unclear whether the use of mechanically-processed GFRP waste in concrete and mortar can ultimately be considered sustainable.

Similarly, the use of short fibers after the mechanical processing of GFRP to reinforce gypsum is possible. However, the effort required for mechanical processing is high due to the strength of GFRP (Feng et al. 2016).

Conclusions on mechanical recycling

The mechanical recycling of GFRP has thus far reached clear limits; going forward, the most promising options seem to be:

- Application as aggregate in concrete and mortar
- An improvement in mechanical recycling through new pulverization processes

Arguments against:

- Possible increased release of plastics into the environment when used in concrete and mortar
- The high energy inputs required by alternative processing methods

4.5.2.2 Chemical recycling of GFRP

Chemical recycling processes for GFRP could offer an alternative to mechanical recycling. The goal of chemical recycling in this context is generally the recovery of the fibers used, as well as the utilization of the resins.

In principle, thermo-chemical processes, such as oiling or pyrolysis, appear to be suitable for recovering the reinforcing fibers. However, it must also be taken into account that both processes can lead to changes in the glass fibers. It is also important to bear in mind that glass fibers do not consist of the actual glass alone, but that the surface quality, which is crucial for the material's strength, is achieved by applying a coating that is destroyed during chemical recycling. Accordingly, recycled glass fibers generally have diminished strength, with considerable differences depending on the quantities of the recycled fibers used. Better values are achieved in particular with low proportions of recycled fibers (Beauson et al. 2014).

One possible strategy, however, can be a cascade use of the glass fibers. In such a case, the fibers should be used in suitable applications in each instance, rather than attempting to use them for the original application. In this manner, the maximum benefit can be derived from the glass fibers over their service lives and, if necessary, cost savings could also be achieved (Hagnell and Åkermo 2019).

Pyrolysis

The development of most pyrolysis processes, i.e., thermal decomposition in the absence of air, has largely been in laboratory conditions. However, they are now progressing into commercial application (Rybicka et al. 2016). It can be difficult to optimize the process parameters in this area, as a higher processing temperature too greatly affects the mechanical properties of the fibers, but a lower temperature leads to an unacceptably long cycle time. In most of the tests, a significant deterioration in the mechanical properties occurred, especially a reduction in the strength of the glass fibers, although in most cases the stiffness was maintained. If necessary, however, it is possible to reconstitute the strength of the fibers by means of post-treatment (Job 2013).

In addition to a reduction in the fiber's tensile strength by comparison to fresh glass fiber, a significant shortening of the fibers also occurs. Nevertheless, pyrolysis processes appear to have promise, as they allow the dissolution of the composites and the separation of organics and inorganics. However, the gases contain significant amounts of CO and CO_2, and therefore only have a low thermal value. The pyrolysis oils primarily contain oxygenated and aromatic compounds (Naqvi et al. 2018) and have lower thermal values than petroleum (Williams et al. 2005).

However, it has also been shown that it is possible to significantly increase the strength of fibers that have been subjected to even higher thermal loads from thermal recovery by means of post-treatment with NaOH solutions (Thomason et al. 2016). This effect is understandable, as alkaline attacks on silicate glasses attack the structure of the glass network itself, whereas attacks by acids generally dissolve alkali oxides on the surface, but do not attack the glass network. It can therefore be assumed that treatment with NaOH solution alters and erodes the surface as a whole and, thereby, removes existing defects. This is appropriate, as the quality of the surface is key in glass fiber strength. Due to the glass structure and lack of crystal boundaries, even small defects on the surface can significantly affect strength, as crack propagation is not halted by crystal boundaries.

Solvolysis

Solvolytic processes, i.e., the use of solvents to break the chemical bonds of thermosets in particular, currently only exist on the laboratory scale (Rybicka et al. 2016). Compared to pyrolysis, solvolysis produces a lower thermal load in the reinforcing fibers. It is possible that there will be less damage to the fibers. A number of studies have addressed this.

In the case of the solvolysis of GFRP consisting of different fibers (i.e., non-alkali and medium-alkali glass fibers), it has been observed that, depending on the conditions, a large portion of the resins had dissolved in the solution and that the recovered non-alkali glass fiber had a similar texture to the as-received fibers, whereas the medium-alkali glass fiber was damaged during recycling. Accordingly, non-alkali glass fiber retains 94–96% of its original strength, whereas the tensile strength of recycled medium-alkali glass fibers decreases to less than 90% of this value (Yang et al. 2014). Therefore, the strength of the fibers recovered following solvolysis also depends on the composition of the fibers and their chemical resistance.

Similar results were also obtained in another study which showed that glass fiber rovings recovered during solvolysis have the same tensile strength as virgin materials, and a stiffness diminished by only 12% compared to rovings from virgin samples of the same material. This retention of mechanical properties is a distinct advantage over the pyrolysis process, which undermines the mechanical properties of glass fibers (Cousins et al. 2019). However, a disadvantage of the solvolysis of fiber-reinforced composites is the high cost of the solvents used, which also require subsequent disposal. An improved process control, especially the multi-use of solvents for several loads of used GFRP, could reduce solvent consumption and costs (Sokoli et al. 2017). Overall, these complex, expensive, as well as environmentally-harmful processes appear unsuitable for waste treatment on a larger technical scale.

Other approaches seek to depolymerize polyester resins. It should thereby be possible to obtain relatively undamaged glass fibers (Iwaya et al. 2008). The possibilities for recovering the resins and fibers can be substantially improved if materials more suitable for recycling are used from the outset. In particular, resins can be used whose cross-linking is more easily reversible and which can therefore be more easily depolymerized. Both the resins used and glass fibers with comparable properties can then be recovered and recycled (Lejeail and Fischer 2020).

Conclusions on chemical recycling

In the chemical recycling process, pyrolysis and solvolysis in particular are the subject of ongoing developments. Both approaches carry certain advantages and disadvantages. The following factors speak in favor of pyrolysis:

- Lower costs
- A more advanced stage of development

The following factor speaks in favor of solvolysis:

- The high quality of the recyclates obtained

4.5.2.3 Use of GFRP waste as a secondary fuel in cement plants

Under certain conditions, GFRP waste can also be used as a substitute fuel. It must be taken into account that thermal utilization is only in position four in the waste hierarchy according to the KrWG (Circular Economy Act 2017). However, if higher-ranking recovery options are lacking, it may still be necessary. It must be noted here that, due to the glass fibers contained, the calorific value is significantly reduced compared to non-reinforced plastics. At the same time, however, the glass fibers are melted at high temperatures during the burning process and can be used materially for the production of cement clinker. This means that natural raw materials such as sand or other secondary raw materials, such as foundry or crushed sands, can be saved.

GFRPs consist of a min. 15–20 vol.% to a max. of approximately 60 vol.% of fiber material, and 40–85 vol.% of matrix material (Swiss-Composite 2020). With a glass fiber density of approximately 2,550 kg/m^3 (Wikipedia a), a density of about 1,100 kg/m^3 for epoxy resin (Wikipedia b) and a calorific value (H_u) of some 29 MJ/kg for epoxy resin (Construction Steel n.d.), this results in values for the H_u of the GFRP of between approximately 6.47 and 20.59 MJ/kg. Other data assume 5.2 kWh/kg, or 18.72 MJ/kg for H_u (Construction Steel e.V. n.d.). GFRP’s range of heating values is considerable. Compared to the fuels used as standard fuels in cement rotary kilns (usually hard coal with a thermal value of around 27.4 MJ/kg (Working Group on Energy Balances 2020), as well as certain substitute fuels, such as used tires (thermal value of 26–32 MJ/kg according to the Federal Environment Ministry (2014), the GFRP’s thermal value is lower. At best, however, it lies in the range of other substitute fuels, such as fractions obtained from municipal waste (18 MJ/kg) or waste wood (15 MJ/kg).

However, the thermal value is only one factor relevant to the use of GFRP waste in cement plants. The silica and alkali contents are also facets to be taken into account.

The alkali content of cements must be considered, because aggregates in concrete can be attacked by the alkali-silica reaction (ASR). The determining factor for this reaction is mainly the “alkali sensitivity” of the aggregate and, secondarily, the cement’s effective alkali content. The alkali sensitivity of the aggregate is largely a consequence of higher contents of opaliferous sandstone or flint in the aggregates. Therefore, it is primarily a regional issue (Wendehorst 1992). In this regard, the alkali content, which can be introduced into the cement clinker by secondary fuels, plays a subordinate role in the utilization of the cements. However, the requirements for cements with low alkali contents may need to be taken into account (DIN

1164-10 2013). The alkali content of cements at which this reaction[3] occurs are in the range of approximately 1%. Especially low alkali grades also feature lower contents.

Table 7. Requirements for the alkali content (as Na_2O equivalent) of cements according to DIN 1164-10.

	[%]
CEM 1 CEM V	≤ 0.60
CEM II/B-S	≤ 0.70
CEM III/A (for granulated slag content ≤ 49 M.-%.)	≤ 0.95
CEM III/A (for granulated slag content ≥ 50 M.-%.)	≤ 1.10
CEM III/B	≤ 2.00
CEM III/C	≤ 2.00

The calculation of the permissible alkali content is not based on the total alkali content, but on the so-called "effective alkali content" as Na_2O equivalent. The effective alkali content is calculated as follows:

$$Na_2O - Equivalent\ [M.-\%] = Na_2O + 0.658K_2O$$ (Beton wiki 2017)

Table 8. Typical alkali content of glasses for glass fibers.

	Na_2O [%]	K_2O [%]	Na_2O-Equivalent [%]
E-Glass	0.3	0.2	0.43
C-Glass	8.5	0.0	8.5
S-Glass	0.0	0.0	0.0

Source: Own calculations.

The alkali content of E-glass, which is mainly used in GFRP, is so low, with an Na_2O equivalent of 0.43% (Table 8), that it generally has no substantive influence on the alkali content of cements when GFRP waste is used as a substitute fuel. This also applies to low-alkali cements.

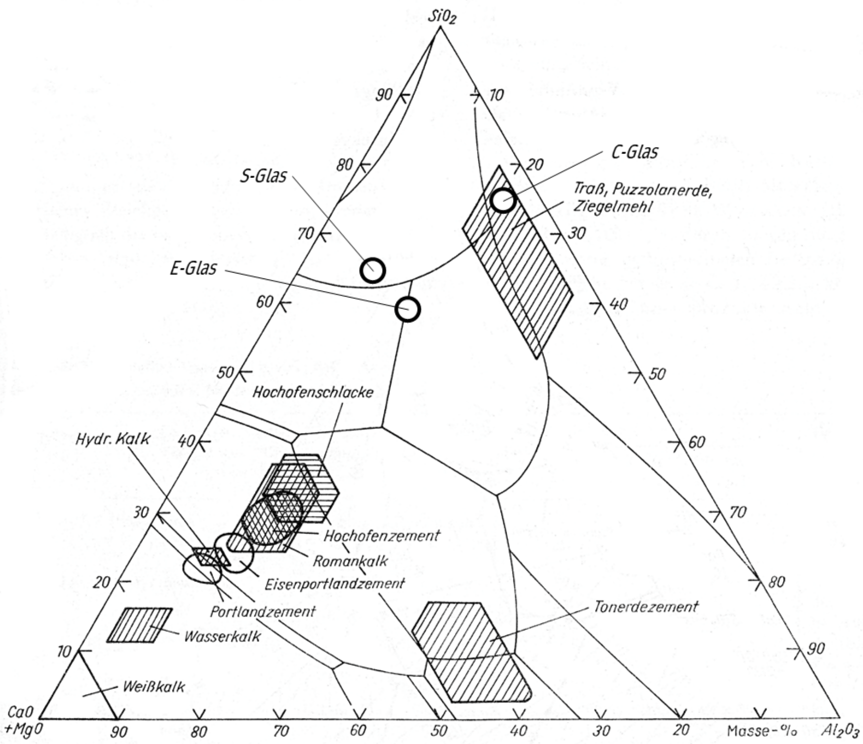
Due to the low alkali quantities expected, it can be assumed that the use of GFRP as a substitute fuel will have little influence on the alkali balance in a cement rotary kiln and will not have any significant impact on its operation.

In addition to the alkali content, the SiO2 content of used GFRP and its possible effects on the clinker matrix must be taken into account. As GFRPs are predominantly composed of glass fibers, the SiO_2 input could be considerable. This is illustrated by a plot in the three-material system SiO_2-Al_2O_3-CaO/MgO (Figure 18). For this purpose, the compositions of the glasses relating only to these oxides were determined and are shown within the three-material system.

3

The use of GFRP must therefore be accompanied by an appropriate substitution if possible in individual instances.

Figure 18. Positions of binders, hydraulic additives and glasses for glass fibers in the system CaO-Al_2O_3-SiO_2 (data in mass %).



Source: Hinz (1971) and own additions for E, C and S-Glass.

The raw material base of Portland cement clinker varies across different locations. There are cement plants that process marl whose natural composition already constitutes a balanced ratio of silicon, aluminum, iron, calcium carbonate, and magnesium carbonate, as well as those whose lime-rich raw material base requires, amongst other things, correction by silicon-rich raw materials (Drozdzewski, 2007; German Cement Works Association, 2002)

The use of GFRP waste in necessary quantities requires a reduction in the input via other material flows, depending on the amount of SiO_2 introduced through it. This is not possible in some cement plants, or only possible to a limited extent, especially those that use SiO_2-rich marl. The decision as to whether GFRP waste can be used must therefore always be made at a plant-specific level, taking into consideration the raw material base and quality requirements for the product.

Conclusions on the use of GFRP waste as a secondary fuel in cement plants

The use of GFRP waste in cement plants appears to be viable on a case-by-case basis if the raw material base is restricted. Depending on the amount of GFRP waste generated annually, the existing capacity in Germany could be sufficient for its full use as a substitute fuel. However, this was not the focus of this project and was therefore not further investigated.

The most important reasons in favor of its use are:

- The possible conservation of primary raw materials with an appropriate raw material base
- Utilization of the energy content

The most important reasons that speak against its use are:

- The somewhat low thermal value
- The SiO_2 content, which is too high depending on the raw material base

Advantages could arise if the use of FRP waste were to be accompanied by a significant substitution of primary raw materials.

4.6 Summary and recommendations

Chapter 4 presented the main recycling technologies for plastic waste emanating from the construction industry. The focus was on the plastics most relevant to the industry in terms of volume (e.g., PVC, PE and PS), as well as the most important product groups of pipes, windows, door and shutter profiles, insulation materials, PVC flooring, cable insulation, and textile floor coverings. To provide a full overview, the chapter first looks at recycling from the point of view of the processes and techniques used for this purpose, then on the basis of the different types of plastic, and finally in terms of the product groups.

An important prerequisite for the mechanical recycling of plastics is their separate collection. Although the technical possibilities exist for sorting mixed construction waste, they are not used to prepare for recycling – even when using with the best sorting technology, the plastic fractions arising from mixed construction waste are only thermally recycled according to current practices.

In terms of volume, the most relevant plastics in the construction sector are mostly thermoplastics, and therefore material recycling is, in principle, feasible and well-developed from a technological point of view. The recycling processes for the individual types of plastic are very similar. A central step in the process is recompounding, in which cleaned plastics are processed into a homogeneous recyclate with a defined property profile. However, the extent to which mechanical recycling is applied in each case depends on whether a sufficiently large and pure material stream exists, and so on whether high-quality mechanical recycling is possible. For economical application, the costs of logistics, sorting and processing must at least be met by saved disposal costs and revenues generated by the recyclates. For the product groups for which voluntary take-back systems already exist (i.e., pipes, windows and doors, PVC flooring), these conditions are met to a high degree, and therefore recycling is possible and already applied. In the case of insulation materials based on EPS, XPS and PUR, recycling is essentially limited to production waste and, in some cases, that from construction sites. Post-consumer waste rarely appears at present due to the longevity of current insulation systems. For demolition, logistical challenges and major contamination still hinder effective recycling. As thermosetting plastics, PUR insulating materials cannot be recycled as such, but they can be repurposed as pressed boards. Textile floor coverings have poor prerequisites for recycling due to their complex structures, high material diversity, and high contamination levels. In addition, efficient take-back logistics and recycling infrastructure are lacking. Cable insulation features good logistical prerequisites for recycling due to the separate collection and metal recycling of cables. In practice, however, this potential has not yet been fully exploited, but is at best used for downcycling.

Solvent-based processes, such as those utilized by NewCycling, CreaSolve or VinylLoop, are being promoted as a means of recycling materials that are otherwise difficult to separate or clean. The extent to which these solutions remain a niche application or can establish themselves on the market on a larger scale is unclear at present.

The possibilities for chemical recycling and its limitations were also discussed. PA6 from textile waste is being recycled on an industrial scale by some innovators.

The recycling of GFRP waste presents a particular challenge, as this is a thermoset material that only has limited suitability as a substitute fuel due to its high glass fiber content. Bitumen is also currently still thermally-recycled, as recycling of it is technologically-challenging.

On the basis of the studies presented in this chapter, the following recommendations for strengthening the circular economy in the construction sector can be advanced:

- Waste avoidance is not possible for most products, and also cannot be prioritized as substantively as, for instance, for packaging waste, due to their long service lives.
- The recycling of products is only an option in a small number of cases.
- A large proportion of the materials used are thermoplastic in nature and so, in principle, are readily recyclable as materials. In this context, purer waste streams enable high-quality recycling. This can be achieved by means of the following measures:

Improving the separate collection of plastic waste. The legal requirements for separate collection exist, but could be more effectively enforced – in particular, the hurdles facing exemption should be reviewed on this basis.

In the area of insulation materials, separate waste codes for insulation materials made of plastics should be introduced or, EPS- PUR- and XPS-based insulation materials included in the waste code for plastics (17 02 03).

Material, group-specific take-back systems enable purer flows. It should be determined at this point whether this offers advantages for individual product groups. If so, the introduction of a voluntary take-back system should be encouraged and supported.

The communication of existing return and recycling options in the technical documentation of the products can be made compulsory. The effort required on the part of the manufacturer for this is estimated to be low.

- The long service lives of construction products should be taken into account in the comparative assessment of the recycling management of different sectors.
- For the recycling of textile floor coverings, the greatest development potential currently lies in the "design-for-recycling" principle. The following approaches exist for this:
  - The use of mixed materials and harmful substances must be avoided
  - Only recyclable materials should be used
  - The separability of individual carpet layers must be ensured
  - Labeling of the materials used in the various layers, such as by stamping or technical documentation, should be performed
  - Carpets should be attached without the use of adhesives
- Expansion of the recycling infrastructure should be promoted.
- Due to its complexity, the collection and recycling process incurs costs that are sometimes difficult to cover by merely selling the recyclates produced. Thus, recyclates are always in

competition with virgin materials. Instruments that create additional financial incentives or prescribe the use of recyclates could play a supporting role in this context.

5 Use of recycled materials in plastic building products

5.1 General

The recycling of secondary plastics into applications of the highest possible quality is becoming increasingly important. Whether initiated by civil society, political overtures, or even industry, closing material and substance cycles is the goal. According to the Conversio study published in August 2020, a total of 14,235 kt of plastics were processed in Germany in 2019. Of this, about 86% was virgin material and 14% recycled. In the construction industry, this ratio shifts in favor of recyclates, with approximately 77% of primary plastic and about 23% recyclate having been used in the manufacture of construction products. In general, these reuse rates indicate that there is still great potential in terms of a circular economy (Lindner and Schmidt 2020).

The aim of this chapter is to identify potential uses of recyclates in plastic construction products – the use of recyclates in construction products being the central topic of this study. Due to their high relevance, pipes in particular but also cable ducts, are considered, with current standards and requirements for the use of recyclates being explained and the technical limits and further obstacles outlined. At the same time, building products from other application areas (drawing, amongst other sources, on the research on construction products made of plastics presented in Chapter 2) are also named and the possibility of using recyclates for their manufacturing is examined. Waste streams rich in plastics are identified and evaluated in terms of their suitability for the production of high-quality plastic recyclates. The results are also based on expert interviews.

5.2 Plastic waste: Quality and Quantities

In this chapter, the qualities and quantities of domestically-generated waste are considered as a raw material basis for the use of plastic recyclates.

Drawing on data from the German Federal Statistical Office, various quantity analyses were already presented in Chapter 2, above. Although these dealt exclusively with waste types that are generated specifically in the context of demolition work, plastic waste from other sources (e.g., from the packaging sector) will also be considered in the following. This, too, can be used as a raw material for the manufacture of construction products, provided that the construction-related product regulations allow it. A critical factor in this regard, however, is that the plastic would be removed from its original product system and be missing, which could require more extensive adjustments to be made. For instance, PP food packaging is utilized and compounded completely differently than PP wall liner. Focusing purely on the main polymer group is therefore not adequate for achieving a high-quality closed-loop system with few rejects.

It was already discussed in Chapter 2 that the long service lives of building products offer environmental advantages over plastic products with short service lives due to waste prevention. However, for reprocessing and reuse purposes, service lives of several decades are a hindrance due to aging phenomena and potential damage. Therefore, the viability of mechanical recycling and subsequent reuse for the manufacturing of new building products will be examined in more detail below. At the same time, aging resistance is also important for assessing the suitability of plastics and plastic recyclates for use in building products.

Depending on their field of application and functional purpose, the plastic products used in the construction sector are exposed to different environmental conditions that accelerate aging, i.e., polymer chain degradation. These include:

- Mechanical stress (static loads, dynamic loads, and wear)

- Chemical stress (oxidation, hydrolysis, swelling, and stress cracking)
- Biological stress (microorganisms, plants, and animals)
- Radiation (energetic radiation, wavelength, and intensity)
- Atmospheric stress (UV light, oxidation, humidity, water, and impurities)
- Temperature (thermal degradation, thermal–oxidative degradation, and alternation of heat and cold)

Attempts are currently being made to delay the aging of plastic by inserting appropriate additives, e.g., antioxidants. However, complete prevention has not yet been possible. The use of additives is also harmful from an ecological point of view. Individual considerations regarding this are outlined in Chapter 4.

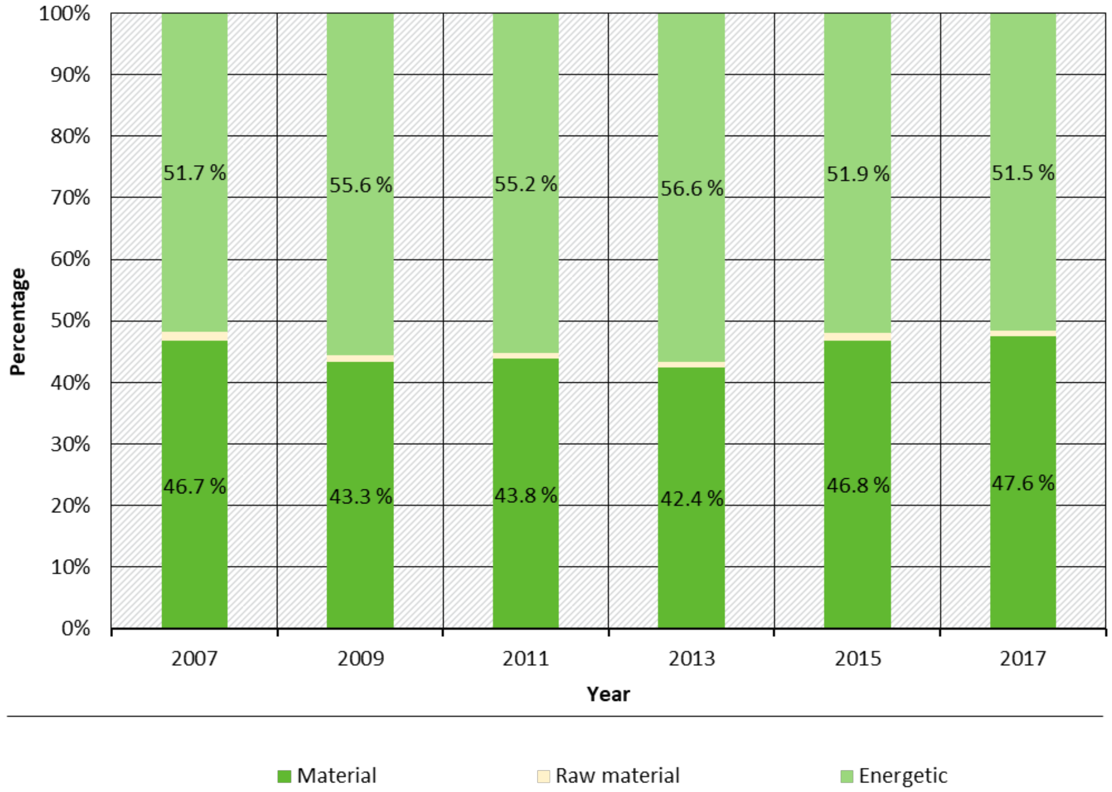
The aging of plastic materials manifests itself, for instance, as a loss of elasticity, fading color, cracks in the product, or erosion of its surface. In addition to polymer chain degradation, old plastic products from civil engineering applications in particular tend to be heavily contaminated. Here, too, the waste must first undergo extensive cleaning before it can be reprocessed, which consumes additional resources and is often not viable from an economic perspective.

Assuming a long service life in a building, the application contributes to the avoidance of waste. Given the aging, contamination, need for additives, and possible pollutant loads, which ultimately reflect the state of relevant legislation at the time the product enters the market, the environmental benefits of recycling are limited compared to short-lived goods, and the quantitative recycling issue is therefore also less urgent.

Plastic waste from other sectors, such as packaging, has the advantage exhibiting comparatively low signs of aging and, in this respect, is more suitable for high-quality mechanical recycling. However, the degree of resistance of these materials to aging is uncertain. Furthermore, other hurdles arise, such as multilayer composites. Another negative aspect lies in the unpredictable and industry-untypical nature of contamination, such as food residues, which often lead to problems of odor in the product and require costly washing procedures.

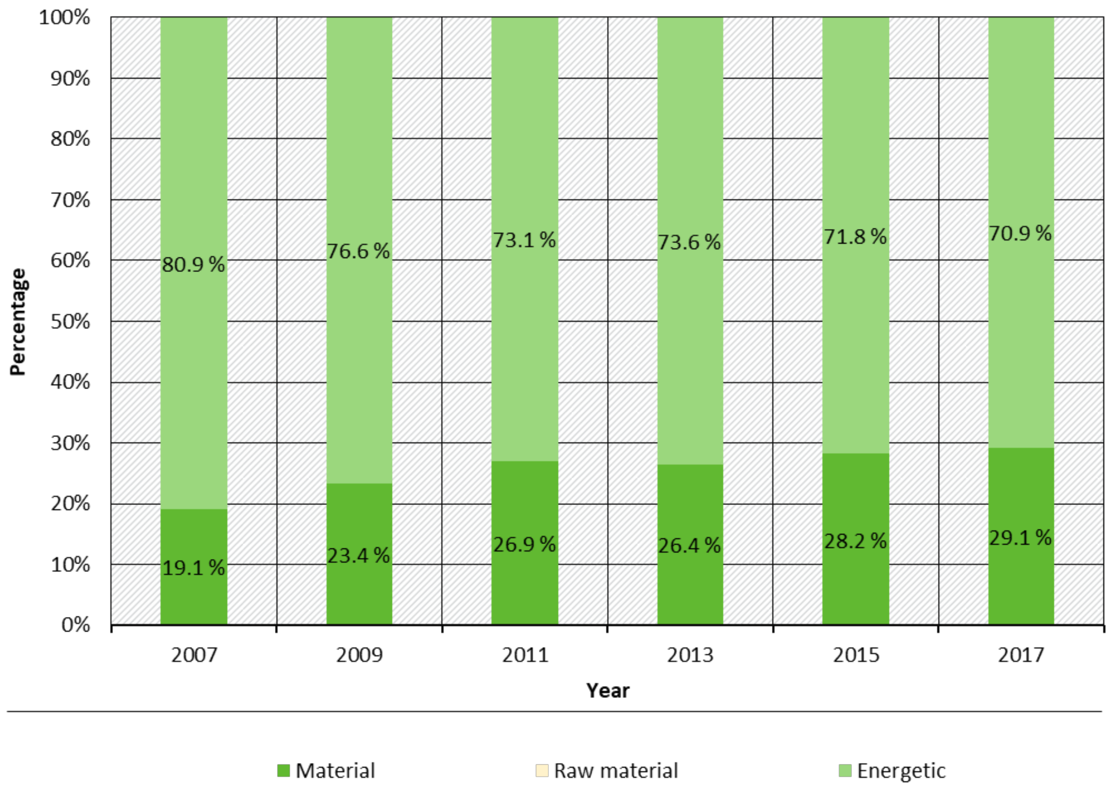
The following figures depict developments in plastic recycling in recent years. On the one hand, the quantitative development of recycling types for the sum of all plastic waste not originating from the construction sector is shown in Figure 19, as well as that of all plastic waste from the construction sector (Figure 20). As is apparent, the share of mechanical recycling for other plastic products dropped to around 42.4% between 2007 and 2013, before finally rising again, to 47.6%, in 2017 – roughly the same as the initial level in 2007. Virtually the entire share of the plastic wastes that could not be recycled was sent for energy recovery, whereas the feedstock recycling of plastic wastes only played a minor role in the period under consideration. In the same period, plastic waste from the construction sector tended to develop more strongly in the direction of mechanical recycling. Whereas only 19.1% of plastic waste from the construction sector was recycled in 2007, the figure had grown to around 29.1% by 2017. The share of energy recovery, which is the predominant form of recovery in the construction sector, displayed an opposite trend and thus a steady decline over the same period, whereas the raw material recovery of plastics in the construction sector did not yet play a role.

Figure 19. Proportional development of recycling types used for plastic waste from all sectors other than construction in the period from 2007 to 2017.



Source: Own illustration (see Lindner 2008, 2010, 2012, 2014, 2016; Lindner und Schmidt 2018b) SKZ – Das Kunststoff-Zentrum.

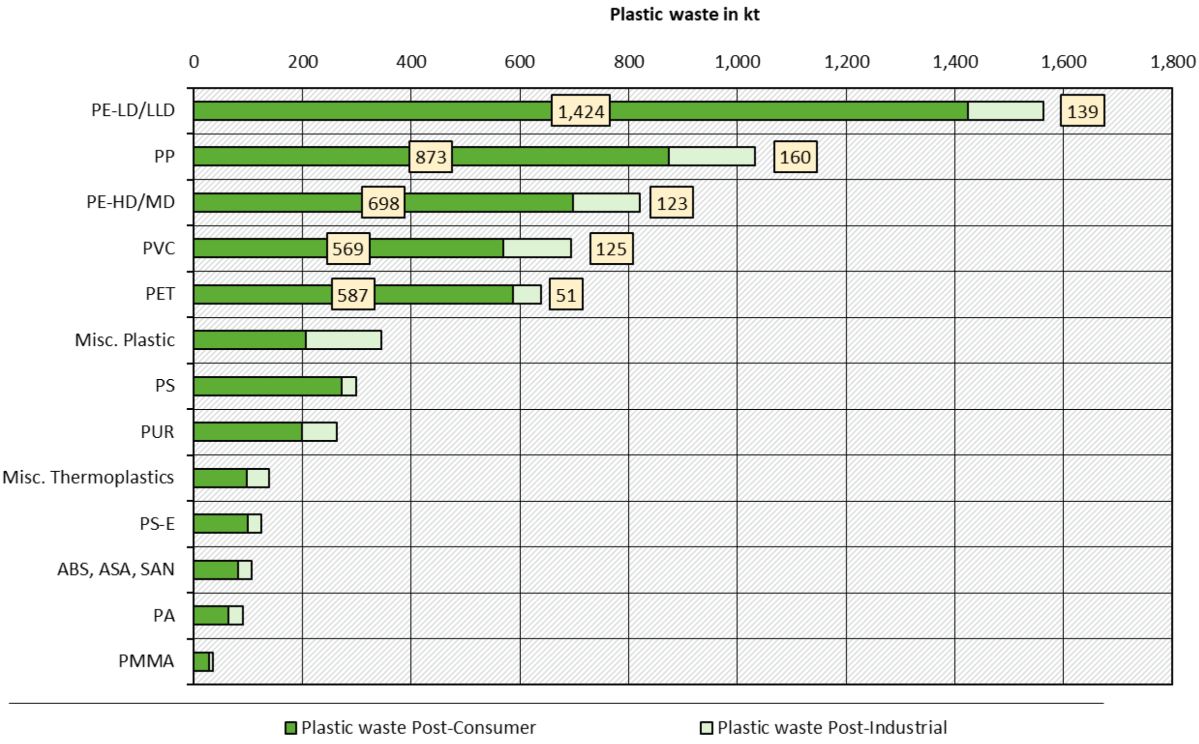
Figure 20. Proportional development of recycling types used for plastic waste from the construction sector in the period from 2007 to 2017.



Source: Own illustration (see Lindner 2008, 2010, 2012, 2014, 2016; Lindner und Schmidt 2018b) SKZ – Das Kunststoff-Zentrum.

Figure 21, below, depicts the plastic waste generated in Germany in 2017 by type (i.e., post-consumer or post-industrial waste) and by type of plastic. As is apparent, especially relevant quantities of plastic waste are specifically generated in the form of polyolefins (PE-LD/LLD, PE-HD/MD, and PP) and in the form of PVC or PET. The total amount of plastic waste generated is estimated to be around 6,154 kt, of which approximately 5,201 kt can be allocated to the post-consumer sector and around 953 kt to the post-industrial one (i.e., waste generated by producers and processors) (Lindner and Schmidt 2018).

Figure 21. Plastic waste in 2017 by plastic type and origin in kilotons.



Source: Own illustration according to Lindner and Schmidt (2018) SKZ – Das Kunststoff-Zentrum.

It is far more difficult to determine the *quality* of plastic waste than its quantities. Its composition has a strong influence on the quality of the recyclates produced. Initial conclusions regarding plastic waste composition can already be drawn by looking at its respective place of accumulation. For instance, it can be assumed that plastic waste that ends up in the yellow bags of private end consumers along with other waste is generally significantly more contaminated and heterogeneous than, for example, waste generated directly by a plastic producer. The following table highlights the different sources of plastic waste in 2017 according to the amount of waste present and the type of waste treatment/recycling carried out on it (Lindner and Schmidt 2018).

Table 9. Plastic waste in 2017 by place of generation, amount of waste present, and type of waste treatment carried out (Lindner 2018).

	Total volume of waste [kt]	Quantity recycled [kt]	Material recycling [kt]	Energy recovery [kt]	Disposal [kt]
Commercial waste via private disposal firms	1208	1197	319	878	11
Waste similar to household waste via public waste disposal firms	221	217	0	217	4
Shredding firms incl. car recyclers & repair shops	187	182	46	136	5
Collection and recycling systems for commercial packaging	418	418	269	149	0
Other collection and recycling systems	121	121	105	16	0
Sales packaging (dual systems, manufacturer-based take-back systems)	1551	1551	1161	390	0
Residual household waste	1026	1011	0	1011	15
Bulky household waste	197	197	48	149	0
Collection of recyclable materials	63	63	32	31	0
E + E scrap from private households, trade and industry	209	209	44	165	0
Plastics producers	68	66	46	20	2
Plastics processors	885	883	803	80	2
Total	6154	6115	2873	3242	39

Source: Own illustration according to Lindner and Schmidt (2018).

As Table 9 shows, in 2017 about 3,242 kt of plastic waste was recycled for energy and only 39 kt was sent for disposal. Approximately 2,873 kt were sent for material recycling, of which 2,024 kt came from the post-consumer sector and 849 kt from production and processing. At about 1,161 kt, a large proportion of the plastic waste recycled originated from sales packaging generated by private end consumers and was collected through the dual systems (just over 40%). In addition to plastic waste generated directly by producers and processors (just under 30%), the collection and recycling systems for commercial packaging (9%), commercial waste via private disposal firms (11%), and other collection and recycling systems (e.g., RoofCollect, AgPR, KRV; just below 4 %) represent substantial sources of plastic waste for recycling.

About ¾ of the mechanical recycling of discarded products (post-consumer waste) can be attributed to the recovery of packaging waste. This includes packaging waste generated by both commercial and private end consumers) (Lindner, 2018). PE, PP and PET encompass almost 90% of the plastics processed in the packaging sector. Accordingly, these plastics also make up the main share of recycled plastics. In the construction sector, PET is used to a lesser extent, and PE-LD almost not at all. This is in contrast to the packaging sector 50% of whose waste, for example, consists of PE-LD.

Only about 22% of the total of 2.6 million t of plastic construction products manufactured each year are made of polyolefins or PET. As can be seen in Figure 8, approximately 425 kt of PE, 124 kt of PP, and 22 kt of PET are used each year.

The key prerequisite for the use of recyclates in construction products is compliance with the relevant construction standards and requirements on the part of legislators and customers, as well as the availability of suitably processed recyclates.

PVC, a plastic that is especially widely used and recycled in the construction sector, plays a subordinate role in the packaging one (< 5% of the total quantity processed in the packaging sector or approximately 200,000 t/a), and so packaging processing does not provide these secondary plastics in sufficient quantities at a suitable quality (Lindner and Schmidt 2018). The amount of PVC used in Germany is 785,000 t/a (Figure 8). In 2017, the waste volumes of PVC totaled 695,000 t, of which 257,000 t were recycled. It should be noted at this point that the actual amount of PVC recycled is higher, as the specific quantities sent for in-house recycling are not recorded (AGPU 2019).

The amount of recyclate produced domestically in 2017 was 1.90 million t, whereas the amount processed was reported to be just under 1.77 million t. With around 758 kt (about 43%) of the processed recyclate quantity, the construction sector accounted for the largest share of the total quantity of processed recyclates, followed by the packaging sector at 23%, and agriculture with 11%. Most of the recyclates processed in the construction sector comprised PVC.

The quality of recyclates ultimately depends on the quality of the input material. If the recyclability of a plastic product is planned for prior to it being produced (i.e., design-for-recycling) and if, for example, the number of different materials used in a piece of packaging or their coloring is minimized, this facilitates the production of high-quality recyclates at the end of the product's life. The quality of recyclates could also be improved, for instance, by increasing consumer education regarding the separate collection of waste. Investments in technical sorting and treatment processes could also increase waste quality and thereby that of recyclates (Working Group on Packaging + Environment e.V. 2019).

Finally, reference should be made to the mismatch of plastic waste generated and raw materials required in the construction sector. The figures presented for different materials in this chapter indicate a mismatching of existing waste and the required qualities or plastic grades. From this, it can be deduced that under current conditions, the possibilities for the use of recyclates from the reprocessing of packaging for construction products are limited. In comparison, the PVC recycling loop leads to fairly high construction industry-specific recyclate use rates.

5.3 Use of recyclates

The conditions for the use of recyclates in the manufacturing of construction products can differ depending on the application area of the product in question. In 2017, the following recyclate use rates were achieved at production sites in Germany (Lindner, 2018):

- Road construction products: 100–150 kt

- Window and door profiles: 100–150 kt
- Pipes: 50–70 kt
- Construction films: 30–60 kt

In the following, the prerequisites for the use of recycled materials will be described first in general terms and then in more product-specific ones by way of reference to a number of examples. For this purpose, the basic requirements for building structures as set out in the Construction Products Regulation of the European Union (European Commission 2011c) will first be outlined. Then, the current use of plastic recyclates for the manufacture of construction products in the context of different product groups – but especially for piping systems – will be presented and examined, the requirements for the use of recyclates considered, and their potentials and limits identified.

5.3.1 Basic requirements for structures according to the European Construction Products Regulation, EU-BauPVO

As a legal regulation, the EU Construction Products Regulation has the main objective of establishing EU-wide harmonized product and testing standards for construction products and thus functions, amongst other things, as the basis for the CE marking of products and for manufacturers' declarations regarding performance. Its content serves to establish harmonized conditions for the marketing of construction products, i.e., EU-wide harmonized product and testing standards, which should facilitate the market placement and marketing of construction materials and products within the European internal market by the respective manufacturers. The specifications listed in the regulation naturally also apply to construction products made from secondary raw materials and already offer an initial overview of the basic requirements that a structure and its segments must meet (European Commission 2011c).

Annex I of the Construction Products Regulation lists the so-called basic requirements for construction projects, which contain the most fundamental requirements for construction materials and products, or for construction works as a whole. These requirements are as follows:

- Mechanical strength and stability
- Fire protection
- Hygiene, health, and environmental protection
- Safety and accessibility of use
- Sound insulation
- Energy conservation and thermal insulation
- Sustainable use of natural resources

The basic requirement, "Sustainable use of natural resources," which is especially relevant in the context of the present study, is as follows (European Commission 2011c):

7. Sustainable use of natural resources

The structure must be designed, constructed, and demolished in such a way that natural resources are used sustainably and, in particular, the following are ensured:

(a) The structure, its materials, and parts must be capable of reuse or recycling after demolition;

(b) The structure must be durable;

(c) The structure must use environmentally-compatible raw materials and secondary building materials.

Thus, the use of recycled materials is in principle a goal that legislators are striving for. In this context, however, the durability of structures and the environmental compatibility of the secondary raw materials used must be ensured in the same manner as all of the other basic requirements with respect to sustainability.

The harmonized technical specifications, which (as noted at the beginning of this report) already exist for numerous construction products, and in which the essential characteristics of the respective construction products are described in an EU-standardized form, are based on the above-mentioned basic requirements for construction works and contribute to their compliance. The utility of using recycled materials can therefore be assessed on a case-by-case basis by evaluating the possible non-fulfillment of essential characteristics in terms of technical specifications.

5.3.2 General requirements for the use of recycled materials

The recyclability of plastics is influenced by different properties. As plastic waste, especially in the post-consumer sector, accumulates as a heterogeneous mixture and the different types of plastic are often very difficult to mix with one another, separation into individual plastic fractions (for example, by means of near-infrared spectroscopy) is usually a mandatory prerequisite for the production of a high-quality recyclate. The enormous variety of plastic types, blends, colorants, and additives used often make this step significantly more difficult. Table 10 presents an overview of how good the compatibility is when mixing two different plastic types. For instance, PVC blends well with PMMA without significantly degrading the processing potential or mechanical properties. Mixing PVC with PP, PE or PET, on the other hand, is not possible. At the same time, the plastic waste must be freed from contaminants and impurities. New developments in sorting technology offer promising solutions here that cannot be achieved using NIR processes. One example is the so-called tracer-based sorting process. Plastic products can be equipped with fluorescent markers and thus easily identified. The sorting process is then no longer cascaded over several stages, but can be performed directly, similar to letter-sorting (Moesslein 2020).

Table 10. Compatibility matrix of the mixability of different plastics.

	PS	ABS	PA	PC	PMMA	PVC	PP	PE	PET
PS		6	5	6	4	6	6	6	5
ABS	6		6	2	1	3	6	6	5
PA	5	6		6	6	6	6	6	5
PC	6	2	6		1	5	6	6	1
PMMA	4	1	6	1		1	6	6	6
PVC	6	3	6	5	1		6	6	6
PP	6	6	6	6	6	6		6	6

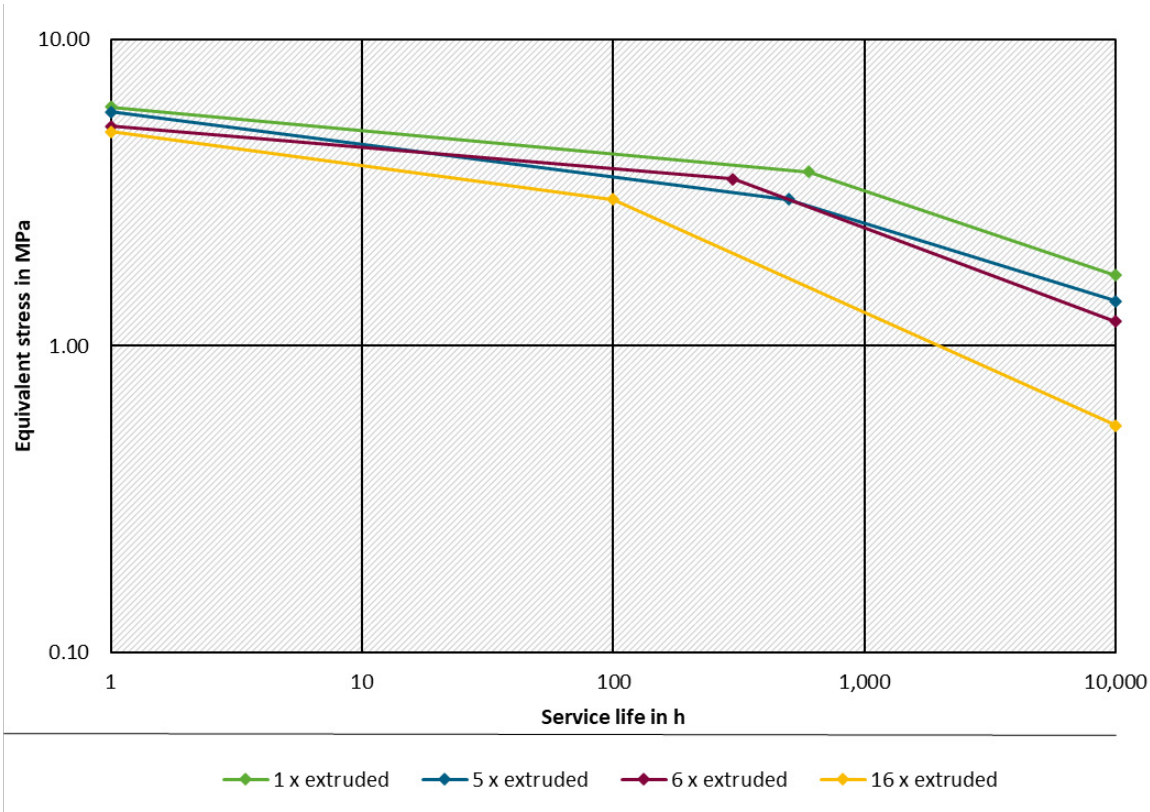
	PS	ABS	PA	PC	PMMA	PVC	PP	PE	PET
PE	6	6	6	6	6	6	6		6
PET	5	5	5	1	6	6	6	6	

Legend: 1 = easy to mix; 6 = difficult to mix.
Source: Own illustration based on Martens and Goldmann (2016).

The oxidative degradation of polymers, which occurs under the influence of atmospheric oxygen, heat or UV radiation during the processing, storage and use of plastic products, can also lead to a deterioration in their material properties over time. In this context, the literature concerning the application area of pipes notes that with each reprocessing step of plastics in particular, their long-term characteristic values/properties significantly decrease. Particular emphasis is placed on creep behavior under internal pressure (Winkler 2020). The test considers the equivalent stress over time. Equivalent stress is an important parameter for ensuring that the mechanical requirements are met and if it falls below a defined value, it cannot be guaranteed that the pipe can withstand a compressive load, i.e., it will highly likely burst. Figure 22 shows the equivalent stress in relation to the service life as a function of the extrusion runs. It can be seen that the equivalent stress significantly decreases from a service life of about 102 h. The more frequently a plastic is extruded, the more this phenomenon intensifies.

Moreover, the increased use of recyclate can result in negative optical properties (e.g., a lack of gloss or transparency) of the product made from recyclate or an alteration in the processing properties (e.g., melt temperature, viscosity) (Maile and Roos 2015; Martens 2011). Surface treatment can eliminate simple material defects and inconsistencies. Processes applied in this context include blasting, lasering, painting, PVD coating, and metallization. In addition, decorative foils are often also used to facilitate homogenization of the surface appearance.

Figure 22. Creep rupture internal pressure behavior in pipes made of PE and extruded with different frequencies.



Source: Own representation according to Maile und Roos (2015) SKZ – Das Kunststoff-Zentrum.

In addition, certain process engineering considerations are also of crucial importance in the use of recyclates. These are detailed below.

1. Filtration:

Regardless of the application for which the plastic recyclate is intended, thorough filtration of the plastic melt is necessary. This processing step is necessary for removing existing impurities and thus to raise the recyclate quality level (Erema 2016).

2. New and readjustment:

If there is a transition from virgin material to recyclate, or if recyclate is proportionally added, the process parameters must be adjusted. The recalibration of the plant equipment is an often time-consuming and cost-intensive process that requires a high level of expertise. In addition, due to possible inhomogeneities among recyclates, it is rational to support the extrusion through the optimized geometries of screw extruders, twin-screw extruders, and viscosity control.

3. Increased complexity:

Especially in the area of profiles (e.g., windows) and pipes, the process of co-extrusion is utilized when using recyclates. The extruder is designed such that primary and secondary plastics are processed across several layers. The core consists of the recyclate and the outer layer is virgin material. If pure virgin material is processed, the equipment can be less complex. In addition, significantly more process parameters must be coordinated, which also increases complexity during processing. The company Engel Austria GmbH of Schwertberg has developed a similar process in which virgin material is followed by recycled material through an injection molding process, whereby the component consists of virgin material on the outside, and is filled with recycled plastic on the inside. This technology has been on the market under the name *skinmelt* and enables the processing of complex component geometries with a high recycled content. In this process, the two melts are brought together prior to injection, with the virgin material reaching the cavity first and being displaced by the downstream recyclate melt. As a result, the virgin material is pressed against the wall of the cavity, while the core is filled with the recyclate melt in parallel.

Finally, the prerequisites, as well as obstacles, concerning the use of plastic recyclates are summarized and presented in the following bullet points:

Prerequisites for the use of plastic recyclates:

- Well-sorted batches
- As few contaminants and impurities as possible
- As little degradation of the polymer chains as possible
- Fulfillment of structural engineering standards and customer requirements
- Good processability
- Modified process/plant technology

Obstacles to the use of plastic recyclates:

- Frequently heterogeneous plastic waste (especially in the post-consumer sector)
- Somewhat heavy contamination (especially in food packaging and plastic products used in civil engineering applications)
- Oxidative degradation of polymers due to environmental impacts over long service lives (mechanics)
- Negative optical properties (lack of gloss or transparency, limited color selection)
- Low price differences between recyclates and virgin material
- Availability (Maile and Roos 2015; Winkler 2020)

5.3.3 Use of recyclates in pipes

Plastic piping systems are subject to numerous different quality requirements depending, for example, on the material used (i.e., PVC-U, PP or PE) or the type of application (e.g., wastewater, drinking water, or gas supply) of the pipe. The manufacturers of plastic pipes therefore typically have their products voluntarily certified by an authorized body, thus providing certifying the quality requirements stipulated by the relevant standards.

Within these standards, requirements are placed, for instance, on the geometric, mechanical, and physical properties, as well as on the color or condition of a pipe. At the same time, the respective standards specify corresponding test methods and parameters whereby piping systems can be tested for compliance with the respective requirements. In the following, various properties and requirements of piping systems, as well as cable ducts made of different materials and with different types of applications, are listed as examples. In order to provide a better overview, the specific test parameters and testing methods are not stated (these can be found in the corresponding standards).

Table 11. Typical requirements for plastic pipes for underground, non-pressurized sewers and pipes made of PVC-U, taken from DIN EN 1401.

DIN EN 1401

Plastic piping systems for underground, non-pressurized sewers and pipes – Plasticizer-free polyvinyl chloride (PVC-U)

Feature	Requirement
PVC-U content	≥ 80%
Resistance to internal pressure	No failure during the test period
Resistance to external impact stress (circumferential method)	TIR ≤ 10%
Density	1350 kg/m³ ≤ density ≤ 1600 kg/m³
Longitudinal shrinkage	≤ 5%, no cracks or bubbles
Vicat softening temperature (VST)	VST ≥ 79 °C
Uniaxial tensile test	Elongation at break ≥ 80%
Resistance to dichloromethane at a specified temperature	No attack
Maximum permitted percentage of recycled material	100%
Maximum permitted percentage of recycled material and recyclate with agreed specifications	20%
Permissible limit deviation for recycled material and recyclates: density	+/-20 kg/m³
Permissible limit deviation for recycled material and recyclates: VST	+/-2 °C
PVC-U content	+/-4% (mass fraction)
Origin of the material	PVC-U products

Source: Own illustration corresponding to DIN EN 1401.

In the case of profiled pipes for underground, non-pressurized sewers and pipelines, PVC-U return material and recyclate derived from PVC-U pipes and fittings may be used (alone or added to virgin or recycled material, or a mixture of the two, provided that all other requirements of the standard are met in the process). Return material and recyclates from PVC-U products other than pipes and fittings may be used in either a middle layer of specific pipe types, or added to virgin material, recycled material, or a mixture of the two if it meets the requirements listed in Table 12, below. With respect to profiled pipes for underground, non-pressurized sewers and pipes made of PP and PE, the use of returned and/or recycled material from products other than PP pipes or fittings, or corresponding to PE pipes or fittings, is excluded (in contrast to PVC-U). Table 13 also lists the requirements and conditions that the corresponding recycled material and recyclate from pipes and fittings must meet.

Table 12. Typical requirements for piping systems with profiled walls made of PVC-U, PP, and PE with special consideration of the requirements for recyclates and return materials, drawn from DIN EN 13476.

DIN EN 13476	
Plastic piping systems for buried non-pressure sewers and pipes – Piping systems with profiled walls made of unplasticized polyvinyl chloride (PVC-U), polypropylene (PP), and polyethylene (PE)	
PVC-U (requirements for returned material and recyclates from sources other than PVC-U pipes and fittings)	
Feature	**Requirement**
Density	1390 kg/m³ ≤ density ≤ 1700 kg/m³
Ash residue as contents of the filler	PVC-U content for pipes at least 80 %; if PVC is replaced by CaCO3, the PVC content can be reduced to 60 % or 75 % (depending on whether middle or outer layer)
K-value*	56 ≤ K-value ≤ 70
VST	≥ 62 °C
Grain size	> 1000 µm: ≤ 15% (mass fraction) < 1400 µm: 100% (mass fraction)
Impurities	≤ 0.15 %
PP (Requirements for return material and recyclate from PP pipes and fittings)	
Feature	**Requirement**
Density	> 900 kg/m³
Ash residue	Middle layer A1 pipe ≤ 40% All other layers ≤ 25%
Melt flow rate (MFR)	≤ 1.5 g/10 min
Foreign polymers	≤ 5 %
Type of pigments and/or additives	Mesh size to be agreed between manufacturer and supplier
Impurities	Mesh size to be agreed between manufacturer and supplier

DIN EN 13476	
Thermal stability OIT	≥ 8 min
Volatile substances	≤ 300 mg/kg
PE (Requirements for returned material and recyclate from pipes and fittings made of PE)	
Feature	**Requirement**
Density	> 930 kg/m³
Ash residue	Middle layer A1 pipe ≤ 40% All other layers ≤ 25%
Melt flow rate (MFR)	≤ 1.6 g/10 min
Foreign polymers	≤ 5%
Type of pigment and/or additives	Mesh size to be agreed between manufacturer and supplier
Impurities	Grain size is to be agreed between the manufacturer and supplier
Thermal stability OIT	≥ 20 min
Volatile substances	≤ 300 mg/kg

* "The K-value is – like the viscosity number – a quantity that characterizes the average molar mass (molecular chain length). It is calculated from the viscosity ratio according to an equation formulated by Fikentscher in 1929. Incidentally, the latter is also the experimental basis for calculating the viscosity numbers. Thus, the ranking of a group of products in terms of molar mass characterization is the same for both the K-value and viscosity number. It is only for historical reasons that the K-value is still used to identify the molecular weight of PVC. Typically, the molecular weight of PVC-U is determined by means of the K-value and is in the range between 60 and 70 for PVC-U pipes. Conversion tables for the viscosity number and K-value can be found in EN ISO 1628-2" (KRV e.V. s.a.).

Source: Own illustration corresponding to DIN EN 13476.

Table 13. Typical requirements for plastic piping systems for the discharge of wastewater (low- and high-temperature) within the building structure made of PE with special consideration of the requirements for recyclates and returned materials, taken from DIN EN 1519-1

DIN EN 1519-1	
Plastic piping systems for the drainage of wastewater (low- and high-temperature) within the building structure – PE	
Feature	**Requirement**
Internal creep pressure behavior	No failures during the test
Melt mass flow rate	0.2 g/10 min ≤ MFR (190/5) ≤ 1.1 g/10 min
Thermal stability OIT	≥ 20 min
Ring stiffness exclusively for the “BD” application	≥ 4 kN/m²
Longitudinal shrinkage	≤ 3%, no fractures or bubbles
Melt flow rate (MFR)	0.2 g/10 min
Dimensions	Dimensions determined according to ISO 3126; for more details, see the table in the DIN standard
Wall thickness	see table in DIN
Texture	Smooth, clean, free of grooves, bubbles, impurities, pores, and irregularities; ends cut perpendicular to the pipe axis and free of burrs
Color	Continuous coloring, preferably in black; other colors allowable
Circulation material, recycled material, recyclates	
Circulation material	Clean circulation material from pipeline components complying with this standard, or EN 12201-2, EN 12201-3, EN 1555-2, EN 1555-3, or EN 12666-1 allowed without restriction
Material made of PE products other than pipes and fittings	Not allowed
Return material from pipes and fittings of other materials than virgin material	
Density	To be agreed with suppliers
Thermal stability (OIT)	To be agreed with suppliers
MFR	To be agreed with suppliers

DIN EN 1519-1	
Ash residue	≤ 25%
Foreign polymers	≤ 5%
Impurities	To be agreed with suppliers
Nature of pigments and/or additives	To be agreed with suppliers
Volatile components	≤ 300 mg/kg
Origin	PE pipes/fittings, no other origin

Source: Own illustration in accordance with DIN EN 1519-1.

Table 14. Typical requirements for plastic piping systems for underground, non-pressurized sewers and pipes made of PP with special consideration of the requirements for recyclates and returned materials, derived from DIN EN 1852-1

DIN EN 1852-1 Plastic piping systems for below-ground, non-pressurized sewers and pipelines – PP	
Feature	**Requirement**
Melt flow rate (MFR)	MFR (230/2.16) ≤ 1.5 g/10 min
Resistance to internal overpressure	No failure during the test period
Thermal stability (OIT)	≥ 8 min
Modulus of elasticity of PP molding compounds	1250 Mpa ≤ E (1min) ≤ 2500 Mpa
Average density	0.9 g/cm³
Average coefficient of linear expansion	0.14 mm/mK
Thermal conductivity	0.2 * 1/(WK*m)
Specific heat capacity	2000 J/kgK
Surface resistivity	> (10^12) Ω
Melt mass flow rate (MFR)	0.2 g/10 min
Longitudinal shrinkage	≤ 2%, no fractures or bubbles
Ring stiffness	Depending on SN

DIN EN 1852-1	
Resistance to external impact stress (circumferential method)	TIR ≤ 10%
Resistance to external impact stress (step method)	H50 value ≥ 1 m, max. one break below 0.5 m
Dimensions	Dimensions determined according to ISO 3126; for details see the table in the DIN standard
Wall thickness	See the table in the DIN
Texture	Smooth, clean, free of grooves, bubbles, impurities, pores, and irregularities; ends cut perpendicular to the pipe axis and free of burrs
Color	Continuous coloring, preferably in black, orange-brown or dusty gray; other shades are allowable
Returned materials and recyclates – Properties that must be taken into account according to the agreed specification	
Density	To be agreed with suppliers
Thermal stability (OIT)	To be agreed with suppliers
MFR	To be agreed with suppliers
Ash residue	To be agreed with suppliers
Foreign polymers	≤ 5%
Impurities	To be agreed with suppliers
Type of pigments and/or additives	To be agreed with suppliers
Volatile components	≤ 300 mg/kg
Origin	PP pipes/fittings, no other source

Source: Own representation according to DIN EN 1852-1.

Table 15. Typical requirements for plastic piping systems for hot and cold water installations made of PP, with special consideration of the requirements for recyclates and returned materials, taken from DIN EN 15874-2.

DIN EN 15874-2

Plastic piping systems for hot and cold water installations – PP

Feature	Requirement
Longitudinal shrinkage	≤ 2%
Thermal stability under internal pressure test	No breakage during the test period
Behavior under impact stress	≤ 10%
Melt mass flow rate (granules)	≤ 0.5 g/10 min
Melt mass flow rate (pipe)	30% maximum difference compared to granules from the same batch
Resistance to internal pressure	No failure during the testing period
General	Determine the dimensions according to ISO 3126
Dimensions, wall thicknesses	See the tables in DIN
Texture	Inner and outer surface smooth, clean, free of grooves, bubbles, and other inhomogeneities; no visible impurities; minor color deviations allowable; pipe ends must be perpendicular to the axis
Opacity	PP pipes designated as opaque must not transmit more than 0.2% visible light when tested on the basis of ISO 7686
Circulation and return material	Use of recycled material from the production and testing of products according to this standard allowed, return material and recyclates prohibited (see 15874-1, 5.3)

Source: Own illustration according to DIN EN 15874-2.

Table 16. Typical requirements for plastic piping systems for gas supply made of PE, with special consideration of the requirements for recyclates and recycled materials, drawn from DIN EN 1555-2.

DIN EN 1555-2

Plastic piping systems for the supply of gas – PE

Feature	Requirement
Longitudinal shrinkage (wall thickness ≤ 16 mm)	≤ 3%, original condition must be preserved
Melt mass flow rate (MFR)	After processing, deviation from the lot measured for the production of the pipe must not exceed (+/-) 20%
Oxidation–induction time (thermal stability)	≥ 20 min
Target level internal pressure behavior at 20 °C, 100 h	No failure during the test period
Target level internal pressure behavior at 80 °C, 165 h	No failure during the test period
Target level internal pressure behavior at 80 °C, 1000 h	No failure during the test period
Elongation at break	≥ 350%
Resistance to slow crack growth PE 80 and 100 e ≤ 5mm (cone test)	≤ 10 mm/day
Resistance to slow crack growth PE 80 and 100 e > 5mm (test of notched pipes)	No failure during the test period
Resistance to slow crack growth PE 100-RC	< G(p) >> 50 Mpa
Strain-hardening test (pressed sheet made from the regrinding of pipes)	No failure during the test period
Resistance to slow crack growth PE 100-RC	≥ 1.5 x 10(^6)
(accelerated test of notched pipes)	Cycles
110 mm	pc ≥ 1.5 MOP with pc = 3.6 pc, s 4 + 2.6
SDR 11	Dimensions determined according to ISO 3126
Resistance to slow crack growth PE 100-RC	See the tables in DIN
Test of a notched round bar (machined from a pipe, e > 16 mm)	Inner and outer surface smooth, clean, free of grooves, bubbles, and other

DIN EN 1555-2	
	surface defects; pipe ends must be perpendicular to the axis
110 mm	Must be black (PE 80, 100, 100-RC), yellow (PE 80), or orange (PE 100, 100-RC); in addition, black PE 80 pipes may be marked with yellow stripes and black PE 100 and 100-RC pipes with yellow and orange stripes, depending on preference; additional, specific rules for co-extruded pipes

Source: Own illustration according to DIN EN 1555-2.

Table 17. Typical requirements for plastic piping systems for buried non-pressure sewers and pipes - PVC-U, PP, PE: Requirements for manholes and accessories with shallow installation depth, taken from DIN EN 13598

DIN EN 13598	
Plastic piping systems for below-ground, non-pressurized sewerage and drainage – PVC-U, PP, PE: Requirements for manholes and accessories with shallow installation depths	
Feature	**Requirement**
Material properties	Must comply with the requirements of EN 1401-1, EN 12666-1, EN 13476-1, EN 13476-3 and EN 14758
Appearance	Smooth, clean, free from grooves, bubbles, impurities, pores, and irregularities; insertion ends must be cleanly cut and the ends of the pipes and fittings must be perpendicular to their axis
Color	In the case of production in layers, the coloration of the inner and outer layers must be uniform throughout, with the outer layer preferably black, orange-brown, or dusty gray; other shades permissible
General	Dimensions determined according to ISO 3126; for details, see the table in the DIN standard
Dimensions	See the table in DIN EN 13598
Rigidity of the riser pipe (installation depth ≤ 1.25 m)	No crack or break, stiffness ≥ 0.7 kN/m²
Stiffness of the riser pipe (installation depth > 1.25 m and ≤ 2.0 m)	No crack or break, stiffness ≥ 2.0 kN/m²
Resistance to negative pressure	No damage to the inspection chamber, leading to restricted serviceability
Resistance to vertical load	Horizontal deformation of no more than 6%, no crack or break, deformation of the cover must comply with EN 1253-2
Physical properties	Physical properties of the injection molded accessories must comply with: EN 1401-1, EN 1852-1, EN 12666-1, EN 13476-1, EN 13476-3, or EN 14758-1
Circulating material made of products complying with this standard	Possible without additional applications

Source: Own illustration corresponding to DIN EN 13598.

Table 18. Typical requirements for plastic piping systems for below-ground non-pressurized sewers and pipes - PVC-U, PP, PE: Requirements for manholes and accessories with shallow installation depths with special consideration of the requirements for recyclates and recycled materials, taken from DIN EN 13598

DIN EN 13598	
Plastics piping systems for buried non-pressure sewerage and drainage – PVC-U, PP, PE: Requirements for manholes and accessories with shallow installation depths	
PE	
Minimum features of the agreed specifications	
Feature	**Requirement**
Density	To be agreed with suppliers
Thermal stability (OIT)	To be agreed with suppliers
Melt flow rate MFR	To be agreed with suppliers
Ash residue	To be agreed with suppliers
Foreign polymers	To be agreed with suppliers
Impurities	To be agreed with suppliers
Types of pigments/additives	To be agreed with suppliers
Volatile components	**≤ 300 mg/kg**
Properties of materials that are not virgin materials	
Rotational molding	
Feature	**Requirement**
Max. deviation from the specified value in [kg/m³].	(+/-) 25
Max. deviation from the specified value in [min]	≥ 10
Max. deviation from the specified value	Not applicable
Max. deviation from the specified value in [g/10 min]	Y > 1.5: +20 %
Max. deviation from the specified value in [%]	Y ≤ 1.5: +0,3
Injection molding	
Values identical to rotational molding	

DIN EN 13598

PP

Minimum properties of the agreed specifications	
Feature	**Requirement**
Density	To be agreed with suppliers
Thermal stability (OIT)	To be agreed with suppliers
Melt flow rate MFR	To be agreed with suppliers
Ash residue	To be agreed with suppliers
Foreign polymers	To be agreed with suppliers
Impurities	To be agreed with suppliers
Type of pigments/additives	To be agreed with suppliers

Properties of materials that are not virgin materials

Injection molding	
Feature	**Requirement**
Max. deviation from the specified value in [kg/m³].	(+/-) 25
Max. deviation from specified value in [min].	≥ 8
Max. deviation from the specified value	Not applicable
Max. deviation from the specified value in [g/10 min]	Y > 1.5: +20 % Y ≤ 1.5: +0.3
Max. deviation from the specified value in [%]	(+) 10% of the specified value

Injection molding

Values identical with rotational molding

PVC-U

Minimum features of the agreed specifications	
Feature	**Requirement**
PVC-U content or filler content according to ash residue	To be agreed with suppliers
Density	To be agreed with suppliers

DIN EN 13598	
Victat softening temperature	To be agreed with suppliers
Grain size	Test procedures to be agreed and formalized (e.g. EN 15346) with suppliers
Impurity	Test procedures to be agreed and formalized (e.g., EN 15346) with suppliers
Origin of the material	PVC-U products
Properties of materials that are not virgin materials	
Injection molding	
Feature	**Requirement**
Max. deviation from the specified value in [kg/m³].	(+/-) 25
Max. deviation from specified value in [min].	NA
Max. deviation from the specified value	(+/-) 3
Max. deviation from the specified value in [g/10 min]	Not applicable
Max. deviation from the specified value in [%]	(+) 10% of the specified value of the specified value

Source: Own illustration according to DIN EN 13598.

For the production of drinking water pipes, the current standards do not currently permit the use of any recycled material or recyclates. In concrete terms, this is specified in the following standards: DIN EN ISO 15874 (for plastic piping systems for hot and cold water installations made of PP); DIN EN ISO 15876 (for plastic piping systems for hot and cold water installations made of PB); DIN EN ISO 15877 (for plastic piping systems for hot and cold water installations made of PVC-C); and DIN EN ISO 22391 (plastic piping systems for hot and cold water installations made of PE). According to experts, this is due to the problematic technical issues that arise from the fact that drinking water pipes are subject to pressure. Other mechanical properties (e.g., MFR or impact strength), like geometric and color properties, are far easier to influence and therefore do not constitute directly limiting factors.

The potential use of recyclates in the pipe sector also depends especially on the type of plastic used. The use of recyclates is therefore easier with PVC-U pipes than PP- or PE-based piping systems. This is primarily due to the fact that in the production of PVC-U pipes, subsequent stabilization is relatively easy to carry out and is also the reason why, as can be seen in the above tables, other PVC-U starting products can also be considered for a corresponding recyclate, whereas in the case of PP and PE, according to DIN EN 1519-1 and DIN 1852-1, only return material and recyclates from pipes and fittings can be used.

Whereas DIN EN 1401 already contains a specification for the maximum use of recycled material and recyclates (max. 20%) for non-pressurized, below-ground wastewater pipes made of PVC-U, the corresponding standards for such pipes made of PP and PE are currently being revised and will subsequently also indicate specifications within a similar range. At the same time, however, it should be noted that a recyclate content of 20% can already be considered high. Although a recyclate content at this order of magnitude would be feasible from a technical point of view, it generally fails due to the lack of availability of recyclates of corresponding quality. The technical feasibility of a higher recyclate content without quality losses in pipes is currently being tested on an industrial scale, but mass production is not possible at present because the supply of recyclates is simply too low (Winkler 2020).

In addition, manufacturers often do not distinguish between wastewater pipes (for which lower quality requirements obtain, and for which the use of recyclates would in principle be possible) and pipes with higher quality requirements (for which the use of recyclates is excluded). For instance, wastewater pipes are often made of the same plastic material as pressure-retaining ones, although this material would in fact be suitable for much higher-quality applications. The reason for this is that it is not economically viable for manufacturers to commence a second, dedicated production line. The reasons for this are listed below by way of highlights:

- Second recipe
- Additional silos for storage of the second material
- Additional goods receiving point for the recyclate
- In-house monitoring, as well as quality inspection of the recyclate
- Fundamental change of operation
- Use of higher-priced material is thus more cost-effective overall

5.3.3.1 Assessments of the Plastic Pipe Association on the use of recycled material in pipes

In the context of piping systems, old pipes have been collected and recycled since 1994 by the manufacturers represented by the German Plastic Pipe Industry Association (KRV), with the recyclates obtained subsequently being primarily used in wastewater, cable protection, and drainage pipes. According to the trade association, the amount of scrap currently recycled in the pipes sector is estimated to be around 40,000 tons (as of 2018). The fact that there is still great potential for increasing the use of secondary plastics in the area of piping systems becomes clear when one considers the KRV's goal for the coming years, according to which the volume of recyclates used in the manufacture of piping systems is to be doubled (target: 82,000 t of recycled scrap) (KRV Impulse 2019).

A higher amount of secondary plastics used in the area of piping systems is not considered feasible currently due to various factors that limit the use of recyclates. According to the KRV, these include:

- The fluctuating/insufficient quality of recyclates
- Their inconsistent availability
- Price differences between laboriously- and expensively-produced recyclates and inexpensive virgin materials
- Insufficient mechanical properties (especially strength)
- Customer requirements concerning the color of the products to be manufactured
- Negative odor properties in manufactured products

- Disadvantages in production (e.g., higher machine wear, lower production speed)
- Continually increasing quality requirements from customers and regulators (KRV n.d.)

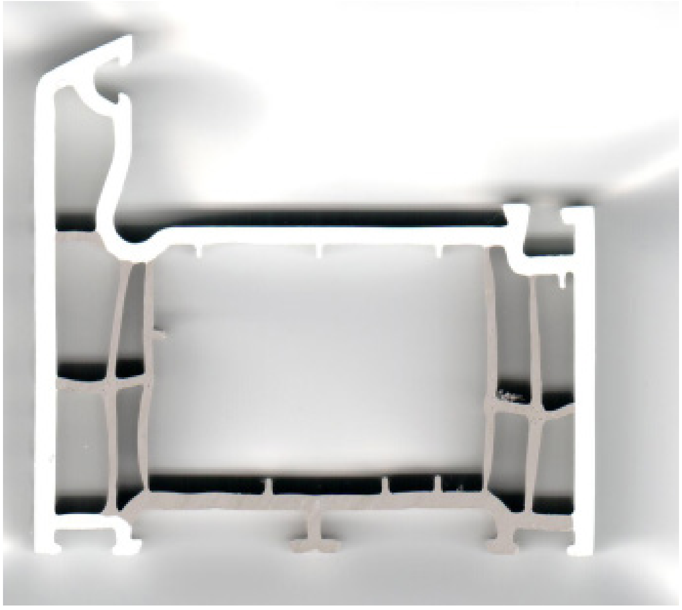
The KRV cites the fulfillment of the technical, regulatory and political framework conditions as being an indispensable prerequisite to achieving this goal. From its point of view, the recycling of plastic materials must not be made more difficult or prevented by European chemical policy (see REACH). A blanket ban on the use of certain chemicals is also considered unhelpful.

5.3.4 Use of recycled material for the production of window profiles

In the area of profiles, a well-functioning material cycle has already been established, especially for window profiles. Old windows and offcuts are collected by manufacturers, in collaboration with the Rewindo window recycling system, and then first shredded in reprocessing plants, then cleaned, sorted by color, and separated into the constituent materials. Care must be taken here, for example in separating the sealing lip of old windows, which consists of PVC-P, from the profiles, which consist of PVC-U, as otherwise there will be an undesirable change in the recyclate's color (Martens and Goldmann 2016). At the same time, all components of existing rubber seals must be fully separated, as these would not melt during extrusion and could cause undesirable defects in the surface finish. Subsequently, the PVC is regranulated by means of melt filtration and can be used again as plastic granulate for the production of recycled profiles. Depending on the current market situation and general conditions, the original waste owner can also has the opportunity to generate revenues here (Holzmann Medien GmbH & Co. KG and GFF 2013; Martens and Goldmann 2016).

Around 10% of the plastic used for window profile production in Europe, and about 18% in Germany, consists of recyclate (EPPA 2018). Different values are reported in the literature regarding the maximum recycled content. The average, maximum recycled content in window profiles is often given as 50%, although this is limited by production technology, as only the profile core – but not the outer wall – consists of recycled material (see also Figure 23) (EPPA 2018). A value of 70% is assumed to be the upper limit for recyclate content, which can be achieved without discoloration of the outer wall if the recyclate is also extruded into the outer layer of the profiles. However, by introducing recyclate into the outer layer, the virgin material layer becomes thinner, whereas the wall thickness remains the same, increasing the risk of revealing the differently colored recyclate layers (such as when removing the weld bead). There are no qualitative differences between windows made exclusively from virgin material and those with a high recycled material content (EPPA 2018).

Figure 23. Window profile system with recycled content due to the incorporation of recycled material into the profile core



Source: EPPA (2018).

A further increase in the proportion of recycled material, to the point where it would be possible to produce window profiles exclusively from recycled material, is not currently economically-feasible. The reason for this is that the development and application of technologies that would enable the generation of correspondingly high-quality recyclate would be highly complex and cost-intensive. The recyclate produced would also be so expensive that its use would cease to be economical (Frömmig 2019). Due to the high requirements regarding weathering and UV stability, the DIN EN 12608 standard for plastic window profiles also excludes the use of recyclates for their outer walls (EPPA 2018).

As with piping systems, the increased use of recycled materials for the manufacturing of window profiles is limited not only by technical and design considerations but also by the availability of recycled materials. For instance, the quantities of used window recyclate currently available are in some cases insufficient to achieve recyclate percentages of over 60% (as promoted in some municipal programs) (EPPA 2018). In this regard, an increase in the amount of recycled material in the coming years is also seen from a critical viewpoint. The reason for this is, amongst other things, that constant technical developments entail the increased use of composite materials (e.g., glass fiber-reinforced plastics or aluminum parts are increasingly being incorporated into profile cores to increase stability, especially in the case of large-area window frames), which in some cases significantly increases the amount of material that must be separated during the processing of old windows (GFF, 2013).

5.3.5 Use of recycled material in the manufacturing of insulation materials

In principle, production and offcut waste can be reused in the manufacturing of insulation materials from EPS. The waste material is collected for this purpose and transported to the EPS manufacturer. After a visual quality inspection, as well as a flame retardation quickest, the material is shredded, separated according to grading curves and further processed in the EPS plant. More details on the rapid flame retardant test are provided in Chapter 4. Possible recycling products include plaster aggregates, loose bulk thermal insulation in double-shell masonry, aggregates in lightweight concrete or screed, or recycled beads for use as filling material for beanbags (Rigid Foam Industry Association e.V. (IVH) 2020).

EPS construction waste collected and slightly mixed with plaster, adhesives, and sand can also be freed from coarse impurities, ground in a mill, dedusted, and finally processed into EPS granulate. In EPS-foaming machines, the granulate can then be processed into EPS boards, which can in turn be used as drainage boards for perimeter or floor insulation (a total recycled content of 100% is possible in this context). The production of insulation boards in the usual facade quality is not yet technically possible (Albrecht and Schwitalla 2015).

For both ecological and economic reasons, a take-back system such as that which exists for window production is not yet feasible for insulation materials, as the quantities of recycled material currently produced are too small. However, as these quantities are expected to grow significantly in the future, as is outlined in the first part of this study and in the technical literature, a corresponding system is currently being developed. Against this background, a process for raw material recycling has also been under development for a number of years for insulating materials made of plastics, which has the advantage of purifying the material at the molecular level and removing quality-reducing impurities, while retaining the same polymer properties. In addition, a first industrial plant is currently being built in the Netherlands as part of the PolyStyreneLoop initiative, which will be able to recover basic polystyrene material or even bromine from existing flame retardants using the CreaSolv process from EPS waste generated during conversion or demolition work (Albrecht and Schwitalla 2015; Rigid Foam Industry Association e.V. (IVH) 2020).

5.3.6 Use of recycled material in other building products

The examples of the uses of plastic recyclates in the field of other building products are fairly diverse. Based on research presented in the catalogs of dealers and manufacturers, the following products can be noted by way of example:

- Cable ducts
- Sanitary supplies (e.g., odor traps)
- Panels (e.g., drainage or construction panels)
- Fence elements
- Amphibious protection elements
- Pallets
- Construction films
- Spacers
- Noise protection elements/walls
- Roadway protection elements
- Beacon bases
- Delineator bases
- Guide cones

- Containers and tanks
- Raised beds
- Palisades
- Grass stop plates
- Grass pavers
- Garbage cans
- Mats (e.g., maintenance path mats on flat roofs or fall protection mats)
- Railroad crossings
- Public furniture, such as park benches

As can be seen from these examples, the areas of application for construction products made of plastic, in the manufacture of which recyclates are used in whole or in part, are highly diverse. It can be seen that road construction, as well as gardening and landscaping, offer good opportunities for the use of recyclates, even though demand for these products is comparatively low.

In addition, some of the products considered for recyclate use are construction products that do not require proof of usability in compliance with Part D of the Model Administrative Regulation on Technical Construction Provisions (MVVTB), and which have no recognized technical rules. For such products, it can be assumed that the increased use of recycled materials is relatively easy to implement. Construction products made of plastic for which, according to Part D of the MVVTB, no specified use is required and for which no generally recognized rules of technology exist (German Institute for Structural Engineering (DIBt) 2017), include the following:

- Drainage elements
- Shuttering panels and bodies
- Slatted floors
- Products for sealing joints (e.g., sealing tapes)
- Edge insulation strips for screeds
- Supports and skirts for bathtubs
- Mobile partition walls
- Unpressurized containers

One advantage of the above-mentioned construction products is that they are generally produced in much smaller quantities than, for example, pipes or profiles. The problem of the insufficient availability of suitable recyclates, as is frequently mentioned in the area of piping systems or profiles, is therefore much less of an issue for these products, if at all. As the quality requirements for these products are often comparatively low, it can be assumed that the problem of inefficiency due to excessively expensive recycling processes does not apply here. Overall, this means that they are especially suitable for the increased use of recyclates.

As engineering plastics are also used in the construction sector, the recycling and use of recycled plastics can also offer potential for new product cycles. Products made of acrylonitrile copolymers (Table 19), polyamides (Table 20), polycarbonate, and polymethyl methacrylate (Table 21), including their construction standards, have therefore been compiled as examples. The total quantity of these engineering plastics used annually is estimated to be about 200 kt (see also Figure 8).

Table 19. Construction products from acrylonitrile copolymers incl. standards

Construction product	Norm
Skylight domes made of styrene-acrylonitrile copolymer (SAN)	List EAD; DIN EN 1873
Skylight domes made of acrylonitrile-butadiene-styrene copolymer (ABS)	List EAD; DIN EN 1873
Roof light band made of styrene-acrylonitrile copolymer (SAN)	List EAD; DIN EN 14963
Roof light band made of acrylonitrile-butadiene-styrene copolymer (ABS)	List EAD; DIN EN 14963
Piping systems (non-flexible) made of acrylonitrile-butadiene-styrene (ABS)	MuVe_TeBau; DIN EN 1455
Piping systems (non-flexible) made of styrene copolymer blends (SAN+PVC-U)	MuVe_TeBau; DIN EN 1565
Cisterns made of acrylonitrile-butadiene-styrene copolymers (ABS)	List EAD; DIN EN 14055

Source: Own illustration, SKZ KFE gGmbH.

Table 20. Polyamide construction products incl. standards

Construction products	Norm
Sports flooring (outdoor) made of polyamide (PA) (interspersing of EPDM/SBR granules possible)	List EAD; DIN EN 14904
Textile floor covering made of polyamide (PA)	List EAD; MuVe_TeBau; DIN EN 14041
Textile flooring made of a composite of polyamide, polypropylene, and/or polyethylene terephthalate (PA, PP, PET)	List EAD; MuVe_TeBau; DIN EN 14041
Cable insulation/sheathing made of polyamide (PA)	List EAD; DIN EN 50575; Harmonization regulation 2014/35/EU
Window profiles made of polyamide (PA)	List EAD; MuVe_TeBau; DIN EN 14351; DIN EN 16034; DIN 18056
Fittings made of polyamide (PA)	List EAD; DIN EN 14846; DIN EN 179; DIN EN 1125; DIN EN 1154; DIN EN 1155; DIN EN 1158
Foils made of polyamide (PA)	Own research
Nets made of polyamide (PA)	Own research
Stationary tanks made of polyamide (PA)	List EAD; DIN EN 13341
Piping systems (flexible) made of polyamide (PA)	In-house research (flexible, as it is subdivided in this way in the list of goods)
Plastic dowels made of polyamide (PA)	MuVe_TeBau; ETAG 020;
Screw fittings made of polyamide (PA)	Own research; List HEN, reference number: 180022-00-0704

Source: Own illustration.

Table 21. Construction products made of polycarbonate or polymethyl methacrylate incl. standards

Construction product	Norm
Liquid plastic sealants made of polymethyl methacrylate (PMMA)	MuVe_TeBau; only requires general building inspection certificate according to § 19, para. 1, sentence 2 MBO
Sockets and switches made of polycarbonate (PC)	MuVe_TeBau; does not require usability certificate according to § 17, para. 3 MBO
Fire alarm systems made of polycarbonate (PC)	List EAD; MuVe_TeBau; DIN EN 54
Smoke detectors made of polycarbonate (PC)	List EAD; MuVe_TeBau; DIN EN 14604; DIN EN 54-7
Traffic control systems made of polycarbonate (PC)	List EAD; DIN EN 12352
Polymethyl methacrylate (PMMA) skylight domes	List EAD; DIN EN 1873
Polycarbonate (PC) skylight domes	List EAD; DIN EN 1873
Polycarbonate (PC) skylight strip	List EAD; DIN EN 14963
Roof light band made of polymethyl methacrylate (PMMA)	List EAD; DIN EN 14963
Plastic sheets made of polycarbonate (PC)	List EAD; DIN EN 1013; DIN EN 13830; DIN EN 14428
Plastic sheets made of polymethyl methacrylate (PMMA)	List EAD; DIN EN 1013; DIN EN 13830; DIN EN 14428
Cable ducts made of polycarbonate (PC)	Own research
Bath tubs made of polymethyl methacrylate (PMMA)	List EAD; DIN EN 14516; DIN EN 12764
Shower trays made of polymethyl methacrylate (PMMA)	List EAD; DIN EN 14527; DIN EN 12764

Source: Own illustration.

In the corresponding standards for the products listed in the above tables (Table 19–Table 21), information on the use of secondary material is only provided for the ABS or SAN and PVC-U pipe systems. DIN 1455 (ABS pipe systems) permits the use of recycled material, but waste before or after use cannot be processed. The situation is similar in the withdrawn standard 1565 (pipe systems SAN and PVC-U). Under this precept, the use of recycled material is also permitted, but return material or recyclates may not be processed.

For all of the other products made of engineering plastics listed here, no information is given regarding the use of secondary material, which is why there is nothing that prevents the use of recycled material from a normative point of view. Whether this is in fact feasible in practice must, of course, be checked for each product on a case-by-case basis.

5.4 Product labeling for the circular economy in the construction industry

As things currently stand, manufacturers are not required to specify recycled content or the recyclability of a product. However, as was already stated above, the European Construction Products Regulation (European Commission 2011c) requires environmentally-compatible raw materials and secondary building materials to be used in construction.

Information on the use of recycled materials in construction products and their recyclability is an important sustainability criterion in the procurement of construction products. These aspects may become especially relevant in the future, for instance in the context of sustainable construction in accordance with DIN EN 15643 (CEN 2010). Based on this European standard, a number of systems for assessing the sustainability of buildings have now become established. In Germany, the Sustainable Building Rating System (BNB) of the Federal Ministry of the Interior, Building and Community, is used in the public sector, and the system of the German Sustainable Building Council in particular is used in the private sector. By clearly and prominently indicating the recycled content and recyclability, these systems can be employed in the future to promote the use of secondary plastics by giving them good ratings.

With the goal of creating more transparency in value chains and with respect to builders, the following section describes which additional information should be provided on the recycled content and the recyclability of building products, and which means of communication are suitable for this purpose.

Recycled content

According to DIN EN 15343, the recycled content must be stated as the mass fraction [%] in the produced component, which is calculated using the following formula:

$$\text{Percentage of recyclate in the product} = \frac{\text{Mass of recyclate in the product x 100}}{\text{Total mass of the product}}$$

According to the standard, only production and utility waste should be included in the calculation of the product's recycled content. Material recovered during the same production process in which it was generated must not be included in the recycled content. In this context, ISO 14021 explicitly indicates that this means that there is no actual recycling process, but that by-products and waste can still be generated in the course of manufacturing. Such by-products and waste must therefore be taken into account when determining the mass of recycled material included in the equation for calculating the recyclate content.

Recyclability

For the evaluation of recyclability, the following criteria, amongst other considerations, are relevant according to the construction guidelines "Recycling" of the Federal Ministry of the Interior, Building and Community and the Federal Ministry of Defense (BMI and BMVg 2018):

- Material composition (mono- or multilayer materials)
- Resistance to weathering (water absorption, frost)
- Resistance to impact stresses
- Purity (color, odor, foreign substances)

- Pollutants (whether pollutants are already released with the building material itself, via use, or by environmental influences)
- Separability (the more purely sorted materials can be separated, the greater the chance of being able to reuse them).
- Utilization (direct recycling, energy recovery, material recycling, landfill, or hazardous waste)

Manufacturers are faced with the complex challenge of evaluating the various criteria and drawing meaningful conclusions from them for an overall result in terms of recyclability, which is already possible using standardized tools and can also be certified. Current developments are still limited to the packaging sector. Examples include:

- RecyClass: recyclability of packaging using a specific formula, in accordance with European standards
- CHIRA – CHI Recyclability Assessment: A software tool for assessing the recyclability of packaging, under development by the Cyclos-HTP institute

It is highly likely that such possibilities will also emerge and find application for products from the construction sector. In addition to the use of such calculation tools or certifications, or through their own explanations of the afore-mentioned criteria, manufacturers should indicate whether take-back systems such as those described in Chapter 3 exist for their specific products.

Declarations of performance and technical datasheets

Suitable communication tools for the recycled content and recyclability of products identified include manufacturers' performance declarations and technical datasheets and environmental product declarations. In the following, the background and content of these will be briefly explained and the places in which the product labels in question can be placed indicated.

Declarations of performance

The European Construction Products Regulation (European Commission 2011c) stipulates that manufacturers of products bearing a CE marking, and for which harmonized technical specifications already exist, must draw up so-called 'declarations of performance.' Thereby, manufacturers guarantee the properties of the specified construction products. The form and content of the declarations of performance are regulated in Annex III of BauPVO, and are presented in Table 22.

Table 22. Contents of a declaration on performance according to Article 4 of the Construction Products Regulation

Nr.	Contents of the declaration of performance
0	Declaration of performance no.
1	Identification code of the product type
2	Identification of the construction product, e.g., by type, batch or serial number
3	Intended use
4	Trade name

Nr.	Contents of the declaration of performance
5	Contact address of the authorized representative
6	System for assessing and verifying the constancy of performance
7	Indicated body and certificate of conformity
8	Declaration of performance with regard to the European Technical Assessment
9	Declared performance, e.g., essential characteristics / properties / performance / harmonized technical specifications
10	The performance of the product according to points 1 and 2 corresponds to the declared performance in accordance with point 9. The sole entity responsible for drawing up this declaration of performance is the manufacturer, as per point 4. Signed for and on behalf of the manufacturer by: (Name and function): (Place and date of issue) (signature)

Source: Bachl (2019); European Commission (2011b).

Technical data sheets

In technical data sheets, manufacturers outline the properties and possible applications of their products. In contrast to declarations of performance, data sheets are available for all technical construction products and therefore have a broader applicability. For the construction product categories of piping systems, insulation materials, profiles, and floor coverings, the following common specifications (Table 23) were identified among the technical data sheets:

Table 23. Contents of a technical data sheet

Nr.	Contents of the technical data sheet
1	Product type
2	Product description with scope
3	General or construction (with material specified)
4	Properties
5	Technical data
6	Thickness
7	Manufacturer and contact Manufacturer
8	Status / publication of the data sheet
9	Other: Certificates and labels, CE marking

Due to the ever-increasing relevance of the topic, it is advisable to add a separate supplementary section to both the declarations of performance and technical data sheets with the heading “Recycling” or “Sustainable use of natural resources.” Inclusion in other categories runs the risk of this information being lost. Table 24 displays what information could be provided in this section.

Table 24. Possible additional section, "Sustainable use of natural resources," in the declaration of performance and technical data sheets

Nr.	Aspect of sustainable use	Information
1	Percentage of recycled material	Calculation: mass of recyclate/product mass [%]
2	Source of the recyclate	E.g., production waste, commercial waste, used waste, post-consumer waste
3	Circulation, recycling	Reference to existing take-back systems and recycling processes
4	Recyclability	Indications of recyclability: ▪ Based on the result of a design-for-recycling tool (name the tool used) ▪ With reference to certified recyclability ▪ Through specific information on the basis of own tests/practical experience

Source: Own illustration, SKZ KFE gGmbH.

Environmental product declarations

In the context of sustainable construction as per DIN EN 15643 (CEN, 2010), environmental product declarations (EPDs) in accordance with DIN EN ISO 14025 and DIN EN 15804+A2 are the relevant documents for communicating the environmental performance of construction products. A large number of construction product manufacturers therefore publish EPDs via so-called program holders, such as the Institute for Construction and Environment e.V., which contain, in particular, life cycle assessment (LCA) results for holistic sustainability assessments at the building level. Currently, in EPD Chapter 5, in the section "Results of LCA Resource Use," the quantity of secondary raw material used for the construction products in question is non-specifically stated. More precise information on the type and origin of the secondary raw materials is lacking though. However, in EPDs, construction product manufacturers also have the option of placing further information they wish to communicate to their customers in the EPD in Section 2, "Product." As the EPD continues to gain in importance as a means of communicating the sustainability of building products, it is recommended that the information proposed in Table 24 be added as well.

As of 2022, circularity modules will be added to EPDs in accordance with DIN EN 15804 + A2. This will be performed with the goal of providing realistic and comparable LCA data for the product's end-of-life of and the building balance. In a sense, these constitute data on recyclability. The Circularity Modules (CMEPD) bundle contain all relevant end-of-life data for a product in a standardized format that fits the established EPD methodology. CMEPDs are created on the basis of data from recycling and disposal companies and designed to provide concrete information on the recycling of specific product groups and material types. In this manner, CMEPDs enable recycling-friendly planning and the realization of construction projects, as well as their complete ecological assessment.

5.5 Summary and recommendations

In this chapter, the potential uses of recyclates in plastic construction products were outlined. For this purpose, the accumulation of plastic waste was first examined with respect to its quality and quantities. Then, general prerequisites and basic requirements for the use of recyclates in the manufacturing of building products were examined in detail. Based on this, an assessment was made of the potential use of recyclates in the four major application areas of *pipes*, *profiles*, *insulation materials*, and *others*. Finally, it was shown how the labeling of recycled content and the recyclability of plastic building products can be implemented in the communication media of *declarations of performance*, *technical data sheets*, and *environmental product declarations*.

The quality of plastic recyclates is largely determined by the quality of the secondary raw materials used. For instance, grade purity, the reduction of impurities and impurities, and the integrity of the polymer chains, are important parameters for assessing input quality. In addition, taking design-for-recycling precepts into account during product development favors the product recycling and creates a good starting point for the production of high-quality recyclates. In principle, it can be assumed that plastic waste from the post-industrial sector can be classified as being of higher quality than that from the post-consumer sector.

The quantitative tracking of the plastic waste generated in 2017 returned a figure of 6,154 kt, of which around 5,201 kt could be assigned to the post-consumer sector and around 953 kt to the post-industrial one. Most of this waste is still recycled for energy recovery and thus removed from the material cycle. Another aspect to be considered in this context is the current mismatching of plastic waste generated by, and raw materials required in, the construction sector. The figures presented in this chapter indicate an imbalance of existing waste and the required grades or types of plastics in the construction sector for different materials. One way to remedy this is, for instance, to use plastic waste from other sectors, such as the packaging industry. But here, too, a fundamental mismatch arises between the available and required grades.

Furthermore, the wisdom of raw material transfer between different material and product cycles against the background of necessary additive use, as well as the maintenance of volumes in the respective system, must be questioned. In principle, the aim should be to achieve a genuine and closed-loop system. Ideally, this would mean using take-back systems to keep the respective material and product cycles closed, as is already functioning well for PVC. The PVC recycling loop leads to relatively high construction industry-specific recyclate use rates, even if demand cannot be fully met yet. The supply of qualitatively-suitable recyclates must therefore be increased in accordance with the specific demand, and this should also be sought for other types of plastic.

Another factor that has been examined in detail in this chapter is the preconditions for the use of recyclates in the manufacturing of construction products. On the one hand, products manufactured from recyclates must meet the basic requirements of the European Construction Products Regulation, which are laid down in certain harmonized specifications; on the other, building and customer requirements must be met. At the same time, the BauPVO requires the sustainable use of natural resources. In concrete terms, this means that the structural or building materials must be reused or recycled following demolition. Moreover, the structure must be durable and utilize environmentally-compatible raw and secondary materials in its construction. Durability, recyclability, and the use of recycled materials, are considerations that have already been taken into account, in principle, by legislators. However, normative and product-specific specification is often lacking.

Many standards already permit the use of recycled material in principle, but the use of such secondary materials is often still viewed with reluctance by manufacturers and customers. The main reasons for this are inadequate quality and quantity of recyclates, negative optical properties, small price differences between virgin and recycled materials, and the need for costly changes to be made process technologies already utilized in plants. Despite these obstacles though, a trend reversal is now emerging, albeit slowly, that will serve to facilitate the circular economy.

In the following, the recyclate use potential of the four application areas investigated is outlined.

Pipes

The variety of pipe and tube systems is large. For example, a distinction can be drawn between pressurized and non-pressurized pipes or the type of medium. Depending on the application, corresponding quality requirements must be met. These include mechanics, color, geometry, and test methods. The current standards already offer good indications as far as the use of recycled materials is concerned. In the case of pressurized pipes, the standards do not permit the use of recyclates or returned materials, whereas in the case of non-pressurized pipes, a maximum of 20% recyclate may be used. Of course, this only applies when all of the other requirements, such as those pertaining to mechanics and optics, have been adequately met. The type of plastic used also has a limiting effect on the possibilities for the use of recyclates. Subsequent stabilization of PVC is relatively easy to carry out, which is why its reuse as a recyclate is quite viable. This is more difficult in the case of polyolefins though. For this reason, the standards only allow the use of recycled materials and recyclates from pipes and pipe sections. Recyclates from non-product sources, as is the case with PVC, are not permitted. With a total of more than one million tons of the construction products examined, pipes and pipe systems represent the largest share in terms of volume. The supply of recyclates cannot currently meet demand from companies, which is why there is the potential for the use of recyclates to be further increased in this area.

Window profiles

In window profile production, recyclates make up 18% of the feedstocks currently used, and a well-functioning material cycle (Rewindo) has already been established. However, experts estimate the potential for using recyclates to be much higher, at 50–70%. There are a number of reasons why the current use of recyclates remains low. On the one hand, there are economic factors. The development and application of technologies is still highly complex and cost-intensive. The high prices for recyclates also reduce their more widespread use in window profile production. On the other hand, current standards also limit the use of recycled materials. In principle, window profiles must meet stringent requirements in terms of weathering and UV stability. Recyclates may be used in profile cores, but the corresponding standard does not permit this in outer walls. The trend towards composite systems also reduces the good recyclability of old windows. With the installation of glass fibers or aluminum parts in the profile core, separation, if viable at all, is only possible with increased effort and additional costs. As with pipes, the demand for recyclates for window profile manufacturing cannot be met by the existing supply either.

Insulation materials

Compared to pipes and window profiles, the current situation for insulation materials with respect to the use of recyclates is generally worse. Appropriate take-back systems have not yet been established, as the quantities of recycled material remain too small. However, as these are very likely to increase in the future, a take-back system is already under development. Furthermore, insulation boards with recycled content cannot yet be produced to the usual facade standard. Mechanical recycling is not optimal for insulation materials, which is why raw material processes appear more promising.

Others

The areas of application for the use of plastic recyclates in other construction products are highly diverse. Many applications in road construction, gardening, and landscaping are already well-established and viable. Products corresponding to Part D of the Model Administrative Regulation for Technical Building Regulations are also well-suited in principle, as no proof of usability must be provided here and there are no recognized r technological rules. Another advantage is that, due to the relatively small product quantities, the available recyclate quantities do not have a limiting effect, as is the case with pipes and window profiles.

To strengthen the use of recyclates in plastic building products, the following recommendations can be made:

- ► In addition to investments in technical sorting and processing equipment, it is desirable to promote the separate collection of waste already in the previous step and make stakeholders aware of this.
- ► Even if recyclates from the construction industry are still used in very small quantities at present, the goal of increasing these means that the aim should be to achieve genuine closed-loop recycling, i.e., "construction product to construction product," instead of diverting waste from other product cycles and making it usable by means of complex processing steps and additives.
- ► Comparatively high reuse rates of recyclates prevail in the cases of PVC-U and window profiles, which have been made possible by the Rewindo take-back system. For building products made from other plastics, for which an increasing volume of waste is expected in the future, similar take-back systems should be sought and their economic viability assessed.
- ► If, due to low quantities being available, waste from the construction sector cannot be used again to manufacture the same product (e.g., pipe to pipe), efforts should be made to use these materials for other construction products. Especially in the case of products that do not require proof of usability in accordance with Part D of the Model Administrative Regulation for Technical Building Regulations and for which there are no recognized rules of technology, there is still much potential for increasing the use of recycled materials.
- ► It is recommended that the recycled content and recyclability of plastic construction products be indicated in *declarations of performance* in accordance with Annex III of the European Construction Products Regulation, *technical data sheets*, and *environmental product declarations*. In order to ensure that this information is received as well as possible, an additional section entitled "The sustainable use of natural resources" (see Table 24), should be included in the documentation.

6 Plastic packaging for construction products

6.1 Introduction

The main focus of this chapter on plastic packaging for construction products is on the possibilities for avoiding and ecologically-optimizing packaging, and increasing the use of recycled materials. To this end, the following questions are clarified:

- How high is the industry-specific demand for plastic packaging, which plastics are used, and does this packaging offer the possibility for recyclate use?
- How is disposable packaging returned and recycled within construction industry-specific supply chains, and how is this packaging reused or recycled in a high-quality manner?
- What is the potential for increasing reusable solutions, the mechanical recycling of plastic packaging, or the use of recyclates therein? Which recyclates could be suitable for this?

In order to answer these questions, the scope of the study and the terms used are defined. The materials and forms packaging used for construction products are then described, and the stages of waste generation illustrated by means of a material flow diagram. The section concludes with a quantitative assessment of the amount of construction product packaging waste generated. In the next section, the potential for ecological improvement is determined and the potential volume of plastic recyclates usable in construction product packaging estimated. Finally, some recommendations for measures to increase the use of recyclates are conveyed. This study is based on research of the literature and internet, as well as interviews with experts, the results of which are presented anonymously.

6.2 Framework and definitions of terms

6.2.1.1 Definition and categorization of construction products

The scope of this chapter covers packaging for products typically sold in hardware stores and garden centers, as well as in the construction materials trade. This includes both construction products that fall under the EU Construction Products Regulation and other hardware and garden products.

However, the range of products on offer in different markets varies considerably, which is why a further restriction is made here on products used in the construction industry or in private DIY or gardening activities. Later in this study, all of these goods will be subsumed under the construction products rubric. Even this consideration still includes a large number of different products, which place a wide variety of requirements on their packaging. For this reason, related product groups are identified for further categorization based on the catalog of packaging, requiring system participation (Zentrale Stelle Verpackungsregister 2020a). This categorization is primarily based on consideration of the product's characteristics, such as the chemical composition and functionality of the packaged product (Zentrale Stelle Verpackungsregister 2019), as the product's content is the decisive factor for determining which type of packaging must be selected. The four product groups used are "08-010 Construction chemicals," "08-020 Building materials and installations," "08-030 Floor coverings," and products assigned to the category, "08-040 DIY and garden." Thus, all product groups beginning with "08-" are included in the catalog of packaging requiring system participation (Zentrale Stelle Verpackungsregister 2020a). Product group 08-020 is further divided into "building materials" and "installations," and these two groups are treated separately.

As the catalog includes both packaging requiring system participation and packaging not requiring it, this definition does not restrict the scope of consideration to private final consumption. Table 25 lists selected product examples for the categories under consideration.

Table 25. Product groups and product group numbers with examples according to the Zentrale Stelle Verpackungsregister (2020a).

Construction chemicals 08-010	Construction materials 08-020	Floor coverings 08-030	DIY and gardens 08-040
Paint colors	Sand	Laminate	Power tools
Powder coatings	Powdered building materials such as cement, lime, gypsum, and mortar	Parquet	Hand tools
Dispersion paints	Bricks and building blocks	Floorboards	Pins, nails, staples, dowels
Putty, sealing compound	Materials and panels for heat and sound insulation	Floors made of PVC, linoleum, rubber, etc.	Paint brushes, paint rollers
Wood preservatives	Decorative stones	Construction carpet	Garden and flower articles
	Installations 08-020		
	Fittings and siphons		
	Radiators and heating systems		
	Washbasins, bathtubs, shower trays		
	Tiles		
	Wooden boards		

6.2.1.2 Legal definition of the term packaging

The concept of packaging is legally defined in the Packaging Act (VerpackG), which came into effect on January 1, 2019 and transposed EU Directive 94/62/EC into German law. Packaging is defined therein as "products made of any materials for the receipt, protection, handling, delivery, or presentation of goods" (§ 3(1) of the Packaging Act). The Packaging Act distinguishes between three different types of packaging, namely: sales packaging, outer packaging, and transport packaging. The Act also introduces a differentiation between privately- and commercially-used packaging types. Distributors of packaging intended for private final consumers or comparable sources of waste must financially participate in a dual system or an industry solution that ensures the nationwide take-back of packaging (§ 7(1) of the Packaging Act), i.e., they are legally required to participate in the system. Manufacturers of packaging subject to system participation pursuant to § 7(1) of the Packaging Act must register this packaging with the Central Packaging Register (§ 9(1) of the Packaging Act).

The packaging of building products subject to participation in the system must be disposed of via yellow waste receptacles or the yellow bags provided as part of the dual system. Private end users who fall within the scope of this study are defined as those who use construction products in the domestic environment, also referred to as the DIY ('do-it-yourself') sector. Comparable sources of waste in this context derive, for instance, from craft enterprises, "whose packaging waste can be disposed of by means of standard household collection containers [...], but with a maximum of one 1100-liter emptying container per collection group, under the standard household collection frequency" (§ 3 (11) of the Packaging Act). The system participation obligation for packaging that becomes waste at so-called "comparable points of generation" is thus measured by the so-called "quantity criterion" (Central Packaging Register 2019). However, according to an expert on dual systems, this distinction entails many cases of doubt and clear allocation is not always possible.

In contrast, packaging intended for commercial end-consumption is exempt from both the system participation stipulation and the obligation to register with the central body (§ 3, Paragraph 8, in conjunction with § 7, Paragraph 1 and § 8, Paragraph 1 of the Packaging Act). Their disposal is regulated between the distributor and a private waste disposal firms. According to the assessment of experts representing two authorities, the majority of packaging volume generated by the construction industry is allocated to commercial end-use.

6.2.1.3 Technical categorization of packaging

In addition to the above-mentioned categorizations introduced by legal mandate, further technical distinctions are established in this section. On the one hand, this is important in order to classify the production, use and volume of packaging in greater detail, and on the other, this categorization enables a more differentiated consideration of recyclability and use of recyclates to be attained.

Flexible and rigid packaging products

Plastic packaging is divided into flexible and rigid groups. Flexible plastic packaging includes films as well as bags, carrier bags, and sacks. Rigid or dimensionally-stable plastic packaging encompasses hollow containers, such as bottles, cups, cans, drums, canisters, buckets, and intermediate bulk containers (IBCs), as well as other rigid packaging, such as cases, crates, pallets, packaging straps, and fasteners (Society for Packaging Market Research 2019). According to the Industrial Association of Plastic Packaging e.V., both flexible and rigid plastic packaging account for around 50% of total production volume (IK 2018).

Food- and non-food-packaging

Furthermore, a distinction can be made between food and non-food packaging. In this context, the legal requirements and approval procedures for food-contacting materials are key.

Regulation (EU) No. 10/2011 sets out the composition requirements for plastic materials intended for contact with foodstuffs. For plastic recyclates, the stricter Regulation (EU) 282/2008 applies, which only certain recycling concepts and recyclates can satisfy. The use of recyclates in food-contacting material is therefore only possible in exceptional cases. According to the GVM, around 44% of the plastic packaging produced in Germany is intended for food contact (Society for Packaging Market Research 2020).

Packaging for construction products and other consumer goods must not meet these strict requirements, which can make the use of recyclates far easier. Thus, the cascading use of discarded food packaging, which is recycled and used as non-food packaging, seems feasible.

Verpackungsfunktionen

The distinctions for packaging introduced by the Packaging Act are based on different functions (Table 26), which are in turn fulfilled by different packaging materials, some of which are listed in Table 26.

Although sales packaging is typically offered as a sales unit consisting of goods and packaging, and can thereby fulfill a number of the packaging functions listed in § 3 (1) Packaging Act (receipt, protection, handling, delivery, and presentation), e.g., enable the transport of a product from the retailer to the end-consumer, with outer packaging specified as containing a certain number of sales units that are typically offered to consumers or used to stock shelves (§ 3 (1) No. 2 Packaging Act). Transport packaging primarily assumes a protective function, as it is intended, amongst other things, to protect goods from possible damage during transportation from the manufacturer to distributor (Pfohl 2018).

Table 26. Packaging categories according to the Packaging Act, packaging functions according to Pfohl (2018), and examples of packaging materials used.

Packaging categories according to the Packaging Act	Primary functions (in parentheses: assigned functions from § 3, Para. 1 of the Packaging Act)	Packaging examples
Sales packaging	Storage and transport function (receipt, protection, delivery), use function (handling)	Bottles, buckets, bags, and boxes, which together with the product, form a sales unit
Outer packaging	Identification and information function, retail function (presentation)	Blisters, films, cardboard boxes or similar wrappings used as additional packaging around retail packages
Transport packaging	Protection function (protection)	Barrels, canisters, boxes, bags, pallets, cardboard boxes, foam trays, shrink films and similar wrappings used primarily for goods transport and storage

6.2.2 Packaging materials and plastics used for the packaging of construction products

This section outlines which packaging and associated plastic grades are of particular importance for building products. Accounting for a total of 87% of all plastic packaging, polyethylene (PE-LD; PE-HD), polypropylene, and polyethylene terephthalate are the most widely used types. Polystyrene, polyvinyl chloride, and expanded polystyrene are also common (IK 2018).

These polymers may differ in their chemical and physical properties, such as their melting points and density. However, such material differences are not always visually-apparent (Kaßmann and DIN – German Institute for Standardization e.V. 2014). This high heterogeneity already complicates the sorting process, as IR spectroscopy- and density-based sorting methods are necessary.

Sales and outer packaging

Initial indications regarding the packaging used for construction products can be found in the catalog of packaging required to participate in the system (Central Packaging Register 2020a). However, only retail packaging and outer packaging are listed in detail. Table 27 displays this list with further information. Furthermore, the most widely-used plastics are also listed, insofar as they are known.

Table 27. Packaging and application by product category according to the Central Packaging Register (2020a) and plastics typically used for this purpose (Beswick & Dunn 2002; Valpak 2013; Niaounakis 2020).

	Construction Materials	Installations	Construction Chemicals	DIY and Garden	Primary Plastics Used
Films	X	X		X	PE-LD, PE-HD, PP
Impacts	X	X	X	X	PE
Shrink wraps		X		X	PE-LD
Stretch film		X			PE-LLD
Bags	X	X	X	X	PET, BOPP, PE, nylon, other polymers, other materials
Sacks	X		X		PE-LD, PE-HD, PP
Big bags	X		X		PE-HD, PP
Blanks				X	
Padding material	X	X		X	Air cushions made of PE-LD, PE-HD, EPS
Banderoles				X	PP, OPP, PET, PE-LD, PVC, PS
Edge protection	X	X		X	
Blisters				X	PVC, PP
Hangers				X	
Holders				X	
Hanging labels				X	
Strapping				X	PP, PET
Stiffeners		X			
Wrapping sleeves	X	X		X	
Formed parts	X	X		X	
Boxes				X	PE-HD, PP,
Suitcases				X	
Dispenser				X	
Boxes				X	PE-HD, PP
Pens			X		

	Construction Materials	Installations	Construction Chemicals	DIY and Garden	Primary Plastics Used
Bottles			X		PET, PE-HD, PP. PS, PE-LD
Cans			X		PS,
Barrels			X		PE-HD
Buckets	X		X		PE-HD,
Pipes			X		PE-LD,
Hobbocks			X		
Canisters			X		HD-PE,
Hoses			X		
IBCs			X		
Cartridges			X		
Tight-head drums			X		
Closures			X		PE-LD, PP

X = Packaging material is used in this product category.

Transport packaging

The catalog of packaging requiring. system participation (Zentrale Stelle Verpackungsregister 2020a) also compiles the most important materials for use in transport packaging. Films are of particular importance in this area (Niaounakis 2020). Depending on their function, these are referred to as transport, stretch or bundling films, and are mostly used to wrap palletized goods (Central Packaging Register 2020a). Such films fully or partially cover goods or products and are typically also applied to pallets themselves. This serves to secure a load, as well as to protect it from weather conditions (Niaounakis 2020). A study by the UBA (Schüler 2020) also notes that in the construction products sector, stretch and shrink films are primarily used as pallet packaging for building materials and installations. In addition, there is strapping for the securing of loads (Niaounakis 2020). These films are typically only made of a single layer. PE-LD, PE-LLD, PE-HD, and PP polymers are mostly used here, although polymer blends in monolayer films cannot be ruled out.

In the predominantly commercial trade in building products, reusable packaging, which mostly includes pallets, is also very common and its use is described in Chapter 6.3.1.

6.2.3 Material flow diagram of the packaging used

Construction product packaging passes through several stages of the value chain, from production, through the use phase, to disposal. Quantifying industry-specific packaging demand and waste generation first requires a qualitative analysis of the processes (Figure 24).

In the first value-adding stage ("production of plastic packaging"), polymers are processed into plastic packaging materials. These polymers and packaging materials are examples of the types of packaging described in detail in the previous chapter. The import and export of empty packaging also occurs in this stage.

In the second stage (“packaging use”), the packaging is used in the manufacturing of construction products and placed on the market along with these. Imports and exports of packaged building products also take place in this stage of the value chain.

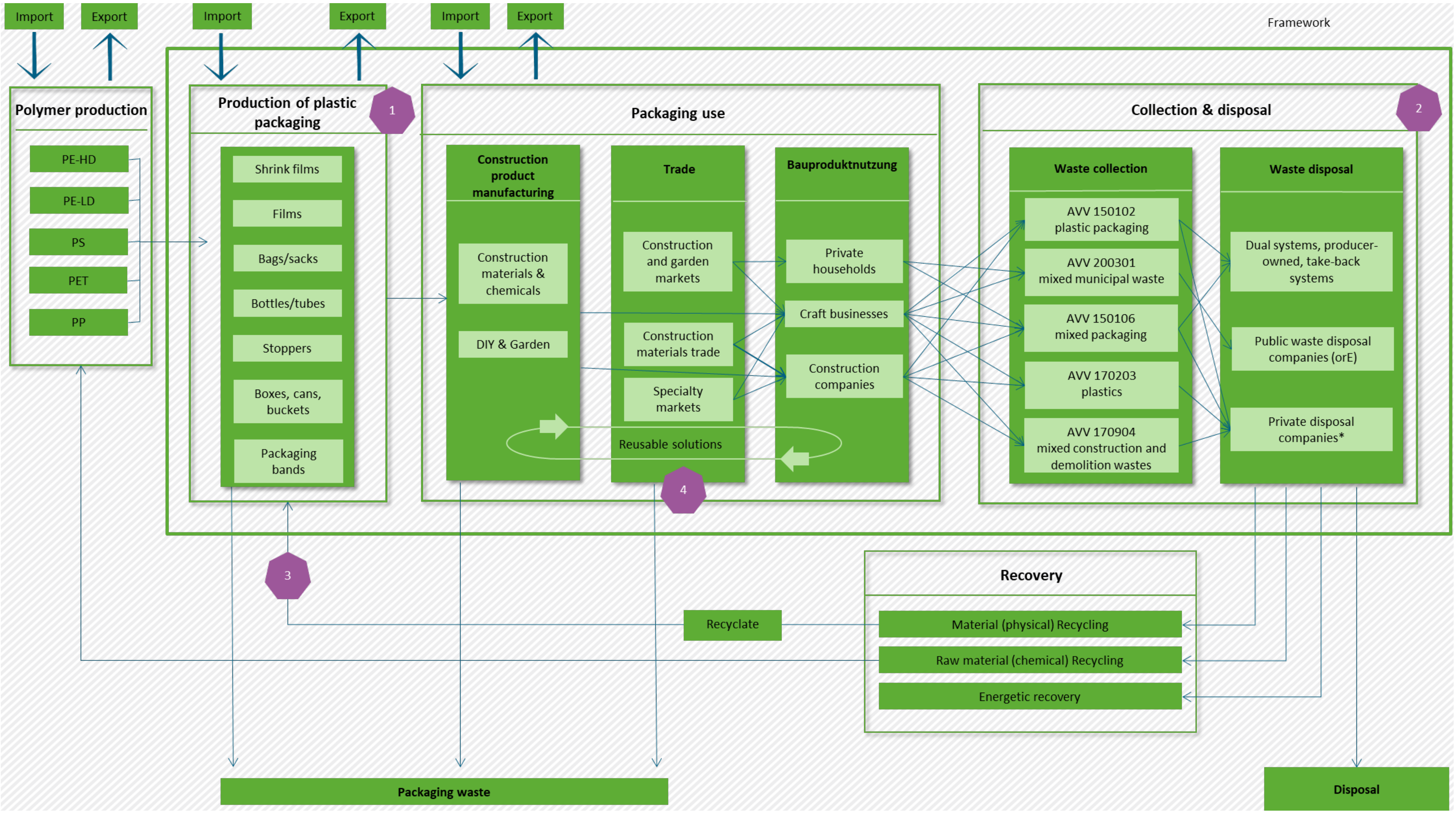
As indicated by the three vertical arrows in Figure 24 that leave the balance framework, packaging waste is already generated during the manufacturing of packaging, construction products, and trade. However, as these considerations are at the sectoral level and not attributed to the construction industry in particular, but to manufacturing or trade, these wastes are not considered in further detail in this chapter. However, the waste is sorted by type and high-quality recycling is required for economic reasons alone, and corresponds to the typical case.

The packaging waste arising from the use of construction products is differentiated according to where it arises, i.e., private end users, comparable and commercial sources (see also Chapter 6.2). This classification determines which waste codes are to be used and the disposal route at the third value-added stage of “collection and disposal.”

Packaging waste generated by private end-consumption is collected and catalogued as mixed packaging (waste code: 150106) or mixed municipal waste (waste code: 200301) in accordance with the Waste Catalogue Ordinance. Construction product packaging used by commercial end users is collected as either plastic packaging (waste code: 150102), mixed packaging (waste code: 150106), mixed construction and demolition waste (waste code: 170904), or plastic (waste code: 170203). In an interview with a private waste management company, it became clear that, in the case of commercial end users, the available space, e.g., on a construction site, is especially decisive in determining how many containers are provided for sorting collection. For high-quality recycling, it is of course advantageous if there is compliance with the requirements of the Packaging Act and packaging-specific collection systems are used.

Packaging waste from private end-users is disposed of via the dual systems. Commercial end-users commission private disposal firms. Some of the packaging waste collected in this way is recycled for materials and less frequently for raw materials, thus closing the circle of packaging and polymer production. Disposal plays only a very minor role in plastic packaging (Schüler 2020), in accordance with its position at the end of the waste hierarchy.

Figure 24. Material flow diagram of the value chain of plastic packaging types used in the packaging of construction products.



*Private disposal may only take place within the framework of the legal requirements. The transfer requirements according to § 17 KrWG must be observed. Figures (1)–(4) refer to the circular economy strategies mentioned in the text.

Source: Own representation Wuppertal Institute for Climate, Environment, and Energy.

The material flow diagram shows which circular economy strategies can be applied at which stages of the value chain in order to reduce the use of raw materials and energy, as well as the economic and ecological costs associated with waste disposal: In the production of plastic packaging and building products (1), a *waste prevention strategy* can be applied via optimized product and packaging design. The collection and disposal of packaging waste (2) can be geared towards the highest possible quality *mechanical recycling* by means of appropriate waste management. In the production of plastic packaging (3), the *use of recyclates* can be pursued, whether from sources of the same material cycle or different ones.

Reusable solutions alternate between construction product manufacturing, trade and use (4) and, figuratively speaking, enable the material cycle to be “short-circuited,” as this packaging is reused after use without assuming any waste characteristics. The stages of waste recycling, polymer production, and packaging manufacture can thus be skipped for a certain number of use cycles, which also constitutes an effective *waste prevention strategy*.

The various circular economy strategies are discussed in detail in Chapter 6.3.

6.2.4 Estimation of packaging used for construction products

In this study, the estimation of packaging generated by the plastic packaging of building products comprises three levels of consideration. These are packaging production, packaging use, and packaging consumption. The use of these terms is based on the definition by Schüler (2020) and is outlined below.

6.2.4.1 Quantification of packaging volumes at different levels

Production volume

The *production volume* of plastic packaging offers a first indication as to the amount of plastic packaging used and consumed in Germany. However, Germany has an export surplus of 28% (Conversio Market & Strategy GmbH 2018). Thus, domestic packaging use is significantly lower than domestic production. The export quantity is not differentiated according to packaging products and, for this reason, can only be applied as an average value.

Packaging input

The domestic *packaging input* describes the demand for packaging products by the manufacturers of building products in Germany (Schüler 2020). The packaging used derives from both domestic packaging production and imported empty packaging. Figures on packaging use serve as the basis for estimating the plastic packaging demand specific to the construction industry.

Packaging consumption

Packaging consumption describes the plastic packaging waste generated by construction products. This value is calculated by adjusting the quantity of construction products manufactured in Germany, including their packaging, for imports and exports. The value provides an indication of the potential input into plastic packaging recycling from construction product packaging.

In this study, packaging consumption is considered separately for private and commercial end-users.

6.2.4.2 Presentation of the available data

First, the following displays how the levels of waste generation can be calculated (Table 28). This is based on the methodology in Schüler (2020). However, as the data required for this specifically for the building products sector in particular is not available, approximations of this are made below.

Table 28. Calculation method of packaging volumes (own representation according to Schüler (2020)).

	Index	Required data in the ideal case
1	Production volume of plastic packaging for construction products	Volume of construction product packaging produced in Germany
2	Packaging used for construction products manufactured in Germany	Data from 1 Exported plastic packaging Imported plastic packaging
3	Packaging consumption for construction products used in Germany	Data from 2 Export of packaged building products Import of packaged building products
4	By commercial end-users	Data from 3 differentiated by points of generation

Production volumes

In Germany, a total of 4378 kt of plastic packaging was produced in 2017 (Conversio Market & Strategy GmbH 2018). Of this, 56%, or around 2452 kt, was accounted for by packaging for non-food use (Society for Packaging Market Research 2020). For 2018, the production figures according to the manufacturers’ association are 4461 kt (IK n.d.)

Hereinafter, the confirmed figures for 2017 will be used. These can now be further broken down by volume produced per packaging segment (Table 29).

Table 29. Production volume of non-food plastic packaging in 2017 (own illustration according to the Society for Packaging Market Research, 2020).

Upper segment	Packaging segment	Volume of non-food in kt	Sum per upper segment in kt
Bottles and stoppers	PET bottles	29	275*
	Other bottles	135	
	Stoppers	112	
Films and small containers	Cups	85	1218*
	Bags, trays, wrappers	759	
	Transport films	341	
	Plant pots	24	
Large packaging	Canisters, buckets, barrels, IBCs	200	579*
	Boxes, crates, pallets	272	
	Packaging straps	104	
Rest		361	
Total		**2452***	

* Divergent totals are due to rounding errors.

No statistical data is available regarding the packaging requirements specific to the construction industry. Thus, only estimates are possible. The authors estimate the share of the volume of non-food packaging to be 15%, which corresponds to around 370 kt for the production volume in 2017. Under the simplifying assumption of a proportional distribution across the entire non-food sector, the following distribution applies to the packaging segment:

- Bottles and stoppers: 40 kt
- Films and small containers: 180 kt
- Large packaging: 90 kt
- Rest: 50 kt

Although these data are subject to large uncertainties, they allow the order of magnitude to be estimated. At the same time, they serve to highlight the potential use of recyclates and are taken up again in Chapter 6.3.3.4.

Packaging utilization

Taking into account an export surplus of 28% (Conversio Market & Strategy GmbH 2018), around 270 kt of this production volume remains for the domestic use of plastic packaging for construction products.

Packaging material consumption

The total consumption of plastic packaging across all sectors in 2018 was 3,235.8 kt (Schüler 2020).

The annual study on the generation and recycling of packaging waste published by the Federal Environment Agency provided information on the consumption of construction product packaging in 2018 (Schüler 2020). In order to classify the results of this study, the framework it utilized is first contextualized to that selected for this study. Schüler (2020) quantified the packaging consumed by the use of construction products in Germany. This includes the used packaging materials that formerly held construction products. These originate from both domestic production and imports. All products placed on the market to any relevant degree via DIY stores, garden centers, and the building materials trade were selected as the analytical basis (Schüler 2020). For the purposes of clarity and to illustrate which products fall under this definition, three product categories were formed. These were “Building materials and construction chemicals,” “Tools, hardware, construction elements, installations,” and “Other articles of the DIY and building materials trade.” Detailed product examples are provided within these categories. Compared to the categories and products to be assigned, which were defined as the framework for consideration herein, the number of products is more extensive. For this reason, it must be assumed that packaging consumption is also correspondingly higher. Due to the lack of a detailed breakdown of the packaging consumption of each product, the results cannot be adapted to the narrower scope of this study. However, the results are instructive and it can be concluded that they indicate the consumption of plastic packaging for building products in an upwards direction.

Overall, 235.9 kt of plastic packaging was found to have been consumed in 2018. Broken down by product category, 67 kt/a is accounted for by building materials and construction chemicals, 69 kt/a by tools, hardware, construction elements, installations, and 99.9 kt/a by other items of the DIY and construction materials trade (Schüler 2020). These figures include packaging for commercial end consumption, as well as packaging from private households and comparable sources. This is not shown in differentiated form, which makes additional, more detailed allocations are impossible.

A possible validation of this calculated quantity is achieved by calculating packaging consumption based on waste volume. This is supported by the assumption that 95% of the packaging materials consumed can be found in the waste stream in the same year (Conversio, 2018). Evidence on the proportion of plastic packaging in the construction waste stream can be found in a study performed in the UK, which indicates that 26% of construction waste is comprised of packaging. Of this, 17% is attributed to plastic packaging (WRAP 2005, as cited in Envirowise, 2006). This results in 4.4% of plastic packaging waste among the total construction waste. If this is related to the 3.87 million t of mixed construction and demolition waste generated in Germany in 2017 (Destatis 2019), this yields about 170 kt of plastic packaging waste. However, this only represents the consumption of packaging on construction sites.

6.2.4.3 Results

The previous section makes it clear that the value chain’s levels must be considered in a differentiated manner. The analysis of packaging production indicted that an estimated 368 kt/a of the plastic packaging produced in Germany is used for the packaging of construction products.

The packaging use for construction products was 170 kt/a of plastic packaging, according to an estimate based on the total amount of waste. The data situation is comparatively poor, and therefore these figures are subject to a great deal of uncertainty.

The results of packaging material consumption, on the other hand, are more far-reaching and provide approximate information on the consumption of plastic packaging via construction products.

By taking into account the three levels of packaging consumption noted above, it is possible to draw conclusions regarding the amount of plastic packaging consumed through the use of construction products. The UBA study, "Generation and recycling of packaging waste," assumes for 2018 that the annual consumption amounts to around 240 kt. This was further verified through the estimation of the amount of plastic packaging waste emanating from construction sites in Germany. This amounted to 170 kt/a, but only includes the share of commercial end-users. It can be concluded from this that the difference of 70 kt/a is accounted for by private end consumption.

6.3 Ecological improvement potentials

In the previous section, an overview of the plastic packaging used for construction and DIY products was presented and quantified. This already indicates starting points for circular economy strategies (cf. Section 1.2), the potential of which for saving resources is discussed below.

The aim of this chapter is to highlight the opportunities for saving resources that currently exist for plastic packaging for construction products and show how the various stakeholders can contribute to this, amongst other things, by increasing recycling rates. In addition to the assessments from the relevant literature, practical examples are given at appropriate points in order to illustrate the applicability of the proposed measures.

First, Chapter 6.3.1 discusses approaches to waste prevention. Then, Chapter 6.3.2 outlines recyclability, separate collection and waste management as preconditions for the high-quality mechanical recycling of packaging and presents the state of relevant sorting and recycling technologies. Finally, Chapter 6.3.3 shows the potential for the use of recyclates in the production of packaging under consideration, both theoretically and via practical examples.

6.3.1 Waste avoidance and recycling

In terms of the waste hierarchy, waste avoidance is the priority measure to be pursued when dealing with waste and an important emphasis in both European and German legislation (cf. § 6 KrWG). This naturally also applies to the case of construction product packaging considered here. The ecological advantage lies in the fact that recycling (reuse systems) or dispensing with packaging minimizes the energy consumption and emissions associated with production and disposal. Waste avoidance also makes economic sense, as the environmental and disposal costs caused by packaging waste can thus be avoided.

6.3.1.1 Packaging avoidance and optimized packaging design

The simplest measure for avoiding packaging waste is to dispense with packaging altogether, which is comparatively widespread in the context of construction products. For example, some hardware stores offer various products, from small parts such as screws and nails, to simple tools, and even pipes and profiles, unpackaged. Construction lumber is also frequently sold without packaging. Transport packaging is limited to pallets and packing securing aids. Bulk building materials in the construction industry are frequently delivered unpackaged in silos, truck mixers, or dump trucks.

Optimized packaging design also offers opportunities for waste prevention. One approach to this is to reduce material masses, such as can be achieved by substituting film pouches for blister packs (Klose 2019), reducing material thicknesses (Schmidt et al. 2020), or using material-saving manufacturing or packaging techniques, such as injection stretch blow molding for the production of bottles (PackTheFuture 2016) or stretch hooding for the packaging of palletized goods (Schüttgut-Magazin 2015). Packaging material use can also be reduced by combining typical consumption quantities into larger pack sizes and reducing air gaps (Schmidt et al. 2020). Substitution by other materials, such as paper and cardboard or bio-based plastics, is another reduction approach that has been proposed (Schmidt et al. 2020), although its ecological advantage must first be proven in individual cases by means of an LCA comparison and cannot be assured. An example of this is the use of paper bags with a thin PE protective layer instead of pure plastic bags for cement packaging (Grimm 2020). A recycling-friendly packaging design and the use of plastic recyclates are further facets of ecologically-optimized packaging designs; cf. chapters 6.3.2.1 and 6.3.3.

In addition to manufacturers, retailers also have the opportunity to influence ecological packaging design, which some hardware stores are already making use of, especially in the area of private labels (Bauhaus n.d.; BaumarktManager 2019; Hornbach Holding 2019, 8; Klose 2019).

6.3.1.2 Recyclability and reuse systems

A third approach to waste prevention is the reusability of packaging. One example of packaging that can be reused by end consumers is the delivery of bulk goods in reusable big bags (FIBCs – flexible intermediate bulk containers). Reusable packaging in the narrower sense pursues the goal of reuse through systematic return and reutilization of the packaging materials. In the following, a few examples from the construction sector are given before the logistical challenges and ecological profiles of different reuse systems are discussed.

Reusable packaging in the construction sector

The classic example of reusable packaging is the pallet. According to the expert opinion of a manufacturer of plastic pallets, pallets currently used for construction products are mostly made of wood. The main factor that speaks against the use of plastic pallets is their higher costs compared to wooden ones, which weighs heavily in relation to the comparatively low prices of construction products. However, the use of plastic pallets is also feasible in principle. This corresponds to the results of research among manufacturers of plastic pallets: A wide range of possible applications are apparent, especially in combination with plastic crates (Plastic Pallets 2014). These include both the transport of construction products to building sites and the removal of waste. The advantages cited over wooden pallets include durability, high strength and load-bearing capacity, lower weight, insensitivity to weather conditions, and good cleanability and higher occupational safety (nails and wood splinters in the case of wooden pallets). Moreover, unlike wood, plastic does not absorb moisture, so on the one hand the transported products are better protected from moisture, and on the other the empty weight of the pallet is constant and can therefore be known. Due to their higher durability, plastic pallets are considered more cost-efficient, despite the higher initial costs. Some plastic pallets can also be stacked inside each other in such a way that they require less space for storage and empty transport than wooden pallets (Simplexity 2019; Marschner 2017; Jones 2018; Plastic Pallets 2014).

Plastic pallets appear to be fairly suitable for use in the construction sector due to the advantages mentioned above. However, the expert already quoted above sees the establishment of an industry- or product-specific standard pallet and of a returnable exchange system as a necessary precondition for the use of plastic pallets, which experience from other industries reflects. Whether the use of plastic pallets also makes sense from an ecological point of view requires a more detailed analysis, which cannot be fully undertaken herein. Taking the life cycle assessment into account indicates large fluctuations, depending on the pallet considered and the accounting method chosen, and strong dependency on the origin of the plastic used. For example, although plastic pallets made from primary material have a significantly higher CO_2 balance of 22–166 kg CO_2-eq than wooden ones (up to 9.9 kg CO_2-eq), this is reduced to 3.7–4.1 kg CO_2-eq through the use of secondary materials (Deviatkin u. a. 2019). This illustrates the potential for environmental-performance improvement that lies in the use of recyclates in plastic packaging for building products, which is discussed in greater detail in Chapter 6.3.3.

In addition to *flat pallets*, according to a report by the UK Waste and Resources Action Programme (WRAP) a number of other returnable packaging materials are suitable for use in the construction industry. Only plastic packaging or plastic packaging-replacing returnable packaging for other packaging materials are discussed here. Foldable *box pallets* with lids offer a high degree of product protection and are therefore especially suitable for holding sensitive construction products such as lighting and replacing single-use packaging made of cardboard, film, and wooden pallets. Reusable *big bags*, equipped with a discharge valve at the bottom, can hold fine bulk materials such as sand and used instead of paper or plastic bags or single-use big bags. Reusable wooden *cable drums* can also replace single-use cardboard or plastic drums. Small foldable or nestable *boxes* are suitable for packaging small quantities of mixed and loose products, such as fixtures, fittings and tools, and replace primary packaging made of cardboard or film (Waste and Resources Action Programme n.d.).

According to expert testimony from a plastic packaging manufacturer, trials were conducted on *plastic reusable buckets* some ten years ago, but were discontinued due to a lack of environmental-compatibility. The approach was to provide these buckets with a replaceable, single-use inlay in order to minimize the bucket contamination that was unfavorable for reuse. However, the buckets were still so heavily soiled that they ultimately had to be replaced. An expert from a construction company cited the use of *reusable tarpaulins* instead of disposable ones as another real-world example. Moreover, a reusable solution for *plant pallets* is already being offered in the hardware and garden center sector. The plastic trays are made of recycled post-consumer polypropylene and managed through a pool system. They can be fully recycled at the end of their service lives (Klose 2019).

Following this overview of reusable packaging that can be utilized in the construction sector, the following section considers the logistical challenges posed by reuse systems and various approaches to solutions for container management.

Logistical challenges and solution approaches for reuse systems

As elaborated in the literature review in Chapter 3 (Voluntary Take-Back Systems), the reverse logistics relevant to reuse systems pose unique challenges compared to forward logistics. These include more difficult forecasting, variable product quality and conditions, indeterminate locations, complex and non-transparent pricing, more complicated product life cycles and customer relationships, and more difficult negotiations between the actors involved (Hallmann and Jäger 2010). However, unlike in the business-to-consumer sector, where reusable systems face the challenge that consumers are reluctant to deal with the collection and return of packaging (boxline n.d.), the business-to-business sector offers comparatively good conditions for the establishment of reusable packaging systems.

The Austrian logistics association, Mehrweg, offers an analysis tool on its website that can be used to examine the potential for using reusable transport packaging (MTV) for given product ranges. Eleven factors are included, which can be assessed by the user on a ten-point ordinal scale and assigned a weighting, which enables their aggregation to an overall evaluation. According to this, a reusable solution is ever more promising

- the less primary packaging must be adapted to be packed in the MTV,
- the more appropriate the size and quantity of the product for the MTV under consideration,

- the more suitable the number of products per MTV for the dispensing points,
- the greater the advantages of an MTV in transport packaging,
- the greater the increase in product protection offered by the MTV,
- the more regularly a total weight of 12 kg is maintained,
- the better the MTV can be used to present the product,
- the better marketing aspects are met,
- the more modes of transport the MTV are suitable for,
- the faster the products sell, and finally,
- the more extensive synergies can be exploited with other products, especially those in the same product group (Logistics Reuse Association 2017).

For reuse systems, it is generally rational to make use of standardized containers in order to realize economies of scale, as has already been illustrated by the expert assessment of a plastic pallet manufacturer regarding the necessary industry-wide standardization of pallets. Examples include EUR-pallets, the small load carrier system of the Association of the German Automotive Industry (EUR-boxes), various folding box systems, and big bags. A number of logistical concepts exist for implementing reusable systems, the most common of which are described below.

In exchange systems, full load carriers are exchanged at the loading point and/or the unloading point for empty ones of the same type in the same quantity and quality. The exchange is made between the sender and transporter or between the carrier and recipient. The best-known system of this type is the Euro Pallet Pool. In this, standardized pallets can be used in return for a licensing fee to the European Pallet Association (EPAL) and exchanged among all licensees. Two variants have become prominent in Germany: In the Bonn pallet exchange, the pallets are only exchanged at the unloading point, with an obligation to return empty pallets to the sender. This model is suitable if carriers regularly make the same trips. In the Cologne pallet exchange, the pallets are exchanged at both the loading and unloading points. This variant is especially suitable for alternating routes (Grimm 2013).

Another possibility is to credit the number and quality of delivered pallets to a pallet account at the time of delivery, and to return the corresponding quantity at a later date (Elbert and Lehner 2019).

With pooling systems, in contrast, a pooling provider is made responsible as manager for the procurement, repair, distribution, and disposal of the load carriers. The load carriers are then returned to the pooling provider after use, which takes over quality control, cleaning and, if necessary, repair and replacement of the load carriers and charges a fee for its services (Elbert and Lehner 2019).

On the one hand, there is the option of renting load carriers, whereby the filler rents the load carriers from the pooling provider for a certain period of use. The pooling provider then collects them from the unloading location. This model is implemented, for instance, by rental pallet providers such as the CHEP or LPR. Another model is so-called pool management, in which the load carriers remain in possession of the pooling supplier. Upon proper return, an electronic voucher is issued or a credit is posted to an inventory account. This model is used, for example, by the pallet pools of Inter.PAL, Polymer Logistics, PAKi, PALETTEN-SERVICE Hamburg, and vPOOL (GS1 Austria and the Logistics Reuse Association 2018).

In theory, the *exchange system* offers the advantage that additional trips to transport empty load-carriers can be avoided. In practice, however, the issuing of debt or vouchers is often used, whereby a return of the load carriers is agreed at a later date. As a result, further journeys become necessary after all. Furthermore, there is typically no contractual relationship between the shipper and recipient, and so there are often discrepancies in the exchange of landing carriers, such as with respect to the assessment of quality, which is subject to a certain degree of subjectivity despite standardizations for determining it. In addition, seasonal fluctuations mean that sometimes there are insufficient numbers of carriers available for exchanges (Elbert and Lehner 2019).

Another problem with the barter system is its relatively high costs. Lange and Hoffmann determined the cycle costs (the total costs for the one-time use of a pallet, including empties logistics) of EUR 3.81–4.96 per EUR-pallet for the EUR-pallet pool (Lange und Hoffmann 2009). Accordingly, the factor with the largest cost by far is replacement and repair, followed by costs for operational activities such as sorting and quality control, as well as administrative costs. The costs for additional transports and outstanding receivables only play a minor role. The costs are also distributed unevenly among the actors involved: carriers bear the highest share of the circulation costs at 60–65%, shippers at 25–30%, and recipients at 10–15%. In a similarly designed study of the circulation costs of half-pallets, Lange und Hoffmann (2009) conclude that the exchange system centered on the Düsseldorf half-pallet generates total costs of between EUR 3.39 and 4.81 per rotation, whereas a comparable half-pallet in the pool system only has circulation costs of EUR 0.16–0.55. However, a usage charge is added here. In this case though, a usage fee is also paid to the pool provider, which was not systematically investigated in this study but is estimated to be up to EUR 2.00. In any case, this results in significantly lower total costs, of a maximum of approximately EUR 2.50 per cycle (Lange and Siedlarek 2015).

Ecological advantages of reusable systems

With respect to the ecological assessment, it can be seen that by using reusable packaging (flat and box pallets, big bags, cable drums, and crates) instead of corresponding disposable packaging, both waste and greenhouse gas emissions can be avoided. Depending on the logistics system being used, there is a certain number of cycles above which the higher expenditure is ecologically compensated. For foldable plastic box pallets, this amounts to ten cycles – in terms of greenhouse gas emissions – without additional empty transports, whereas 15 cycles are required in the case of separate collection. For reusable big bags, the payback point in both cases is calculated to be 1.2 cycles (Waste and Resources Action Programme n.d.).

In the case of IBCs, a comparative life cycle analysis indicates that multiple use, including logistics and reprocessing of the containers, is ecologically superior to the use of disposable containers with subsequent recycling or disposal from as few as two cycles, and that the environmental benefits increase as the number of cycles do (Biganzoli et al. 2018).

In addition to the number of cycles of reusable packaging, Wood and Sturges (2010) identify a number of other factors as being relevant to the life cycle assessment comparison of reusable and single-use packaging: raw materials and energy used for the production of packaging are more significant in the case of single-use packaging, as the entire burden is attributed to a single shipment. Shorter transport distances favor reusable solutions, although this factor is less significant for foldable or stackable secondary packaging. With reuse systems, on the other hand, the entire pool of containers must be considered on a case-by-case basis, as this is always larger than the units currently in use. Moreover, due to the frequently larger masses and volumes of reusable packaging in circulation, the use of transport vehicles is generally lower. If packaged goods are included in the life cycle assessment, the typically better product protection applied to reusable packaging also plays a role (Wood and Sturges 2010).

In the life cycle assessment comparison of different reuse concepts, it was shown in a case study for a retail supply chain that for both pooling and exchange systems, the establishment of a central transfer point enables significant ecological savings to be made, the benefits of which are more decisive than the differences between the various systems (Accorsi et al. 2019).

In summary, waste prevention and reuse solutions can contribute to reducing the resource use and environmental impact of building product packaging. However, such approaches require systematic, possibly industry-wide, or even cross-industry coordination and management. It became clear that it is logical to closely integrate reuse and recycling solutions by using recyclate for the production of reusable containers and/or by recycling containers at the end of their life cycles.

6.3.2 Material recycling

The mechanical recycling of plastic packaging makes it possible to save primary resources and energy. For instance, substituting primary plastic with secondary material can save around 1–2 tons of raw materials and 40–90 gigajoules of energy per ton of secondary material, depending on the type of plastic (Kranert 2017). The proportionate use of recyclates also has positive ecological effects: Using PET bottles, for example, it was shown that a recyclate content of 35% can lead to a reduction of the ecological footprint by about a quarter, whereas the footprint of a bottle made from 100% recyclate is reduced by three quarters (Kägi and Dinkel 2018).

In the next section, the recyclability of plastic packaging is first presented as a condition for mechanical recycling. As a further prerequisite, separation at the point of generation is explained from a legal and organizational perspective. The section concludes with a presentation of the state of the art of sorting and recycling technologies.

6.3.2.1 Recyclability

One prerequisite for the high-quality recycling of plastic packaging is its recyclability. Unless otherwise stated, the following explanations are derived from the publication, “Circular Packaging Design Guidelines – Recommendations for the Design of Recyclable Packaging” (FH Campus Wien et al. 2019), which is geared towards Austrian commercial and regulatory conditions, but can also be applied to Germany, as the waste management structures are similar (ibid.). The more specific criteria defined in the “Minimum standard for measuring recyclability” (Central Packaging Register Office 2020b) are reproduced below.

The “design for recycling” or “recyclability” of packaging “describes the suitability of a packaging to correctly pass through a sorting process, as well as to be recycled in a recycling process” (FH Campus Wien et al. 2019, 10). The assessment of recyclability always refers to the entire packaging system, consisting of sales, outer and transport packaging, and is limited to a defined spatial and temporal scope, as the available collection and recovery systems play a central role. Quantitative as well as qualitative methods are also used and combined in order to evaluate recyclability. A packaging system is considered recyclable if a suitable sorting and recycling infrastructure is available, sorting and recycling are technically possible, and a secondary raw materials market exists.

The following general design recommendations apply to plastic packaging:

- Use of widely available materials such as polyolefins or PET
- Use of as few additives as possible
- Easy separability of the components
- Use of transparent, recyclable inks as much as possible

Composite and multilayer materials are generally problematic, but certain composites can be used, such as co-extruded films made from different PE polymers.

Specific recommendations can also be made regarding packaging aids and certain types of plastics:

- Avoid detachable small parts, such as caps
- Use the same material and color for stoppers for bottles or pipes made of PE or PP
- Avoid PET in multilayer films, as well as blister packaging

Criteria on recyclability have also already found their way into German legislation. Pursuant to § 21 (3) of the German Packaging Act, minimum standards for the recyclability of packaging are defined by the Central Packaging Register Office in agreement with the Federal Environment Agency. These are updated annually and serve as a basis for the dual systems to create financial incentives for recyclable packaging design. Although this minimum standard is only directly applicable to packaging that is required to participate in the system, the authors believe that it represents a good guideline for assessing the recyclability of commercially-generated packaging waste as well.

The minimum standard of the Central Body (Central Packaging Register 2020b) includes three criteria: The existence of a suitable sorting and recycling infrastructure, machine sortability and separability, and the recyclability of packaging materials.

A *sorting* and *recycling infrastructure* is considered to be in place for the following plastic packaging materials:

- Corporeal plastic packaging (e.g., bottles, tubes, buckets, canisters, etc.) made of PE or PP, apart from cartridges for sealing compounds
- Transparent bottles made of PET-A
- Large-format, non-aluminum-vaporized films (> DIN A4) made of PE

The limited extent of a recycling infrastructure can also be assumed for shaped plastic packagings made of PS, large-format films made of PP, and flexible plastic packaging (bags, pouches, foams, etc.) made of PE and PP. An individual proof of the existence of a recycling infrastructure is required for flexible plastic packaging made of PP, as well as EPS packaging (edge protection, impact protection, etc.). All other plastic packaging is (currently) not considered recyclable due to the lack of a suitable recycling infrastructure.

Machine sortability and *separability* are assumed to obtain if none of the following exclusion criteria apply:

- Large-area labeling (> 50% of the surface) with foreign materials
- Full-sleeve labeling
- Multilayer construction (except PE/PP-EVOH)
- Metallization (except metallized inner/within the middle layer)
- Different types of plastic on the front and back sides
- Metal pigments applied over large areas (> 50% of the surface)
- For polyolefins: Exceeding a density of 0.995 g/cm^3 due to additives.

With respect to *recycling incompatibilities*, material-specific exclusion criteria are defined; for films and PE-LD, various barrier layers are excluded. In the case of dimensionally-stable packaging made of polyolefins, silicone components, foamed elastomers, and non-PO plastics with densities of < 1 g/cm^3 are considered incompatible with recycling processes; in the case of PE and PP, PET sleeves and various barrier layers are also excluded. For dimensionally-stable packaging made of PS, foreign plastics or multilayers of density classes of 1–1.08 g/cm^3 are excluded. For the aforementioned packaging, waterproof adhesives in combination with wet-strength paper labels are also considered incapable of being recycled. For transparent PET bottles, components made of PET-G, POM and PVC, various barrier layers, silicone components, labels or sleeves made of PVC, PS or PET-G, PA additives, non-soluble adhesive applications, non-magnetic metals, elastomer components of density > 1 g/cm^3, as well as direct printing, are excluded.

As is outlined in Chapter 6.2.4, a large proportion of plastic packaging for construction products consists of films made from monomaterials that accumulate on construction sites. According to the above criteria, these are well-suited for mechanical recycling. Additionally, the film waste generated by large commercial waste producers is less contaminated compared to that from private end consumption (Niaounakis 2020), which also has a positive impact on recyclability. However, a systematic application of the outlined criteria to the recyclability of the different plastic packaging types used for construction products is not within the scope of this study.

6.3.2.2 Separation of plastic packaging wastes

In addition to recyclable packaging design, separation at the point of generation is another important prerequisite for high-quality plastic recycling (Moser et al. 2016). Accumulation points of construction product packaging were described in Chapter 6.2.3.

Separation requirements

As was already stated in Section 6.2, packaging that is typically accumulated by private end consumers and for which system participation is required is fed into the dual system for separate collection. According to § 13 of the Packaging Act, mixed municipal waste (20 03 01) must be separately collected.

For construction companies that are not classified as private end consumers or household-like sources of waste due to the larger quantities of packaging waste generated, the Trade Waste Ordinance is key. According to § 3, para. 1 of the Commercial Waste Ordinance, producers and owners of construction and demolition waste are required to collect plastics (waste code: 17 02 03) separately. However, this obligation does not apply if separate collection is technically-impossible or economically-unreasonable (§ 3 (2) of the Commercial Waste Ordinance). Separate collection is deemed to be technically-unreasonable in particular if there is insufficient space available for the installation of separate waste containers (§ 3 (2), sentence 2 of the Commercial Waste Ordinance). Separate collection is deemed economically-unreasonable if, for a very small quantity of the waste fraction, the costs of separate collection are disproportionate to those of mixed collection and subsequent pre-treatment (§ 3, para. 2 S. 3 of the Commercial Waste Ordinance).

These exceptions to the obligation to keep waste separate, as laid down in the Commercial Waste Ordinance, are seemingly frequently utilized in practice. According to expert statements by waste recyclers, the separation of plastic packaging waste on construction sites is not always consistently executed. Packaging waste is often disposed of as mixed construction and demolition waste (waste code: 17 09 04), which is incompatible with high-quality recycling.

Packaging waste management at construction sites

In order to separately collect plastic packaging waste from construction sites for recycling, optimized packaging waste management practices are necessary. For this, an understanding of the temporal generation patterns of the waste in question is helpful. In an analysis of ten residential construction sites, González Pericot et al. (2014) found that most plastic packaging waste is generated during the erection of reinforced concrete structures, partition walls, and in finishing works (i.e., tiling, plastering, cladding, stair construction, acrylic coatings, interior painting, floor finishes, and the insertion of false ceilings), each of which account for about 20 percent by weight or volume. Apart from building installation services, which generate only small quantities of plastic packaging, plastic packaging is utilized in all phases between the start of reinforced concrete construction and the completion of the finished structures.

For the optimization of waste management at construction sites, the following measures are recommended (González Pericot 2011):

- Include packaging waste in a construction site's waste management plan.
- Create directories of the nearest recyclers.
- Calculate the space required for the placement of separate collection containers; if space is sufficient, set up separate containers for cardboard, plastic, and wood. Color-code to avoid misplaced litter.
- Unpack delivered building products only immediately before use in order to avoid contamination of the packaging and, at the same time, to optimally protect the products.
- Educate construction personnel on waste management and the reasons for separate collection of the packaging materials.

The first three requirements have now been codified by the Commercial Waste Ordinance. In addition, as a high proportion of the plastic packaging generated is film used to wrap palletized construction products (González Pericot et al. 2014), it is recommended that collection containers for plastic and wood waste be placed in the locations where palletized products are unpacked (González Pericot 2011).

6.3.2.3 Sorting and recycling of plastic packaging waste

If the conditions described above (recyclability and separate collection) are met, plastic packaging can be sent for recycling. Material recycling processes for plastic packaging are widely used and tested in practice.

Feil and Pretz (2020) describe the current state of the art, which is summarized as follows: Different recycling paths are implemented depending on the origin and composition of the waste. Waste streams collected separately by plastic type, such as transport or outer packaging generated in trade and commerce, can be processed directly in dedicated recycling plants. Mixed commercial waste, on the other hand, is treated in mechanical processing plants. If such waste is generated in relevant quantities and without major impurities, it can be sent for mechanical recycling; otherwise it can be recycled for energy recovery. Depending on the degree of purity, enrichment is initially required in sorting plants before the actual recycling process known as refining is carried out in recycling plants. In the case of separately-collected packaging waste from private households, as collected in Germany in the dual systems, such enrichment is always practiced. In the case of mixed collection, as conducted in other countries, further pre-enrichment occurs beforehand in mechanical–biological treatment plants (Feil und Pretz 2020).

For the recycling of heavily-soiled packaging, such as used big bags, special pre-treatment may be required. Corresponding plants, such as for the recycling of heavily-soiled PE films, are already in operation. In pre-washing plants, the waste is freed from impurities before the regular recycling process commences (recovery 2018).

In the first stage of enrichment (also called sorting), the delivered waste is extracted from the waste bags with the help of counter-comb shredders, which do not shred the bags themselves, as this would be disadvantageous for the continuing process. The subsequent conditioning process serves to prepare the material stream for the best possible sorting. Drum screens and so-called trash screens are then used to classify the waste stream into tpically three fractions according to particle size. The fine fraction (approximately less than 40 mm) is ejected, whereas the medium (approximately up to 160 mm) and coarse fractions are processed separately. Subsequently, flat 2D (such as films and paper) and 3D particles (such as bottles and trays) are separated from each other using ballistic separators, airflow classifiers, or drum separators. After conditioning has occurred, sorting takes place with the aim of producing recyclable pre-concentrates. First, ferrous and non-ferrous metals are sorted using magnetic or eddy current separators. In sensor-based sorting, particles of specific plastic types are detected on the basis of their chemical structures using near infrared (NIR) sensors or on the basis of optical article properties, such as shape, size or color using visible light (VIS) sensors and separated by a targeted compressed air flow. A combination of different sensors and the use of laser triangulation sensors for the detection of 3D shapes is also possible. Manual sorting, on the other hand, is used almost exclusively for quality control. When the enrichment process is complete, the pre-concentrates are compacted into bales with balers in order to prepare them for efficient transport to the recycling plant (Feil und Pretz 2020)

Refining (recycling in the narrower sense) begins with shredding the delivered pre-concentrate bales using single-shaft shredders. Subsequently, metallic impurities and bale wire are initially removed to protect the machines. This is followed by wet or dry processes for cleaning and sorting. In both cases, friction washers are first used to remove adhesives and labels. Wet methods used for sorting include static float-sink separation, which can also be performed in combination with wet washing, and dynamic float-sink separation using hydrocyclones or centrifuges. These methods are all based on the density of the waste to be separated, and can therefore separate plastic grades and contaminants with sufficiently different density ranges. Among the dry sorting methods used, zigzag sifting, in which heavy particles are separated from light ones in a vertical air stream, also makes use of density differences. Sensor-based methods are utilized to separate different polymers or impurities with similar density ranges, as was already the case for enrichment. In addition to NIR and VIS sensors, inductive sensors are employed. These are used to sort out residual metal impurities. Electrostatic separation as another dry sorting process makes use of differences in the dielectric constants and electrical conductivity of different types of plastics. The cleaned and sorted plastic fractions are finally processed into flakes with the aid of granulators. These are then mechanically- or thermally-dried and finally processed into granules using agglomerators or extruders to facilitate the subsequent processes of storage, transport, and processing (Feil und Pretz 2020).

The subsequent use of the recyclates ultimately determines whether a closed-loop system is achieved or the reprocessed materials are used for lower-quality applications, in the sense of downcycling. In the case of PE-LD and PE-LLD recyclates, according to estimates by the Plastic Recyclers Europe association, up to 50% of the PE-LD and PE-LLD recyclates placed on the market today could already be suitable for reuse in film applications if there is a corresponding demand (Plastics Recyclers Europe 2019).

6.3.3 Use of recyclates

In addition to the mechanical recycling of packaging waste, the use of recyclates in the manufacturing of new packaging is a core component of the circular economy. Although closed cycles are generally strived for and often present themselves, in principle the use of recyclates can also take place within all sectors. The following is an assessment of the potential for the use of plastic recyclates in building product packaging, which encompasses a political, qualitative, and finally a quantitative, analysis.

6.3.3.1 Political and ecological relevance of the use of plastic recyclates

For some years now, the image of recyclate use in packaging has been significantly improving. This is reflected in the winners of the "Pack The Future" award among whom, in 2014, 2015, and 2017, only a maximum of one packaging was awarded, mainly for recyclate use, and there were five in 2019 and three in 2020 (PackTheFuture 2020). The topic is also gaining importance in the political discourse. In its Plastics Strategy (European Commission 2018a), the European Commission highlighted weak demand for recycled plastics as an obstacle and announced that, in addition to enhancing quality standards, promoting research and innovation projects and initiating a self-commitment campaign, it would also consider targeted, sector-specific measures to prompt the market uptake of recycled plastics. In the new Circular Economy Action Plan, the Commission proposes mandatory requirements for recycled content in packaging (European Commission 2020). The industry followed the voluntary commitment campaign. The Circular Plastics Alliance, initiated by the European Commission as part of its Plastics Strategy, aims to increase the EU market for recycled plastics to 10 million t/a by 2025, and is now supported by 240 signatory organizations (European Commission n.d.). The Plastics Packaging Industry Association (IK) has set itself the target of using one million t/a of recyclates or renewable raw materials for the production of plastic packaging in Germany by 2025 (IK n.d.). In a joint discussion paper, the Packaging + Environment Working Group (AGVU) and IK called on politicians to define targets and lay out a regulatory suitable framework (AGVU and IK 2020).

The ecological advantages of substituting primary plastics with recyclates were already mentioned in the previous chapter, and also apply in the case of the proportionate use of recyclates.

6.3.3.2 Possibilities for the use of plastic recyclates in construction product packaging

Compared to food packaging, construction product packaging, as is typical of non-food packaging, offers good potential for the use of recyclates. In a study commissioned by the Trade Association of Germany, the Society for Packaging Market Research estimates that, based on consumption quantities, 73% of the plastic packaging used mainly in the non-food sectors features zero to moderate barriers to the use of recyclates (Society for Packaging Market Research 2019). The study considers different packaging materials and, in addition to food and non-food applications, also distinguishes between predominantly private and other end uses. In terms of recyclate origin, the study focuses on post-consumer recyclates. The results for the use of these in non-food packaging are summarized in Table 30, below.

Packaging materials with no or low barriers to the use of recycled materials include plant pots for private end use and crates, trays, pallets and packaging straps for other end use; packaging materials with low barriers are not separately shown. Goods with moderate barriers include canisters and buckets for all end-users, PET and other bottles, labels, carrier bags, small containers, and stoppers for private end-use, as well as drums, IBCs, transport films, bags, shells, wraps, and big bags for other end-use. Major barriers exist for bags, liners, wraps, big bags as well as EPS and other foams for private end-use (Society for Packaging Market Research 2019).

Table 30. Suitability of plastic packaging mostly used in the non-food sectors for recyclate use, differentiated by primary source (own representation based on the Society for Packaging Market Research 2019).

Barriers	Type of packaging	Primary point of origin	
		Private end-user	Other end use
No to very low barriers	Boxes, crates, pallets		X
	Packaging straps		X
	Plant pots	X	
Low barriers	n/a	n/a	n/a
Moderate barriers	Canisters, buckets	X	X
	Barrels, IBCs		X
	PET bottles	X	
	Transport films		X
	Labels	X	
	Carrier bags	X	
	Other bottles	X	
	Other small containers	X	
	Stoppers	X	
	Bags, trays, envelopes, big bags		X
Major barriers	Bags, trays, wraps, big bags	X	
	Foam / EPS	X	

With the exception of foams and flexible packaging mainly intended for private end-use, there are only minor to moderate barriers to the use of recyclates in non-food packaging. In the following, low to moderate barriers are analyzed and suggestions for overcoming them are outlined.

6.3.3.2.1 Barriers to the use of recyclates in selected packaging materials

In the study by the Society for Packaging Market Research cited above, five criteria are defined for evaluating the use of recyclates, namely: The availability of recyclates, the ability to fulfill the necessary functions using them, the legal situation regarding the application, the costs compared to the use of virgin material, and the ecological utility of their use. These criteria are further differentiated across a total of 17 sub-criteria. These evaluation criteria were adopted for the present study and applied to packaging categories that are especially relevant for the construction sector (e.g., pallets, crates/sidewalks, buckets, canisters and bottles, films). In semi-structured interviews with experts, the obstacles to the use of post-consumer recyclate were specified for each packaging category on the basis of the above-mentioned criteria.

In the case of plastic pallets, according to a pallet manufacturer, the use of recyclates is already widespread due to the cost advantages they offer and no technical barriers exist to limit their use. The availability of recyclates is sufficient and the legal context also does not hinder their use. Only an altered odor was noted, which was also detectable in the cardboard packaging in which it is transported. However, this minor obstacle can be considered less relevant for building products. With respect to costs, it was noted that minor adjustments may need to be made to the processing machines used, such as by using different screw geometries. In terms of ecology, it was noted that more material may be required to achieve the same stiffness. However, as this does not have a significant effect on the pallet's total weight, only a minor obstacle can be assumed in this instance. To the knowledge of one expert interviewed, plastic pallets are not currently used in the construction sector, but this would in principle be possible (see 6.3.1). Thus, there is nothing to prevent the use of recycled material in this context.

According to one recycler, there are also no fundamental barriers to the use of recyclates in the production of buckets, boxes and crates. Suitable recyclates are available, and there are no legal barriers (with the exception of the packaging of hazardous goods; see below). As far as the packaging function is concerned, a restriction in terms of designability was noted with respect to the color scheme; on the other hand, the use of recyclates could in the meantime already be positively highlighted for marketing purposes. As with pallets, the altered odor in construction product packaging is not classified as an obstacle. Sufficient mitigation of this can be achieved by admixing small amounts (about 10%) of virgin material. With respect to costs, the lack of competitiveness of recyclates compared to virgin material was considered an obstacle. However, this was strongly dependent on the variable price level of the primary raw materials. Another cost factor noted was the sometimes necessary retrofitting of extraction systems in order to reduce the odor nuisance during the processing of recyclates. In terms of ecology, the expert pointed out that although the material thicknesses were unchanged, the density of the recyclates could be slightly increased through the use of fillers, which results in a very slight deterioration in material efficiency. In addition, in the case in which coloration plays a decisive role in the marketing of the product, special measures, such as the use of appropriately-designed in-mold labels, would be necessary, which could serve to slightly increase material consumption.

For canisters and bottles, essentially the same barriers apply as for buckets, boxes and crates. However, an additional barrier cited was that the PE-HD primarily used for this packaging is not available in large quantities as post-consumer recyclate.

In the expert interview conducted with a film manufacturer, no fundamental barriers to the use of recyclates in film packaging for construction products were identified. However, obstacles were noted with respect to the availability of recyclates in the event of a strong overall increase in demand for recyclates. In particular, it was seen as problematic that high-quality recyclate was only available in limited quantities, whereas recourse to poorer qualities would lead to an increase in layer thicknesses and thus in the amount of material to be used. No obstacles were identified in relation to the other criteria queried, but it was noted that there was currently no convincing incentive for construction product manufacturers to utilize recycled films.

When assessing whether packaging is suitable for the use of recyclates, packaged goods must also be taken into account. This applies in particular to the packaging of hazardous goods.

6.3.3.2.2 Prerequisites for the use of recyclates in packaging for dangerous goods

Regardless of the specific form of packaging, special requirements apply to the use of recyclates in packaging for hazardous goods. These are described in ISO 16103 (International Organization for Standardization 2005) and cover some of the products relevant to the construction industry and their packaging, such as paints, adhesives, or cleaning agents. ISO 16103 is implemented through various international trade agreements and is recognized as a European standard. The following points are also mentioned in the standard as being prerequisites for the use of recyclates:

- The recyclates used must originate from industrial packaging.
- The recyclates must not be derived from packaging that has itself been manufactured from recycled material.
- The packaging from which the recyclates originate must not be more than ten-years-old and must not have been used for packaging toxic, highly oxidizing, or infectious materials.
- The recycled packaging must have been separated according to plastic type, as well as manufacturing process.
- The containers must have been emptied and the materials used homogenized.
- The quality and homogeneity of the batches must be ensured and documented by testing the recyclate on the basis of the material parameter density, melt flow index, and elongation at break. In addition, drop and stack pressure, as well as leak tightness and hydraulic internal pressure tests, must be performed on the products.
- Compatibility with the filling material must be ensured.

The standard thus demonstrates how quality assurance pertaining to the use of recycled materials in packaging can be designed. Similar tests based on the safety requirements of the packaged goods are also conceivable for other packaging types.

6.3.3.3 Examples of recyclate use in plastic packaging

The analysis of the obstacles made it clear that the use of recyclates is possible for a large portion of the plastic packaging relevant to construction products. This is supplemented by research into specific examples.

For DIY, gardening and building materials, the following packaging examples for recyclate use were found:

- Cover film for palletized paving stones (RINN 2018)
- Foil bags for tools and hardware (Bauhaus n.d.)
- Bubble wrap as a packaging aid for adhesives packaging (Uzin n.d.)
- Bucket for dispersion paints (REWE Group 2018), varnishes (Interseroh n.d.), sealants, mortars and primers (PCI 2020, 20), or wallpaper paste (Henkel 2020)
- Canister for PU and dispersion primers (Uzin n.d.)
- Cartridges for sealants (Fischbach n.d.)
- Bottles for adhesive (Henkel 2018), cleaning agents (Dr. Schnell n.d.), and liquid fertilizers (Systalen 2018)
- Plant pots (Bauhaus n.d.) and pallets (Klose 2019)
- Case for power tools (expert interview with a recycler)

In order to identify further possible areas of application, the research was extended to other packaging materials, provided that a transfer to construction products seemed possible. The results are shown in Table 31, with only one example per packaging type and material being included. Where no information on the recycled content or origin was provided in the sources listed, the relevant suppliers were contacted, if known, and the details supplemented.

Table 31. Examples of the use of recyclates in plastic packaging.

Packaging type	Material	Description	Recyclate portion	Recyclate origin	Source
Shrink films and hoods	PE-LD	Transparent PE-LD film made from at least 5% post-consumer recyclate. Film thickness, as well as processing parameters are the same as for films made from virgin material	At least 50%	Post-Consumer	(Barbier Group n.d.)
Stretch film	PE-LD/LLD	Stretch film made from at least 25% post-consumer recyclate. No significant loss in performance. Film thickness: 8 microns, available both as hand- and machine-stretched film	25%	Post-Consumer	(Elipso and IK 2020; IK and Plastics Europe Germany e.V. 2020b)

Packaging type	Material	Description	Recycleate portion	Recycleate origin	Source
Hand-stretched film	PE-LLD	Hand-stretched film made from 75% recycled material, of which again at least 51% is post-consumer	75%	Post-Consumer / Pre-Consumer (mixed)	(PlasticWeb 2020c)
Foil bags	PE-LD	Various bags with up to 100% recycled content, available as post-consumer and post-industrial types	Up to 100%	Post-Consumer / Pre-Consumer (depending on version)	(Strubl n.d.)
Tubes	PE-HD	Tube body made of 96% post-consumer recyclate. Used for cosmetic products	96%	Post-Consumer	(Brunn 2019)
Tubes	PE-LD	Plastic tubes made from 19% pre-consumer recyclate obtained by means of solvent-based recycling from multi-layer film waste	19%	Pre-Consumer	(PlasticWeb 2020a)
Big bags	PP	Closed material loop for big bags from production to use, take-back to recycling, and use of the recyclate. The recycled content of the fabric is specified as “high”	“high”	Post-Consumer	(Plasticker 2019)
Big bags	PET	Big Bags made from post-consumer recyclate obtained from used PET bottles. After use, the big bags can be returned to the recycling loop	96%	Post-Consumer	(Elipso and IK 2020; IK and Plastics Europe Germany e.V. 2020a)
Buckets	PP	Buckets for wall paints, varnishes and insulating coatings made from almost 100% recycled plastic, mainly from post-consumer waste	Near to 100%	Post-Consumer (primarily)	(RECYCLING magazine 2011)
Boxes	PP	Euro-boxes made from recycled pre-consumer polypropylene	n/a	Pre-Consumer	(SSI Schäfer n.d.)
Pallets	PE / PP (mixed)	Disposable pallets made of recycled PE and PP	100%	Post-Consumer	Information from the manufacturer upon request

Packaging type	Material	Description	Recyclate portion	Recyclate origin	Source
Pallets	PE-HD	Reusable pallets made of recycled PE-HD for long-term and frequent use	100%	Post-Consumer	Information from the manufacturer upon request
IBCs and plastic drums	PE-HD	Bulk packaging made from a mixture of post-consumer and pre-consumer recyclate from the company's own production	35% to 95% (depending on model)	Post-Consumer / Pre-Consumer (mixed)	(Mauser Packaging Solutions 2019)
Canisters	PE-HD	Canisters of various sizes for PU and dispersion primers made of 100% recycled PE-HD	100%	Post-Consumer	(Plasticker 2020)
Bottles	PE-HD	One-liter bottle for cleaning agents made of recycled PE-HD. The stopper is made of 100% recycled PP	100%	Post-Consumer	(New Packaging 2018)
Bottles	PP	Adhesives packaging with applicator nozzle made from post-consumer recyclates	100%	Post-Consumer	(Henkel 2018)
Bottles	PET	Bottles for household and cosmetic products. Depending on the product, 20–100% of post-consumer waste comes from the dual system, with the remainder coming from single-use deposit bottles	100%	Post-Consumer	(Frosch n.d.)
Cartridges	PE-HD	Cartridge for plastic and permanently elastic sealants such as silicone	At least 30%	n/a	(Fischbach n.d.)
Stoppers	PP	Closures for packaging cleaning and household products	50%	Post-Consumer	(PlasticWeb 2020b)
Protective packaging	EPS	Protective packaging made of recycled polystyrene foam material for protection during transport	100%	Post-Consumer	(Elipso and IK 2020)
Bubble wrap	PE	Bubble wrap made of at least 50% PE recyclate from the company's own production waste, as well as external sources	At least 50%	Pre-Consumer	(Packaging journal 2019)

Packaging type	Mate rial	Description	Recyclate portion	Recyclate origin	Source
Strapping-bands	PET	Strapping made from bottle mill material	100%	Post-Consumer	(Plasticker 2008)
Strapping bands	PP	Strapping made from 100% recycled polypropylene	100%	n/a	(Bindemann Packaging n.d.)
Plant pots	PP	Plant pots made using post-consumer recyclate, blue color additive, and fillers	100%	Post-Consumer	(The Green Point 2020; Pöppelmann n.d.)
Plant pallets	PP	Reusable plant pallets made from post-consumer recycled material	100%	Post-Consumer	(Klose 2019)

The overview makes it clear that the use of recyclates is possible in all forms of packaging relevant for construction products. In addition to the examples already mentioned, the use of recyclates seems conceivable in the following exemplary types of plastic packaging for construction products:

- Stretch films, shrink films and hoods for palletized construction materials
- Film bags for installations, DIY and garden articles, as well as small parts
- Big bags for bulk construction materials
- Plastic pallets for construction materials
- Boxes for small-scale building products
- Bottle canisters, IBCs and drums for liquid building products
- Cartridges and tubes for viscous masses
- Bubble wrap, strapping, and EPS insulation materials as packaging aids

In summary, it can be noted that recyclates are already used sporadically in plastic packaging for construction products, although there remains great potential for increase. By opening up further areas of application, broader industry-wide use and increasing the recyclate content, an overall increase in the amount of recyclate used can be achieved. A prerequisite, however, is the availability of adequate quantities of the corresponding grades of recyclates.

6.3.3.4 Estimation of the volume potential for the use of plastic recyclates in construction product packaging

The quantification of the recyclate input potential in construction product packaging is based on the production volume of plastic packaging used for construction products in Germany. This was estimated in Chapter 2.4.2 as being 370 kt/a, distributed over four packaging upper segments. However, only a portion of this production volume is suitable for recyclate use, and this varies greatly depending on the packaging material. Table 32 lists various packaging material upper segments, in addition to the production volumes estimated for construction products and current recyclate shares, in which additional shares of recyclates could be realized in the presence of moderate restrictions. The percentage figures are taken from the study "Potential for the use of recycled plastics in the production of plastic packaging in Germany" (Society for Packaging Market Research 2020). For the sake of simplicity, it is assumed here that the relative recyclate use potentials for building product packaging correspond to the average values presented there for the respective packaging material upper segments.

Table 32. Production volumes, current and potential use of recyclates with moderate restrictions.

Production volume estimates were taken from Chapter 2.4.2, Presentation of the available data. The percentage figures were taken from the Society for Packaging Market Research (2020).

Packaging Materials Upper Segment	Production volume of construction product packaging in kt/a	Current use of recyclates		Additional recyclate use with moderate restrictions	
		Share of production volume	Absolute quantity in kt/a (construction product packaging)	Share of production volume	Absolute quantity in kt/a (construction product packaging)
Bottles and stoppers	40	16%	7	21%	9
Films and small containers	180	8%	15	1%	2
Large packaging	90	17%	15	36%	31
Rest	50	0%	0	9%	5
Total	**370***	**10%**	**37**	**12%**	**44***

The production quantity is included in the calculation to one place more precisely than shown here in order to keep the potential for error propagation low.
*Different totals result from rounding errors.

The calculation shown in Table 32 yields an estimate of current recyclate use in plastic packaging for building products of around 40 kt/a, which could be increased by a further 40 kt/a, to 80 kt/a, if moderate restrictions are implemented. Although this estimate is based on numerous assumptions due to the lack of data, it can be considered a guideline for increasing the use of recyclates in construction product packaging.

6.4 Recyclate quotas in film products

As was already shown in chapters 5.1 and 6.1, there is a broad consensus at both the EU and national levels that the further development of the circular economy is a goal for the near future, which implies an increase in the use of high-quality recyclates.

One way to increase the use of recyclates is to impose mandatory quotas (Resource Commission 2019). The recyclate quota indicates the share of recyclate in the total mass of material used for production. Thus, a recyclate ratio of 25% would mean that a quarter of the material used in production was recyclate. This can be specified for individual products, as well as for entire product groups, or national production in its entirety.

The recyclate rate can be taken as an indicator of the extent to which the third stage of the waste hierarchy (recycling) is implemented. In contrast to the recycling rate, the recyclate rate measures the point at which the cycle is closed again; see Figure 24. If a minimum recyclate rate is prescribed by regulators, this can be used to achieve recycling implementation targets as part of a circular economy. Two resulting, positive effects can be expected from this. First, relevant data must be collected from manufacturing firms. This will enable significantly improved monitoring of the use of recycled materials. Secondly, the recyclate quota creates a stable demand for recyclate, which can in turn trigger a cascade of positive effects. The induced demand for recyclates enables planning security on the disposal side and therefore makes investments in high-quality, effective recycling technologies possible (Umweltbundesamt 2016). This, in turn, facilitates higher-quality recyclates that are more competitive than virgin materials.

In terms of recyclate quantity, various design options are conceivable. A minimum recyclate content can be defined for the product categories. Manufacturers of these are then responsible for achieving this minimum. An average recyclate ratio, as an overall ratio for a manufacturer's various products, can account for products with extensive requirements in special applications. Another approach is to define the ratio between recyclates and virgin material for the entire production chain of a material type. This ratio is implemented through certificate trading – producers of recyclates receive certificates for recyclate sold, which producers of virgin plastics must then acquire before selling their products. In the case of certificate trading, substitution with recyclates is expected to be as cost-efficient as possible. In the case of manufacturer-specific recyclate quotas, all manufacturers would build up know-how on the use of recyclates. It should be critically noted that a recyclate quota, both as an instrument and a benchmark, does not convey any information on the development of the absolute quantities used. If the ratio were to remain constant, for example, volume growth would not be reflected, although this may also not be desirable.

As also noted for product labels in Chapter 5, the discussion should consider whether post-industrial waste streams will be included for the recyclates encompassed by the quota. These streams are already being economically-recycled even today. If they are included, therefore, the quota must be correspondingly higher. Quotas mentioned in this text should thus be understood as excluding post-industrial quantities.

In Germany, the introduction of a recyclate quota for certain areas is being considered and has been included in the “Draft bill of a law to implement the requirements of the Single-Use Plastics Directive and Waste Framework Directive of the Packaging Act and other laws.” The aim of this is to achieve an initial recyclate quota of 25%, which is set to increase over time. In the area of PET bottles thus affected, a recyclate quota is logical, as a high-quality material stream is already available due to the compulsory deposit system, which can be recycled well.

Film packaging for construction products is also suitable for recycling and here, too, positive effects can be expected from a recyclate quota. Films make up a significant proportion of the plastic used for construction product packaging. The main types of plastic used for this are PE-LD and PE-LLD. Both can be easily recycled and are also used for packaging subject to system requirements. Thus, a substantial supply of recycled material can be assumed for this application, which currently constitutes a hurdle for the widespread use of recycled material, as was shown in Chapter 5. It is therefore recommended that the introduction of a recyclate quota in this area be examined in detail and supported at the European level (see also Chapter 7).

In order to assess the technical feasibility of using recyclates in packaging films for construction products, the following section outlines the film manufacturing process, along with the specific challenges of using recyclates. Then, two best practices examples are presented that demonstrate the feasibility of using high proportions of post-consumer recyclate in these products.

For film production, a distinction is made between blown and cast films, with the former making up a larger share in the packaging sector. To produce blown films, plastic melt is forced through a ring die by an extruder and simultaneously inflated from the inside with compressed air. The resulting film is air-cooled and then wound up. To produce shrink film, the film is heated again, stretched, and then cooled. Challenges to the process when using recyclates primarily comprise particulate impurities, as well as fluctuations in the melt flow index. However, existing production lines can be converted into process recyclates without major investment.

For the production of cast films, the plastic melt is forced by an extruder through a wide slot die and poured onto a cooled roll. Here, too, impurities and the melt flow index present process-specific challenges for recyclate use. In general, the requirements are somewhat lower due to the greater film thickness. Consequently, the use of recycled material is quite feasible.

In order to achieve recyclate content targets, either blends of recyclate and virgin material can be processed, or multilayer films be produced by means of coextrusion, with only a portion of the layers containing recyclate. The first approach is more suitable for the production of cast films, as the die technology for multilayer films is more complex to implement in this context. For the production of blown films, corresponding equipment is widely used.

With respect to the manufacturing process, further challenges arise due to product requirements. These are, on the one hand, functional standards, such as tensile strength or elongation at break and, on the other hand, aesthetic requirements such as transparency, printability, or odor.

The fact that a high recyclate content is nevertheless possible in films for construction product packaging is demonstrated by the best practices examples presented below.

PE film, stretch hoods – Trioloop Sifab

The Trioplast company offers various films featuring a high recyclate content under the Trioloop umbrella brand. In addition to the stretch hoods presented here, the firm’s program also includes waste sacks in various sizes, as well as silage and crop films.

- Production: Extrusion, film blowing
- Recyclate content: > 50% PCR
- Other features: According to the manufacturer, one of the thinnest films on the market, black or white, printable, anti-slip functionality, and recyclable.

Sources: Trioplast (2019, 2021)

PE film, shrink film – Barbier Recyplast 50

Launched in 2016, the Recyplast 20 brand, with 20% PCR, has been upgraded by Barbier to Recyplast 50. The new brand now offers shrink films that utilize half-PE recyclate.

- Production: Extrusion, film blowing
- Recyclate content: 50% PCR
- Other features: Transparent, film thickness and processing parameters correspond to virgin material

Sources: (Barbier Group n.d.)

In the agricultural sector, where films account for a large share of plastic production, the recyclate use for 2019 was 36.5% PC and PI recyclate. The association of European plastics recyclers, "Plastic Recyclers Europe," expects the share of PE film products made from recyclates to more than double in the coming decade. In principle, therefore, film recycling is technically feasible. A recyclate quota of 30% seems possible and should therefore be pursued as a target if a quota is introduced.

As was already shown in Chapter 5, investments are necessary for the use of recyclates, as additional storage places and quality controls must be kept available or taken. Introducing a recyclate quota per manufacturer does not entail a competitive disadvantage, as it applies to all packaging manufacturers who wish to serve the market.

In summary, a recyclate content quota for films in building product packaging is ecologically-rational and technically-feasible. The advantages and disadvantages of the various options for implementation should be further investigated.

6.5 Recommendations and measures

The preceding analysis showed that approaches to both waste prevention and plastic recycling in the packaging sector exist and can be increased in the construction industry. Implementation of the following recommendations and measures will serve to further strengthen the circular economy:

- Optimization of the management of reusable containers and transport packaging. In particular, useful applications could be identified for plastic pallets and IBCs, whereby plastic pallets can already be entirely manufactured from recyclate. However, these would require a suitable container management system, which must be managed from an economic perspective. On the basis of this investigation, pooling systems seem to be suitable for this purpose. It should also be determined whether increasing the cost of disposable packaging, e.g., by means of a levy, could promote the introduction of reusable solutions.
- In the case of repackaging, the extent to which this is in fact necessary must be determined in each instance. The investigation has shown that trading with unpackaged goods is also possible in many cases, and such solutions are to be preferred.
- Reuse solutions should also be implemented for sales packaging. In this manner, customers can be encouraged to use their own containers and bags, etc. for transport.
- Decisions in favor of or against reuse solutions should be optimized on the basis of both ecological and economic considerations. The ecological dimension in particular may require a further basis for decision-making, such as in the form of representative, publicly-available life cycle analyses.
- The consistent separate collection of packaging for B-to-B firms and a conscientious supply of material recycling is an essential condition for the closing of cycles within the area of

plastic packaging for construction products. One clear obstacle that has emerged on the road to more extensive recycling is the mixing of packaging with other construction and demolition wastes at the point of generation, especially at construction sites. Although this should be prevented by the Commercial Waste Ordinance, the concessions made therein with respect to reasonableness compel frequent circumvention of the regulations made, in accordance with assessments of the facts. The justifications for exemptions in the Commercial Waste Ordinance should therefore be reviewed. In particular, the question of economic utility should be mentioned here, as disposal costs are often passed on to building owners. Thus, the aforementioned restrictions could be reduced to technical feasibility.

- The preceding hypothesis that packaging for construction products has high potential for the use of plastic recyclates is confirmed on the basis of the findings obtained. However, this is linked to a number of preconditions. These concern, amongst other things, packaging properties with respect to their recyclability and, on the other hand, the introduction of market or regulatory prerequisites:
  - With respect to packaging design, a consistent design should be implemented according to the minimum standard for assessing recyclability of the Central Packaging Register. Although the minimum standard is addressed in certain (dual) systems, it specifies the *technical* and *design* requirements that can also be used by manufacturers (design-for-recycling) to expand high-quality recycling. Recycled packaging should also meet the recyclability requirements.
  - Plastic recyclates are subject to price competition with primary materials. Especially in times when primary material is available at historically low prices, this places recyclates at a disadvantage, as they must be brought to market at greater expense (cleaning, sorting, treatment, etc.) and also generate higher costs during the processing stage. Improving recyclability in the sense of "design-for-recycling" can already have a cost-reducing effect here. Other options for increasing the use of recyclates on the regulatory side include the introduction of minimum use quotas for recyclates and making primary materials more expensive, such as by levying taxes on them. However, both approaches are demanding and require intensive preparatory analysis, which is beyond the scope of this work. They should also be pursued at the European level if possible in order to avoid market distortions and reflect the complexities of the supply chains.
  - In order to ensure that recyclates of suitable quality are available in sufficient quantities, even in the event of increased use, it should be determined whether appropriate recycling infrastructures are available or can be built in a timely manner. If necessary, it may be justifiable to promote the construction of suitable infrastructure.
  - In this context, voluntary commitments by the industry are welcome, such as the IK's goal of increasing the use of recyclates (or renewable raw materials) in packaging from 0.4 million to 1 million t/a (IK 2018). These voluntary commitments constitute suitable targets for substantially enhancing the implementation of a resource-efficient circular economy.
- The system requires a significant improvement in terms of the decision-making framework for policymakers and companies. A prerequisite for this is an improvement in the databases. Providing data on the market placement, traceability and whereabouts of packaging can reduce search and transaction costs, increase market transparency, and also make regulatory control more effective.

- Due to the generally positive view of the use of recyclates on the part of end consumers, a product's recycled content can be indicated on its packaging in accordance with DIN 6120 in a manner that is both effective for advertising and factually accurate. This can provide an additional incentive to use of recyclate content as an aid for purchasing decisions.

7 Recommendations

Based on the results presented in the previous chapters, the following recommendations can be made to various actors, such as industry, government and research.

7.1 Technical documentation / product labeling

Information on the use of recycled materials in construction products and their recyclability is an important factor in their sustainable use. The clear identification of recycled material use and recyclability can therefore also be seen as a prerequisite for promoting and guaranteeing the sustainable procurement of plastics in the construction sector. The following aspects can be considered useful for this purpose:

- Introduction of an obligation for manufacturers to provide information on the recyclability of their products and the use of recyclates therein:
  - Specification of the recyclate content as a mass fraction [%] in the produced component. According to the DIN EN 15343 standard, only production and service waste should be included in the calculation. Material recovered as part of the same value chain in which it was produced must not be included in the recyclate content.
  - Information on the origin of the recyclate should be provided: For instance, is it manufacturing or commercial waste?
  - Possibilities for recycling should be outlined. For example, information on existing take-back systems for discarded building products could be provided.
  - To map recyclability, it is recommended that information be provided on the material composition of the product, the degree of degradation of the polymer chains, the purity of the materials, pollutants, as well as separability and recovery. The recyclability should be determined on the basis of a design-for-recycling tool that states its precise designation. In addition, reference to certified recyclability by means of recognized labels is desirable. Specific information on recyclability based on own tests or experience could also be a viable option.
- It is recommended that the recycled content and recyclability of plastic construction products be identified in *declarations of performance* according to Annex III of the European Construction Products Regulation, *technical data sheets* and *environmental product declarations*. In order to ensure that this information is perceived as well as possible, a separate, additional section on the “sustainable use of natural resources” (see Table 24) should be included in each of the documents.
- Further concretization with respect to the implementation of the principles of durability, recyclability, and the use of recycled materials in the Construction Products Regulation and in standards should be performed.

7.2 Recyclate quota for films for construction product packaging

A recyclate quota for film packaging for construction products of 30% is recommended. On the one hand, this promotes the consistent implementation of recycling as part of a circular economy. On the other, it is expected that this will trigger further transformation processes within the system. Investments in high-quality recycling infrastructure can be better planned due to a secure demand. Companies will be empowered to use recyclates and be able to apply these capabilities in other areas (such as crop films). Data on recyclate use will improve. The technical feasibility of such a recyclate quota was demonstrated in the examples in 6.4. However, such a quota also requires that some parameters be taken into account. For example, recyclate of the desired quality must be available in sufficient quantities, and a way of dealing with possible supply bottlenecks for recyclates must be defined. In addition, it must also be possible to verify the actual recycled content of imported products. At the same time, such an approach should be pursued at the European level, in order to avoid relocations or market distortions, for instance. This also appears to be necessary on the basis of the EU Waste Framework Directive.

7.3 Application of design-for-recycling

There is a need for larger quantities of higher-quality recyclates, but at the same time, the entire waste stream is not currently recycled. The proportion of recycled products must therefore be increased. An important starting point for this is the consistent application of the design-for-recycling principle. In this context, this means, amongst other things:

- The use of monomaterials or good separability of the various material fractions used. Positive examples here include floor coverings with easily separable backing layers or monomaterial films from the packaging sector. Negative examples are non-recyclable multilayer floor coverings made of different plastics, or additivated polyolefins with a density of more than 0.995 g/cm^3.
- The use of pollutants must be minimized. The knowledge required for this objective and possible alternatives must be made freely available and easily accessible.
- Construction product packaging can be based on the minimum standards for measuring recyclability of the Central Packaging Register. Here, the existence of sorting and recovery infrastructure for high-quality mechanical recycling is necessary. Likewise, sortability of the packaging, separability of the components, and avoidance of incompatibilities of the components are cited as requirements.
- Attention to easy dismantling– many plastic products used are optimized for cost-effective and rapid installation and easy dismantling only plays a subordinate role, if any. An example of easy dismantling are textile floor coverings, which do not need to be bonded, whereas bonded insulation materials are difficult to dismantle. This aspect of easy dismantling must already be considered in the planning stage. The knowledge required for this should be included in training for the trades involved and of architects and engineers.

Design-for-recycling should not stand in the way of possible waste avoidance, reuse or other, higher-value steps. Increased adoption of these principles must ultimately be implemented by the manufacturing industry. From the regulatory side, design-for-recycling for construction products is difficult to demand. On the other hand, all regulatory approaches that lead to higher recyclate use favor increased design-for-recycling practices.

7.4 Generation of pure waste streams

Waste streams from the construction industry must become more recyclable. Various measures can be taken to achieve this, such as the following:

- The separate collection of plastic waste still has much potential for improvement. The necessary legal regulations for this exist. The Waste Management Ordinance includes a separation requirement for various fractions. However, exceptions are possible if separate collection is not economically- or technically-viable. If purer plastic waste streams from construction and demolition waste are desired as a basis for better recyclate use, the exceptions to the separation obligation must be reconsidered. A reduction in the exemption criteria or a more precise examination of their actual existence would thus be appropriate. Although the Ordinance provides for treatment in pretreatment plants as a substitute solution, this is not expedient for high-quality recycling, as the plastic streams thus generated cannot be recycled to a high standard. This also applies in particular to plastic packaging from building products.
- In addition to investments in technical sorting and processing plants, it is desirable to already push for the separate collection of waste in the previous step and raise awareness among the relevant stakeholders.
- The allocation of plastic insulating materials to waste code 17 06 04, together with mineral insulating materials, should be altered. The introduction of a separate waste code for insulation materials made of plastic or their inclusion in the waste code for plastics would be helpful for fostering high-quality recycling.
- The technical documentation of products should contain information on mandatory return and recycling options. The necessary additional effort on the part of manufacturers for this is low.
- The limits on the content of plastics in construction waste should be reviewed. Due to the low density of plastics compared to minerals and mass-based balancing, considerable amounts of plastics can be discharged here.
- For the individual product groups, the extent to which a take-back system with subsequent mechanical recycling is advantageous and can contribute to high-quality recycling should be examined.
- Packaging must be collected separately from product waste. The Packaging Act applies, on the one hand (irrespective of the system participation obligation) and the Commercial Waste Ordinance on the other.

7.5 Regulation of additives

The regulation of additives is an important aspect of mechanical recycling. It has two fundamental, contradictory characteristics. On the one hand, the early prohibition of substances of concern is important in order to avoid sites in the system becoming contaminated. These make the later complex and expensive removal of additives necessary, or hinder mechanical recycling. On the other hand, a blanket ban on certain additives can make existing business models and functioning recycling loops impossible. Fact-based decisions based on independent studies of toxicology and migration are important in this context. Both over-regulation and excessively light-handed regulation stand in the way of mechanical recycling in the long term. Germany and the EU should further build on their pioneering progress in this area. From the point of view of the manufacturing industry, planning security is also important.

7.6 Enabling price competition among recyclates

Recyclates must compete against virgin material, for which many costs are externalized. In the existing system, the price difference between recyclates and virgin material is not large enough to justify the use of the former from an economic perspective. The following approaches could conceivably counter this imbalance:

- From this point of view, the introduction of a recyclate quota has several positive effects. Firstly, the mandatory recycled content in the production volume can be decoupled from competition with virgin material. This guarantees resource and environmental protection and prevents price from being used as the main criterion for the selection of materials. On the other hand, the recyclate quota creates a stable demand, which enables investments in sorting and processing technology. The recyclate quality increases, the production costs decrease, and a “spill-over” effect becomes possible, whereby in the long run, recyclates are used in larger proportions than mandated by the quota. The additional production costs on the part of manufacturers for production with recyclates are also lower, as entry hurdles such as the purchase of recyclates or production processes using them will already have been overcome and additional expenses can be reduced in this manner.
- Internalization of the environmental costs of virgin material would improve its price-competitiveness. Assuming a cost of at least 180 EUR per ton of CO_2, as recommended by the UBA, recycled plastic is more price-competitive as a function of its lower greenhouse gas emissions (Federal Environment Ministry 2019: 9). Depending on the plastic, a price increase in the lower double-digit percentage range can be expected for virgin material.
- Other measures addressed in this chapter, such as design-for-recycling, cleaner waste streams, or promotion of a recycling infrastructure, can also be assumed to exert a positive impact on the price difference between virgin and recycled materials.

7.7 Further measures

The following additional measures are recommended:

- Promoting the establishment of a viable recycling infrastructure is already being practiced and can contribute to high-quality mechanical recycling, such as by integrating new technologies.
- Create a basis for decision-making. In order to be able to make targeted decisions, an appropriate database is required in many instances. This is only possible in some domains,

however, as was shown in chapters 2 and 6. The collection of corresponding data in aggregated form should be promoted by the government.

- Recycling material from the construction industry still comprises very small quantities at present. As a higher volume of construction waste is to be expected in the future, genuine closed-loop recycling, i.e., "construction product to construction product," should nevertheless be sought, rather than diverting waste from other product cycles and only making it usable following elaborate processing steps and the insertion of additives.
- Comparatively high reuse rates of recyclates have been achieved in the case of PVC and window profiles by the Rewindo take-back system. For building products made of plastic, for which an increasing volume of waste is expected in the future, similar take-back systems should be sought and their economic viability assessed.
- If, for reasons of low quantity availability, waste from the construction sector cannot be reused for the manufacturing of the same product (e.g., pipe-to-pipe), efforts should be made to utilize these materials for other construction products. Especially in the case of products that do not require proof of usability in accordance with Part D of the Model Administrative Rules on Technical Building Regulations and for which there are no recognized rules of technology, there is still great potential for increasing the use of recycled materials.

The results were discussed with experts with different viewpoints and perspectives on the recycling of plastic construction products. It became clear once again that these plastics represent a particular challenge for recycling due to their long service lives and the difficulty of separating waste streams. However, due to the high and increasing quantities, they nevertheless exhibit much relevance for environmental and climate protection. In addition, the enormous challenge posed by the system changing from a linear structure to a circular economy was emphasized, as it entails the transformation of the entire value chain. Apart from factors of technical and economic feasibility, this also requires a cultural change. On the part of the plastics industry, old routines must be displaced, business models adapted and, in some cases, existing functioning business relationships reformulated. At the same time, a fundamental rethink must also take place on the part of consumers if the change is to be successful. Recyclates must be recognized as being a material of equal value. Another prerequisite for the transformation is thus close cooperation between all of the actors involved. On the one hand, this cooperation must take place along the value chain, in order that transparency and so trust are created with respect to the quality and origin of the materials. The standardized, digital transfer of information and data along the value chain will be important for this, but here too the long useful life of building products poses a challenge. Design for recycling was also identified as another important component within the value chain, and should be addressed as far as possible in coordination between market participants. The cooperation of politics and authorities with the industry was named as a further key area of collaboration. A form of regulation in favor of superior recycling is seen as necessary and positive by many different actors. However, it is important for change to take place within the bounds of what is possible, for major changes to be introduced gradually, and for companies to be involved or supported in implementing them. Here, too, it became apparent that measures such as a recyclate quotas should be codified at the European level. Moreover, the consistent implementation of "Green Procurement" is required in order to establish viable markets for recyclates.

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A Appendix – List of Products

Level 1	Level 2	Level 3	Level 4	Plastic type	Building standards
Pipes	Pipes and shafts	Piping systems (non-flexible)	Piping systems (non-flexible) made of rigid polyvinyl chloride	PVC-U	DIN EN 1329; DIN EN 1401; DIN EN 13598; DIN EN 1453; DIN EN 13476
			Piping systems (non-flexible) made of polypropylene	PP	DIN EN 1451; DIN EN 13598; DIN EN 13476
			Piping systems (non-flexible) made of acrylonitrile-butadiene styrene	ABS	DIN EN 1455
			Piping systems (non-flexible) made of styrene-copolymer blends	SAN, PVC	DIN EN 1565
			Piping systems (non-flexible) made of chlorinated polyvinyl chloride	PVC-C	DIN EN 1566
			Piping systems (non-flexible) made of polypropylene with mineral additives	PP-MD	DIN EN 14758
			Piping systems (non-flexible) made of polyethylene	PE	DIN EN 13478; DIN EN 12666; DIN EN 13598; DIN EN 13476
			Piping systems (non-flexible) made of HD polyethylene	PE-HD	DIN EN 12666; DIN EN 1519
			Piping systems (non-flexible) made of glass fiber reinforced polyester resin	UP-GFPR	DIN EN 14364; DIN EN 15383
			Piping systems (non-flexible) made of polyester resin	UP	DIN EN 14636; DIN EN 15383
		Piping systems (flexible)	Piping systems (flexible) made of polyvinylidene fluoride	PVDF	n/a
			Piping systems (flexible) made of polyethylene	PE	
			Piping systems (flexible) made of HD polyethylene	PE-HD	
			Piping systems (flexible) made of soft polyvinyl chloride	PVC-P	
			Piping systems (flexible) made of polypropylene	PP	
			Piping systems (flexible) made of polyurethane	PUR	

			Piping systems (flexible) made of polybutene	PB	
			Piping systems (flexible) made of polyamide	PA	
			Piping systems (flexible) made of cross-linked polyethylene	PE-Xa	
		Shafts	Access/inspection chambers made of glass fiber-reinforced polyester resin	UP-GFPR	DIN EN 15383
			Access/inspection chambers made of polyester resin	UP	DIN EN 14636
			Entry/inspection chambers made of unplasticized polyvinyl chloride	PVC-U	DIN EN 13598
			Polypropylene access/inspection chambers	PP	
			Access/inspection chambers made of polyethylene	PE	
			Polycarbonate cable ducts	PC	n/a

Insulation/isolation	Insulation materials	Thermal insulation	Thermal insulation materials made of expanded polystyrene	EPS	DIN EN 13163; DIN EN 14309; DIN EN 14933
			Thermal insulation materials made of extruded polystyrene	XPS	DIN EN 13164; DIN EN 14934; DIN EN 14307
			Thermal insulation materials made of polyurethane	PUR	DIN EN 13165; DIN EN 14315; DIN EN 14318; DIN EN 14319; DIN EN 14320; DIN EN 14308
			Thermal insulation materials made of phenolic resin rigid foam	PF	DIN EN 13166; DIN EN 14313
			Thermal insulation materials made of flexible elastomer foam	FEF	DIN EN 14304
			Thermal insulation materials made of polyethylene foam	PEF	DIN EN 14313
			Sandwich elements for thermal insulation	EPS	DIN EN 14509
			Sandwich elements for thermal insulation	XPS	DIN EN 14509

			Sandwich elements for thermal insulation	PUR	DIN EN 14509
			Sandwich elements for thermal insulation	PF	DIN EN 14509
			Polyurethane foam plastics (spray/in-situ foams)	PUR	DIN 18159
			Foam plastics (sprayed/in-situ foams) based on urea-formaldehyde	UF	DIN 18159
		Sound insulation	Footfall sound insulation made of polyethylene foam foil	PE	n/a
			Footfall sound insulation made of expanded polystyrene	EPS	
			Footfall sound insulation made of extruded polystyrene	XPS	

Profiles	Windows and doors	Windows	Polyurethane window profiles	PUR	DIN EN 14351; DIN EN 16034; DIN 18056
			Window profiles made of polyvinyl chloride	PVC	
			Window profiles made of polyamide	PA	
			Window profiles made of glass fiber-reinforced plastic	GFRP	
		Doors	Doors made of polyvinyl chloride	PVC	DIN EN 16034; DIN EN 14351
			Doors made of glass fiber-reinforced plastic	GFRP	
		Rolling shutters	Shutters made of polyvinyl chloride	PVC	RolladKästRL 2016-07
	Other profiles	Building profiles (drywall profiles, handrails, skirting boards, etc.)	Building profiles made of hard polyvinyl chloride	PVC-U	n/a
			Building profiles made of soft polyvinyl chloride	PVC-P	
			Building profiles made of glass fiber reinforced plastic	GFRP	
			Building profiles made of polypropylene and ethylene-propylene-diene rubber	PP, EPDM	
			Building profiles made of polypropylene	PP	
			Building profiles made of polyethylene	PE	

Others	Waterproofing material	Bitumen sheeting/shingles	Elastomer bitumen sheet with reinforcing inserts made of polyester fleece	Bitumen, Polyester	DIN SPEC 20000-201 up to 203; DIN EN 13707; DIN 52129; DIN EN 534; DIN EN 544; DIN EN 13970; DIN EN 14695; DIN EN 14967.
			Plastomer bitumen sheet with reinforcing inserts made of glass fabric	Bitumen	
			Plastomer bitumen sheet with reinforcing inserts made of glass fleece	Bitumen	
			Plastomer bitumen sheet with combined reinforcing inserts made with predominant glass content	Bitumen, Polyester	
			Plastomer bitumen sheeting with combination carrier layer with predominantly polyester content	Bitumen, Polyester	
			Plastomer bitumen sheet with reinforcing inserts made of metal-plastic composite	Bitumen, Polyester	
		Polymer bitumen sheets/shingles	Combination elastomer/plastomer bitumen sheet with reinforcing inserts made of polyester nonwoven	Elastomer bitumen, Polyester	
			Combination elastomer/plastomer bituminous sheeting with reinforcing inserts made of glass fabric reinforcement	Elastomer bitumen	
			Combination elastomer/plastomer bituminous sheeting with reinforcing inserts made of glass fleece	Elastomer bitumen	
			Combination elastomer/plastomer bitumen sheet with combined reinforcing inserts made with predominant glass content	Elastomer bitumen, Polyester	
			Combination elastomer/plastomer bitumen sheeting with combined reinforcing inserts made with predominant polyester content	Elastomer bitumen, Polyester	
			Combination elastomer/plastomer bituminous sheet with reinforcing inserts made of metal/plastic composite	Elastomer bitumen, Polyester	

Others	Waterproofing material	Polymer bitumen sheets/shingles	Elastomeric bitumen sheet with reinforcing inserts made of polyester fleece	Elastomer bitumen, Polyester	DIN SPEC 20000-201 up to -203; DIN EN 13707; DIN 52129; DIN EN 534; DIN EN 544; DIN EN 13970; DIN EN 14695; DIN EN 14967
			Plastomer bitumen sheet with reinforcing inserts made of glass fabric	Plastomer bitumen	
			Plastomer bitumen sheet with reinforcing inserts made of glass fleece	Plastomer bitumen	
			Plastomer bitumen sheet with combined reinforcing inserts with predominant glass content	Plastomer bitumen, Polyester	
			Plastomer bitumen sheeting with combined reinforcing inserts with predominantly polyester content	Plastomer bitumen, Polyester	
			Plastomer bitumen sheet with reinforcing inserts made of metal-plastic composite	Plastomer bitumen, Polyester	
			Combination elastomer/plastomer bitumen sheet with reinforcing inserts made of polyester nonwoven	Elastomer bitumen, Plastomer bitumen, Polyester	
			Combination elastomer/plastomer bituminous sheeting with reinforcing inserts made of glass fabric	Elastomer bitumen, Plastomer bitumen	
			Combination elastomer/plastomer bituminous sheeting with reinforcing inserts made of glass fleece	Elastomer bitumen, Plastomer bitumen	
			Combination elastomer/plastomer bitumen sheet with combined reinforcing inserts with predominant glass content	Elastomer bitumen, Plastomer bitumen, Polyester	
			Combination elastomeric/plastomeric bituminous sheeting with combined reinforcing inserts with predominantly polyester content	Elastomer bitumen, Plastomer bitumen, Polyester	
			Combination elastomeric/plastomeric bituminous sheet with reinforcing inserts made of metal/plastic composite	Elastomer bitumen, Plastomer bitumen, Polyester	

Others	Waterproofing material	Plastic/elastomer sheeting	Plastic sheeting made of ethylene copolymer bitumen	ECB	DIN SPEC 20000-201 to -202; DIN EN 13967; DIN EN 13859; DIN EN 13956; DIN EN 13984; DIN EN 14909
			Plastic sheeting made of ethylene-vinyl acetate copolymer	EVAC	
			Plastic sheeting made of polyethylene	PE	
			Plastic membrane made of polypropylene	PP	
			Plastic membrane made of polyisobutene	PIB	
			Plastic sheeting made of polyvinyl chloride	PVC	
			Plastic sheeting made of thermoplastic elastomer	TPE	
			Plastic web made of ethylene-propylene-diene terpolymer	EPDM	
			Plastic sheeting (with glass nonwoven insert, reinforcement or lamination) made of ethylene copolymer bitumen	ECB	
			Plastic membrane (with glass fleece insert, reinforcement or lamination) made of ethylene-vinyl terpolymer/copolymer	EVAC	
			Plastic membrane (with glass fleece insert, reinforcement or lamination) made of polyethylene	PE	
			Plastic sheeting (with glass mat reinforcement or lamination) made of polypropylene	PP	
			Plastic web (with glass fleece insert, reinforcement or lamination) made of polyisobutene	PIB	
			Plastic sheeting (with glass fleece insert, reinforcement or lamination) made of polyvinyl chloride	PVC	
			Plastic sheeting (with glass fleece insert, reinforcement or lamination) made of thermoplastic elastomer	TPE	
			Plastic sheet (with glass fleece insert, reinforcement or lamination) made of ethylene-propylene-diene terpolymer	EPDM	

Others	Waterproofing material	Geosynthetic waterproofing membranes	Geosynthetic plastic sheeting made of HD polyethylene	PE-HD	DIN EN 15382; DIN EN 13361; DIN EN 13362; DIN EN 13491 to 13493; DIN EN 13249; DIN EN 13250 to 13257; DIN EN 13265
			Geosynthetic plastic sheeting made of LLD polyethylene	PE-LLD	
			Geosynthetic plastic sheeting made of VLD polyethylene	PE-VLD	
			Geosynthetic plastic sheeting made of plasticized PVC	PVC-P	
			Geosynthetic clay liner made of polyethylene with bentonite component	PE	
			Geosynthetic clay geomembrane made of polypropylene with bentonite component	PP	
		Liquid plastic waterproofing	Liquid plastic waterproofing made of polymethyl methacrylate	PMMA	Only requires a general test certificate from the building authorities in accordance with § 19, para. 1, sentence 2, MBO
			Liquid plastic waterproofing made of unsaturated polyester resins	UP	
			Liquid plastic waterproofing made of polyurethane	PUR	
		Elastomer seals	Elastomer pipeline seals made of acrylonitrile butadiene rubber	NBR	DIN EN 681; DIN EN 682
			Elastomer pipe seals made of ethylene-propylene-diene rubber	EPDM	
			Elastomer pipeline seals made of chloroprene rubber	CR	
			Elastomer pipeline seals made of chlorosulfonated polyethylene	CSM	
			Elastomeric pipeline seals made of fluororubber	FKM	
			Elastomer pipeline seals made of silicone rubber	VQM	

Others	Flooring	Sports floors	Sports floors (indoor) made of polyurethane	PUR	DIN EN 14904
			Sports floors (indoor) made of polyvinyl chloride	PVC	
			Sports floors (outdoor) made of polyurethane and ethylene-propylene-diene rubber	PUR, EPDM	
			Sports floors (outdoor) made of polypropylene (interspersing of EPDM/SBR granules possible)	PP, EPDM	
			Sports floors (outdoor) made of polyethylene (interspersing of EPDM/SBR granules possible)	PE, EPDM	
			Sports floors (outdoor) made of polyamide (interspersing of EPDM-/SBR-granules possible)	PA, EPDM	
		Elastomer flooring	Flooring made of styrene-butadiene rubber and acrylonitrile-butadiene rubber	SBR, NBR	DIN EN 14041
		Industrial flooring	Floor covering made of epoxy resin	EP	
		PVC flooring	Heterogeneous flooring made of polyvinyl chloride	PVC	DIN EN ISO 10581; DIN EN 650; DIN EN 651; DIN EN 652; DIN EN ISO 26986; DIN EN ISO 10595
			Homogeneous flooring made of polyvinyl chloride	PVC	
		Textile flooring	Polyamide textile flooring	PA	DIN EN 14041
			Polypropylene textile flooring	PP	
			Textile flooring made of polyethylene terephthalate	PET	
			Textile flooring made of a composite of polyamide, polypropylene and/or polyethylene terephthalate	PA, PP, PET	

Others	Electrical installation/material	Cables, wires	Cable insulation/sheathing made of polyvinyl chloride	PVC	DIN EN 50575
			Cable insulation/sheathing made of LD polyethylene	PE-LD	
			Cable insulation/sheathing made of HD polyethylene	PE-HD	
			Cable insulation/sheathing made of polyurethane (PUR)	PUR	
			Cable insulation/sheathing made of polyamide	PA	
			Cable insulation/sheathing made of polytetrafluoroethylene	PTFE	
			Cable insulation/sheathing made of fluoroethylene propylene	FEP	
			Cable insulation/sheathing of ethylene tetrafluoroethylene	ETFE	
			Cable insulation/sheathing made of perfluoroalkoxy	PFA	
			Cable insulation/sheathing made of chloroprene rubber	CR	
			Cable insulation/sheathing made of silicone rubber	SI	
			Cable insulation/sheathing made of ethylene vinyl acetate	EVA	
			Cable insulation/sheathing made of ethylene-propylene-diene rubber	EPDM	
			Cable insulation/sheathing made of thermoplastic elastomer	TPE	
		Power sockets, switches	Power sockets, switches made of polycarbonate	PC	Does not require a certificate of usability according to § 17, para. 3, MBO
			Power sockets, switches made of polyester resin	UP	

		Fixed installations	Fire alarms made of polycarbonate	PC	DIN EN 54
			Smoke detectors made of polycarbonate	PC	DIN EN 14604; DIN EN 54-7
			Traffic management systems made of polycarbonate	PC	DIN EN 12352

Others	Stationary containers/tanks	Containers	Drinking water storage tanks made of polyethylene	PE	n/a
			Drinking water storage tanks made of polypropylene	PP	
			Other storage tanks made of glass fiber-reinforced plastics	GFRP	
		Tanks	Stationary tanks made of polyethylene	PE	DIN EN 13341
			Stationary tanks made of polyamide	PA	
			Stationary tanks made of glass fiber reinforced plastics	GFRP	
	Films, fleeces and textiles (for purposes other than the waterproofing of buildings)	Films	Films made of polyethylene	PE	n/a
			Films made of LD-polyethylene	PE-LD	
			Films of HD polyethylene	PE-HD	
			Films made of ethylene-vinyl acetate copolymers	EVA	
			Films made of polyethylene and ethylene-vinyl acetate copolymers	PE, EVA	
			Films made of polyvinyl acetate	PVC	
			Films made of polyamide	PA	
		Fleeces	Fleeces made of polypropylene	PP	
			Fleeces made of polyester	PES	
			Fleeces made of polyester with polyurethane coating	PES, PU	
		Nets	Nets made of polyethylene	PE	
			Nets made of HD polyethylene	PE-HD	
			Nets made of polyamide	PA	
			Nets made of polypropylene	PP	
	Sanitary equipment	Flushing cisterns	Flushing cisterns made of polyvinyl chloride	PVC	DIN EN 14055
			Flushing cisterns made of polystyrene	PS	
			Flushing cisterns made of acrylonitrile-butadiene-styrene copolymer	ABS	

		Bath/shower tubs	Bathtubs made of polymethyl methacrylate	PMMA	DIN EN 14516; DIN EN 12764
			Shower trays made of polymethyl methacrylate	PMMA	DIN EN 14527; DIN EN 12764
		Others (sanitary equipment)	Odor traps made of polyethylene	PE	DIN 19541; DIN EN 997
			Odor traps made of polypropylene	PP	
			Drains made of polypropylene	PP	DIN EN 1253
			Drains made of polyethylene	PE	
			Drains made of hard polyvinyl chloride	PVC-U	
			Toilet-connecting components made of HD polyethylene	PE-HD	DIN 1389
			Toilet fittings made of polypropylene	PP	
			Toilet lids made of polyester resin	UF	n/a
			Toilet lids made of polypropylene	PP	

Others	Plates and panels	Panels (except insulation panels)	Plastic sheets made of polyvinyl chloride	PVC	DIN EN 1013; DIN EN 13830; DIN EN 14428
Others	Plates and panels	Panels (except insulation panels)	Plastic sheets made of unplasticized polyvinyl chloride	PVC-U	DIN EN 1013; DIN EN 13830; DIN EN 14428
Others	Plates and panels	Panels (except insulation panels)	Plastic sheets made of polycarbonate	PC	DIN EN 1013; DIN EN 13830; DIN EN 14428
Others	Plates and panels	Panels (except insulation panels)	Plastic sheets made of polymethyl methacrylate	PMMA	DIN EN 1013; DIN EN 13830; DIN EN 14428
Others	Plates and panels	Panels (except insulation panels)	Plastic sheets made of glass fiber reinforced plastics	GFRP	DIN EN 1013; DIN EN 13830; DIN EN 14428
Others	Other products for gardening and landscaping	Fence systems	Garden fences made of polyvinyl chloride	PVC	n/a
Others	Other products for gardening and landscaping	Design objects	Benches and tables made of polyolefin blends	PP, PE	n/a
Others	Other products for gardening and landscaping	Design objects	Benches and tables made of polyolefin blends	PP, PE	n/a
Others	Other road construction products	Glare/noise control systems	Anti-glare systems for roads made of HD polyethylene	PE-HD	DIN EN 12676
Others	Other road construction products	Glare/noise control systems	Noise barriers for roads made of polypropylene and polyethylene	PP, PE	DIN EN 14388
Others	Other road construction products	Guidance systems	Traffic cones made of soft polyvinyl chloride	PVC-P	n/a
Others	Other road construction products	Guidance systems	Traffic cones made of polyethylene	PE	n/a
Others	Other road construction products	Guidance systems	Delineators made of HD polyethylene	PE-HD	n/a
Others	Other road construction products	Guidance systems	Traffic cones made of polypropylene	PP	n/a
Others	Other road construction products	Light poles	Light poles made of fiber-reinforced polymer composite material	GFRP	DIN EN 40-7
Others	Other road construction products	Asphalt reinforcement	Asphalt reinforcement grid made of polypropylene	PP	n/a

Others	Other construction products	Dowels, screw fittings	Plastic dowels made of polyamide	PA	ETAG 020
			Plastic dowels made of polypropylene	PP	
			Plastic dowels made of polyethylene	PE	
			Screw fittings made of polyvinyl chloride	PVC	List hEN, Reference number 180022-00-0704
			Screw fittings made of polyamide	PA	
			Screw fittings made of polypropylene	PP	
		Joint tapes	Joint tapes made of styrene-butadiene rubber	SBR	DIN 7865
			Joint tapes made of ethylene-propylene-diene rubber	EPDM	
			Joint tapes made of chloroprene rubber	CR	
			Joint tapes made of polyvinyl chloride and acrylonitrile-butadiene rubber	PVC, NBR	DIN 18541
			Joint tapes made of plasticized polyvinyl chloride	PVC-P	
			Joint tapes made of polyethylene	PE	
		Gratings	Plastic gratings made of glass fiber-reinforced polyester resin	UP-GFRP	DIN 24537-3
		Drains	Drainage mats/grids made of polyvinyl chloride	PVC	n/a
			Drainage mats/grids made of polypropylene	PP	
			Drainage mats/grids made of HD polyethylene	PE-HD	
			Drainage mats/grids made of HD polyethylene and polypropylene	PE-HD, PP	
		Drainage channels	Drainage channels made of polyvinyl chloride	PVC	n/a
			Drainage channels made of polypropylene	PP	
			Drainage channels made of HD polyethylene	PE-HD	
			Drainage channels made of glass fiber reinforced plastic	GFRP	

		Bearings, cylinders, coils	Bearings made of polytetrafluoroethylene	PTFE	List hEN, reference number 050013-00-0301
		Fittings	Fittings made of polyamide	PA	DIN EN 14846; DIN EN 179; DIN EN 1125; DIN EN 1154; DIN EN 1155; DIN EN 1158
			Fittings made of fiber-reinforced plastics	GFRP	
Others	Others construction products	Light domes	Skylight domes made of glass fiber reinforced polyester resin	UP-GFRP	DIN EN 1873
			Skylight domes made of polyvinyl chloride	PVC	
			Skylight domes made of polymethyl methacrylate	PMMA	
			Skylight domes made of polycarbonate	PC	
			Skylight domes made of styrene-acrylonitrile copolymer	SAN	
			Skylight domes made of acrylonitrile-butadiene-styrene copolymer	ABS	
			Skylight domes made of glycol-modified polyethylene terephthalate	PETG	
		Roof lighting bands	Roof lighting bands made of glass fiber-reinforced polyester resin	UP-GFRP	DIN EN 14963
			Roof lighting bands made of polyvinyl chloride	PVC	
			Roof lighting bands made of polycarbonate	PC	
			Roof lighting bands made of polymethyl methacrylate	PMMA	
			Roof lighting bands made of glycol-modified polyethylene terephthalate	PETG	
			Roof lighting bands made of styrene-acrylonitrile copolymer	SAN	
			Roof lighting bands made of acrylonitrile-butadiene-styrene copolymer	ABS	
		Skylight frames	Skylight frames (e.g., for skylight domes, light strips) made of glass fiber-reinforced polyester resin (UP-GFRP)	UP-GFPR	DIN EN 1873; DIN EN 14963

			Skylight frames (e.g., for skylight domes, light strips) made of polyvinyl chloride	PVC	

Thermoplastics
Thermosets
Elastomers
Bitumen
Composites

B List of relevant regulations

The following is a list of the laws and regulations cited in this report:

- Regulation (EC) No. 1907/2006 of the European Parliament and Council from December 18, 2006 concerning the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No. 793/93 and Commission Regulation (EC) No. 1488/94, as well as Council Directive 76/769/EEC and Commission directives: 91/155/EEC, 93/67/EEC, 93/105/EC, and 2000/21/EC
- Commission Regulation (EC) No. 282/2008 from 27 March, 2008 on recycled plastic materials and articles intended to come into contact with food and amending Regulation (EC) No 2023/2006
- Commission Regulation (EU) No. 10/2011 from 14 January, 2011 on plastic materials and articles intended to come into contact with foodstuffs
- Regulation (EU) No. 305/2011 of the European Parliament and Council from 9 March, 2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC
- Commission Regulation (EU) No. 494/2011 from May 20, 2011, amending Regulation (EC) No. 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) as concerns Annex XVII (cadmium)
- Directive 2011/65/EU of the European Parliament and Council from June 8, 2011, on the restriction of the use of certain hazardous substances in electrical and electronic equipment
- Regulation (EU) 2019/1021 of the European Parliament and Council from June 20, 2019, on persistent organic pollutants (recast)
- Act Governing the Sale, Return and Environmentally Sound Disposal of Electrical and Electronic Equipment
- Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal
- Act on the Sale, Take-Back and High-Quality Recycling of Packaging
- Regulation on the European Waste List
- Regulation on the Management of Commercial Municipal Waste and Certain Construction and Demolition Waste
- State building codes: State Building Code for Baden-Württemberg , Bavarian Building Code, Building Code for Berlin, Brandenburg Building Code, Bremen State Building Code, Hamburg Building Code, Hesse Building Code, Mecklenburg-Western Pomerania State Building Code,

Lower Saxony Building Code, Building Code for the State of North Rhine-Westphalia – State Building Code, Rhineland-Palatinate State Building Code, Saxony Building Code, Saxony-Anhalt State Building Code, Schleswig-Holstein State Building Code, Thuringia Building Code

- TRGS 905, Technical Rules for Hazardous Substances – List of carcinogenic, germ cell mutagenic, or reprotoxic substances
- Model Administrative Regulation for Technical Building Regulation