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Summary



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# Mapping of the anthropogenic stock in Germany for optimizing the secondary raw material economy

## Summary

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## Summary


### Mapping the anthropogenic material stock in Germany in order to optimize the use of secondary raw materials

One of the greatest economic, social and ecological challenges of our time is to ensure an efficient consumption of natural resources in order to preserve the natural environment. This aim is increasingly gaining prominence on the national and international political agendas. Efforts in Europe have led to the drawing up in 2011 of a Road Map for a "Resource Efficient Europe". The German government has also made progress in meeting these challenges by setting up its own resource efficiency programme, "ProgRess". Here the main aim is to reduce the consumption of natural resources, thereby protecting against environmental damage and pollution while maintaining living standards and potentials for further development. One important aspect of resource efficiency is to expand the opportunities for the recycling of materials.

### Project aims

Germany has accumulated an enormous wealth of buildings, infrastructures and other durable goods. This constitutes a valuable reservoir of secondary raw materials – an anthropogenic material stockpile. It should be understood as representing a capital reserve for the future, which must be systematically managed.

This capital reserve has so far been largely ignored in the basically input-dominated discussion on resource efficiency. This can be attributed in part to the insufficient body of knowledge on the size and composition of this material stockpile as well as how it changes over time. The project entitled "Mapping the Anthropogenic Material Stockpile in Germany in Order to Optimize the use of Secondary Raw Materials" (KartAL) is intended to greatly expand the knowledge base in this regard. Here "mapping" is used in the rather loose ecological sense to describe the capturing of objects by means of specific features (creating inventories) within a defined area. The area of observation in the current project is Germany.

The current report summarizes the results of the KartAL-I[2] project. The primary aim, as described, of expanding the knowledge base, was realized by creating the groundwork for a continuously updated data bank model of the anthropogenic material stockpile, allowing us to determine the potential for secondary raw materials contained in durable goods and buildings. The research encompassed:

- estimating the size and composition of the current anthropogenic stockpile of raw materials in Germany in the form of buildings, infrastructures and selected durable goods as well as
- analyzing data sources and indicators in order to describe trends in the size and composition of the anthropogenic stock


[2] The project is part of a long-term research endeavour "KartAL", which aims to understand, systematically analyze and manage the anthropogenic material stockpile as the capital reserve of the future. KartAL-I is the first project in this endeavour.

### Objects of investigation and analytical approach

The project looked at material flows and material stocks of durable goods in the Federal Republic of Germany, specifically:

- structures that are part of the technical infrastructure,
- buildings (residential and non-residential),
- building services,
- capital goods and
- durable consumer goods.

Diverse analytical approaches were applied and combined. On the one hand, it was investigated whether general economic data could provide sufficiently precise base data for the calculation of material flows and the material stockpile of durable goods. Such investigations can be described as following a top-down approach. A second approach was to undertake analysis at the level of individual objects. Here goods-based material indicators were developed to describe durable goods, and these applied to data on durable goods to permit an estimation of the total stock of each good and changes to this stock. This created the foundation for estimations of anthropogenic material stockpiles as well as material flows. Such methods can be described as following a bottom-up approach. Both approaches were then combined to create a Multi-level Material Flow Model (MMFM).

### Multi-level material flow model as an analytical tool

The multi-level material flow model (MMFM) can be used to analyse and illustrate material inflows to and outflows from the anthropogenic material stockpile as well as flows within the stockpile itself and indeed its material composition. The MMFM should be understood as an analytical model to help structure the research, whereby three levels of analysis must be distinguished. These levels apply different analytical methods (top-down and bottom-up) to diverse data sources. Analyses of material flows (MFA) and of waste material are carried out and combined for each of these layers. Material flow analyses model the material flow of goods. Waste analyses look at the various ratios of waste materials, thus pursuing an entirely different form of classification, which therefore cannot be directly compared to stockpiles of materials and goods.

Analysis Level 1 of the MMFM follows a top-down approach, using in particular data from the *Umweltökonomische Gesamtrechnung* (UGR) (System of Integrated Environmental and Economic Accounting). This method can be used to describe, distinguish and quantify the main input and output flows of the stockpile. The picture is supplemented by an estimate of waste material flows that occur outside the anthropogenic stockpile. There are some obvious limits to the detail specification of material flows using the employed data. Thus only the main material groups and categories of stockpile inputs and outputs can be determined. At Analysis Level 1 we also consider the degree to which basic economic data can be used to define not only material flows but also the actual material stockpile. This is achieved through observation of the growth in the net stockpile over a period of 50 years.

Analysis Level 2 of the MMFM attempts to remedy the deficiencies of Analysis Level 1, i.e. the limited ability to distinguish material flows according to material type as well as goods. A top-down approach is followed in Level 2. In addition to the analysis of input and output flows of the stockpile according to material type, MFA and waste analysis at Level 2 focus on the determination of flows in the anthropogenic material stockpile.

The object-based bottom-up analyses of Analysis Level 3 provide a higher degree of freedom regarding the description of flows as well as the description of material stockpiles. The approach here is to make quantitative estimations using material codes for specific groups of goods. The basic unit is the individual good or homogenous group of goods. Goods baskets are considered, which inevitable leads to data gaps.

The various analyses in the three levels are combined in the MMFM in order to qualify and validate results. Disparities can be discerned and patterns of explanation considered in the framework of this synthesis. This constitutes a useful foundation to improve the interpretation of data and to formulate a concept to capture the anthropogenic material stockpile.

### Definitions and system boundaries

Germany's anthropogenic material stockpile is defined according to the economic system proposed by the *Umweltökonomische Gesamtrechnung* (UGR). The following input and output flows are considered:

- domestic extraction,
- imports to Germany,
- exports to foreign countries as well as
- domestic disposal of material into the natural environment.

The focus is on flows and stockpiles that are linked to durable goods, or which illustrate their input and output flows. These are to be distinguished from nondurable goods such as foodstuffs or fossil fuels. An exception is made for residual materials from combustive processes, such as ash and slag, which can be considered as additional input material flows. The analysis is based on data for the reference year 2010.

### Results of analysis of material flows into and out of the stockpile (Analysis Level 1)

*Net Additions to Stock*

The parameter Net Additions to Stock (NAS) of the UGR can be reasonable interpreted as the growth in the anthropogenic stockpile of durable goods. Using data from the UGR it was possible to calculate the annual NAS of anthropogenic stock in the period 1960 to 2010.

In this period a total NAS of 42.3 b(illion) tonnes was determined for Germany's anthropogenic stockpile. This implies average growth of 829 m(illion) tonnes per year. For the year 2010 NAS was calculated at 820 m tonnes, which corresponds to a specific Net Additions to Stock for that year of 10 tonnes per resident.

Gaps in the base data in the long period of analysis are the origin of potential inaccuracies in estimations, as are differences in the way data is generated, e.g. the methods used in the calculation of goods combusted and the production of ash and slag. This limits the usefulness of NAS as an indicator of stock growth over the long term.

*Quantitative estimates of input and output flows for 2010*

Basic economic data of the UGR, supplemented by data on exports and data supplied by the Food and Agriculture Organisation (on the extraction of timber) allows us to quantify stockpile-relevant domestic extraction processes as well as flows of material imports and exports. As the import and export of waste materials are not captured in the named data sources, data from the monitoring agency for waste management (export, import and transit) is used instead. Analysis of waste management provides details on disposals into the natural environment, which include waste burned to generate electricity, waste used as backfill as well as waste that is thermally treated. The resulting ash and slag from these and other combustion processes create an additional input flow.

Using this data it is was possible to estimate an input material flow for 2010 at 757.2 m tonnes and an output flow at 227.8 m tonnes. This gives a growth in the material stockpile for 2010 of 529.4 m tonnes. This figure is around 40 % lower than the calculated NAS for that year (820 m tonnes). Likely sources of error behind this disparity are, in particular, the method of determining the NAS (adjustment items).

Domestic extraction constitutes the largest flow of material at 523 m tonnes. Imports and exports of raw materials, half-finished goods as well as building materials, capital goods and durable consumer goods, are much lower, at 185 m tonnes and 174 m tonnes respectively. Disposals into the natural environment and return flows (e.g. ash and slag) are of approximately the same size, contributing 4 % of input and 14 % of output.

Using the base data it is possible to draw a rough picture of the inflows and outflows of the anthropogenic stockpile. This picture can be rendered more precise by introducing waste management data to the material flows. Quantification of the main input and output flows according to the basic material groups is the most that we can achieve using this method. It is not possible using this method to make any further classification according to groups of goods.

**Results of the differentiated analysis of material flows into and out of the stockpile as well as within the stockpile (Analysis Level 2)**

The findings of Analysis Level 1 cannot be broken down according to groups of goods and also do not give any details on the internal dynamics of the material stockpile. This was the aim of the investigations at Analysis Level 2, which makes use of additional, more finely differentiated statistical data on manufacturing and exports as well as non-governmental data, e.g. from trade associations. The accompanying analysis of waste materials makes use of official statistics, supplemented and refined with the results of existing studies and other data sources.

*Material flows of domestic production and exported goods*

In order to transfer statistical data on production and export into the classification system of groups of goods, the data was classified into the following groups: capital goods, consumer goods and building materials (following the pattern adopted by European Statistics). The transformation of stocks of goods into material indicators was achieved in particular through use of the conversion factors of the "economy-wide MFA Questionnaire".

In some cases it proved difficult to classify data to the groups of goods and categories of materials. This undermined the validity of the resulting findings. The problem is particularly noticeable in relation to production data, so that here no clear picture of the details of the anthropogenic material stockpile can be drawn. This deficiency is not true for import and export flows, for which it was possible to differentiate between groups of goods. Classification problems were obviated by the fact that in addition to groups of goods, the import and export of raw materials and half-finished goods are handled separately.

*Input flows to Germany's stock of goods*

In order to mitigate the inherent limitations of the production statistics, the analysis was expanded to include data from trade associations. Data was sought in the form of "input flows to Germany's stock of goods", namely those flows which also increased the stock in the observation year. The validity of the gathered data was determined by comparison with other independent parameters and any disparities found were discussed. In fact, the validation process confirmed the usefulness of the data. The determined input flows therefore form the foundation for the modelling of flows into the stockpile of goods in Analysis Layer 2. Any errors can be attributed to the ignoring of secondary raw material flows, which however are captured by the analysis of waste.

*Waste-related material flows*

In total Germany exports more waste than it imports. In 2006 this export surplus was something in the region of 3 to 5 m tonnes per year. However, the picture is highly differentiated at the level of individual material groups.

The base data for the analysis of waste-related material flows in the material stockpile is borrowed from official statistics. The main aim is to gather details of the amounts of different kinds of waste as well as information on their processing at various waste disposal facilities and the material flows that result from the waste treatment. Some deficiencies in this data are: the sporadic availability and quality over the period of interest, the possibility that waste is double-counted, the specification of stock-relevant waste flows and non-relevant waste flows, as well as a lack of data consistency between the levels of the main waste groups of the European Waste Catalogue. Therefore, waste-related analysis is realized as a succession of analytic steps in order to determine stock-relevant flows of waste material.

Two separate flows must be distinguished within the stockpile of waste materials: storage processes at waste depots as well as the circulation of materials within the stock. Experts estimate that between 1975 and 2005 around 2.5 b tonnes of household waste was deposited in dumps throughout Germany; for 2010 the figure is about 16 m tonnes. This contrasts with the figure of 121 m tonnes of waste-related flows in the anthropogenic material stockpile.

Waste material flows into waste treatment and waste processing facilities. Their task is to identify and reprocess forms of waste that can be sensibly reused and for which there is a viable market, as well as to neutralize materials that could have a harmful impact on society and the environment.

In addition to waste treatment and reprocessing, it is also necessary to consider the waste flow into thermal treatment processes, such as waste incinerators and some power stations. Waste treated in such fashion is initially viewed as an output flow, i.e. material leaving the stockpile. Yet a share of this will be returned in the form of ash and slag, thereby creating an input flow. An estimate of the size of this output and input flow for 2010 is around 33 and 32 m tonnes, respectively.

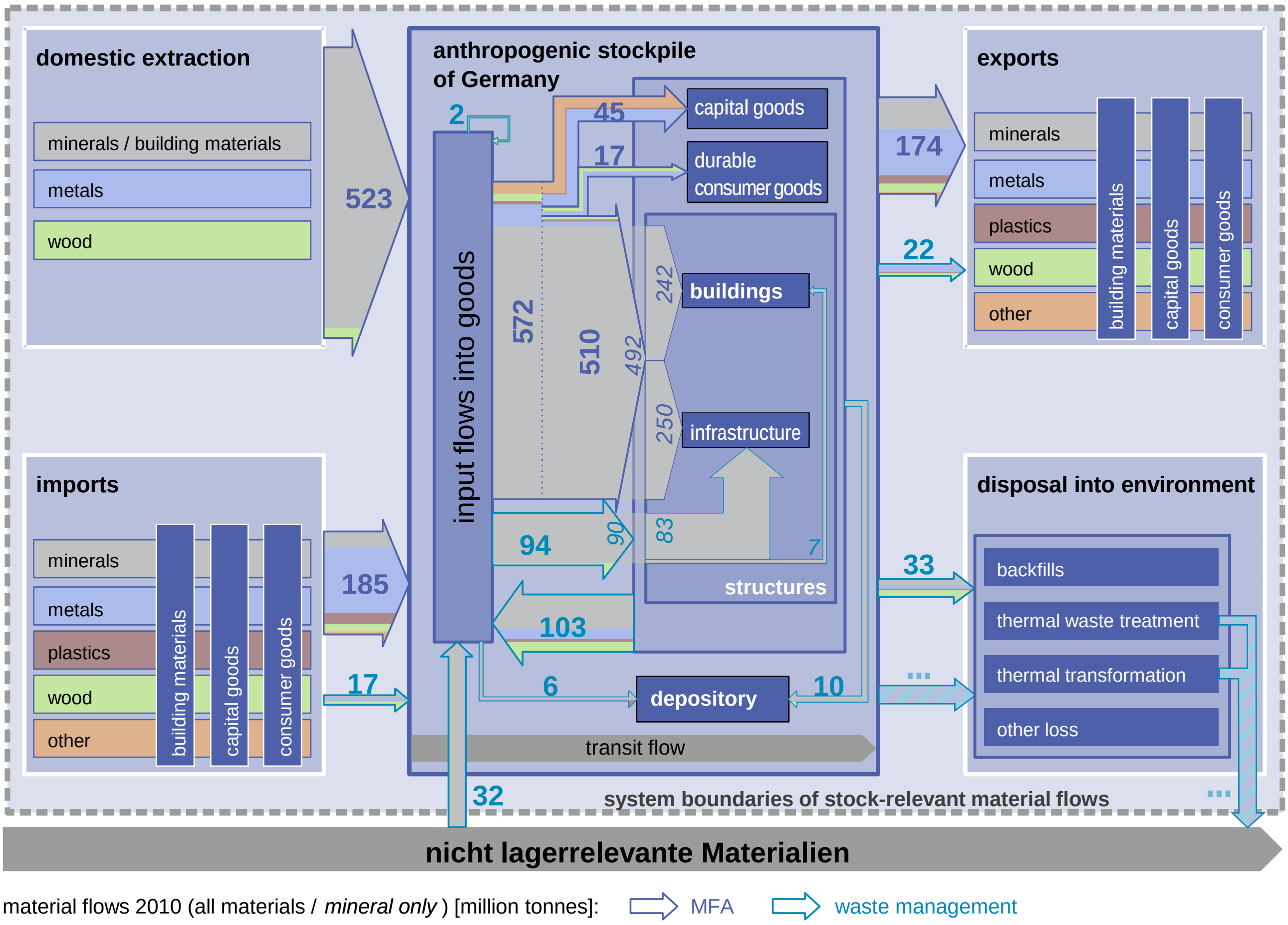
If we balance the waste-related material input and the storage of waste in dumps against the output streams, then more waste is retained that is destroyed, thereby contributing to growth in the anthropogenic material stockpile. In 2010 the figure for the amount of new waste held over the long-term in the stockpile was around 114 m tonnes.

*Top-down analysis of material flows*

The production-related input flow to the stock of goods is made up of the input flow into the stockpile (757 m tonnes) as well as the flows within the stock (105 m tonnes). The total input flow is therefore 860 m tonnes. This leaves a positive difference of 188 m tonnes, which can be interpreted as transit flow through the stock. This direct transit flow lies below the figure for the output flow (227.8 m tonnes + unquantified disposals to the natural environment).

In summary, the results show no obvious inconsistencies. However, there clearly exist disparities between Analysis Level 1 and Analysis Level 2 of the material flow model. It is impossible to increase the consistency of findings using the available base data.

Figure 1: Material flows in the anthropogenic stockpile - Layer 2 of the MMFM (2010), differentiated according to the main material groups [million tonnes]




Source: own illustration

### Calculation of flows and stockpiles (bottom-up)

Bottom-up analyses were carried out to determine the distribution of materials in the following main goods and groups of goods

- Technical infrastructures
- Transport infrastructure (roads, track, domestic shipping, inland water transport, air transport including civil engineering structures and road features such as traffic lights, barriers, etc)
- Drinking water and wastewater infrastructure (pipes, facilities)
- Energy infrastructure (electricity and gas networks, district and local heating grids, power generation facilities)
- ICT infrastructure (data lines, switching centres, data centres and mobile phone facilities)
- Buildings
- Residential buildings (including sealed plot surfaces)
- Non-residential buildings
- Building services
- in residential buildings (heating systems and heat generators, heating and water supply pipe networks, wastewater pipes, radiators, sanitary fittings)
- in non-residential buildings (pipe networks)

- Durable goods
- Durable consumer goods (approx. 30 types: large household appliances, small kitchen devices, consumer electronics, telecommunication devices, computers, vehicles, clothing, jewellery)
- Durable capital goods (estimation of the material content of capital goods using IO analysis)

*Technical infrastructure*

Estimates of the material stockpiles and material flows within Germany's technical infrastructure are based on numerous sub-analyses. Specific material indicators (MI) were developed using literature evaluations and expert assessments for each type of material contained in the observed infrastructures. Suitable units were selected for each of these codes (e.g. $m^2$ road surface or MW power generation). In order to determine the mass of each material, the quantifiers of each infrastructural element were estimated and multiplied by the material indicators.

The same basic approach was adopted for estimates of material flows. However, in this case the data on MIs as well as on changes in the material stock is much more patchy; for this reason it was necessary to turn more frequently to expert estimates and values derived from theoretical models. For 2010 the material stockpiles and flows in the area of technical infrastructure were determined as follows:

Germany's existing transport infrastructure encompasses a material stockpile of around 9.4 b tonnes. While the absolute figure for non-mineral raw materials is higher than for other infrastructures systems at around 58 m tonnes, this is still merely 0.61 % of the total stockpile of raw materials contained within transport infrastructure. The estimate for annual consumption of material for new construction, expansion and renovation is 193 m tonnes. Of this figure, the amount of material for renewal and maintenance is estimated at 165 m tonnes, much greater than that for new construction or expansion (28 m tonnes).

The material stockpile within water and wastewater infrastructures is estimated at 2.29 b tonnes, of which 99 % is mineral-based raw materials. The annual material flows are calculated at 18.4 m tonnes. In contrast to transport infrastructure, the annual material flows within water and wastewater infrastructure are dominated by new construction (17.1 m tonnes). This is due to the expansion of the sewer and drainage network, and the high demand for sand as pipeline bedding. Regarding maintenance, it is assumed that sand for bedding can be reused when pipelines are replaced, and the pipes can be relined rather than replaced.

The material stockpile within infrastructure for energy distribution or generation is estimated at 830 m tonnes. Of this figure, mineral-based raw materials make 771 m tonnes, which is 93 % of the total. Mineral-based raw materials are primarily sand/gravel at 673 m tonnes and concrete at 95 m tonnes, all of which are primarily used for the bedding of pipes and cables. 74 % of concrete is stored in power generation facilities, with the remaining 26 % in distribution networks, mostly in the masts and foundations of overhead lines. There is also a significant stockpile of metallic raw materials, estimated at 45 m tonnes. Annual demand for new material for construction and maintenance is 21 m tonnes. Particularly striking is the high ratio of non-mineral materials, largely plastics and metals, at over 17 %.

The material stock of ICT infrastructure is estimated at a total of 1.93 m tonnes, largely metals and plastics. Of this figure, landline infrastructure contributes 1.69 m tonnes while data centres and mobile phone facilities make up 120,000 tonnes respectively. No annual material flows could be estimated due to the lack of base data.

*Building stock*

The building stock can be divided into residential buildings (RB) and non-residential buildings (NRB). These two sub-groups differ in terms of the degree of heterogeneity and the availability of data, so that diverse analytical methods and procedures were adopted for each case. The method to estimate material stocks and flows is basically the same as that for infrastructure: Determination of MIs and multiplication with data on stock and data on changes to the stock.

Official data is available on the stock of RBs. Based on data from 2010, the total floor area was estimated at 3.57 billion $m^2$. The determination of material stocks and flows for RBs was assisted by the availability of suitable building typologies as well as studies on typical forms of construction.

There exists no statistical data on the stock of NRBs. Data was generated by a newly developed model using as base data the gross fixed assets of structures as indicated in the national accounts system (VGR) and other sources. For 2010 the estimate of the total floor space of non-residential buildings in Germany was approximately 3 billion $m^2$. This estimation made use of existing MIs determined on the basis of assessments of the BKI *(Building Costs Information Centre*) object data bank.

The material stockpile in RBs is calculated at between 8.4 and 9.3 b tonnes; for NRBs the figure is 6.7 b tonnes. This mass is primarily mineral-based building materials. The share of other materials (especially metals, plastics and wood) is 13 % for NRBs, roughly double that of RBs (5 % to 7 %).

In order to investigate material flows the MIs were linked to statistically determined inflow and outflow values. Estimates were also made regarding renovation work. A material input for new construction and renovation in 2010 was estimated at 53 m tonnes for RBs and 67 m tonnes for NRBs. The output for RBs is 20 m tonnes and for NRBs 23 m tonnes. Both building subgroups are currently undergoing a period of additional growth.

It is necessary to point out current gaps in the base data. For example, small outbuildings are not included in the calculated material masses. The same is true of excavated soil and small structures such as walls or railings that indicate plot boundaries.

*Building services*

Building services encompass all technical apparatus of residential buildings, non-residential buildings as well as infrastructural buildings. In this project the latter objects are classified to infrastructure. Similarly, production facilities are not classified as belonging to technical apparatus but rather to capital goods. The group of goods specified as "building services" is here restricted to the services of residential and non-residential buildings. This encompasses heating systems, supply pipes for heating systems, radiators, drinking water and wastewater pipes as well as some sanitary fittings. These are, however, only considered for residential buildings. Due to gaps in the base data and a lack of usable models, the estimation of material mass in building services in non-residential buildings is restricted to the supply and waste disposal pipe networks.

The MIs employed to determine material mass within building services are primarily based on evaluations of manufacturers' specifications. The computational factors used in calculations basically correspond to those for buildings, namely $m^2$ living space or $m^2$ usable floor area. In addition, characteristic values for building services were determined with the help of specific modelling approaches (e.g. m heating pipes per $m^2$ living space). These characteristic values were developed using design guidelines for technical services, especially technical specifications (e.g. heat output) or norms for building services (sanitary equipment).

The material mass of building services within the residential building stock is estimated at 16.5 m tonnes. This corresponds to a small fraction of the total mass contained within buildings. However, as building services are primarily made of metals and plastics, this mass has particular importance for material recycling. The input flow for 2010 was determined at slightly over 0.5 m tonnes, while the output was 0.65 m tonnes. In contrast to the materials used for building construction, here material input is below the output flow. The reason for this is the increasing use of plastics instead of metals, as well as improvements in material efficiency.

In non-residential buildings a material mass of 4.5 m tonnes was determined (only pipe networks). Material flows are 0.08 m tonnes (input) and 0.05 m tonnes (output). The input surplus can be explained by the fact that the substitution of plastic for metal is less pronounced in the building services of non-residential buildings.

The problem of the incomplete goods basket also impacts the area of building services. However, it can be assumed that the majority of material masses and flows in building services is captured by means of the selected base data. The rather sweeping assumptions made in connection with the data model introduce, of course, a degree of modelling uncertainty. Therefore the calculated values serve more as a basic orientation of the size of masses and flows.

*Durable consumer goods*

Estimation of the annual consumption of raw materials for durable consumer goods is made on the basis of life cycle data for around 30 durable household goods. Life cycle data inventories (e.g. the bill of materials for a refrigerator) are multiplied by the annual total of domestically produced and net imported goods in Germany. In general, only one bill of materials is available for a specific product of one category of goods, which serves as a standard for the entire product group.

The estimate of the material mass is realized by two methods: For statistically captured household goods (Income and Consumption Survey, ICS), an estimate of the material mass can be realized by considering the number of households and the provision of household goods. These are particularly household appliances (white goods), consumer electronics, transport items as well as telecommunication devices. For household goods that are not captured in the ICS, estimates of material mass were based on the products' useful life and assumptions of the annual total sales. Such methods were adopted to capture in particular the material mass of small domestic appliances such as toasters or coffee machines.

The total material mass of the selected durable household goods was estimated at 69 m tonnes. Almost 60 % of this consisted of metallic raw materials.  The mass of plastic materials, while highly diverse, is dominated by polypropylene. In addition there are a number of "other materials".

In order to calculate annual flows, estimates were made of the sales and useful lifetime of products. Source data here were production statistics, export statistics as well as currently available data from a representative survey on the useful lifetime of selected goods, carried out on behalf of the Federal Environmental Agency. For 2010 input flows of 4.6 m tonnes were determined for the selected goods basket. The output flow was 7.5 m tonnes. This implies that the material mass of durable goods is decreasing. A feasible explanation for this could be changes in the material composition of goods (from CRT displays to flat screens). It should, however, be pointed out that the figures presented here are rather tentative in view of the comparatively sketchy base data and the rough estimates of input and output flows.

*Durable capital goods*

Currently there is no available base data on durable capital goods (investment goods) upon which to carry out a bottom-up analysis of material masses and flows. We possess neither data on the physical stock of goods nor a typology of investment goods. Therefore an alternative approach was adopted here, in which a subgroup of investment goods was defined that excludes buildings and infrastructures. This corresponds to the category of final usage for "Investments in equipment and other facilities” as defined by the “Volkswirtschaftliche Gesamtrechnung” (VGR) *(German national accounts*). Data on annual changes in the volume of investments in capital goods can be taken from financial input-output tables (IOT) and investment statistics of the Federal Statistical Office “Destatis”. This dataset constitutes the financial counterpart to the annual net material flow.

The mass estimates were realized on the basis of an IOT (expanded to take account of the sectoral material input) and an attribution model based on IO principles. This enabled calculation of the material flows in an iterative process up to the final usage. In a further step the estimated material mass was combined with the corresponding financial flow values in order to determine a physical-financial ratio (the material intensity) for every product group. These represent the material-specific intensities of the observed groups of investment goods, serving as reference values for the calculation of the total material demand for the respective group. This estimate is realized by combining the material intensities from the annual IOTs with financial data regarding the total capital value of equipment and facilities from the VGR.

By making use of the most recent available data on intensities of specific raw materials (from the year 2005), the material mass in stockpile-relevant capital goods can be estimated at 255 m tonnes. This figure can be subdivided into 133.19 m tonnes of mineral-based material, 94.33 m tonnes of metallic material, 18.05 m tonnes of wood and 9.42 m tonnes of other materials. Total material flows of 19 m tonnes could be determined for 2005.

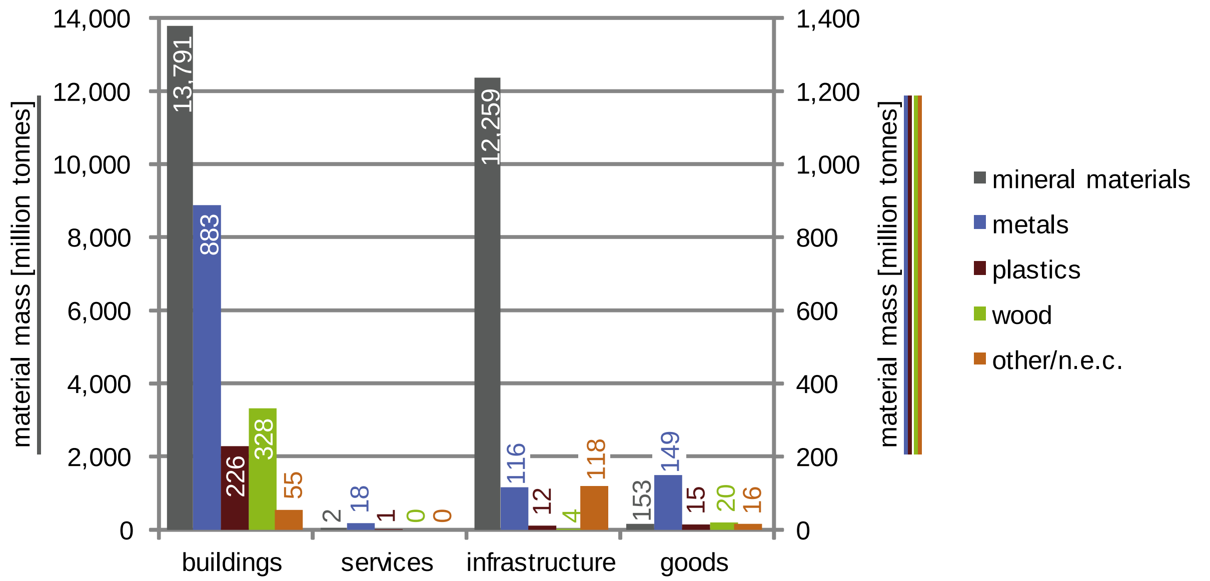
One interesting finding is the obvious drop in material intensity over the years investigated (1995, 2000, 2005). However, it should be pointed out that the underlying base data and the methods used to achieve this finding have not been fully validated. The methods used for calculation are prone to error. Furthermore, the assumption that product groups are homogenous is an over-simplification.

*Material stockpile bottom-up*

The total material stockpile for all investigated groups of durable goods is estimated at 28 b tonnes. According to the modelling methods adopted here, this can be broken down into 93 % mineral-based materials, 4.1 % metals, 1.3 % wood and 0.9 % plastics. 0.7 % of the total mass could not be assigned to any material group.

The largest part can be attributed to the building sector, which accounts for 27.8 b tonnes. Material mass from building services as well as consumer and capital goods totals 373 m tonnes, which is less than 2 % of the former figure. While mineral-based materials dominate in buildings, metals form the largest material mass in other groups of goods. These are, alongside ferrous metals, non-ferrous metals such as copper and aluminium.

Figure 2: Material stockpiles classified by main material groups for the year 2010




Source: own illustration

**Waste management parameters to model aspects of recycling**

Various parameters were defined in order to model recycling processes:

- Consumed mass of secondary raw materials: the estimated absolute mass of secondary raw materials consumed in a year [t];
- Level of consumption of secondary raw materials: Ratio between the mass of consumed secondary raw materials and the available mass of secondary raw materials [%];
- Recycling ratio: Ratio of consumed mass of secondary raw material and total input mass (primary and secondary raw materials) [%].

In order to quantify these parameters it is necessary to carry out numerous separate investigations. Often it is impossible to determine output flows for specific groups of goods. On the input side, however, it is possible to make good estimates of secondary material flows for specific groups. Data on the ratio of recycled materials used in producing goods is extremely patchy.

Exemplary calculations were undertaken to determine the above named parameters in relation to the building sector. Around 30 different secondary input materials were noted, which have their origin in diverse levels of material flow in the waste industry.

The mass of secondary raw materials flowing into the building sector in 2010 was estimated at 12.3 m tonnes. Thus 8 % of the total flow of secondary raw materials (determined by Level 1 and 2 at 153 m tonnes) is consumed by the building sector. The recycling ratio for buildings is 10 %.

The recycling industry primarily alters the length of time that materials remain in the anthropogenic material stockpile. In the time period under consideration, recycling materials had a positive effect on the material balance of the stockpile. They help to reduce the outflow of materials as well as the inflows of primary materials.

The actual reduction effects on input flows (particularly flows from extraction) into the anthropogenic stock by the employment of secondary materials cannot be conclusively determined from data on recycled materials. The mass of consumed secondary materials is not necessarily identical to the mass of substituted primary materials. It is frequently the case that the mass of substituted materials is much higher, when, for example, raw materials for the processing of primary raw materials are substituted. However, such considerations belong to a wholly separate field of research and are not the object of this current study.

### Synthesis of approaches

To realize a synthesis of methods, results were compared from the individual analysis levels. This served to reveal and examine disparities, thereby qualifying results and providing an orientation for the interpretation of values.

Input and output flows from the top-down approach were compared with flows from the bottom-up approach were also opposed. Further, input and output flows within the analysis levels. Groups of goods and materials were compared as far as possible. The focus was on flows for which findings could be generated at all levels.

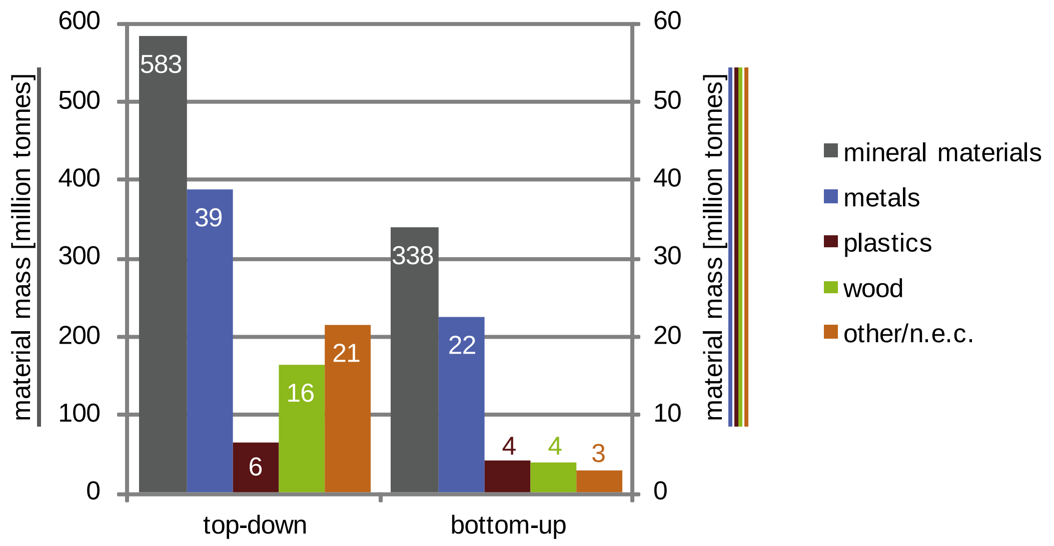
*Comparison of input flows*

A comparison of summed input flows from Analysis Level 2 (top-down) and Level 3 (bottom-up) shows that much higher flows were estimated using the first approach. The total input flow determined using the bottom-up approach was only 56 % of that determined using top-down analysis. This tendency was apparent in all material groups as well as groups of goods.

A more complicated picture was revealed when examining material flows individually. Standard correction factors cannot be applied, because disparities can be both positive and negative. It cannot therefore always be assumed that top-down values form the upper boundary of results.

These disparities can be explained in various ways: gaps in the observed mass of goods, insufficient consideration of secondary material flows as well as discrepancies in the assignment of individual goods to groups of goods within the various data sources.

Figure 3: Comparison of top-down and bottom-up input flows for durable goods (excluding capital goods) according to main material groups




Source: own illustration

*Comparison of output flows*

The comparison of top-down/bottom-up output flows can be achieved by considering the results of Analysis Levels 2 and 3, as here corresponding findings are available. Looking at the main material groups we discover considerable disparities. The causes of these opposing tendencies are partly the same as those observed for the input data. A further effect is that waste-related statistics only recognize material flows that accord with the legal definition of waste material. Output flows that do not conform to this definition are therefore not captured, and are excluded from the corresponding top-down analysis.

*Comparison of inputs and outputs*

The input and output flows at the individual levels offer a plausible picture of growth in the material stock.

For mineral-based materials the calculated output is only 60 % of the input, while for metals the figure is 64 %. These results should, however, not be too hastily interpreted in view of a potential underestimation of output, particularly in the mineral- and metal-dominated building sector. In the case of plastics and wood, the estimated values for input and output were practically identical. This could be an indication of the low dynamic within these stocks.

At the level of groups of goods, input-output disparities are determined in both directions. In the building sector there are large positive input-output disparities, whereas in the material groups encompassing building services and consumer goods the input-output differences are negative. These decreasing material stocks can be attributed at least in part to an increase in resource efficiency in the production of facilities (material-saving building services) and appliances (flat screens instead of CRT displays). Here it seems worth undertaking further research, particularly in view of the methodological uncertainties regarding the systemic limits of the goods baskets and likely discrepancies in the definition of groups of goods.

No closer analysis is possible for capital goods due to the deficient underlying data.

### Data gathering and updating to capture dynamic processes

Long-term monitoring of the anthropogenic stock can be realized by continuously updating data to reflect changes in material masses. This process can be supported by standardized methods of data gathering and processing. The following conceptual aspects are proposed for such methods:

*Qualifying data*

The comparison of results of the top-down and bottom-up analytic methods for groups of materials and goods has indicated the existence of discrepancies in both directions. Thus, it is not always true that the top-down values form an upper boundary.

In those cases where possible (e.g. mineral-based materials), an additional quantification of the bottom-up approach should be carried out (in some cases this has already been performed). Furthermore, the application of standard factors has to be discussed under consideration of the knowledge gained by synthesizing the two approaches.

Such an approach is generally impossible in those cases where the top-down value is lower than the value determined by the bottom-up method (e.g. steel in the building sector). In these cases the remaining gaps should be pointed out.

A particularly difficult situation is where the top-down value is higher than the bottom-up value, but the former contains unquantifiable double counting. In this case it would be wrong to simply align the bottom-up value with the higher top-down value. The actual size of the gap is unknown. Here the safe alternative is to use the bottom-up value along with an additional rough estimate of the lower boundary value. Other forms of data qualification (e.g. determination of a spread of values) remain to be discussed.

*The material dynamic in the anthropogenic stock*

A standard method to describe the stock dynamic is the retention time, i.e. the period in which the goods remain in the stockpile. There exist a range of approaches for the observed groups of goods. Statistical inflow and outflow rates are used for residential and non-residential buildings. The presumed useful working life is taken as the basis for the determination of the rates of renovation of buildings and building services.

Upgrading and maintenance cycles of technical infrastructures are determined by the useful lifetimes of appliances. These can differ substantially from the real upgrading and maintenance cycles. It is important to consider the age structure, especially in the case of young infrastructure sectors with a comparatively high annual growth. Here the estimation of the renewal rate cannot be merely based on the annual write-off of goods, as the demand for renewal for growth in goods only occurs at the end of their useful lifetimes. In regard to the data gathering concept, it is important that a realistic classification according to age is attempted in the field of renewable energies.

For durable consumer goods that are recorded by the Income and Consumption Survey (IVS), retention time can be determined from the data on changes to the stock. For small household devices with a relatively short useful lifetime of, say, 3 years in the case of toasters or coffee machines, this is taken to be retention time.

At the end of the retention time the goods are available for recycling. Some fraction of goods leaves the stock as output. Waste economy analytical methods can be used to quantify the respective material flows.

*Data quality, updating and availability*

The concept for evaluating data quality encompasses four assessment criteria, complemented by a simple traffic-light rating system. Together these provide a basis for designing the various steps of data processing, updating and interpretation. The data gathered as part of this study was evaluated in this way. The following aspects of data quality were considered:

- reliability (type of source/data basis)
- time representativeness (relation to reference year)
- geographical representativeness (geographic relation of the data to the area of observation, here Germany)
- technological representativeness (evaluated datasets, on the basis of which relevant material indicators can be developed)

*Documentation and data gathering concept*

As part of the data gathering concept, the data for the reference year 2010 was electronically processed in tabular form. In order to permit the potential transfer of study findings into a software-supported analytical tool, a systematic structuring was determined for the tables resulting from the bottom-up analyses, so as to create the basis for implementation in a software tool. The processing was carried out on top-down and bottom-up data. In the latter case, the main groups (buildings, building services, infrastructure and durable consumer goods) were processed separately.

For each main group of goods there is:

- A basic table with specific definitions of the underlying reference indicators for goods (e.g. $m^2$ living space, 1,000 km road length). These definitions contain the absolute set values for stock, input and output in the reference year 2010, along with an assessment of data quality.
- A table with the material indicators taken as reference units (subdivided according to goods and material groups) as well as an assessment of data quality.
- Three results tables for the absolute masses of the stocks, the input flows and output flows for the reference year, classified according to type of good and material group. These absolute masses are determined from the material indicators and the values for material mass.

The determined stock of goods for the reference year 2010 is designated as the *status quo*, i.e. the base data for future updating of the stock model. The stock fluctuation can be captured for the individual groups of goods using the flow datasets generated every year or at longer intervals. The analytical methods developed here can be applied to the relevant group of goods.

Regarding the frequency of model updating and the achievable level of data quality, it is important to distinguish between the reference indicators (set indicators) and the material indicators. The reference indicators form the basis upon which material flows are quantified. The material indicators reflect technological developments. Data availability and data quality is invariably higher in the case of set indicators than material indicators.

Some official statistical data is available to determine set indicators. This is true for buildings, building services, some forms of infrastructure as well as consumer goods. Data on residential buildings can be updated on an annual basis using official data sets. Consumer goods are captured by the Income and Consumption Survey, with which the set of stock can be calibrated every 5 years. In other cases non-governmental data must be used.

Generally the material indictors are more or less derived from complex data analysis as well as computation models of the individual subsystems. The validity of the material indicators, particularly in the case of input mass, depends on the innovation dynamic in the respective sector of goods. Before every updating cycle it is therefore necessary to detect and assess the current state of innovation development, so as to determine whether the material indicators or the underlying goods basket have to be adapted.