Texte
84/2023

Final report

Determining climate protection potentials in the circular economy for Germany and the EU

Partial report Germany

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publisher:
German Environment Agency

German Environment Agency

Umwelt Bundesamt

TEXTE 84/2023

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

Project No. (FKZ) 3718 41 305 0

Report No. (UBA-FB) FB001101/ENG

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On behalf of the German Environment Agency

Imprint

Publisher
Umweltbundesamt
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Report completed in:
February 2023

Edited by:
Section III 2.4
Dr. Julia Vogel

Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4804

Dessau-Roßlau, June 2023

Abstract: Determining climate protection potentials in the circular economy for Germany and the EU – Partial report Germany

Climate protection potentials of the circular economy are determined holistically by means of the life cycle assessment method of waste management in this study. It includes emissions from all waste treatments as well as the benefits from the generation of secondary raw materials and energy and the resulting possible substitution of primary products.

For Germany and the EU, the given greenhouse gas mitigation potential is shown for the base year 2017, and for the target year 2030, it is outlined how contributions can also be achieved in the future. In addition to municipal solid waste, food waste is considered in more detail as a special balance, and industrial and commercial waste as well as construction and demolition waste are considered roughly. Also considered are possibilities to include preparation for re-use and waste prevention. This partial report presents the results for Germany.

All balance areas show GHG emission savings potentials in the net result. In the 2030 scenarios, these are declining due to the defossilisation of the energy system. This effect, which necessarily occurs with increasing implementation of the climate protection targets that urgently need to be achieved, is counteracted by waste management optimisation measures. Conclusion is that important climate protection potentials still exist. Joint efforts are needed to support ambitious targets for increasing separate collection and recycling. This applies to a greater extent at the EU level, in parallel with measures for a rapid end to landfilling.

Kurzbeschreibung: Ermittlung der Klimaschutzpotentiale in der Kreislaufwirtschaft für Deutschland und die EU – Partial report Germany

Klimaschutzpotenziale der Kreislaufwirtschaft sind in dieser Studie mittels Ökobilanzmethode der Abfallwirtschaft ganzheitlich ermittelt. Es ist die Gesamtheit der Emissionen aus der Abfallbehandlung umfasst sowie auch die Leistungen durch die Erzeugung von Sekundärrohstoffen und Energie und die damit mögliche Substitution von Primärprodukten.

Für Deutschland und die EU wird das gegebene Treibhausgas-Minderungspotenzial für das Basisjahr 2017 aufgezeigt und für das Zieljahr 2030 dargelegt wie auch künftig Beiträge erzielt werden können. Neben Siedlungsabfällen sind Lebensmittelabfälle als Sonderbilanzraum eingehender und Produktions- und Gewerbeabfälle sowie Bau- und Abbruchabfälle überschlägig betrachtet. Betrachtet sind zudem Möglichkeiten die Vorbereitung zur Wiederverwendung sowie die Abfallvermeidung einzubeziehen. Dieser Teilbericht stellt die Ergebnisse für Deutschland vor.

Alle Bilanzräume zeigen im Nettoergebnis THG-Entlastungspotenziale. In den Szenarien 2030 sind diese aufgrund der Defossilisierung des Energiesystems rückläufig. Diesem Effekt, der notwendigerweise mit zunehmender Umsetzung der dringlich zu erreichenden Klimaschutzziele eintritt, wirken abfallwirtschaftliche Optimierungsmaßnahmen entgegen. Fazit ist, es bestehen weiter wichtige Klimaschutzpotenziale. Es bedarf gemeinsamer Anstrengungen, um ambitionierte Ziele zur Steigerung der getrennten Erfassung und des Recyclings zu unterstützen. Dies gilt verstärkt auf EU-Ebene begleitend zu Maßnahmen für eine schnelle Beendung der Deponierung.

Table of content

List of figures

List of tables

List of abbreviations

AD	Anaerobic digestion
BMU	Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz / Federal Ministry for Environment, Nature Conservation and Nuclear Safety (Germany)
C&D waste	Construction and demolition waste
CEWEP	Confederation of European Waste-to-Energy Plants
CHP	Combined heat and power
C&I waste	Commercial and industrial waste
CO2	Carbon dioxide
COP	Conference of the Parties
ECN	European Compost Network
EEA	European Environment Agency
EEA-model	European Reference Model on Municipal Waste Generation and Management
ESTAT	Eurostat
EU	European Union
EU-ETS	EU Emissions Trading Scheme
EU27 (w/o) DE	EU27 without Germany
EWC-Stat	European Waste Classification for Statistics
EWC-Stat code	European Waste Classification for Statistics code
FEAD	European Waste Management Association
FS19, R1	“Fachserie 19, Reihe 12 (German waste statistics, Destatis)
FW	Food waste
GHG	Greenhouse gas
HC	Home composting
INC	Incineration
kg/cap	kilogram per capita
LCA	Life Cycle Assessment
LF	Landfill
LoW	European List of Waste
LoW-code	European List of waste code
LS	Lead scenario
LWP	Lightweight Packaging
MBT	Mechanical biological treatment
MS	EU Member States
MT	Mechanical treatment
MSW	Municipal solid waste

NACE	**Nomenclature statistique des activités économiques dans la Communauté européenne/Statistical Classification of Economic Activities in the European Community**
NDC	**Nationally Determined Contributions (in Paris-Agreement)**
NIR	**National Inventory Report**
N2O	**Nitrous oxide (laughing gas)**
OECD	**Organisation for Economic Co-operation and Development**
RDF	**Refuse Derived Fuel**
t	**Tons**
UBA	**Deutsches Umweltbundesamt / German Environment Agency**
UN	**United Nations**
UNFCCC	**United Nations Framework Convention on Climate Change**
WEEE	**Waste electrical and electronic equipment**
WFD	**Waste Framework Directive**
WStatR	**Waste Statistics Regulation (2150/2002/EC)**

Summary

Climate protection is one of the greatest global challenges of the 21st century. With the Paris Agreement of December 2015, following the Kyoto Protocol, member states have once again committed to reducing anthropogenic greenhouse gas (GHG) emissions and limiting global warming to well below 2 °C compared to pre-industrial levels. This requires in-depth efforts across all climate-relevant sectors and source groups, including the waste sector.

The waste sector is limited to direct and non-energy GHG emissions under the general reporting requirements of the Kyoto Protocol to avoid double reporting. As a result, the contribution of the waste sector is mainly represented by diversion from landfill. However, this does not include future GHG emissions from landfilling, nor the additional GHG emission savings potentials triggered by waste management that result from material and energy recovery. The overall contribution to climate protection that is achieved and achievable in this way can be demonstrated with the help of the life cycle assessment method of waste management (e.g. documented in (Dehoust et al. 2010), (Vogt et al. 2015)).

In this project, the waste management situation as of 2017 is examined and the potential climate protection contribution of the circular economy for the target year 2030 is shown against the background of the further developed political and legal framework conditions. Furthermore, the possibilities of preparation for re-use (for used goods in the case of MSW) and waste prevention (in the case of food waste) are considered.

This partial report documents the work and results of the project "Climate Protection Potentials in the Circular Economy - Germany, EU"[1] for Germany. The results for the EU are published in a separate partial report ("Partial Report EU"). Both partial reports examine the situation of waste management by the following types of waste:

- Municipal solid waste (MSW)
- Food waste (special balance)
- Commercial and industrial waste (C&I waste)
- Construction and demolition waste (C&D waste)

A separate quantity survey and GHG balancing was carried out for each waste type. Methodologically, the balancing areas for MSW, C&I waste, and C&D waste are complementary areas, while food waste is investigated as a special balancing area. This includes food waste from the MSW sector as well as from the C&I waste sector.

For the MSW and food waste, detailed GHG balances are presented, whereas only a rough assessment is conducted for C&I and C&D waste. For MSW and food waste, the actual situation in the base year 2017 is analysed for Germany, for the current EU27, the previous EU28 (including the UK) and for two clusters defined from the EU member states. For C&I and C&D waste, the analysis is limited to Germany and the EU27. The future GHG emission savings potentials for the target year 2030 are also analysed more comprehensively for the MSW and the food waste with two scenarios for each: Germany, the EU27 and the two EU clusters. For the C&I and the C&D waste, there are two scenarios for Germany and one scenario for the EU27.

Data situation, procedure for collecting data

For the four waste types or system areas, only non-hazardous waste is evaluated and balanced; hazardous waste is excluded from this study. As far as possible, the study refers to data for 2017. The main source is the official German waste statistic. Other sources such as associations,

[1] Long title: Determining climate protection potentials in the circular economy for Germany and the EU as a contribution to achieving the goals of national and international climate protection commitments.

interviews with experts and relevant studies were used to evaluate the statistical data and supplement it where necessary. As far as waste quantities per capita are mentioned in this study for 2017, the population of 82,792,351 from 31.12.2017 according to Destatis is used[2].

The differentiation of the waste quantities for the four system areas is described in detail in the partial report EU. For the balances of MSW and C&D waste, it is carried out by defining the relevant EWC-Stat codes[3] in connection with the LoW-codes assigned to them. There is no overlap between the system areas. For the C&I waste balance, there would be overlaps with both the MSW balance and the C&D waste balance due to the LoW-codes contained in the EWC-Stat codes considered. The corresponding quantities were accordingly deducted from the quantities to be considered for the C&I waste balance. The special balance food waste represents a subset of the MSW balance and the C&I waste balance. It is not additive.

Background for the GHG balances

The climate protection potentials of the circular economy are determined using the Life Cycle Assessment (LCA) method of waste management based on ISO 14040/44 44, which has already been applied and described in detail in many studies (e.g. Dehoust et al. (2010) and Vogt et al. (2015)). It permits a holistic approach, since it includes not only the direct emissions from waste treatment (debits) but also the potentially avoided emissions through the substitution of primary products and conventionally generated energy (credits). To evaluate the impact from GHG emissions on climate change the global warming potential for the 100 year horizon (GWP100) according to IPCC (2013) was used.

Certain rules apply to the LCA method of waste management, such as that system comparisons may only be carried out for the same absolute waste quantities and qualities. The balancing includes all emissions arising from the treatment of a defined amount of waste, and thus also those that occur over several decades in the future when landfilled. Another relevant aspect for LCA of waste management is that the technical substitution potential is taken into account for material recycling, not the substitution potential according to the market mix. In case of co-incineration of waste in cement kilns or coal power plants the substitution of standard fossil fuels is accounted for. The generation of electricity and heat from waste by thermal treatment is credited by substituting the average electricity and heat generation in order to be able to understand the dynamics from the energy transition in future scenarios. One exception is the possibility of flexible power generation; for this, the substitution of fossil reserve power plants is taken into account.

For the separately considered balance area Germany, national emission factors are used for electricity and heat. For the consolidation with the balancing area of the EU27 (and EU28), the balances for Germany are additionally calculated with the EU27 emission factors for consistency reasons. The resulting differences are shown. In addition, as a sensitivity for the base year 2017, the use of the UBA avoidance factors for renewable energy sources as a credit for electricity from waste is considered for the example of MSW. The generally used average emission factors are adjusted to a changed energy source mix for the 2030 scenarios. Since changed emission factors for electricity also affect primary production, a correspondingly reduced substitution potential for electricity-intensive primary processes (aluminium, paper) was also estimated. Basically, as in the previous study (Vogt et al. 2015), harmonised emission factors are used for substituted primary processes.

[2] https://www-genesis.destatis.de/genesis//online?operation=table&code=12411-0001&bypass=true&levelindex=0&levelid=1611656806242#abreadcrumb (date of access 29.06.2021)

[3] In the case of construction and demolition waste, all relevant codes are fully assigned to NACE sector F in the statistics.

The balancing for the individual waste streams and balancing areas is described in detail in the study. It is based on own expertise, on current studies and on exchange with experts. For Germany, two expert discussions were held with representatives from the science community and from associations. The results for MSW in Germany for 2017 are also compared to those of the previous study (Dehoust et al. 2010).

Municipal solid waste

The focus of this study for the generation and destination of waste is on all domestic waste quantities, including those from the company's own operations, but does not take into account quantities delivered from abroad. Exports are added. The list of the German Environment Agency on transboundary shipments of waste requiring consent is used as a source for exports by waste type (UBA 2017).

According to the Destatis definition, all waste listed under the LoW-codes 20 and 15 01 is classified as MSW. In total, this amounted to around 40.5 million tons for 2017 under LoW-code 20, of which 634,400 tons came from abroad, so that the initial quantity for this study is around 39.85 million tons. In addition, there are around 12.2 million tons under LoW-code 15 01 (packaging waste), of which 472,800 tons were delivered from abroad, leaving an initial value of around 11.68 million tons, or a total of around 51.5 million tons for MSW with LoW-code 20.

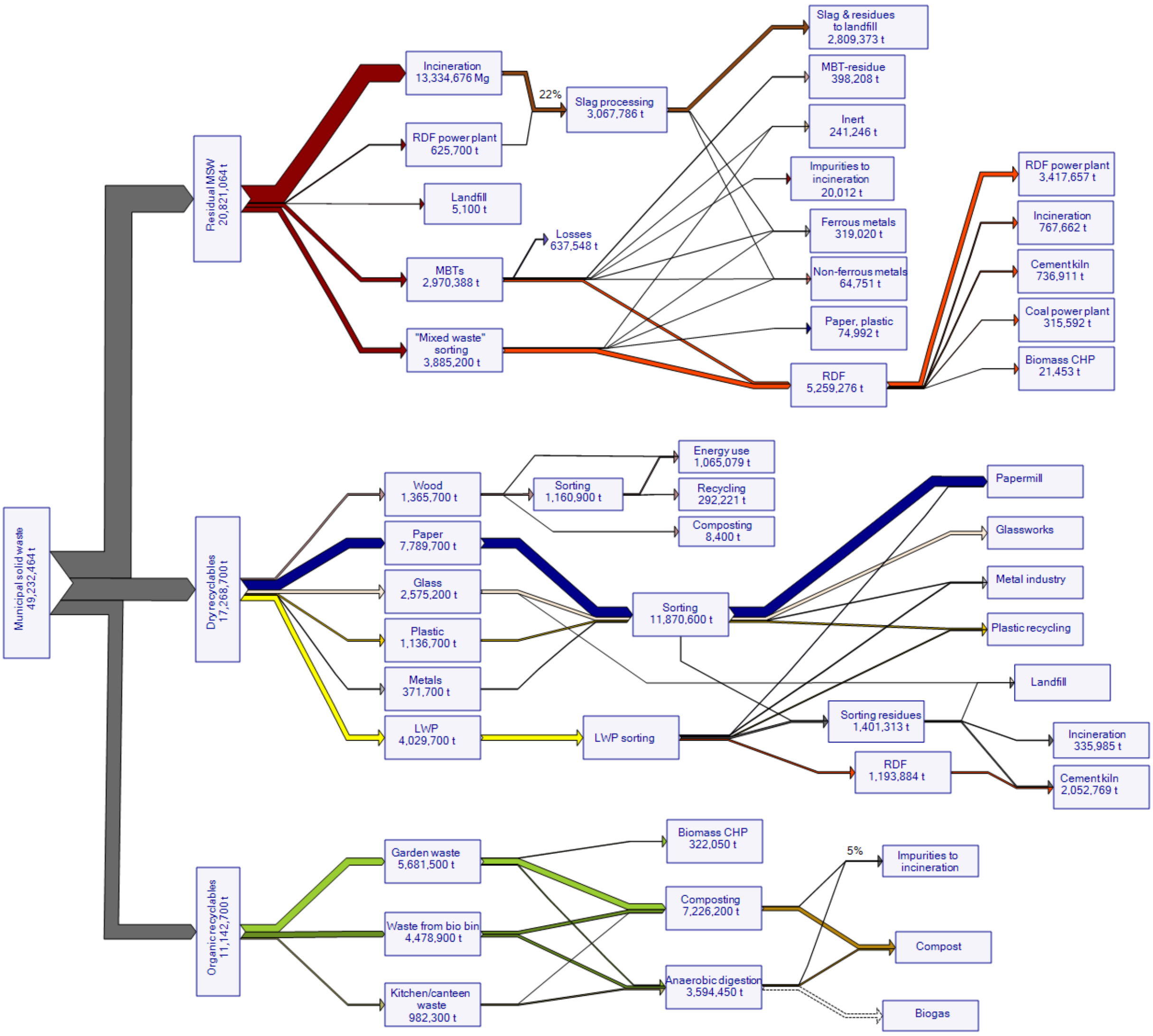
Excluded from this are hazardous waste, textiles, edible oils and fats, paints, printing inks, adhesives and synthetic resins, cleaning agents, pharmaceuticals, batteries and accumulators, soil and stones, street sweepings as well as other fractions, sewage sludge and waste from sewer cleaning, resulting in a total volume of 49.47 million tons of MSW. If exports are added, the total amount is 49.7 million tons.

The amount of waste generated is compared with the amount treated in plants and a difference of 2.7% is found, which is due to data protection reasons (Destatis only shows values if more than 3 individual plants are included in the data set). To close this gap, assumptions are made for glass packaging, household waste and commercial waste similar to household waste, as well as for biowaste that goes to sewage sludge composting or other biological treatment. Special data tables are checked for thermal waste treatment plants, incineration plants and biological treatment plants, but their data are discarded for further consideration, with the exception of biological treatment plants. For the material flow model, additional sources are collected and fed into the model. Figure 1 shows the final material flow model for MSW from generation to final destination.

The Sankey diagram shows that comprehensive separate collection is already established in Germany. Separately collected dry recyclables (incl. wood) account for 35% of the total volume and separately collected organic waste for 23%. This leaves a residual waste stream of 42%, which is mainly fed into thermal waste treatment plants (waste incineration plants, RDF plants) for primary treatment (67%).

For the 2030 scenarios, the legal target of a recycling quota of 60% for MSW is decisive. The most important lever for achieving this target lies in increasing the separate collection of recyclable materials by removing them from the residual waste. For 2017, the recycled share of the MSW volume considered in this study is 48%. Due to the system, this recycling rate (RC rate) should not be confused with the official recycling quote, but it is a good approximation for it. For the 2030 scenarios, the RC rate is to be increased accordingly to 60%. The starting point for the potential increases is the waste composition of residual waste in 2017, which is well documented for household waste (Dornbusch et al. 2020). For commercial waste similar to household waste and for bulky waste, plausible estimates had to be made on the basis of orienting values. In order to reach the 60%, about 6 million tons of recyclables must be removed from residual waste by 2030 (corresponds to 29% of the residual waste volume in 2017). Even if a further increase in separate collection can be assumed since 2017, the mathematically required increase by 2030 is very ambitious. Both the feasibility and the achievable qualities of recyclable separately collected fractions are in question.

Figure 1: Sankey diagram MSW Germany 2017



Source: own illustration, ifeu

Since a less ambitious scenario would fail to meet the legal targets, the following two approaches, which were also discussed during the expert discussions, are taken for the consideration of the future 2030 scenarios:

- Base comparison: Comparison of the baseline year 2017 with a lead scenario 2030, which is based on a comparatively valid database, but is very ambitious.
- Comparison with home composting in the RC rate: Scenario in which a home composting quantity is counted towards the RC rate; this lowers the ambition level, but there are very high data uncertainties.

The accounting of home composting is a model-theoretical solution to be able to discuss the range of different ambition levels. It is neither intended nor possible in the study to investigate potential interactions between separate collection of native-organic waste and home-composting.

A home composting quantity for Germany is not known; it was estimated at 7.9 million tons (95 kg/(cap*a)). This quantity is added to the base year 2017 as well as in the 2030 scenario (condition of equal total quantities in the LCA of waste management; accordingly, a comparison between the two 2030 scenarios is only possible qualitatively and on a specific level). The level of ambition for increasing separate collection is roughly halved. With the home composted quantity, the RC rate for 2017 is calculated at 55% and the additional quantity to be collected separately by 2030 at around 2.7 million tons (corresponds to 13% of the residual waste quantity in 2017). In addition to the quantity, there are also considerable data uncertainties regarding the GHG emissions from home composting. According to the studies evaluated, net debits are to be expected. In this study, home composting is valued at zero in order to keep the influence on the GHG balance as neutral as possible and thus have as little impact as possible on the actual question of the scenario. With all other assumptions (waste volume treatment, technical optimisations), the scenario with home composting in the RC rate corresponds to the lead scenario 2030.

The assumptions in the lead scenario 2030 are as follows (quantities approximately halved in the scenario with home composting in the RC rate):

- For the main quantity of the increased separate collection, approx. 3.2 million tons of native organic waste (2017 with 30% main fraction in residual waste), collection via the organic waste bin with subsequent anaerobic digestion is assumed; knowing that this is also very ambitious. For example, with a treatment capacity of 30,000 tons per year, this would mean the construction of around 100 plants; treatment with soldier fly larvae and with hydrothermal carbonisation (HTC) is assumed as new processes in small proportions.
- The additional dry recyclables collected separately (plastics, paper, glass, metals) are recycled.
- The volume of light weight packaging waste (LWP) determined for 2017 is kept constant, as no suitable allocation to the sub-fractions is possible. In the lead scenario 2030, LWP is accounted for in the same way as Scenario 1 for 2030 in Dehoust et al. (2016b).
- For the additional separately collected quantity of waste wood, waste wood processing is assumed and pyrolysis as a new process for a small quantity.
- The quantity removed from residual waste is reduced evenly across the primary treatment plants (waste incineration plant, MBT, "mixed waste sorting"[4]) (29% of the treatment quantity in 2017 for each); the breakdown between MSW and RDF incineration plants is unchanged; for MBT it is assumed that the input quantity in MBS and the percentage share in MPS remain, the difference is deducted evenly for aerobic MBT and anaerobic MBT.
- For the new residual waste composition in 2030, the characteristic data, calorific value, fossil and biogenic carbon content, have been recalculated. They differ moderately (somewhat significantly lower fossil C content in the lead scenario).
- For garden, park and cemetery waste, a redirection of 10% of the previously composted quantities towards anaerobic digestion takes place; kitchen/canteen waste will be exclusively anaerobically digested and no longer composted in 2030.

[4] Sorting of mixed MSW in different types of facilities according to waste statistics such as "sorting facilities", "other treatment facilities".

- Secondary waste that has been co-incinerated in coal-fired power plants until now (primarily RDF, rejects from paper recycling) is used in waste incineration plants.
- Technical optimisation measures are
  - Increased net efficiency for thermal waste incineration plants,
  - Increased yields in the processing of dry recyclables,
  - Increased metal yields from residual waste treatment,
  - Increased proportionate production of biomethane.

In addition to the two scenarios, the following scenarios and sensitivities were calculated:

- Sensitivity 2030 "business as usual",
- Baseline comparison with EU27 electricity and heat emission factors,
- Sensitivity 2017 with avoidance factors for electricity from biogenic waste,
- Sensitivity with preparation for re-use and waste prevention.

The results of the GHG balance in the baseline comparison are shown in Table 1. The results are listed by waste fraction. For residual waste, the result includes the GHG balancing via the various treatment paths, which are shown in the Sankey diagram. Similarly, the treatment paths for the organic recyclable waste from the bio bin, garden, park and cemetery waste, and kitchen/canteen waste are summarised under "organic waste". The results for the separately collected dry recyclables are listed individually by waste type.

Table 1: Absolute and specific net results by waste fraction - base comparison MSW Germany: base year 2017 and lead scenario 2030

Waste fraction	absolute		specific per capita[1]		specific per ton	
MSW	**2017**	**2030 LS**	**2017**	**2030 LS**	**2017**	**2030 LS**
	Million tons CO_2eq		kg CO_2eq/cap		kg CO_2eq/t	
Residual waste	-2.37	-0.71	-28.6	-8.6	-114	-48
Organic waste	-0.60	-0.72	-7.3	-8.3	-54	-50
Paper	-3.35	-1.48	-40.4	-17.9	-430	-171
Glass	-1.20	-1.43	-14.4	-17.3	-464	-460
Plastic	-0.49	-1.43	-5.9	-17.3	-431	-692
LWP	-3.31	-3.57	-39.9	-43.1	-820	-886
Metals	-0.66	-0.98	-7.9	-11.8	-1,769	-1,616
Wood	-0.65	-0.59	-7.8	-7.2	-474	-358
Sum/Average	**-12.6**	**-10.9**	**-152**	**-132**	**-256**	**-222**

1) Calculated with a population of 82,792,351 in 2017 (Statistisches Bundesamt (Destatis) 2017).

Overall, both scenarios, the base year 2017 and the lead scenario 2030, show net emission savings potentials (negative values, credits higher than debits). The absolute net emission savings potential in 2017 is -12.6 million tons CO_2eq. The main contributions are made by paper, LWP and residual waste, which account for 66 % by mass. In the lead scenario 2030, the absolute net emission savings potential is lower at -10.9 million tons CO_2eq This is mainly due to the defossilisation of the energy system (lower emission factors for electricity and heat). On the one hand, the GHG debits from energy demand decrease, but on the other hand, also the substitution potentials for energy and the primary products whose electricity-intensive production was adjusted with the 2030 electricity emission factor (aluminium, paper). This is countered by the optimisations: increased separate collection, technical optimisations.

At the specific level per ton, the metals in particular show high net emission savings potentials. The production of pig iron and aluminium is associated with comparatively high GHG emissions. In the lead scenario 2030, the net emission savings decrease due to the adjusted primary production of aluminium. There are also high specific net emission savings s for LWP and for plastic waste. The latter still have a lower net emission savings potential in 2017, which increases more significantly in 2030. This is due to the lower GHG debit for electricity demand (more pronounced for pure plastic waste than for the LWP mixture). The emission savings potentials for plastic waste are little changed. These could be increased through better qualities and thus stronger substitution of virgin plastics instead of applications as wood and concrete substitutes.

The net emission savings per ton for paper, glass and wood are roughly similar in 2017. For paper and glass, these are characterised by material recycling, and for wood by energy recovery. The chipboard recycling of wood is associated with a comparatively low specific net emission saving. In the lead scenario 2030, the specific net emission savings potential for paper is reduced mainly due to the adjusted primary production. In addition, the energy recovery of rejects plays a role, which are assigned to waste incineration plant instead of co-incineration in coal power plants in 2030. The higher net efficiencies assumed for waste incineration plants only compensate for this proportionally. In the case of wood waste, the reduced specific net emission savings potential is mainly due to defossilisation; the higher heat utilisation efficiency assumed for biomass CHP only compensates for this proportionally. The smaller quantity for which pyrolysis is assumed has hardly any influence. In specific terms, the net emission savings are lower than for energy recovery.

For organic waste, there is a specific net emission saving in the base year 2017, which is primarily achieved through the proportionate anaerobic digestion and biogas utilisation. For garden, park and cemetery waste, the proportionate energy recovery in biomass power plants also plays a role. In the lead scenario 2030, the specific net emission saving for organic waste is somewhat lower. In the sum of the three waste fractions, the effects of defossilisation outweigh the increase in anaerobic digestion. The specific result for composting is largely unchanged. The new processes additionally considered for waste from the bio bin have hardly any influence on the result with the small quantities. With higher quantities, there would be a deterioration. Both the HTC process and even more clearly the treatment with soldier fly larvae cause net debits.

The disposal of residual waste is also associated with specific net emission savings potentials in the base year 2017. The specific emission savings are higher if the RDF produced is also proportionately incinerated in coal power plants and cement kilns and replaces fossil fuels. For the result for residual waste, there are high data uncertainties for the share treated via "mixed waste sorting" (19%). There is a lack of information both on the composition of the input material and on the quantity, quality and destination of the RDF produced. Assumptions had to be made here and the proportional net emission saving may be overestimated. In the lead scenario 2030, the net emission savings potential of residual waste treatment is reduced. The main reason here is also the defossilisation of the energy system. In addition, the diversion of RDF from co-incineration in coal power plants to treatment via waste incineration plants plays a role. On average, this affects 10% of the RDF. This is counteracted by the higher net efficiency for waste incineration plants assumed for the 2030 scenario. The changed residual waste composition due to the increased separate collection has hardly any influence on the result.

In the sensitivity of the "business as usual scenario 2030" it becomes clear that without waste management measures, the possible net emission savings due to defossilisation would decrease much more significantly. Under these circumstances, the treatment of MSW in Germany would achieve an absolute net emission savings potential of -6.5 million tons CO_2eq in 2030. This means that the potential climate protection contribution compared to the base year 2017 would almost halve and compared to the lead scenario 2030 the contribution is 40% lower. The waste management measures on which the 2030 lead scenario is based provide a relevant further climate protection contribution, even if the net emission savings potential is lower than in the 2017 baseline year.

In the scenario with home composting in the RC rate, the absolute net emission savings potential in the balance year 2017 ("MSW HC 2017") is -12.6 million tons CO_2eq. A comparison at the absolute level with the baseline comparison is generally not methodologically permissible due to the different total waste quantities (49.2 million tons in the baseline comparison and 57.1 million tons in the scenario with home composting in the RC rate). However, since home composting itself is valued at zero in the GHG balance, there is no difference in the absolute result for 2017 compared to the result of the base comparison. For the year 2030 ("MSW HC 2030“) the absolute net emission savings potential is just under -10 million tons CO_2eq. Again, a comparison with the baseline comparison, the lead scenario 2030, is fundamentally not methodologically permissible at the absolute level. If it were correct that home composting is quasi-neutral and thus has no influence on the GHG balance, it could be said that a scenario with about half the level of ambition for increased separate collection than the 2030 lead scenario leads to a net emission savings potential reduced by about 1 million tons CO_2eq.

A qualitative comparison for 2030 shows that the recycling of dry recyclables in particular achieves lower absolute net emission savings potentials due to the reduced quantities collected separately. Conversely, there is only a minor influence in the treatment of the quantities remaining in residual waste. The fact that the absolute net emission savings potential is not significantly lower than in the lead scenario 2030 is due to the fact that the main part of the increased separate collection is in organic waste, whose specific net emission savings potential is low compared to that of the recycling of dry recyclables.

The specific result by waste type differs from the baseline comparison only for 2030 and only for the waste fractions of residual waste and organic waste (waste from the bio bin). For residual waste, the specific net emission saving is somewhat lower (different composition of residual waste and no redistribution at MBT plants). For organic waste, the specific net emission saving for waste from bio bins is somewhat lower due to the lower additional quantities for anaerobic digestion compared to the lead scenario 2030. The most significant difference at the specific level is in relation to the total waste quantities. The specific net emission savings potentials are significantly lower overall, as the results refer to around 57 million tons (including the 7.9 million tons of home composting):

- MSW HC 2017: -221 kg CO_2eq/t MSW (14% lower than base year 2017)
- MSW HC 2030: -175 kg CO_2eq/t MSW (21% lower than lead scenario 2030)

In the base comparison with EU27 electricity and heat emission factors, which are lower than the national emission factors in each case, the absolute total net emission savings potentials are reduced by 3% for both 2017 and 2030. There are opposing effects here. Waste fractions with a high electricity demand for waste processing, and for which processing residues are predominantly co-incinerated (especially in cement plants), have lower debits with the lower EU27 emission factor for electricity and sometimes show higher net emission savings potentials than in the result with the German emission factors for electricity and heat (plastics, LWP, paper). For most waste fractions, however, the net emission savings potentials are reduced by energy generation from waste with the lower EU27 emission factors. This is particularly evident for residual waste in 2030.

The sensitivity for 2017 with avoidance factors for electricity from biogenic waste refers exclusively to the emission savings effects. The electricity demand is not affected. If the avoidance factors for electricity from biogenic waste were taken into account, the absolute total net emission savings potential for 2017 would be 8% higher. As the sensitivity relates exclusively to the credit for electricity from waste, it has hardly any impact on the result for dry recyclables, as these are characterised by recycling and treatment residues recovered for energy purposes are predominantly co-incinerated. Contributions to the higher net emission saving result from the energy recovery of waste (residual waste, wood) and from the anaerobic digestion and biogas use of organic waste.

The sensitivity with preparation for re-use and waste prevention shows a methodical approach to include these aspects in the LCA of waste management. For preparation for re-use, studies and data from second-hand department stores were evaluated and a re-used per capita quantity was derived. For the GHG calculation, life extension assumptions were linked to emission factors of the primary production of second-hand goods. Waste prevention was derived using the example of food waste in the special balance food waste. The result is included in the MSW balance for sensitivity. The considered reusable or avoidable quantities result in:

- 75,210 tons of used goods for preparation for re-use, which are deducted from bulky waste (residual waste),
- 1,258,669 tons of food waste from households and out-of-home consumption, which is deducted from organic waste.

The absolute amount of waste considered corresponds to that in the baseline comparison. The sensitivity is based on the lead scenario 2030. The following aggregated prevention factors have been determined for the GHG calculation:

- -0.61 kg CO_2eq/kg second-hand goods for their lifetime extension,
- -1.61 kg CO_2eq/kg of foodstuffs for their waste prevention.

For the sensitivity with re-use and waste prevention, an absolute net emission savings potential of around -13 million tons CO_2eq results for the balance year 2030 (+18% compared to the lead scenario 2030). The increase is mainly characterised by the amount of avoided food waste, which is on the one hand significantly higher and on the other hand associated with a higher avoidance factor. However, the amount identified for re-use does not include used textiles and waste electrical and electronic equipment, which were not examined in this study. Also, a higher potential is to be expected overall than has been traded so far via second-hand department stores. In addition, the preparation for re-use is subject to the fact that the emission savings potential is additional, since the second-hand goods are recycled or energetically recovered at a later point in time after the end of their life.

Special balance food waste

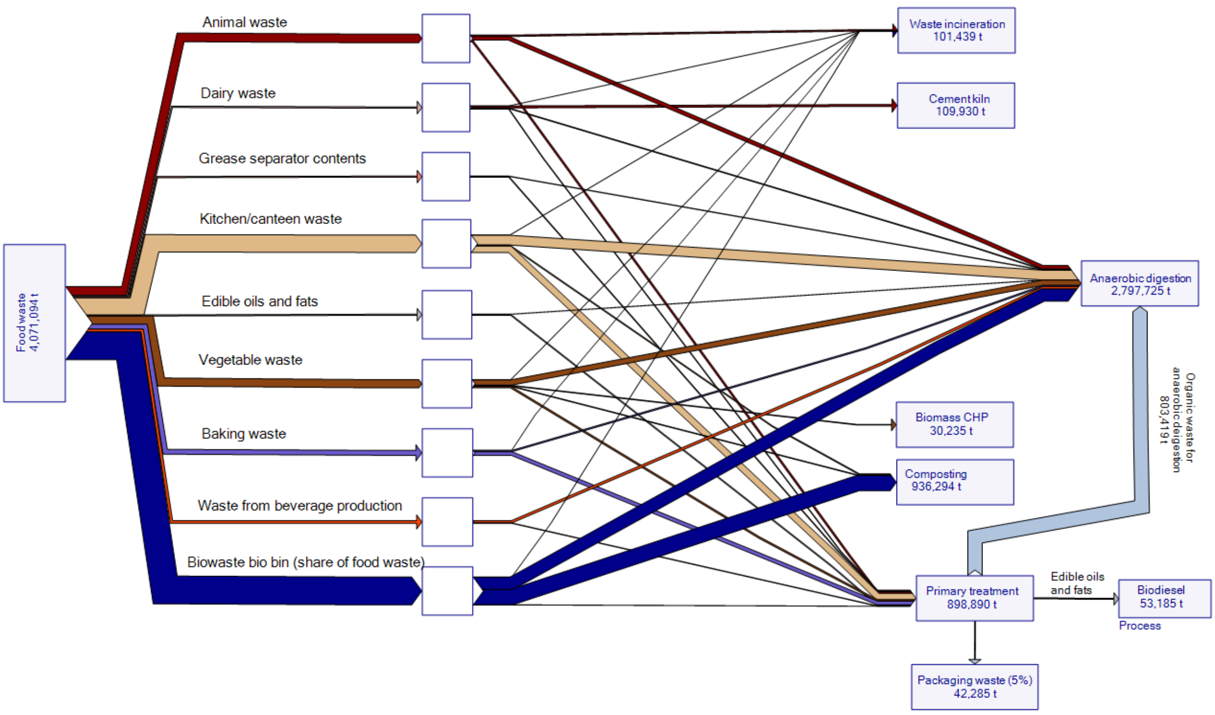
The special balance food waste comprises the food components in the organic waste of MSW and C&I waste. The areas of origin were differentiated in the collection of the basic data and, in particular for the EU, an attempt was made to obtain a differentiation according to this. For the EU, only the EWC-Stat code W091+W092 (animal and mixed food waste; vegetal waste) is reported. Differentiation into W091, W092 for the EU is done by expertise. For the EU balance areas, the German statistics were evaluated in more detail in order to be able to make plausible assumptions for the EU based on them.

The evaluation for the generation and destination was carried out in the following four steps: 1. consideration of all LoW-codes that can contain food waste; 2. deduction of waste quantities from primary production (agriculture, forestry, fisheries); 3. consideration of the proportion of food waste in organic waste; 4. evaluation of the destination under the assumption that the breakdown by facility type reported by Destatis (2019b und c) remains constant for the sub-quantity considered. As a result, only the following streams from MSW are considered for the special balance food waste: Waste from bio bins (20 03 01 04), market waste (20 03 02) and kitchen/canteen waste (20 01 08).

For the further analysis of the destination for primary treatment, the volume of food waste without residual waste is considered, which totals a good 4 million tons. Food waste in residual waste is not considered for methodological reasons. Furthermore, the evaluation showed that food waste is mainly treated in the following four types of facilities: To a smaller extent in thermal treatment plants (waste incineration plants) and combustion plants (cement works) and predominantly in biological and other treatment plants. For the latter, it was assumed that it is overstocked food waste that is unpacked in these plants and then sent for anaerobic digestion. Figure 2 shows the final material flow model for food waste from generation to final disposal.

The main stream, 62%, is food waste from MSW - waste from the bio bin and kitchen/canteen waste - whereby the food waste share of waste from the bio bin is set at 34%. Market waste is also added to the waste from the bio bin (small quantity). The individual types of waste from the C&I waste are often non-identifiable waste. 66% of the quantity is shown in the statistics as "materials unsuitable for consumption or processing".

Figure 2: Sankey diagram food waste Germany 2017



Source: own illustration, ifeu

In addition to the status quo, two scenarios for the development of recycling activities up to 2030 are considered for the GHG balancing.

The following assumptions are made for the lead scenario:

- Kitchen/canteen waste is no longer composted in 2030, but exclusively anaerobically digested.
- The increased share of waste from the bio bin for anaerobic digestion is taken into account; in 2030, 22% more will be digested at the expense of composting (share of anaerobic digestion in the organic waste bin in 2017 rises to 66% in 2030).
- Quantities of C&I waste that have been composted up to now will also be anaerobically digested in 2030 (only concerns vegetable waste).
- Waste fats that have been anaerobically digested so far will be processed into waste fat methyl ester in 2030 (diesel substitute).

The inclusion of waste prevention is only possible for the LCA method of waste management if the avoided products are known and their avoided production can be credited. For food waste, this means that only consumption products can be considered. No original products can be identified for sludges, slops, peeling residues, etc. or the "substances unsuitable for consumption or processing" that predominate in C&I waste. Accordingly, waste prevention is only considered for food waste from MSW (waste from the bio bin, kitchen/canteen waste). For this waste, a halving by 2030 is assumed, following the National Strategy to Reduce Food Waste. Based on shopping baskets for avoidable food waste from households and from out-of-home consumption, the average avoidance factor of -1.61 kg CO_2eq/kg food could be derived in connection with GHG emission factors for the production of the avoided food waste.

The GHG balancing for the food waste is carried out according to the waste types shown in the Sankey diagram. The accounting for kitchen/canteen waste and for waste from the bio bin corresponds to that for MSW. For kitchen/canteen waste this is clear (food waste share 100%). In the case of waste from the bio bin with only a proportionate food waste share, there is no representatively meaningful way to distinguish this from the non-food waste shares in the balance. For the balancing of food waste from C&I waste, assumptions were necessary in many cases due to the lack of data. Most of these are fed into anaerobic digestion for which characteristic data were estimated. Due to the given uncertainties with regard to the type of waste, the GHG results are to be understood as orientational.

The results of the GHG balance in the baseline comparison are shown in Table 2. Overall, both scenarios show net emission savings potentials. For 2017, the absolute net emission saving potential is -0.8 million tons CO_2eq. Animal waste and used fats are the main contributors to this. In the case of food waste from MSW, the emission savings are only slightly higher than the debits, which results in the lower net emission savings. For the lead scenario 2030, the absolute net emission savings potential is -0.7 million tons CO_2eq. Here, too, the slight decrease is mainly due to the defossilisation of the energy system. This is countered by the optimisations for 2030, the increased anaerobic digestion instead of composting and the complete processing of used fat into used fat methyl ester.

At the specific level per ton, used grease in particular shows a high net emission savings potential due to the (2017 proportional) substitution of diesel fuel. Furthermore, there is higher net emission savings potential for animal waste due to high gas yields during anaerobic digestion and its proportionate co-combustion in the cement kiln (animal meal). The thermal use of food waste also shows higher specific net emission savings potentials. However, this is only representative if the comparatively high calorific value of 20.4 MJ/kg with a simultaneous 0 % fossil C content is approximately true in practice. The specific net results of the other types of waste are mainly determined by the anaerobic digestion and whether the material has a high or low water content. Low water content (dairy waste, bakery waste) results in higher gas yields and correspondingly higher net emission savings potentials.

Table 2: Absolute and specific net results by waste fraction - food waste Germany base 2017 and lead scenario 2030

Waste fraction	absolute	absolute	specific. per capita[1]	specific. per capita[1]	specific per ton	specific per ton
Food waste	**2017**	**2030 LS**	**2017**	**2030 LS**	**2017**	**2030 LS**
	1,000 t CO_2eq		kg CO_2eq/cap		kg CO_2eq/t	
FW for waste incineration	-82	-74	-1.0	-0.9	-810	-728
Waste from the bio bin (food waste share)	-63	-77	-0.8	-0.9	-41	-50
Kitchen/canteen waste	-66	-46	-0.8	-0.6	-68	-48
Grease separator contents	-2	0	0.0	0.0	-33	-2
Edible oils and fats	-151	-167	-1.8	-2.0	-2,514	-2,771
Animal waste	-273	-240	-3.3	-2.9	-675	-593
Dairy waste	-29	-11	-0.3	-0.1	-408	-160
Vegetable waste	-18	-9	-0.2	-0.1	-41	-19
Baking waste	-117	-34	-1.4	-0.4	-429	-124
Waste from beverage production	-10	-4	-0.1	0.0	-65	-26
Sum/Average	**-811**	**-662**	**-9.8**	**-8.0**	**-199**	**-163**

1) Calculated with a population of 82,792,351 in 2017 (Statistisches Bundesamt (Destatis) 2017)

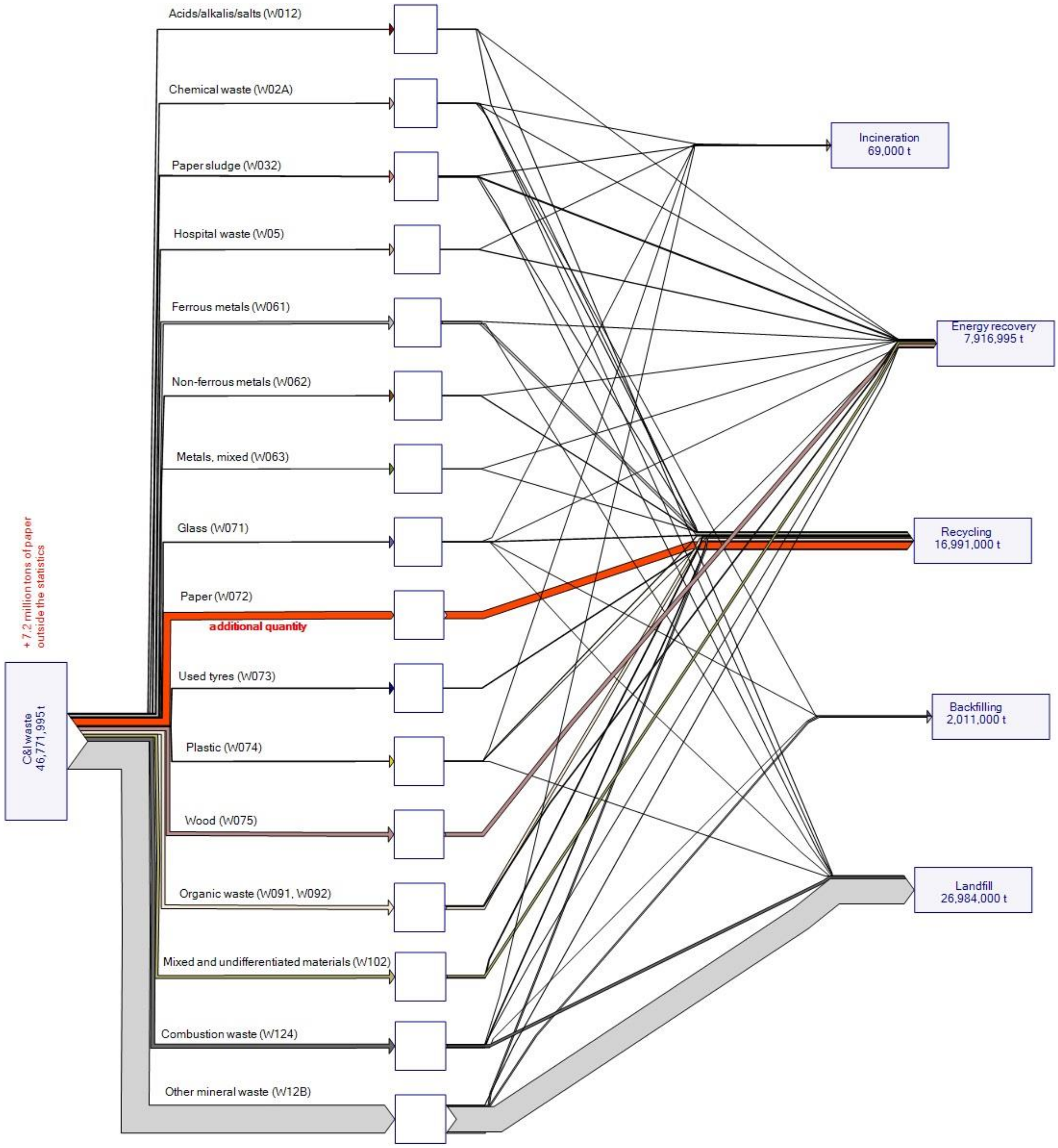
The special balance for food waste was also transferred 1:1 to the balance for the EU27 and accordingly also calculated with the electricity and heat emission factors of the EU27. Compared to the results with emission factors for Germany, the absolute net emission savings potentials are thus 13% lower for 2017 and 5% lower for 2030.

The scenario with waste prevention is based on the lead scenario 2030 for which the prevented food waste quantity of 1,258,669 tons is additionally taken into account and correspondingly deducted from waste from the bio bin and kitchen/canteen waste. The total amount considered corresponds to that in the baseline comparison. With waste prevention, the absolute net emission savings potential for 2030 is -2.6 million tons CO_2eq (almost a factor of 4 higher than in the lead scenario 2030). The significantly higher net emission savings potential results from the relevance of food waste prevention. On the one hand, this is set for 31% of the total food waste. On the other hand, the specific prevention factor is comparatively high and is only surpassed by the recycling of used fat as a diesel substitute.

Commercial and industrial waste

C&I waste originates from a very broad spectrum of different industries and thus contains very different waste streams. Therefore, possible contributions are distributed across all chapters of the European waste statistics. The collection of quantities for the subsequent balancing of the GHG emissions associated with their disposal is only carried out for orientation purposes. In the first step, the EWC-Stat codes to be analysed are determined for the determination of generation and destination, as well as the sectors of origin relevant for the balancing (via NACE categorisation). The following basic specifications are taken into account in order to limit the relevant EWC-Stat codes: Chapters W033, W103, W128, W13, W08 and W11 are excluded; C&I waste that is recorded as MSW is fully allocated to the material flow "MSW"; textiles are also excluded here, C&D waste is considered separately and excluded for C&I waste.

Figure 3: Sankey diagram C&I waste Germany 2017



Source: own illustration, ifeu

As a result, the following EWC-Stat codes are analysed for the C&I waste balance: W012, W02A[5], W032, W05, W06, W071, W072, W073, W074, W075, W091, W092, W101, W102, W124, W12B[6]. In addition, the destination for the relevant LoW-codes is analysed based on Destatis (2019b

[5] The aggregate W02A "Chemical wastes" contains the EWC-Stat codes W014 Spent chemical catalysts, W02 Wastes of chemical preparations and W031 Chemical deposits and residues.

[6] The aggregate W12B "Other mineral wastes" contains the EWC-Stat codes W122 Asbestos wastes (without exception classified as hazardous), W123 Wastes of naturally occurring materials and W125 Miscellaneous mineral wastes.

und c). As a result of this analysis, chapters W012, W02A, W032, W101 and W102 are excluded, and the flows of chapters W071, W074 and W072 are modified. In addition to these quantities, a quantity for paper waste of 7.2 million tons was added. This results from a difference between the figures in the statistics and the quantity reported according to association data. For the latter, it is assumed that it is not delivered to waste treatment plants, but directly to paper mills. Figure 3 shows the final material flow model for C&I waste from generation to final destination.

The figure shows that C&I waste by mass is dominated by "other mineral waste" (W12B). This waste fraction takes up more than 50% of the total quantity. It is followed by the estimated paper quantity with a mass share of 14%. Among the other waste fractions, ferrous metals, wood, organic waste and incineration residues account for between 5% and 7% of the total quantity. The percentage share of the remaining waste fractions is around or < 1% in each case.

In addition to the status quo, **two scenarios** for the development until 2030 are considered for the GHG balancing. Here, the individual waste streams are analysed and the optimisation potential is determined for each stream. On this basis, an ambitious and a less ambitious scenario are derived. For C&I waste, optimisation potentials are seen for the waste streams of used tyres (W073), plastics (W074), wood (W075) and organic waste (W091, W092), which in total result in a shift of 290,080 tons towards recycling for the less ambitious scenario and a shift of 692,330 tons for the ambitious scenario.

The GHG balancing is also carried out here according to the waste types shown in the Sankey diagram. Since the figures derived from the European statistics on the destination are the final destinations, debits from sorting are taken into account insofar as they are relevant from primary treatment and can be depicted. For this purpose, the input quantities are recalculated on the basis of the sorting losses. Dry recyclables and wood are accounted for in the same way as MSW. Differences in specific results per ton result on the one hand from partly different assumed yields from processing, since a higher type purity is assumed for C&I waste. On the other hand, different treatment splits come into play in some cases. The balancing of recycling for organic waste was derived from the balancing for food waste; specific emission values were determined. The disposal of incineration residues and other mineral wastes is not associated with any GHG emissions due to their inert character. Transport expenses are considered. Hospital waste and used tyres are calculated on the basis of own expertise.

The results of the GHG balance for 2017 and the two 2030 scenarios (Scenario 1, Scenario 2) are shown in Table 3. For the actual situation in 2017, there is an absolute net emission savings potential of -13.6 million tons CO_2eq. The main contributors to this are the dry recyclables. The main masses of other mineral waste and also the incineration residues have no influence on the result due to their inert character. The 2030 comparison scenarios differ only slightly in absolute terms. On the one hand, differences are only assumed for four waste types. On the other hand, the percentage shift shares for these overall and between the two scenarios are moderate at 2-5% (Scenario 1) and 5-10% (Scenario 2). For both comparison scenarios in 2030, the rounded absolute net emission savings potential is -10.3 million tons CO_2eq. Here, too, the defossilisation of the energy system is the relevant cause for the reduced net emission saving.

Table 3: **Absolute and specific net results by waste fraction – C&I waste Germany 2017 and comparison scenarios 2030**

Waste fraction	absolute			Specific per capita[1]			Specific per ton		
C&I waste	**2017**	**2030 Sc1**	**2030 Sc2**	**2017**	**2030 Sc1**	**2030 Sc2**	**2017**	**2030 Sc1**	**2030 Sc2**
	Million tons CO_2eq			kg CO_2eq/cap			kg CO_2eq/t		
Hospital waste	0.06	0.09	0.09	0.8	1.0	1.0	180	241	241
Ferrous metals	-3.63	-3.63	-3.63	-43.8	-43.8	-43.8	-1,538	-1,538	-1,538
Non-ferrous metals	-1.97	-1.33	-1.33	-23.8	-16.0	-16.0	-5,029	-3,398	-3,398
Metals	-0.10	-0.08	-0.08	-1.2	-1.0	-1.0	-2,035	-1,803	-1,803
Glass	-0.19	-0.19	-0.19	-2.3	-2.3	-2.3	-464	-459	-459
Paper	-3.16	-1.25	-1.25	-38.1	-15.1	-15.1	-438	-174	-174
Used tyres	-0.75	-0.79	-0.79	-9.0	-9.6	-9.6	-1,311	-1,389	-1,393
Plastics	-0.27	-0.44	-0.50	-3.3	-5.3	-6.1	-515	-831	-958
Wood	-2.21	-1.64	-1.56	-26.6	-19.8	-18.8	-608	-451	-429
Organic waste	-1.60	-1.28	-1.24	-19.3	-15.4	-15.0	-451	-360	-349
Combustion waste	0.04	0.04	0.04	0.4	0.4	0.4	9	9	9
Other mineral waste	0.17	0.17	0.17	2.1	2.1	2.1	6	6	6
Sum/Average	**-13.59**	**-10.33**	**-10.28**	**-164.1**	**-124.8**	**-124.2**	**-273**	**-208**	**-207**

1) Calculated with a population of 82,792,351 in 2017 (Statistisches Bundesamt (Destatis) 2017)

At the specific level per ton, the metals in particular show high net emission savings potentials. The net emission savings potential for used tyres is similarly high as for ferrous metals. This is achieved through material recycling, although only 50% of high-value applications with substitution of fossil thermoplastics are assumed. The other waste fractions mostly show net emission savings potentials of a similar amount. An exception is hospital waste, which shows a debit in the net result. The results for the inert fractions incineration residues and mineral waste include the debits of transport, which have a comparatively low significance despite a high mass share. In the comparative scenarios 2030, the specific net results are changed which are affected by defossilisation and/or for which optimisations are assumed.

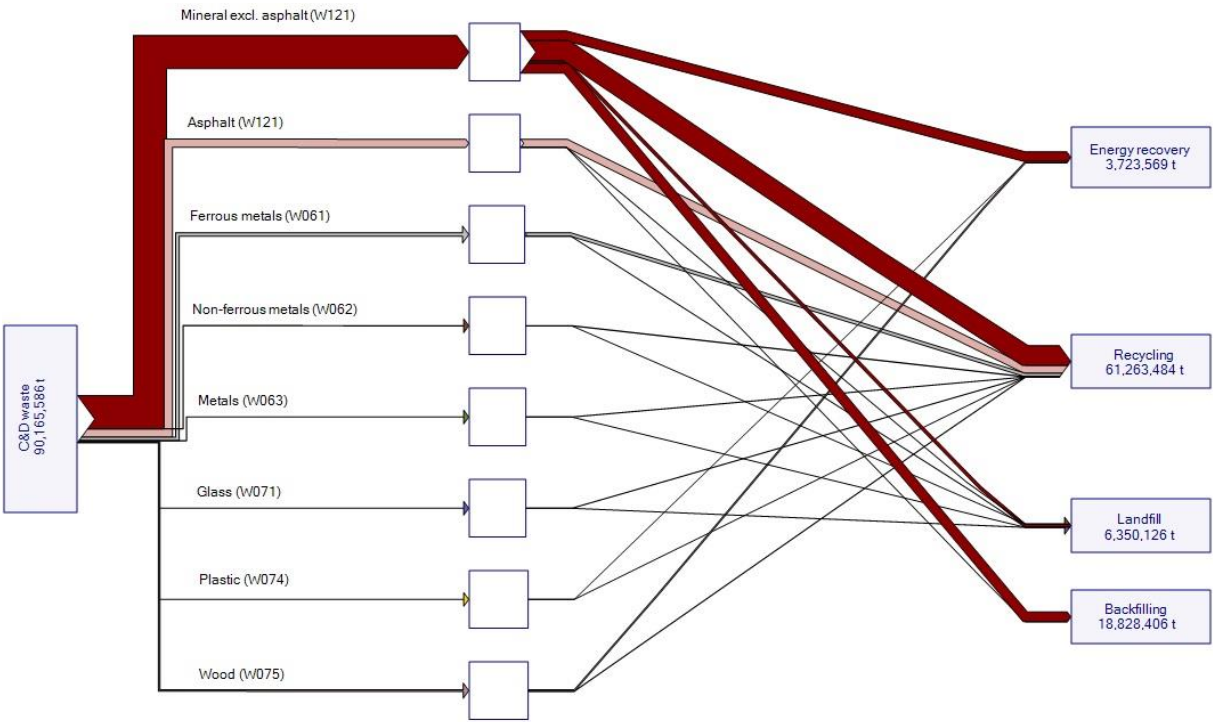
Construction and demolition waste

Construction and demolition waste is defined in the context of this study as all non-hazardous streams of Chapter 17 of the European Waste Catalogue, with the exception of the codes for "soil and stones" (LoW 17 05 04) and "dredged material" (LoW 17 05 06). For these codes, the information from the German waste statistic on the generation and destination in the various treatment facilities in Germany was evaluated (Destatis 2019b). Since data for construction waste processing plants and asphalt mixing plants are collected every two years, no data are available for the reference year 2017, which is why the data basis for 2016 was used in the following. Figure 4 shows the final material flow model for C&D waste from generation to final destination.

The diagram shows that C&D waste by mass is dominated by "mineral waste" (W121). This waste fraction accounts for 70% of the total quantity. It is followed by asphalt, which is considered separately from "mineral waste", with a mass share of 18%. Among the other waste fractions, ferrous metals and wood account for 7% and 3% of the total quantity, respectively. The percentage share of the remaining waste fractions is around or < 1%.

For the GHG balancing, in addition to the status quo, **two scenarios** for the development of recycling activities until 2030 are considered. Here, the individual waste streams are analysed and the optimisation potential is determined for each stream. On this basis, an ambitious and a less ambitious scenario are derived. For C&D waste, the less ambitious scenario considers optimisation potential for the waste streams of glass (W071), plastics (W074) and wood (W075), which in total result in a shift of 70,399 tons towards recycling. For the ambitious scenario, there is additional optimisation potential for mineral waste with and without asphalt (W121), ferrous metals (W061), non-ferrous metals (W062) and mixed metals (W063), resulting in a shift of 7.05 million tons (mainly mineral waste).

Figure 4: Sankey diagram C&D waste Germany 2017



Source: own illustration, ifeu

The GHG balancing is also carried out here according to the waste types shown in the Sankey diagram. The accounting is analogous to the description for C&I waste. Debits from sorting are recalculated, dry recyclables and wood are accounted for as for MSW. Deviations in specific results per ton arise here due to partially different treatment splits (e.g. proportional energy recovery for plastics). The disposal of mineral waste is not associated with any GHG emissions due to its inert character. Transport expenses are considered.

The results of the GHG balance for 2017 and the two 2030 scenarios (Sc1, Sc2) are shown in Table 4. For the actual situation in 2017, there is an absolute net emission savings potential of

-12.4 million t CO_2 equivalents. Metals are the main contributors to this. The main mass of mineral waste has hardly any influence on the result due to its inert character. The net debit results from transport expenses and the proportionate incineration of plastics (sorting fraction from construction waste processing). For the 2030 comparison scenarios, the net emission savings potential is slightly reduced. Here, the influence of defossilisation is lower than for MSW and C&I waste, as the result is characterised by ferrous metals. Scenario 1 results in an absolute net emission saving potential of -11.5 million tons CO_2eq. In scenario 2, it is -11.8 million tons CO_2eq.

At the specific level per ton, metals in particular also show high net emission savings potentials. The waste fractions glass and wood show net emission saving potentials of a similar magnitude. The net emission savings potential for asphalt is comparatively low. The disposal of mineral waste (without asphalt) shows a low net debit. The net emission saving for plastic waste in 2017 is comparatively low due to the proportionate thermal treatment (energy recovery R1). In the comparative scenarios 2030, the specific net emission savings potential for plastics is higher due to the redirection of energy recovery (R1) to recycling and also, as already in the case of MSW and C&I waste, due to the lower GHG debits for electricity demand (defossilisation). In general, the specific net results affected by defossilisation and/or for which optimisations are assumed are changed in the 2030 comparison scenarios.

Table 4: Absolute and specific net results by waste fraction – C&D waste Germany 2017 and comparison scenarios 2030

Waste fraction	Absolute			Specific per capita[1]			Specific per ton		
C&D waste	**2017**	**2030 Sc1**	**2030 Sc2**	**2017**	**2030 Sc1**	**2030 Sc2**	**2017**	**2030 Sc1**	**2030 Sc2**
	Million tons CO_2eq			kg CO_2eq/cap			kg CO_2eq/t		
Mineral waste (excl. asphalt)	0.37	0.49	0.38	4.5	5.9	4.6	6	8	6
Asphalt	-0.19	-0.19	-0.20	-2.3	-2.3	-2.4	-12	-12	-12
Ferrous metals	-8.98	-8.98	-9.17	-108.5	-108.5	-110.8	-1,355	-1,355	-1,384
Non-ferrous metals	-1.65	-1.20	-1.22	-19.9	-14.4	-14.7	-3,540	-2,571	-2,625
Metals	-0.28	-0.27	-0.27	-3.4	-3.2	-3.3	-1,497	-1,434	-1,464
Glass	-0.11	-0.11	-0.11	-1.3	-1.3	-1.3	-433	-438	-448
Plastics	-0.02	-0.05	-0.07	-0.3	-0.6	-0.8	-195	-481	-604
Wood	-1.54	-1.18	-1.11	-18.5	-14.3	-13.5	-511	-393	-371
Sum/Average	**-12.38**	**-11.49**	**-11.77**	**-149.6**	**-138.7**	**-142.2**	**-137**	**-127**	**-131**

1) Calculated with a population of 82,792,351 in 2017 (Statistisches Bundesamt (Destatis) 2017)

Overview of the results

The results for the different source sectors for Germany are presented in overview in Table 5. For MSW, the results from the baseline comparison are used, for C&I and C&D waste for 2030 the results of Scenarios 2, which were also used for the EU27 balances. In total, this results in a total absolute net emission savings potential of around -38.6 million tons CO_2eq for Germany for the balance year 2017. For the selected comparison scenarios for 2030, the total absolute net emission savings potential is around -32.9 million tons CO_2eq. By balance area, all source sectors show similar relevant net emission savings potentials. In terms of waste volume, MSW and C&I waste have a similarly high share (26% each). C&D waste takes up 48%, but consists of 88% mineral waste (incl. asphalt), which contributes only minor GHG effects.

Table 5: Waste Germany - Quantities and absolute and specific net results by source sector, 2030 more ambitious scenarios

Bilanzraum	Quantity	GHG absolute		Specific per capita[1]		Specific per ton	
		2017	2030	2017	2030	2017	2030
	Million tons	Million tons CO_2eq		kg CO_2eq/cap		kg CO_2eq/t	
MSW	49.2	-12.6	-10.9	-152	-131	-256	-221
C&I waste	49.8	-13.6	-10.3	-164	-124	-273	-207
C&D waste	90.2	-12.4	-11.8	-150	-142	-137	-131
Sum/Average	**189.2**	**-38.6**	**32.9**	**-466**	**-398**	**-204**	**-174**

1) Calculated with a population of 82,792,351 in 2017 (Statistisches Bundesamt (Destatis) 2017)

Summary and recommendations

The study carried out is a comprehensive investigation with regard to both waste streams and GHG accounting. The data from the waste statistics were compared with data from associations and other data sources. The balancing was carried out according to the individual waste fractions for each of the four balancing areas. In addition, an approach has been developed and applied on how to integrate preparation for re-use and waste prevention into the LCA of waste management. A separate comprehensive study was carried out for the EU. Overall, a large number of scenarios and sensitivities were considered. However, relevant data uncertainties also remain for Germany and the results, especially for food waste, C&I waste and C&D waste, are to be understood as orientational. Regardless of this, important insights were gained and the complex interrelationships and conflicting influences for GHG accounting were analysed. Relevant findings and recommendations from the study are:

- With the implementation of the energy transition and other measures of the Paris Agreement, the climate protection potential through the circular economy necessarily decreases, as the substitution potential for electricity and heat generation from waste also decreases as a result of the defossilisation of the energy sector. This is already evident for MSW in the lower net emission savings potential for 2017 compared to the previous study and becomes even more apparent in the scenarios for 2030. The influence of defossilisation also exists in the primary production of products and the associated substitution potential for recycling (this study: estimate for electricity-intensive production of aluminium and wood and pulp).
- The study shows that the circular economy can nevertheless continue to make important future contributions to climate protection through measures to increase the separate collection of recyclables, increase recycling and technical optimisation of facilities. This becomes clear in the "business as usual" sensitivity analysis for 2030 for MSW. Without measures, the potential climate protection contribution would almost halve compared to the base year 2017; compared to the 2030 lead scenario, the contribution is 40% lower.

- The 2030 lead scenario for MSW takes into account the target of achieving the legally required recycling quota of 60% through increased separate collection. Both the authors of this study and the participants in the two online workshops with associations see this increase as very ambitious. Here, politics is called upon to identify and implement supporting measures together with the waste management actors.

- In particular, increasing the recycling of dry recyclables achieves high net emission savings potentials. The achievement of corresponding climate protection contributions can only succeed if the data situation and knowledge of volume potentials is improved, e.g. by commissioning analyses of the current situation with dry recyclables at district level, studies on the optimisation of collection systems[7], development of a roadmap for the further increase of separate collection under the premise of good separation qualities, ecologically accompanied pilot projects, financial incentives for actors.

- The results of the study are necessarily based on assumptions or data of limited reliability for certain types of waste. For a better assessment of recycling and its further increase potential, the composition and quality of household-type commercial waste, bulky waste and mixed packaging waste (especially the fractions not sent for recycling) should be analysed. For LWP, the nationwide volume flow data should be published in detail on the website of the Foundation Central Agency Packaging Register (ZSVR) for better data availability and transparency[8].

- For other biowaste and garden, park and cemetery waste, the result shows that these also contribute to climate protection, although to a lesser extent. Fossil-based plastic-containing discards have a negative impact on the result. In order to achieve further climate protection contributions, measures are needed to ensure that the increase in the separate collection of organic waste does not lead to a further increase of impurities. Successful implementation requires the cooperation of citizens, for example. In many cases, there is still uncertainty about what can be put in the organic waste bin, and in many cases disposal is still subject to a fee. Politics should continue to offer support for nationwide harmonisation and intensified public relations work.

- The climate protection contribution of waste from the bio bin is higher in the case of anaerobic digestion (combined material and energy recovery). In order to achieve further climate protection contributions, their share must be increased and corresponding facilities must be built. Planning and construction of the infrastructure require organisational and financial support, and issues of sector coupling and system efficiency for biogas should also be taken into account. The German “Kommunalrichtlinie” (municipal guideline) is an instrument for promoting low-emission and efficient anaerobic digestion plants, which could be further expanded or supplemented by other subsidies. Other important measures include improving the data situation for anaerobic digestion through further measurement programmes and optimisation options for GHG emissions.

- The climate protection contribution from the anaerobic digestion of commercial organic waste (kitchen/canteen waste, commercial food waste, overstocked food waste) can only be determined as an orientation. For a reliable assessment, the data situation needs to be improved through projects to collect data and GHG emissions from anaerobic digestion

[7] E.g. nationwide recycling bins, what infrastructure is needed, what quality requirements, what control mechanisms.

[8] Quantities for liquid beverage cartons, other paper composites, tinplate, aluminium, foils, mixed plastics, types of plastics (ideally further subdivided) and information on RDF quantities and sorting residues.

plants specialising in the treatment of these waste types. Corresponding projects could also help to better assess possibilities for food waste prevention.

- The study shows that residual waste treatment can also continue to contribute to climate protection. Optimisation measures are essential to achieve these further climate protection contributions. For thermal waste treatment, this concerns the increases of net efficiencies assumed for 2030. This requires action. For waste incineration plants and RDF power plants as well as for biomass CHP, possibilities for optimisation must be further examined and implementation supported (especially heat utilisation). The co-incineration of RDF in cement kilns offers a relevant - and, compared to energy recovery, higher - contribution to climate protection as long as coal can still be used as a regular fuel, which can be substituted by RDF. In this respect, it is also important to further support MBT plants in their optimisation efforts.
- The integration of waste prevention and preparation for re-use into the LCA of waste management was shown in this study. The developed approach can also be applied to other waste types.
  - In the case of waste prevention, the prerequisite is that the avoided products are known. This requires analogous data as for food waste regarding the composition, the avoidable amount of waste and its GHG impact from production.
  - The database for re-use needs to be improved. For permanent monitoring, waste streams that are suitable for re-use (such as furniture, textiles, electronic and electrical equipment) should be statistically recorded in order to better identify and control potentials. In addition, further studies are needed to better assess the actual possible extension of the lifetime of products.

Finally, it is recommended for future studies to consider resource conservation in addition to climate protection potentials. The climate protection potentials in the circular economy necessarily decrease with increasing implementation of the climate protection goals that must be achieved to avert the climate catastrophe. GHG net emission saving potentials must become zero for climate neutrality. However, the goal of climate neutrality goes hand in hand with a demand for raw materials, especially for renewable energy plants, which must be kept in mind. The aspect of resource conservation is essentially linked to the contribution of the circular economy. In future projects, it should first be determined which areas or resources are relevant for an investigation of resource conservation and how these are to be assessed.

Zusammenfassung

Klimaschutz ist eine der größten globalen Herausforderungen des 21. Jahrhunderts. Mit dem Übereinkommen von Paris vom Dezember 2015 haben sich in Nachfolge des Kyoto-Protokolls erneut Mitgliedsstaaten verpflichtet, die anthropogenen Treibhausgas (THG-) Emissionen zu reduzieren und die globale Erwärmung auf deutlich unter 2 °C gegenüber vorindustriellen Werten zu beschränken. Dazu sind eingehende Anstrengungen notwendig über alle klimarelevanten Sektoren und Quellgruppen hinweg, so auch im Abfallbereich.

Der Sektor Abfall ist nach den allgemeinen Berichterstattungspflichten des Kyoto-Protokolls auf direkte und nicht-energetische THG-Emissionen beschränkt, um eine Doppelberichterstattung zu vermeiden. Dadurch bildet sich der Beitrag der Abfallwirtschaft vor allem durch die Abkehr von der Deponierung ab. Jedoch sind hierbei weder künftig anfallende THG-Emissionen der Deponierung umfasst, noch die darüber hinaus durch die Abfallwirtschaft ausgelösten weiteren THG-Minderungspotenziale, die sich aus der stofflichen und energetischen Verwertung ergeben. Die Gesamtheit der dadurch erzielten und erzielbaren Beitragsleistungen zum Klimaschutz kann mit Hilfe der Ökobilanzmethode der Abfallwirtschaft demonstriert werden (z. B. dokumentiert in (Dehoust et al. 2010), (Vogt et al. 2015)).

In diesem Vorhaben ist die abfallwirtschaftliche Situation zum Stand 2017 untersucht und vor dem Hintergrund der weiterentwickelten politischen und rechtlichen Rahmenbedingungen der potenzielle Klimaschutzbeitrag der Kreislaufwirtschaft für das Zieljahr 2030 aufgezeigt. Betrachtet sind zudem Möglichkeiten die Vorbereitung zur Wiederverwendung (für Gebrauchtwaren bei Siedlungsabfällen) sowie die Abfallvermeidung (bei Lebensmittelabfällen) einzubeziehen.

Der Teilbericht Deutschland dokumentiert die Arbeiten und Ergebnisse des Projektes „Klimaschutzpotentiale der Kreislaufwirtschaft - Deutschland, EU“[9] für Deutschland. Die Ergebnisse für die EU sind in einem eigenen Teilbericht veröffentlicht („Teilbericht EU“). Beide Berichte beschreiben die abfallwirtschaftliche Situation untergliedert nach den folgenden Abfallarten:

- Siedlungsabfälle (SiAbf)
- Lebensmittelabfälle (LMA, als Sonderbilanzraum)
- Produktions- und Gewerbeabfälle (P&G-Abfälle)
- Bau- und Abbruchabfälle (B&A-Abfälle)

Für jede dieser Abfallarten wurde eine eigene Mengenerhebung und THG-Bilanzierung durchgeführt. Methodisch bilden dabei die Bilanzräume für Siedlungsabfälle, P&G- und B&A-Abfälle komplementäre Bilanzräume, während die Lebensmittelabfälle als Sonderbilanzraum die LMA aus dem Siedlungsabfallbereich und dem Bereich der P&G-Abfälle umfassen.

Für Siedlungsabfälle und LMA sind detailliertere THG-Bilanzen abgebildet, für P&G- und B&A-Abfälle erfolgt eine überschlägige Betrachtung. Für Siedlungsabfälle und LMA ist die Ist-Situation im Basisjahr 2017 für Deutschland, für die aktuelle EU27, die vorige EU28 (mit UK) und zudem für zwei aus den EU-Mitgliedsländern definierte Cluster untersucht. Für P&G- und B&A-Abfälle beschränkt sich die Untersuchung auf Deutschland und die EU27. Künftige THG-Minderungspotenziale für das Zieljahr 2030 sind für die Siedlungsabfälle und LMA mit je zwei Szenarien für Deutschland, die EU27 und die beiden EU-Cluster umfassender analysiert. Für P&G- und B&A-Abfälle sind es zwei Szenarien für Deutschland und ein Szenario für die EU27.

[9] Langtitel: Ermittlung der Klimaschutzpotentiale in der Kreislaufwirtschaft für Deutschland und die EU als Beitrag zur Erreichung der Ziele nationaler und internationaler Klimaschutzverpflichtungen.

Datenlage, Vorgehen Mengendatenerhebung

Für die vier Abfallarten bzw. Systemräume werden nur nicht-gefährliche Abfälle ausgewertet und bilanziert, gefährliche Abfälle sind aus dieser Studie ausgenommen. Die Studie bezieht sich soweit als möglich auf Daten zum Jahr 2017. Hauptquelle ist die offizielle deutsche Abfallstatistik. Weitere Quellen wie Verbände, Interviews mit Fachkundigen und einschlägige Studien wurden genutzt, um die statistischen Daten auszuwerten und bei Bedarf zu ergänzen. Soweit in dieser Studie für 2017 Abfallmengen pro Kopf genannt werden, wird der Bevölkerungsstand von 82.792.351 vom 31.12.2017 gemäß Destatis herangezogen[10].

Die Abgrenzung der Abfallmengen für die vier Systemräume ist im Teilbericht EU detailliert beschrieben. Für die Bilanzen der Siedlungsabfälle und der B&A-Abfälle erfolgt sie über die Festlegung der relevanten EAK-Stat-Schlüssel[11] in Verbindung mit den darunter zugeordneten EAV-Schlüsseln. Dabei entsteht keine Überschneidung der Systemräume. Für die Bilanz der P&G-Abfälle würden sich aufgrund der in den betrachteten EAK-Stat-Schlüsseln enthaltenen EAV-Schlüssel Überschneidungen sowohl mit der Siedlungsabfallbilanz als auch mit der Bilanz der B&A-Abfälle ergeben. Die entsprechenden Mengen wurden demnach von den für die Bilanz der P&G-Abfälle zu berücksichtigenden Mengen abgezogen. Die Sonderbilanz Lebensmittelabfälle stellt eine Teilmenge der Siedlungsabfall- und der P&G-Abfallbilanz dar. Sie ist nicht additiv.

Grundlagen der THG-Bilanzierung

Die Ermittlung der Klimaschutzpotenziale der Kreislaufwirtschaft erfolgt mittels der Ökobilanzmethode der Abfallwirtschaft in Anlehnung an ISO 14040/44. Die Methode wurde bereits vielfach in Studien angewendet und ausführlich beschrieben (z. B. (Dehoust et al. 2010), (Vogt et al. 2015)). Sie erlaubt eine ganzheitliche Betrachtung des Sektors Abfall, da neben den direkten Emissionen der Abfallbehandlung (Belastungen) auch die potenziell vermiedenen Emissionen (Gutschriften) durch die Substitution von Primärprodukten und konventionell erzeugter Energie einbezogen werden. Zur Bewertung der Klimawirkung von THG-Emissionen werden die Charakterisierungsfaktoren für den 100-Jahreshorizont (GWP100) nach IPCC (2013) verwendet.

Für die Ökobilanzmethode der Abfallwirtschaft gelten bestimmte Regeln, wie z. B. dass Systemvergleiche nur für gleiche Gesamtabfallmengen und -qualitäten durchgeführt werden dürfen. In die Bilanzierung werden alle Emissionen einbezogen, die bei der Behandlung einer definierten Abfallmenge anfallen und damit auch die über mehrere Jahrzehnte entstehenden Emissionen aus der Deponierung. Ein weiterer relevanter Aspekt ist, dass für die stoffliche Verwertung das technische Substitutionspotenzial angerechnet wird und nicht das Substitutionspotenzial nach Marktmix. Bei der Mitverbrennung von Abfällen in Zement- oder Kohlekraftwerken wird die Substitution fossiler Regelbrennstoffe berücksichtigt. Die Erzeugung von Strom und Wärme aus Abfall in thermischen Abfallbehandlungsanlagen (TAB) wird durch Substitution der durchschnittlichen Strom- und Wärmeerzeugung angerechnet, um die Dynamik aus der Energiewende in Zukunftsszenarien nachvollziehen zu können. Eine Ausnahme bildet die Möglichkeit der flexiblen Stromerzeugung; für diese ist die Substitution fossiler Reservekraftwerke berücksichtigt.

Für den getrennt betrachteten Bilanzraum Deutschland werden nationale Emissionsfaktoren für Strom und Wärme verwendet. Für die Zusammenführung mit dem Bilanzraum der EU27 (und EU28) sind die Bilanzen für Deutschland aus Konsistenzgründen zusätzlich mit den EU27

[10] https://www-genesis.destatis.de/genesis//online?operation=table&code=12411-0001&bypass=true&levelindex=0&levelid=1611656806242#abreadcrumb (letzter Zugriff 29.06.2021)

[11] Bei Bau- und Abbruchabfällen sind in der Statistik zudem alle relevanten Schlüssel vollständig dem NACE-Sektor F zugeordnet.

Emissionsfaktoren berechnet. Die sich ergebenden Unterschiede werden gezeigt. Als Sensitivität für das Basisjahr 2017 ist zudem am Beispiel der Siedlungsabfälle betrachtet, wie sich die Verwendung der UBA Vermeidungsfaktoren für erneuerbare Energieträger als Gutschrift für Strom aus Abfall auf die Bilanz auswirkt. Die allgemein verwendeten durchschnittlichen Emissionsfaktoren sind für die 2030-Szenarien an einen veränderten Energieträgermix angepasst. Da sich veränderte Emissionsfaktoren für Strom auch auf die Primärproduktion auswirken, wurde auch ein entsprechend reduziertes Substitutionspotenzial für stromintensive Primärprozesse (Aluminium, Papier) abgeschätzt. Grundsätzlich werden wie in der Vorgängerstudie (Vogt et al. 2015) harmonisierte Emissionsfaktoren für substituierte Primärprozesse verwendet.

Die Bilanzierung für die einzelnen Abfallarten und Bilanzräume ist in der Studie ausführlich beschrieben. Sie beruht auf eigener Expertise, auf aktuellen Studien und zudem dem Austausch mit der Fachwelt. Für Deutschland wurden zwei Fachgespräche mit Verantwortlichen der Wissenschaft und aus Verbänden durchgeführt. Die Ergebnisse für Siedlungsabfälle Deutschland für 2017 sind zudem gegenüber denen der Vorgängerstudie (Dehoust et al. 2010) eingeordnet.

Siedlungsabfälle

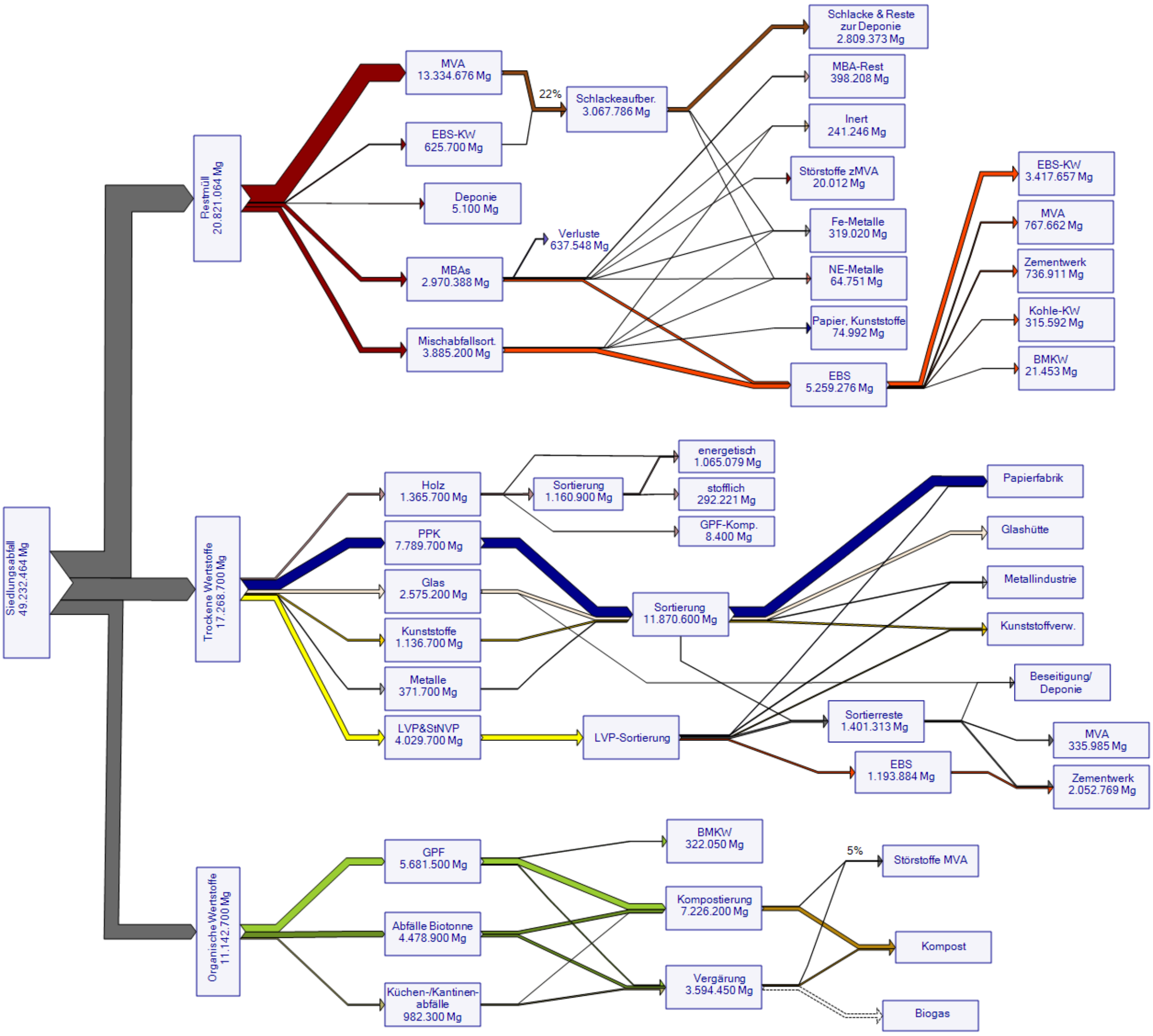
Der Fokus dieser Studie für **Aufkommen und Verbleib** der Abfälle liegt auf allen inländischen Abfallmengen, inklusive derer aus dem eigenen Betrieb, berücksichtigt aber keine Mengen, die aus dem Ausland angeliefert werden. Die Exporte werden hinzugerechnet. Als Quelle für die Exporte nach Abfallart wird die Aufstellung des Umweltbundesamts zur grenzüberschreitenden Verbringung von zustimmungspflichtigen Abfällen herangezogen (UBA 2017).

Als Siedlungsabfälle werden gemäß Destatis-Definition alle Abfälle, die unter den EAV-Schlüsseln 20 und 15 01 aufgeführt werden, eingestuft. Insgesamt waren dies für 2017 unter EAV-Schlüssel 20 rund 40,5 Mio. Mg, davon 634.400 Mg aus dem Ausland, so dass die Ausgangsmenge für diese Studie bei rund 39,85 Mio. Mg liegt. Hinzu kommen rund 12,2 Mio. Mg unter EAV-Schlüssel 15 01 (Verpackungsabfälle), von denen 472.800 Mg aus dem Ausland angeliefert wurden, so dass ein Ausgangswert von rund 11,68 Mio. Mg verbleibt bzw. in Summe mit dem EAV-Schlüssel 20 rund 51,5 Mio. Mg für Siedlungsabfälle insgesamt.

Hieraus werden gefährliche Abfälle, Textilien, Speiseöle und -fette, Farben, Druckfarben, Klebstoffe und Kunstharze, Reinigungsmittel, Arzneimittel, Batterien und Akkumulatoren, Boden und Steine, Straßenkehricht sowie sonstige Fraktionen, Fäkalschlamm und Abfälle der Kanalreinigung ausgeschlossen, was zu einem Gesamtaufkommen von 49,47 Mio. Mg Siedlungsabfälle führt. Werden die Exporte ergänzt beträgt das Aufkommen 49,7 Mio. Mg.

Die Menge an Aufkommen wird mit der in Anlagen behandelten Menge abgeglichen und es wird eine Differenz von 2,7 % festgestellt, welche auf Datenschutzgründe (Destatis weist nur Werte aus, wenn mehr als 3 Einzelanlagen im Datensatz enthalten sind) zurückzuführen ist. Zur Schließung dieser Lücke werden Annahmen für Verpackungen aus Glas, Hausmüll und hausmüllähnliche Gewerbeabfälle sowie für Bioabfälle, welche in die Klärschlamm-kompostierung oder sonstige biologische Behandlung gehen, getroffen. Für thermische Abfallbehandlungsanlagen, Feuerungsanlagen sowie biologische Behandlungsanlagen werden Sondertabellen überprüft, deren Daten aber mit Ausnahme der biologischen Behandlungsanlagen für die weitere Betrachtung verworfen. Für das Stoffstrommodell werden weitere Quellen gesammelt und in das Modell eingespeist. In Abbildung 1 ist das finale Stoffstrommodell für die Siedlungsabfälle vom Aufkommen bis zum finalen Verbleib dargestellt.

Abbildung 1: Sankey-Diagramm Siedlungsabfall Deutschland 2017



Quelle: eigene Darstellung, ifeu

Das Sankey-Diagramm zeigt, dass in Deutschland bereits eine umfassende getrennte Erfassung etabliert ist. Die getrennt erfassten trockenen Wertstoffe (inkl. Holz) nehmen 35 % des Gesamtaufkommens ein und die getrennt erfassten organischen Abfälle 23 %. Es verbleibt ein Restmüllstrom von 42 %, der zur Erstbehandlung überwiegend thermischen Abfallbehandlungsanlagen (MVA, EBS-KW) zugeführt wird (67 %).

Für die **Szenarien** 2030 ist die rechtliche Zielvorgabe einer Recyclingquote in Höhe von 60 % für Siedlungsabfälle maßgeblich. Der wichtigste Hebel zur Erreichung dieser Quote liegt in einer Steigerung der getrennten Erfassung von Wertstoffen durch Entnahme aus der Restmüllmenge. Für 2017 ergibt sich der recycelte Anteil der in dieser Studie betrachteten Siedlungsabfallmenge zu 48 %. Diese Recyclingrate (RC-Rate) ist systembedingt nicht zu verwechseln mit der offiziellen Recyclingquote, stellt aber eine gute Näherung für diese dar. Für die Szenarien 2030 ist die RC-Rate entsprechend auf 60 % zu steigern. Ausgangsbasis für die Steigerungs-möglichkeiten bildet die Abfallzusammensetzung des Restmülls in 2017. Diese ist gut dokumentiert für Hausmüll (Dornbusch et al. 2020). Für hausmüllähnliche Gewerbeabfälle und für Sperrmüll mussten auf Basis orientierender Werte plausible Abschätzungen vorgenommen werden. Um die 60 % zu erreichen müssen dem Restmüll bis 2030 etwa 6 Mio. Mg Wertstoffe entnommen werden (entspricht 29 % der Restmüllmenge in 2017). Auch wenn seit 2017 von einer weitergehenden Steigerung der getrennten Erfassung auszugehen ist, ist die rechnerisch erforderliche Steigerung bis 2030 sehr ambitioniert. Sowohl die Machbarkeit als auch die erreichbaren Qualitäten recycelbarer getrennt erfasster Fraktionen stehen in Frage.

Da ein weniger ambitioniertes Szenario die rechtlichen Zielvorgaben verfehlen würde, werden für die Betrachtung der künftigen Szenarien 2030 folgende zwei Ansätze verfolgt, die auch im Rahmen der Fachgespräche diskutiert wurden:

- Basisvergleich: Vergleich Basisjahr 2017 mit einem Leitszenario 2030, das sich auf eine vergleichsweise valide Datenbasis bezieht, aber sehr ambitioniert ist.
- Vergleich mit Eigenkompostierung in der RC-Rate: Szenario bei dem eine Eigenkompostierungsmenge auf die RC-Rate angerechnet ist; dadurch sinkt das Ambitionsniveau, aber es bestehen sehr hohe Datenunsicherheiten.

Die Anrechnung der Eigenkompostierung ist eine modell-theoretische Lösung, um die Spannweite unterschiedlicher Ambitionsniveaus diskutieren zu können. Es ist in der Studie weder beabsichtigt noch möglich potenzielle Wechselwirkungen zwischen einer getrennten Erfassung von nativ-organischen Abfällen und einer Eigenkompostierung zu untersuchen.

Eine Eigenkompostierungsmenge für Deutschland ist nicht bekannt, sie wurde zu 7,9 Mio. Mg (95 kg/(E*a)) abgeschätzt. Diese Menge ist sowohl dem Basisjahr 2017 als auch im Szenario 2030 zuaddiert (Bedingung gleicher Gesamtmengen bei der Ökobilanz der Abfallwirtschaft; entsprechend ist ein Vergleich zwischen den beiden 2030-Szenarien nur qualitativ und auf spezifischer Ebene möglich). Der Ambitionsgrad der Steigerung der getrennten Erfassung wird etwa halbiert. Mit der eigenkompostierten Menge berechnet sich die RC-Rate für 2017 zu 55 % und die zusätzlich bis 2030 getrennt zu erfassende Menge zu rd. 2,7 Mio. Mg (entspricht 13 % der Restmüllmenge in 2017). Neben der Menge bestehen erhebliche Datenunsicherheiten auch bezüglich der THG-Emissionen aus der Eigenkompostierung. Nach ausgewerteter Studienlage ist tendenziell mit Nettobelastungen zu rechnen. Die Eigenkompostierung ist in dieser Studie mit Null bewertet, um den Einfluss auf die THG-Bilanz möglichst neutral zu halten und so möglichst wenig die eigentliche Fragestellung des Szenarios zu beeinflussen. Bei allen weiteren Annahmen (Abfallmengenbehandlung, technische Optimierungen) entspricht das Szenario mit Eigenkompostierung in der RC-Rate dem Leitszenario 2030.

Die Annahmen im Leitszenario 2030 sind folgende (Mengenangaben etwa halbiert im Szenario mit Eigenkompostierung in der RC-Rate):

- Für die Hauptmenge der gesteigerten getrennten Erfassung, ca. 3,2 Mio. Mg nativ-organische Abfälle (2017 mit 30 % Hauptfraktion im Restmüll), ist eine Erfassung über die Biotonne mit anschließender Vergärung angenommen; wohl wissend, dass auch dies sehr ambitioniert ist und z. B. bei 30.000 Mg/a Behandlungskapazität den Zubau von rd. 100 Anlagen bedeutet; zu kleinen Anteilen ist die Behandlung mit Soldatenfliegenlarve und mit hydrothermaler Carbonisierung (HTC) als neuen Verfahren angesetzt.
- Die zusätzlich getrennt erfassten trockenen Wertstoffe (Kunststoffe, PPK, Glas, Metalle) werden dem Recycling zugeführt.
- Das für 2017 ermittelte Aufkommen an Leichtverpackungsabfällen (LVP) ist konstant gehalten, da keine geeignete Zuordnung zu den Unterfraktionen möglich ist. Im Leitszenario 2030 werden LVP wie Szenario 1 für 2030 in Dehoust et al. (2016b) bilanziert.
- Für die zusätzlich getrennt erfasste Menge Altholz ist die Altholzaufbereitung angenommen und zu einem kleinen Mengenanteil eine Pyrolyse als neues Verfahren.

- Die dem Restmüll entnommene Menge ist gleichverteilt über die Erstbehandlungsanlagen (TAB, MBA, „Mischabfallsortierung“[12]) reduziert (je 29 % der Behandlungsmenge in 2017); die Aufteilung zwischen MVA und EBS-KW ist unverändert; für MBA ist angenommen, dass die Inputmenge in MBS und der prozentuale Anteil in MPS bleibt, die Differenz ist gleichverteilt bei MBA Rotte und MBA Vergärung abgezogen.
- Für die neue Restmüllzusammensetzung in 2030 sind die Kenndaten, Heizwert, fossiler und biogener Kohlenstoffgehalt, neu berechnet. Sie unterscheiden sich moderat (beim Leitszenario etwas deutlicher geringerer fossiler C-Gehalt).
- Für Garten-, Park- und Friedhofsabfälle (GPF) erfolgt eine Umlenkung von 10 % der bisher kompostierten Mengen hin zu einer Vergärung; Küchen-/Kantinenabfälle werden in 2030 ausschließlich vergoren und nicht mehr kompostiert.
- Bislang in Kohlekraftwerken mitverbrannte Sekundärabfälle (v. a. EBS, Rejects aus PPK-Verwertung) werden in TAB eingesetzt.
- Technische Optimierungsmaßnahmen sind:
  - Steigerung der Nutzungsgrade bei thermischen Anlagen,
  - Steigerung der Ausbeuten bei der Aufbereitung trockener Wertstoffe,
  - Steigerung von Metallausbeuten aus Restmüllbehandlung,
  - Steigerung der anteiligen Erzeugung von Biomethan.

Neben den beiden Szenarien wurden folgende Szenarien und Sensitivitäten berechnet:

- Sensitivität 2030 „business as usual“,
- Basisvergleich mit Strom- und Wärmeemissionsfaktoren der EU27,
- Sensitivität 2017 mit Vermeidungsfaktoren für Strom aus biogenem Abfall,
- Sensitivität mit Vorbereitung zur Wiederverwendung und Abfallvermeidung.

Die **Ergebnisse der THG-Bilanz im Basisvergleich** zeigt Tabelle 1. Die Ergebnisse sind nach Abfallarten aufgeführt. Für Restmüll umfasst das Ergebnis die THG-Bilanzierung über die verschiedenen Behandlungspfade, die im Sankey-Diagramm dargestellt sind. Analog sind unter „Organikabfall“, die Behandlungspfade für die organischen Wertstoffe Abfälle aus der Biotonne, GPF und Küchen-/Kantinenabfälle zusammengefasst. Die Ergebnisse für die getrennt erfassten trockenen Wertstoffe sind einzeln nach Abfallarten aufgeführt.

Insgesamt weisen beide Szenarien, das Basisjahr 2017 und das Leitszenario 2030, Nettoentlastungspotenziale auf (negative Werte, Gutschriften höher als Belastungen). Das absolute Nettoentlastungspotenzial 2017 liegt bei -12,6 Mio. Mg CO_2-Äq. Hauptbeiträge bilden PPK, LVP & StNVP und Restmüll, die nach Masse 66 % einnehmen. Im Leitszenario 2030 liegt das absolute Nettoentlastungspotenzial mit -10,9 Mio. Mg CO_2-Äq niedriger. Ursache ist vor allem die Defossilisierung des Energiesystems (niedrigere Emissionsfaktoren für Strom und Wärme). Zum einen sinken die THG-Belastungen aus dem Energiebedarf, zum anderen aber auch die Substitutionspotenziale für Energie und die Primärprodukte, deren stromintensive Herstellung mit dem Stromemissionsfaktor 2030 angepasst wurde (Aluminium, PPK). Dem entgegen stehen die Optimierungen: gesteigerte getrennte Erfassung, technische Optimierungen.

[12] Sortierung von gemischten Siedlungsabfällen in verschiedenen Anlagentypen nach Abfallstatistik wie „Sortieranlagen“, „sonstige Behandlungsanlagen“.

Tabelle 1: Absolute und spezifische Nettoergebnisse nach Abfallfraktionen – Basisvergleich Siedlungsabfälle Deutschland: Basisjahr 2017 und Leitszenario 2030

Abfallfraktion	absolut		spez. pro Kopf[1]		spez. pro Tonne	
SiAbf	**2017**	**2030 LS**	**2017**	**2030 LS**	**2017**	**2030 LS**
	Mio. Mg CO_2-Äq		kg CO_2-Äq/E		kg CO_2-Äq/Mg	
Restmüll	-2,37	-0,71	-28,6	-8,6	-114	-48
Organikabfall	-0,60	-0,72	-7,3	-8,3	-54	-50
PPK	-3,35	-1,48	-40,4	-17,9	-430	-171
Glas	-1,20	-1,43	-14,4	-17,3	-464	-460
Kunststoffe	-0,49	-1,43	-5,9	-17,3	-431	-692
LVP & StNVP	-3,31	-3,57	-39,9	-43,1	-820	-886
Metalle	-0,66	-0,98	-7,9	-11,8	-1.769	-1.616
Holz	-0,65	-0,59	-7,8	-7,2	-474	-358
Summe/Durchschnitt	**-12,6**	**-10,9**	**-152**	**-132**	**-256**	**-222**

1) berechnet mit Bevölkerungszahl von 82.792.351 in 2017 (Statistisches Bundesamt (Destatis) 2017)

Auf spezifischer Ebene pro Tonne zeigen vor allem die Metalle hohe Nettoentlastungspotenziale. Die Herstellung von Roheisen und Aluminium ist mit vergleichsweise hohen THG-Emissionen verbunden. Im Leitszenario 2030 sinkt die Nettoentlastung wegen der angepassten Primärherstellung von Aluminium. Auch hohe spezifische Nettoentlastungen zeigen sich bei LVP & StNVP und bei Kunststoffabfällen. Letztere haben 2017 noch ein geringeres Nettoentlastungspotenzial das in 2030 deutlicher ansteigt. Ursache ist die geringere THG-Belastung für den Strombedarf (bei reinen Kunststoffabfällen deutlicher als beim LVP-Gemisch). Die Entlastungspotenziale für Kunststoffabfälle sind wenig verändert. Diese könnten durch bessere Qualitäten und damit stärkere Substitution von Kunststoff-Neuware statt von Anwendungen als Holz- und Betonersatz gesteigert werden.

Die Nettoentlastungspotenziale pro Tonne für PPK, Glas und Holz liegen 2017 etwa in ähnlicher Höhe. Für PPK und Glas sind diese durch die stoffliche Verwertung geprägt, für Holz durch die energetische Verwertung. Die Spanplattenverwertung von Holz ist mit einer vergleichsweise niedrigen spezifischen Nettoentlastung verbunden. Im Leitszenario 2030 verringert sich das spezifische Nettoentlastungspotenzial für PPK v. a. durch die angepasste Primärherstellung. Zudem spielen die energetisch verwerteten Rejects eine Rolle, die statt zur Mitverbrennung in Kohlekraftwerken in 2030 den TAB zugeordnet sind. Die für TAB angenommenen höheren Nettowirkungsgrade kompensieren dies nur anteilig. Bei Holzabfällen geht das reduzierte spezifische Nettoentlastungspotenzial vor allem auf die Defossilisierung zurück, der höher angesetzte Wärmenutzungsgrad für BMKW kompensiert dies nur anteilig. Die kleinere Menge, für die eine Pyrolyse angenommen ist, hat kaum einen Einfluss. Spezifisch liegt die Nettoentlastung dafür niedriger als bei der energetischen Verwertung.

Für die Organikabfälle ergibt sich im Basisjahr 2017 eine spezifische Nettoentlastung, die vor allem durch die anteilige Vergärung und Biogasnutzung erreicht wird. Bei den GPF spielt auch die anteilige energetische Verwertung in Biomassekraftwerk eine Rolle. Im Leitszenario 2030 liegt die spezifische Nettoentlastung für Organikabfälle etwas niedriger. In Summe der drei Abfallfraktionen überwiegen die Effekte der Defossilisierung gegenüber der Steigerung der

Vergärung. Das spezifische Ergebnis für die Kompostierung ist weitgehend unverändert. Die für Abfälle aus der Biotonne zusätzlich betrachteten neuen Verfahren haben mit den kleinen Mengen kaum einen Einfluss auf das Ergebnis. Bei höheren Mengen würde sich eine Verschlechterung ergeben. Sowohl das HTC-Verfahren und noch deutlicher die Behandlung mit Soldatenfliegenlarve bedingen Nettobelastungen.

Die Entsorgung von Restmüll ist im Basisjahr 2017 ebenfalls mit spezifischen Nettoentlastungspotenzialen verbunden. Dabei ist die spezifische Entlastung höher, wenn erzeugte EBS anteilig auch in Kohle- und Zementwerken mitverbrannt werden und fossile Brennstoffe ersetzen. Für das Ergebnis für Restmüll bestehen für den Anteil, der über „Mischabfallsortierung" behandelt wird (19 %), hohe Datenunsicherheiten. Sowohl in Bezug auf die Zusammensetzung des Inputmaterials als auch in Bezug auf Menge, Qualität und Verbleib der erzeugten EBS fehlen Informationen. Hier mussten Annahmen getroffen werden und ist die anteilige Nettoentlastung eventuell überschätzt. Im Leitszenario 2030 reduzieren sich die Nettoentlastungspotenziale der Restmüllbehandlung. Hauptgrund ist auch hier die Defossilisierung des Energiesystems. Zudem spielt die EBS-Umlenkung von der Mitverbrennung in Kohlekraftwerken zu einer Behandlung über TAB eine Rolle. Im Mittel betrifft dies 10 % der EBS. Dem entgegen wirken die für das Szenario 2030 angenommenen höheren energetischen Nutzungsgrade für TAB. Die durch die gesteigerte getrennte Erfassung veränderte Restmüllzusammensetzung hat kaum einen Einfluss auf das Ergebnis.

In der **Sensitivität des „business as usual Szenario 2030"** wird deutlich, dass ohne abfallwirtschaftliche Maßnahmen die möglichen Nettoentlastungpotenziale bedingt durch die Defossilisierung viel deutlicher abnehmen würden. Unter diesen Umständen würde die Behandlung von Siedlungsabfällen in Deutschland im Jahr 2030 ein absolutes Nettoentlastungspotenzial von -6,5 Mio. Mg CO_2-Äquivalente erreichen. Das heißt, der potenzielle Klimaschutzbeitrag gegenüber dem Basisjahr 2017 würde sich fast halbieren und gegenüber dem Leitszenario 2030 liegt der Beitrag um 40 % niedriger. Die dem Leitszenario 2030 zugrunde gelegten abfallwirtschaftlichen Maßnahmen liefern einen relevanten weiteren Klimaschutzbeitrag, auch wenn das Nettoentlastungspotenzial gegenüber dem Basisjahr 2017 niedriger liegt.

Im **Szenario mit Eigenkompostierung in der RC-Rate** liegt das absolute Nettoentlastungspotenzial im Bilanzjahr 2017 („SiAbf EK 2017") bei -12,6 Mio. Mg CO_2-Äquivalente. Ein Vergleich auf absoluter Ebene mit dem Basisvergleich ist aufgrund der unterschiedlichen Gesamtabfallmengen (49,2 Mio. Mg im Basisvergleich und 57,1 Mio. Mg im Szenario mit Eigenkompostierung in der RC-Rate) methodisch grundsätzlich nicht zulässig. Da die Eigenkompostierung selbst jedoch in der THG-Bilanz mit Null bewertet ist, ergibt sich im absoluten Ergebnis für 2017 kein Unterschied zum Ergebnis der Basisbilanz 2017. Für das Jahr 2030 („SiAbf EK 2030") liegt das absolute Nettoentlastungspotenzial bei knapp -10 Mio. Mg CO_2-Äquivalente. Wiederum gilt, dass ein Vergleich mit dem Basisvergleich, dem Leitszenario 2030, auf absoluter Ebene grundsätzlich methodisch nicht zulässig ist. Wäre es korrekt, dass die Eigenkompostierung quasi neutral ist und damit keinen Einfluss auf die Klimagasbilanz hat, könnte ausgesagt werden, dass ein Szenario mit etwa halb so hohem Ambitionsgrad für die gesteigerte getrennte Erfassung als das Leitszenario 2030 zu einem um etwa 1 Mio. Mg CO_2-Äquivalente reduzierten Nettoentlastungspotenzial führt.

Ein qualitativer Vergleich für 2030 ergibt, dass insbesondere die Verwertung der trockenen Wertstoffe geringere absolute Nettoentlastungspotenziale erzielt, bedingt durch die reduzierten getrennt erfassten Mengen. Umgekehrt zeigt sich nur ein geringer Einfluss bei der Behandlung der im Restmüll verbleibenden Mengen. Dass das absolute Nettoentlastungspotenzial nicht noch deutlich niedriger ausfällt als im Leitszenario 2030 hängt damit zusammen, dass der Hauptteil der gesteigerten getrennten Erfassung bei den Organikabfällen liegt, deren spezifische Nettoentlastungspotenziale im Vergleich zu denen des Recyclings von trockenen Wertstoffen gering sind.

Im spezifischen Ergebnis nach Abfallarten bestehen Unterschiede zum Basisvergleich nur für 2030 und nur bei den Abfallfraktionen Restmüll und Organikabfälle (Abfälle aus der Biotonne). Bei Restmüll liegt die spezifische Nettoentlastung etwas geringer (andere Restmüll-zusammensetzung und keine Umverteilung bei MBAs). Bei den Organikabfällen ist die spezifische Nettoentlastung für Abfälle aus der Biotonne etwas geringer, aufgrund der geringeren zusätzlichen Mengen zur Vergärung gegenüber dem Leitszenario 2030. Der deutlichste Unterschied auf spezifischer Ebene ergibt sich bezogen auf die Gesamtabfallmengen. Die spezifischen Nettoentlastungspotenziale insgesamt sind deutlicher geringer, da sich die Ergebnisse auf rund 57 Mio. Mg beziehen (inkl. der 7,9 Mio. Mg Eigenkompostierung):

- SiAbf EK 2017: -221 kg CO_2-Äq/Mg Siedlungsabfall (14 % niedriger als Basisbilanz 2017)
- SiAbf EK 2030: -175 kg CO_2-Äq/Mg Siedlungsabfall (21 % niedriger als Leitszenario 2030)

Bei dem **Basisvergleich mit Strom- und Wärmeemissionsfaktoren der EU27**, die gegenüber den nationalen Emissionsfaktoren jeweils niedriger liegen, sind die absoluten gesamten Nettoentlastungspotenziale sowohl für 2017 als auch für 2030 um 3 % reduziert. Hier bestehen gegenläufige Effekte. Abfallfraktionen mit einem hohen Strombedarf für die Abfallaufbereitung, und bei denen Aufbereitungsreste überwiegend in die Mitverbrennung (v. a. in Zementwerke) gehen, weisen mit dem niedrigeren EU27 Emissionsfaktor für Strom geringere Belastungen auf und zeigen mitunter höhere Nettoentlastungspotenziale als im Ergebnis mit den deutschen Emissionsfaktoren für Strom und Wärme (Kunststoffe, LVP, PPK). Bei den meisten Abfallfraktionen reduzieren sich jedoch die Nettoentlastungspotenziale durch die Bewertung von Energie aus Abfall mit den niedrigeren EU27 Emissionsfaktoren. Besonders deutlich zeigt sich dies bei Restmüll im Jahr 2030.

Die **Sensitivität für 2017 mit Vermeidungsfaktoren für Strom aus biogenem Abfall** bezieht sich ausschließlich auf die Entlastungseffekte. Der Strombedarf ist davon nicht berührt. Mit Anrechnung der Vermeidungsfaktoren für Strom aus biogenem Abfall würde das absolute gesamte Nettoentlastungspotenzial für 2017 um 8 % höher ausfallen. Da die Sensitivität sich ausschließlich auf die Gutschrift für Strom aus Abfall bezieht hat sie kaum Auswirkungen auf das Ergebnis für die trockenen Wertstoffe, da diese durch das Recycling geprägt werden und energetisch verwertete Aufbereitungsreste überwiegend in die Mitverbrennung gehen. Beiträge zur höheren Nettoentlastung resultieren aus der energetischen Verwertung von Abfällen (Restmüll, Holz) und aus der Vergärung und Biogasnutzung der Organikabfälle.

Die **Sensitivität mit Vorbereitung zur Wiederverwendung und Abfallvermeidung** zeigt einen methodischen Ansatz, diese Aspekte in die Ökobilanz der Abfallwirtschaft einzubinden. Für die Vorbereitung zur Wiederverwendung wurden Studien und Daten von Gebrauchtwarenkaufhäusern ausgewertet und eine wiederverwendete Pro-Kopf-Menge abgeleitet. Für die THG-Bewertung wurden Annahmen zur Lebensdauerverlängerung mit Emissionsfaktoren der Primärherstellung von Gebrauchtwaren verknüpft. Die Abfallvermeidung wurde am Beispiel der Lebensmittelabfälle im Sonderbilanzraum Lebensmittelabfälle abgeleitet. Das Ergebnis ist für die Sensitivität in die Siedlungsabfallbilanz einbezogen. Die betrachteten wiederverwendbaren bzw. vermeidbaren Mengen ergeben sich zu:

- 75.210 Mg Gebrauchtwaren für die Vorbereitung zur Wiederverwendung, die beim Sperrmüll (Restmüll) abgezogen sind,
- 1.258.669 Mg Lebensmittelabfälle aus Haushalten und aus Außer-Haus-Verzehr, die bei den Organikabfällen abgezogen sind.

Die absolut betrachtete Abfallmenge entspricht der im Basisvergleich. Die Sensitivität basiert auf dem Leitszenario 2030. Für die THG-Bewertung sind folgende aggregierte Vermeidungsfaktoren ermittelt worden:

- -0,61 kg CO_2-Äq/kg Gebrauchtware für deren Lebensdauerverlängerung,
- -1,61 kg CO_2-Äq/kg Lebensmittel für deren Abfallvermeidung.

Für die Sensitivität mit Wiederverwendung und Abfallvermeidung ergibt sich für das Bilanzjahr 2030 ein absolutes Nettoentlastungspotenzial von rund -13 Mio. Mg CO_2-Äquivalente (+18 % gegenüber dem Leitszenario 2030). Die Steigerung wird dabei v. a. durch die Menge vermiedene Lebensmittelabfälle geprägt, die zum einen deutlich höher ist und zum anderen mit einem höheren Vermeidungsfaktor verbunden ist. Allerdings bezieht sich die für die Wiederverwendung identifizierte Menge nicht auf Alttextilien und Elektro(alt)geräte, die in dieser Studie nicht untersucht wurden. Auch ist insgesamt mit einem höheren Potenzial zu rechnen als bisher über Gebrauchtwarenkaufhäuser gehandelt wird. Zudem gilt für die Vorbereitung zur Wiederverwendung, dass das Entlastungpotenzial zusätzlich anfällt, da die Gebrauchtwaren nach Lebensdauerende zu einem späteren Zeitpunkt recycelt oder energetisch verwertet werden.

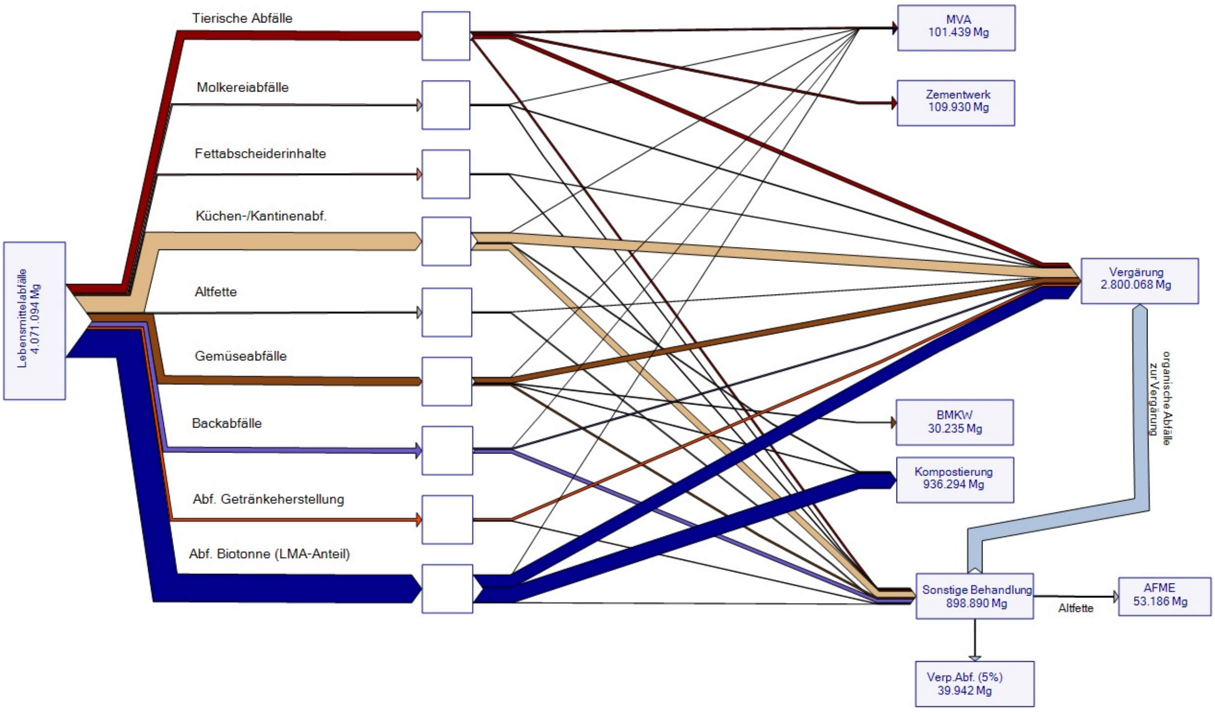
Sonderbilanzraum Lebensmittelabfälle

Der Sonderbilanzraum LMA umfasst die Lebensmittelanteile in den organischen Abfällen der Siedlungsabfälle und der P&G-Abfälle. Die Herkunftsbereiche wurden bei der Erhebung der Basisdaten unterschieden bzw. wurde insbesondere für die EU versucht, hiernach eine Differenzierung zu erhalten. Für die EU wird nur der EWC-Stat-Schlüssel W091+W092 (animal and mixed food waste; vegetal waste) berichtet. Eine Differenzierung in W091, W092 für die EU erfolgt nach Fachwissen. Für die EU-Bilanzräume wurde die deutsche Statistik detaillierter ausgewertet, um basierend darauf plausible Annahmen für die EU treffen zu können.

Die Auswertung für das **Aufkommen und den Verbleib** erfolgte in folgenden vier Schritten: 1. Berücksichtigung aller EAV-Schlüssel, die Lebensmittelabfälle enthalten können; 2. Abzug der Abfallmengen aus der Primärproduktion (Land-, Forstwirtschaft, Fischerei); 3. Berücksichtigung des Anteils der Lebensmittelabfälle in den organischen Abfällen; 4. Auswertung des Verbleibs unter der Annahme, dass die von Destatis (2019b und c) ausgewiesene Aufteilung auf Anlagentypen für die betrachtete Teilmenge konstant bleibt. Daraus ergibt sich, dass von den Siedlungsabfällen nur folgende Ströme für den Sonderbilanzraum Lebensmittelabfälle betrachtet werden: Abfälle aus der Biotonne (20 03 01 04), Marktabfälle (20 03 02) und Küchenabfälle (20 01 08).

Für die weitere Analyse des Verbleibs zur Erstbehandlung wird das LMA-Aufkommen ohne Restmüll betrachtet, das sich auf insgesamt gut 4 Mio. Mg beläuft. LMA im Restmüll werden aus methodischen Gründen nicht betrachtet. Ferner hat die Auswertung ergeben, dass Lebensmittelabfälle hauptsächlich in folgenden vier Anlagentypen behandelt werden: Zu kleineren Anteilen in thermische Behandlungsanlagen (MVA) und Feuerungsanlagen (Zementwerk) und überwiegend in biologischen und sonstigen Behandlungsanlagen. Für letztere wurde angenommen, dass es sich um überlagerte Lebensmittelabfälle handelt, die in diesen Anlagen entpackt und anschließend einer Vergärung zugeführt werden. In Abbildung 2 ist das finale Stoffstrommodell für die Lebensmittelabfälle vom Aufkommen bis zum finalen Verbleib dargestellt.

Abbildung 2: Sankey-Diagramm Lebensmittelabfall Deutschland 2017



Quelle: eigene Darstellung, ifeu

Den Hauptstrom bilden mit 62 % die LMA aus Siedlungsabfällen – Abfälle aus der Biotonne und Küchen-/Kantinenabfälle – wobei der LMA-Anteil bei den Abfällen aus der Biotonne mit 34 % angesetzt ist. Den Abfällen aus der Biotonne sind zudem Marktabfälle zuaddiert (kleine Menge). Bei den einzelnen Abfallarten aus den P&G-Abfällen handelt es sich häufig um nicht näher bestimmbare Abfälle. 66 % der Menge sind in der Statistik als „für Verzehr oder Verarbeitung ungeeignete Stoffe" ausgewiesen.

Für die THG-Bilanzierung werden neben dem Status quo **zwei Szenarien** für die Entwicklung der Recyclingaktivitäten bis 2030 betrachtet.

Für das Leitszenario sind folgende Annahmen getroffen:

- Küchen-/Kantinenabfälle werden im Jahr 2030 nicht mehr kompostiert, sondern ausschließlich vergoren.
- Der gesteigerte Anteil für Abfälle aus der Biotonne zur Vergärung wird berücksichtigt, im Jahr 2030 werden 22 % mehr vergoren, zu Lasten der Kompostierung (Anteil Vergärung Biotonne 2017 44 % steigt auf 66 % im Jahr 2030).
- Bisher noch kompostierte Mengen der P&G-Abfälle werden im Jahr 2030 ebenfalls vergoren (betrifft nur Gemüseabfälle).
- Bisher vergorene Altfette werden im Jahr 2030 zu Altfettmethylester aufbereitet (Dieselsubstitut).

Das **Einbeziehen der Abfallvermeidung** ist für die Ökobilanzmethode der Abfallwirtschaft nur möglich, wenn die vermiedenen Produkte bekannt sind und deren vermiedene Herstellung angerechnet werden kann. Für Lebensmittelabfälle bedeutet das, dass nur Verzehrprodukte betrachtet werden können. Für Schlämme, Schlempen, Schälreste, o. ä. bzw. die bei P&G-Abfällen überwiegenden „für Verzehr oder Verarbeitung ungeeigneten Stoffe" lassen sich keine ursprünglichen Produkte identifizieren. Entsprechend erfolgen Betrachtungen zur Abfallvermeidung nur für die LMA aus Siedlungsabfall (Abfälle aus der Biotonne, Küchen-/-Kantinenabfälle). Für diese Abfälle wird, der Nationalen Strategie zur Reduzierung der

Lebensmittelverschwendung folgend, bis 2030 eine Halbierung angenommen. Auf Basis von Warenkörben für vermeidbare LMA aus Haushalten und aus dem Außer-Haus-Verzehr konnte in Verbindung mit THG-Emissionsfaktoren für die Herstellung der vermiedenen LMA der durchschnittliche Vermeidungsfaktor von -1,61 kg CO_2-Äq/kg Lebensmittel abgeleitet werden.

Die **THG-Bilanzierung für die LMA** erfolgt nach den im Sankey-Diagramm gezeigten Abfallarten. Die Bilanzierung für Küchen-/Kantinenabfälle und für Abfälle aus der Biotonne entspricht der bei den Siedlungsabfällen. Bei den Küchen-/Kantinenabfällen ist dies eindeutig (Lebensmittelabfallanteil 100 %). Bei den Abfällen aus der Biotonne mit nur anteiligem LMA-Anteil besteht keine repräsentativ sinnvolle Möglichkeit diese von den nicht-LMA-Anteilen bilanziell abzugrenzen. Für die Bilanzierung der LMA aus P&G-Abfällen waren aufgrund der mangelnden Datenlage vielfach Annahmen nötig. Überwiegend werden diese einer Vergärung zugeführt für die Kenndaten abgeschätzt wurden. Durch die gegebenen Unsicherheiten in Bezug auf die Art der Abfälle sind die THG-Ergebnisse als orientierend zu verstehen.

Die **Ergebnisse der THG-Bilanz im Basisvergleich** zeigt Tabelle 2. Insgesamt weisen beide Szenarien Nettoentlastungspotenziale auf. Für 2017 liegt das absolute Nettoentlastungspotenzial bei -0.8 Mio. Mg CO_2-Äq. Hierzu tragen vor allem die tierischen Abfälle und Altfette bei. Bei den LMA aus den Siedlungsabfällen liegen die Entlastungen nur wenig über den Belastungen, woraus sich die geringere Nettoentlastung ergibt. Für das Leitszenario 2030 ergibt sich das absolute Nettoentlastungspotenzial zu -0,7 Mio. Mg CO_2-Äquivalente. Auch hier geht der leichte Rückgang vor allem auf die Defossilisierung des Energiesystems zurück. Dem entgegen stehen die Optimierungen für 2030, die gesteigerte Vergärung statt Kompostierung und die vollständige Aufbereitung von Altfett zu Altfettmethylester.

Tabelle 2: Absolute und spezifische Nettoergebnisse nach Abfallfraktionen – Lebensmittelabfälle Deutschland Ist-Situation 2017 und Leitszenario 2030

Abfallfraktion	absolut	absolut	spez. pro Kopf[1]	spez. pro Kopf[1]	spez. pro Tonne	spez. pro Tonne
LMA	**2017**	**2030 LS**	**2017**	**2030 LS**	**2017**	**2030 LS**
	1.000 Mg CO_2-Äq		kg CO_2-Äq/E		kg CO_2-Äq/Mg	
LMA zur MVA	-82	-74	-1,0	-0,9	-810	-728
Abf. Biotonne (LMA-Anteil)	-63	-77	-0,8	-0,9	-41	-50
Küchen-/Kantinenabfall	-66	-46	-0,8	-0,6	-68	-48
Fettabscheiderinhalte	-2	0	0,0	0,0	-33	-2
Altfette	-151	-167	-1,8	-2,0	-2.514	-2.771
Tierische Abfälle	-273	-240	-3,3	-2,9	-675	-593
Molkereiabfälle	-29	-11	-0,3	-0,1	-408	-160
Gemüseabfälle	-18	-9	-0,2	-0,1	-41	-19
Backabfälle	-117	-34	-1,4	-0,4	-429	-124
Abf. Getränkeherstellung	-10	-4	-0,1	0,0	-65	-26
Summe/Durchschnitt	**-811**	**-662**	**-9,8**	**-8,0**	**-199**	**-163**

1) berechnet mit Bevölkerungszahl von 82.792.351 in 2017 (Statistisches Bundesamt (Destatis) 2017)

Auf spezifischer Ebene pro Tonne zeigt vor allem Altfett ein hohes Nettoentlastungspotenzial bedingt durch die (2017 anteilige) Substitution von Dieselkraftstoff. Im Weiteren ergeben sich höhere Nettoentlastungpotenziale bei tierischen Abfällen bedingt durch hohe Gasausbeuten bei der Vergärung und deren anteilige Mitverbrennung im Zementwerk (Tiermehl). Die thermische Nutzung von LMA zeigt ebenfalls höhere spezifische Nettoentlastungspotenziale. Dies ist allerdings nur repräsentativ, wenn der vergleichsweise hohe Heizwert von 20,4 MJ/kg bei gleichzeitig 0 % fossilem C-Gehalt in der Praxis annähernd zutrifft. Die spezifischen Nettoergebnisse der weiteren Abfallarten werden vor allem durch die Vergärung geprägt und dabei ob es sich um Material mit hohem oder niedrigem Wassergehalt handelt. Bei niedrigem Wassergehalt (Molkerei-, Backabfälle) ergeben sich höhere Gasausbeuten und entsprechend ein höheres Nettoentlastungspotenzial.

Die Sonderbilanz Lebensmittelabfälle wurde ebenfalls 1:1 in die Bilanz für die EU27 überführt und entsprechend auch zusätzlich mit den Strom- und Wärmeemissionsfaktoren der EU27 berechnet. Gegenüber den Ergebnissen mit Emissionsfaktoren für Deutschland liegen die absoluten Nettoentlastungspotenziale in Summe damit für 2017 um 13 % niedriger und für 2030 um 5 %.

Das **Szenario mit Abfallvermeidung** basiert auf dem Leitszenario 2030 für das zusätzlich die vermiedene Lebensmittelabfallmenge von 1.258.669 Mg berücksichtigt und entsprechend bei Abfällen aus der Biotonne und Küchen-/Kantinenabfällen abgezogen ist. Die gesamt betrachtete Menge entspricht der im Basisvergleich. Mit der Abfallvermeidung ergibt sich für 2030 ein absolutes Nettoentlastungspotenzial in Höhe von -2,6 Mio. Mg CO_2-Äquivalente (knapp Faktor 4 höher als im Leitszenario 2030). Die deutlich höhere Nettoentlastungsleistung ergibt sich durch die Relevanz der Lebensmittelabfallvermeidung. Zum einen ist diese für 31 % der gesamten LMA angesetzt. Zum anderen ist der spezifische Vermeidungsfaktor vergleichsweise hoch und wird nur durch die Verwertung von Altfett als Dieselersatz übertroffen.

Produktions- und Gewerbeabfälle

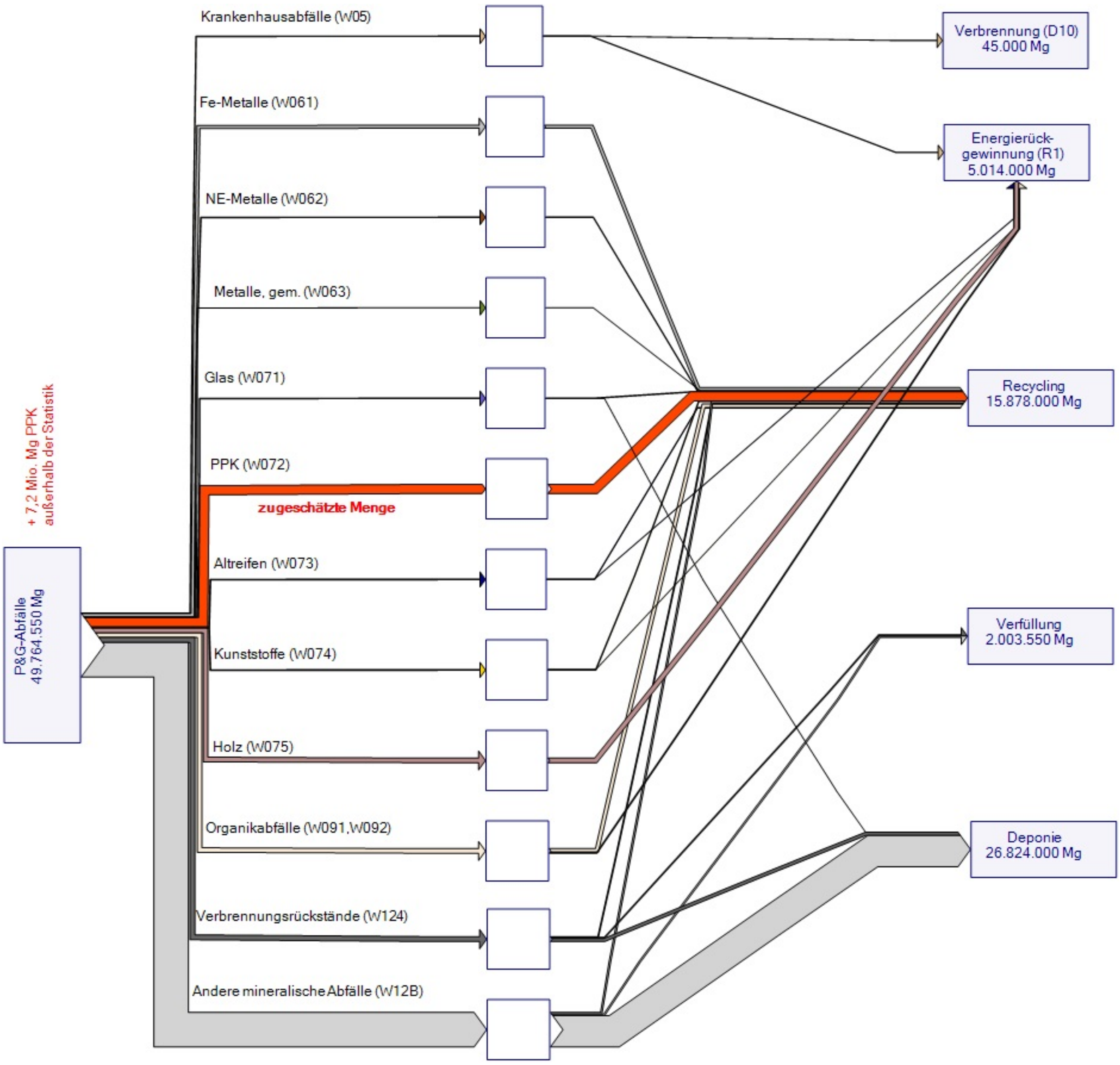
Die P&G-Abfälle entstammen einem sehr breiten Spektrum unterschiedlicher Branchen und enthalten damit verbunden sehr unterschiedliche Abfallströme. So sind mögliche Beiträge quasi über alle Kapitel der europäischen Abfallstatistik verteilt. Die Erhebung der Mengen zur späteren Bilanzierung der mit ihrer Entsorgung verbundenen THG-Emissionen erfolgt nur orientierend. Im ersten Schritt zur Ermittlung von **Aufkommen und Verbleib** werden dafür die zu analysierenden EAK-Stat-Schlüssel festgelegt, sowie die für die Bilanzierung relevanten Herkunftssektoren (über NACE-Kategorisierung). Zur Eingrenzung der relevanten EAK-Stat-Schlüssel werden folgende grundlegende Festlegungen berücksichtigt: Ausgeschlossen werden die Kapitel W033, W103, W128, W13, W08 und W11; P&G-Abfälle, die als Siedlungsabfall erfasst werden, werden vollständig dem Stoffstrom „Siedlungsabfälle" zugerechnet; Textilien werden auch hier ausgeschlossen, Bau- und Abbruchabfälle werden separat betrachtet und für P&G-Abfälle ausgeschlossen. Im Ergebnis werden damit für die Bilanz der P&G-Abfälle die folgenden EAK-Stat-Schlüssel analysiert: W012, W02A[13], W032, W05, W06, W071, W072, W073, W074, W075, W091, W092, W101, W102, W124, W12B[14]. Zudem wird der Verbleib für die relevanten EAV-Schlüssel basierend auf Destatis (2019b und c) analysiert. Als Ergebnis dieser Analyse werden die Kapitel W012, W02A, W032, W101 und W102 ausgeschlossen, sowie die Ströme der Kapitel W071, W074 und W072 modifiziert. Zusätzlich zu diesen Mengen wurde eine Menge für Papierabfälle in Höhe von 7,2 Mio. Mg zugeschätzt. Diese ergibt sich aus einer Differenz

[13] Das Aggregat W02A „Chemische Abfälle" enthält die EAK-Stat-Schlüssel W014 Verbrauchte chemische Katalysatoren, W02 Abfälle chemischer Zubereitungen und W031 Chemische Ablagerungen und Rückstände.

[14] Das Aggregat W12B „Andere mineralische Abfälle" enthält die EAK-Stat-Schlüssel W122 Asbestabfälle (ausnahmslos als gefährlich eingestuft), W123 Abfälle von natürlich vorkommenden Materialien und W125 Verschiedene mineralische Abfälle.

zwischen den Zahlen der Statistik und der nach Verbandsangaben berichteten Menge. Für diese ist angenommen, dass sie nicht an Abfallbehandlungsanlagen, sondern direkt an Papierwerke angeliefert wird. In Abbildung 3 ist das finale Stoffstrommodell für die P&G-Abfälle vom Aufkommen bis zum finalen Verbleib dargestellt.

Abbildung 3: Sankey-Diagramm P&G-Abfälle Deutschland 2017



Quelle: eigene Darstellung, ifeu

Die Darstellung zeigt, dass die P&G-Abfälle nach Masse durch „andere mineralische Abfälle" (W12B) geprägt sind. Diese Abfallfraktion nimmt über 50 % der Gesamtmenge ein. Es folgt die zugeschätzte PPK-Menge mit 14 % Massenanteil. Bei den weiteren Abfallfraktionen nehmen Eisenmetalle, Holz, Organikabfälle und Verbrennungsrückstände zwischen 5 % und 7 % an der Gesamtmenge ein. Der Prozentanteil der restlichen Abfallfraktionen liegt jeweils etwa um bzw. < 1 %.

Für die THG-Bilanzierung werden neben dem Status quo **zwei Szenarien** für die Entwicklung bis 2030 betrachtet. Hierbei werden die einzelnen Abfallströme analysiert und für jeden Strom das Optimierungspotenzial festgestellt. Auf dieser Basis wird ein ambitioniertes und ein weniger ambitioniertes Szenario abgeleitet. Für die P&G-Abfälle werden Optimierungspotenziale für die Abfallströme Altreifen (W073), Kunststoff (W074), Holz (W075) und Organikabfälle (W091, W092) gesehen, die in Summe eine Verschiebung von 290.080 Mg in Richtung Recycling für das wenig ambitionierte und eine Verschiebung von 692.330 Mg für das ambitionierte Szenario bewirken.

Die **THG-Bilanzierung** erfolgt auch hier nach den im Sankey-Diagramm gezeigten Abfallarten. Da es sich bei denen aus der europäischen Statistik abgeleiteten Zahlen zum Verbleib um den Letztverbleib handelt sind Sortieraufwendungen, insofern sie aus der Erstbehandlung relevant sind und abgebildet werden können, berücksichtigt. Hierzu sind die Inputmengen anhand der Sortierverluste rückgerechnet. Die Bilanzierung der trockenen Wertstoffe und von Holz erfolgt analog der Bilanzierung bei den Siedlungsabfällen. Unterschiede in spezifischen Ergebnissen pro Tonne ergeben sich zum einen durch teils abweichend angenommene Ausbeuten aus der Aufbereitung, da für P&G-Abfälle eine höhere Sortenreinheit unterstellt ist. Zum anderen kommen teilweise unterschiedliche Behandlungssplits zum Tragen. Die Bilanzierung des Recyclings für die Organikabfälle wurde aus der Bilanzierung für Lebensmittelabfälle abgeleitet, es wurden spezifische Emissionswerte ermittelt. Die Entsorgung von Verbrennungsrückständen und anderen mineralischen Abfällen ist aufgrund deren inerten Charakters mit keinen THG-Emissionen verbunden. Transportaufwendungen sind berücksichtigt. Krankenhausabfälle und Altreifen sind auf Basis eigener Expertisen berechnet.

Die **Ergebnisse der THG-Bilanz** für 2017 und die beiden Szenarien 2030 (SZ1, SZ2) zeigt Tabelle 3. Für die Ist-Situation 2017 ergibt sich ein absolutes Nettoentlastungspotenzial in Höhe von -13,6 Mio. Mg CO_2-Äquivalente. Hierzu tragen vor allem die trockenen Wertstoffe bei. Die Hauptmassen der anderen mineralischen Abfälle und auch die Verbrennungsrückstände haben aufgrund ihres inerten Charakters keinen Einfluss auf das Ergebnis. Die Vergleichsszenarien 2030 unterscheiden sich im absoluten Ergebnis nur wenig. Zum einen sind Unterschiede nur für vier Abfallarten angenommen. Zum anderen sind die prozentualen Verschiebungsanteile für diese insgesamt und zwischen den beiden Szenarien mit 2-5 % (Szenario 1) bzw. 5-10 % (Szenario 2) moderat. Für beide Vergleichsszenarien 2030 ergibt sich gerundet das absolute Nettoentlastungspotenzial zu -10,3 Mio. Mg CO_2-Äquivalente. Auch hier ist die Defossilisierung des Energiesystems relevante Ursache für die verminderte Nettoentlastung.

Auf spezifischer Ebene pro Tonne zeigen vor allem die Metalle hohe Nettoentlastungspotenziale. Ähnlich hoch wie für Fe-Metalle liegt auch das Nettoentlastungspotenzial für Altreifen. Erreicht wird dies durch das stoffliche Recycling, obwohl nur zu 50 % eine hochwertige Anwendung mit Substitution von fossilen Thermoplasten angenommen ist. Die weiteren Abfallfraktionen weisen überwiegend Nettoentlastungspotenziale in ähnlicher Höhe auf. Eine Ausnahme bilden die Krankenhausabfälle, die im Nettoergebnis eine Belastung zeigen. Die Ergebnisse für die inerten Fraktionen Verbrennungsrückstände und mineralische Abfälle beinhalten die Transportaufwendungen, die trotz hohem Massenanteil eine vergleichsweise geringe Bedeutung haben. In den Vergleichsszenarien 2030 sind die spezifischen Nettoergebnisse verändert, die von der Defossilisierung betroffen sind und/oder für die Optimierungen angenommen sind.

Tabelle 3: Absolute und spezifische Nettoergebnisse nach Abfallfraktionen – P&G-Abfälle Deutschland Ist-Situation 2017 und Vergleichsszenarien 2030

Abfallfraktion	absolut			spez. pro Kopf[1]			spez. pro Tonne		
P&G-Abfälle	**2017**	**2030 SZ1**	**2030 SZ2**	**2017**	**2030 SZ1**	**2030 SZ2**	**2017**	**2030 SZ1**	**2030 SZ2**
	Mio. Mg CO_2-Äq			kg CO_2-Äq/E			kg CO_2-Äq/Mg		
Krankenhausabf.	0,06	0,09	0,09	0,8	1,0	1,0	180	241	241
Fe-Metalle	-3,63	-3,63	-3,63	-43,8	-43,8	-43,8	-1.538	-1.538	-1.538
NE-Metalle	-1,97	-1,33	-1,33	-23,8	-16,0	-16,0	-5.029	-3.398	-3.398
Metalle	-0,10	-0,08	-0,08	-1,2	-1,0	-1,0	-2.035	-1.803	-1.803
Glas	-0,19	-0,19	-0,19	-2,3	-2,3	-2,3	-464	-459	-459
PPK	-3,16	-1,25	-1,25	-38,1	-15,1	-15,1	-438	-174	-174
Altreifen	-0,75	-0,79	-0,79	-9,0	-9,6	-9,6	-1.311	-1.389	-1.393
Kunststoffe	-0,27	-0,44	-0,50	-3,3	-5,3	-6,1	-515	-831	-958
Holz	-2,21	-1,64	-1,56	-26,6	-19,8	-18,8	-608	-451	-429
Organikabfälle	-1,60	-1,28	-1,24	-19,3	-15,4	-15,0	-451	-360	-349
Verbr.rückstände	0,04	0,04	0,04	0,4	0,4	0,4	9	9	9
Andere min. Abf.	0,17	0,17	0,17	2,1	2,1	2,1	6	6	6
Summe/Mittel	**-13,59**	**-10,33**	**-10,28**	**-164,1**	**-124,8**	**-124,2**	**-273**	**-208**	**-207**

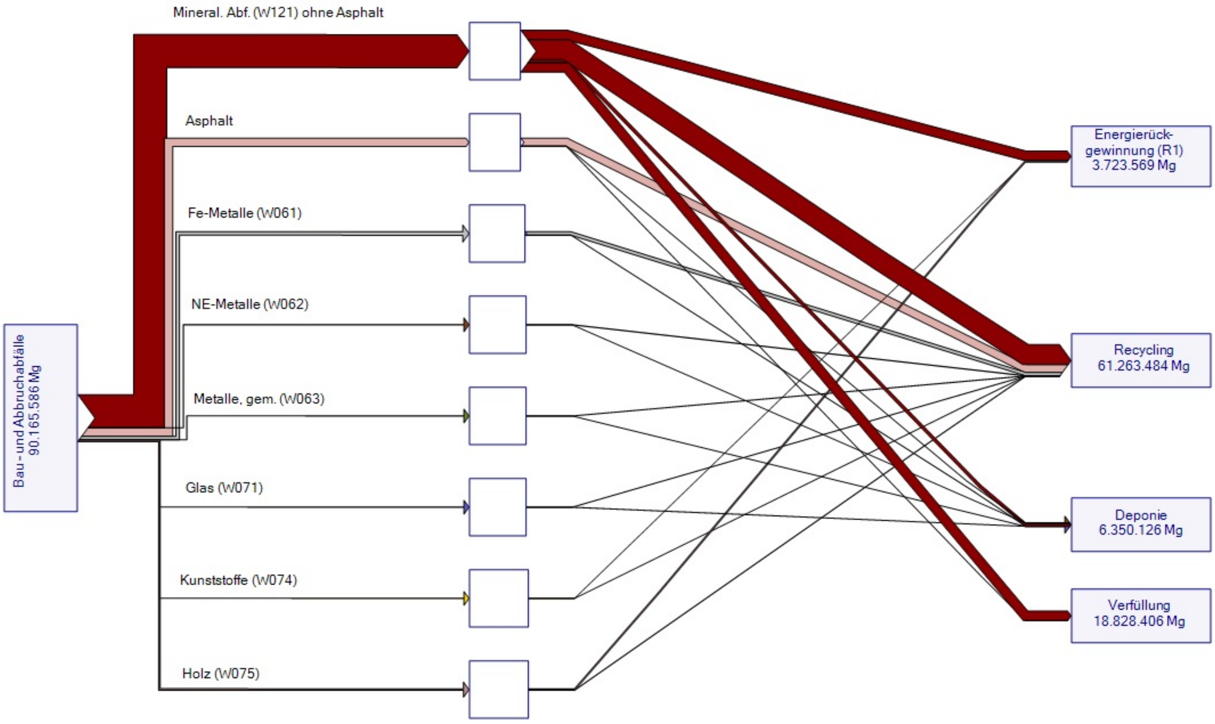
1) berechnet mit Bevölkerungszahl von 82.792.351 in 2017 (Statistisches Bundesamt (Destatis) 2017)

Bau- und Abbruchabfälle

Bau- und Abbruchabfälle sind im Rahmen dieser Studie als alle nicht-gefährlichen Ströme des Kapitels 17 des Europäischen Abfallverzeichnisses definiert, mit Ausnahme der Schlüssel für „Boden und Steine“ (EAV 17 05 04) und „Baggergut“ (EAV 17 05 06). Für diese Schlüssel wurden die Informationen aus der Destatis Fachserie 19, Reihe 1 zum **Aufkommen[15] und Verbleib** in den verschiedenen Behandlungsanlagen in Deutschland ausgewertet (Destatis 2019b). Da Daten für Bauschuttaufbereitungsanlagen und Asphaltmischanlagen im zweijährigen Turnus erhoben werden, liegen keine Daten für das Referenzjahr 2017 vor, weshalb hierfür im Weiteren auf die Datengrundlage des Jahres 2016 zurückgegriffen wird. In Abbildung 4 ist das finale Stoffstrommodell für die B&A-Abfälle vom Aufkommen bis zum finalen Verbleib dargestellt.

[15] Das Aufkommen ist dabei definiert als die Summe aller Abfallströme, die im Referenzzeitraum an Abfallbehandlungsanlagen in Deutschland aus dem Inland angeliefert werden (Input insgesamt aus dem Inland, Tab 1.1 Destatis 2019b). Abfallströme, die direkt in Produktionsanlagen wiedereingesetzt oder direkt ins Ausland exportiert werden, werden somit von der Statistik nicht erfasst.

Abbildung 4: Sankey-Diagramm B&A-Abfälle Deutschland 2017



Quelle: eigene Darstellung, ifeu

Die Darstellung zeigt, dass die B&A-Abfälle nach Masse durch „Mineralische Abfälle" (W121) geprägt sind. Diese Abfallfraktion nimmt 70 % der Gesamtmenge ein. Es folgt die von den „Mineralischen Abfällen" gesondert betrachtete Menge an Asphalt mit 18 % Massenanteil. Bei den weiteren Abfallfraktionen nehmen Eisenmetalle und Holz 7 % bzw. 3 % an der Gesamtmenge ein. Der Prozentanteil der restlichen Abfallfraktionen liegt jeweils etwa um bzw. < 1 %.

Für die THG-Bilanzierung werden neben dem Status quo **zwei Szenarien** für die Entwicklung der Recyclingaktivitäten bis 2030 betrachtet. Hierbei werden die einzelnen Abfallströme analysiert und für jeden Strom das Optimierungspotenzial festgestellt. Auf dieser Basis wird ein ambitioniertes und ein weniger ambitioniertes Szenario abgeleitet. Für die B&A-Abfälle werden im wenig ambitionierten Szenario Optimierungspotenziale für die Abfallströme Glas (W071), Kunststoff (W074) und Holz (W075) gesehen, die in Summe eine Verschiebung von 70.399 Mg in Richtung Recycling bewirken. Für das ambitionierte Szenario kommen zusätzlich noch Optimierungspotenziale für die mineralischen Abfälle mit und ohne Asphalt (W121), Fe-Metalle (W061), NE-Metalle (W062) und gemischte Metalle (W063), hinzu, sodass dort eine Verschiebung von 7,05 Mio. Mg (v.a. mineralische Abfälle) bewirkt wird.

Die **THG-Bilanzierung** erfolgt auch hier nach den im Sankey-Diagramm gezeigten Abfallarten. Die Bilanzierung erfolgt analog der Beschreibung für P&G-Abfälle. Sortieraufwendungen werden rückgerechnet, trockene Wertstoffe und Holz wie für Siedlungsabfälle bilanziert. Abweichungen in spezifischen Ergebnissen pro Tonne ergeben sich hier durch teilweise unterschiedliche Behandlungssplits (z.B. anteilige Energierückgewinnung bei Kunststoffen). Die Entsorgung von mineralischen Abfällen ist aufgrund deren inerten Charakters mit keinen THG-Emissionen verbunden. Transportaufwendungen sind berücksichtigt.

Die **Ergebnisse der THG-Bilanz** für 2017 und die beiden Szenarien 2030 (SZ1, SZ2) zeigt Tabelle 4. Für die Ist-Situation 2017 ergibt sich ein absolutes Nettoentlastungspotenzial in Höhe von -12,4 Mio. Mg CO_2-Äquivalente. Hierzu tragen vor allem die Metalle bei. Die Hauptmasse der mineralischen Abfälle hat aufgrund ihres inerten Charakters kaum Einfluss auf das Ergebnis. Die Nettobelastung resultiert aus Transportaufwendungen und der anteiligen Kunststoff-verbrennung (Sortierfraktion aus Bauschuttaufbereitung). Für die Vergleichsszenarien 2030 zeigen sich in Summe etwas reduzierte Nettoentlastungspotenziale. Hier ist der Einfluss der Defossilisierung geringer als bei den Siedlungsabfällen und den P&G-Abfällen, da das Ergebnis durch Eisenmetalle geprägt wird. Im Szenario 1 ergibt sich ein absolutes Nettoentlastungs-potenzial von -11,5 Mio. Mg CO_2-Äquivalente. Im Szenario 2 liegt es bei -11,8 Mio. Mg CO_2-Äquivalente.

Tabelle 4: Absolute und spezifische Nettoergebnisse nach Abfallfraktionen – B&A-Abfälle Deutschland Ist-Situation 2017 und Vergleichsszenarien 2030

Abfallfraktion	absolut			spez. pro Kopf[1]			spez. pro Tonne		
B&A-Abfälle	**2017**	**2030 SZ1**	**2030 SZ2**	**2017**	**2030 SZ1**	**2030 SZ2**	**2017**	**2030 SZ1**	**2030 SZ2**
	Mio. Mg CO_2-Äq			kg CO_2-Äq/E			kg CO_2-Äq/Mg		
Min. Abf. (ohne Asphalt)	0,37	0,49	0,38	4,5	5,9	4,6	6	8	6
Asphalt	-0,19	-0,19	-0,20	-2,3	-2,3	-2,4	-12	-12	-12
Fe-Metalle	-8,98	-8,98	-9,17	-108,5	-108,5	-110,8	-1.355	-1.355	-1.384
NE-Metalle	-1,65	-1,20	-1,22	-19,9	-14,4	-14,7	-3.540	-2.571	-2.625
Metalle	-0,28	-0,27	-0,27	-3,4	-3,2	-3,3	-1.497	-1.434	-1.464
Glas	-0,11	-0,11	-0,11	-1,3	-1,3	-1,3	-433	-438	-448
Kunststoffe	-0,02	-0,05	-0,07	-0,3	-0,6	-0,8	-195	-481	-604
Holz	-1,54	-1,18	-1,11	-18,5	-14,3	-13,5	-511	-393	-371
Summe/Mittel	**-12,38**	**-11,49**	**-11,77**	**-149,6**	**-138,7**	**-142,2**	**-137**	**-127**	**-131**

1) berechnet mit Bevölkerungszahl von 82.792.351 in 2017 (Statistisches Bundesamt (Destatis) 2017)

Auf spezifischer Ebene pro Tonne zeigen auch hier vor allem die Metalle hohe Nettoentlastungspotenziale. Die Abfallfraktionen Glas und Holz weisen Nettoentlastungs-potenziale in ähnlicher Höhe auf. Das Nettoentlastungspotenzial für Asphalt ist vergleichsweise gering. Die Entsorgung der mineralischen Abfälle (ohne Asphalt) zeigt eine geringe Nettobelastung. Bei den Kunststoffabfällen liegt die Nettoentlastung 2017 vergleichsweise niedrig bedingt durch die anteilige thermische Behandlung (Energierückgewinnung R1). In den Vergleichsszenarien 2030 liegt das spezifische Nettoentlastungspotenzial für Kunststoffe höher aufgrund der Umlenkung von Energierückgewinnung (R1) zum Recycling und zudem wie schon bei den Siedlungsabfällen und P&G-Abfällen durch die geringeren THG-Belastungen für den Strombedarf (Defossilisierung). Allgemein sind in den Vergleichsszenarien 2030 die spezifischen Nettoergebnisse verändert, die von der Defossilisierung betroffen sind und/oder für die Optimierungen angenommen sind.

Ergebnisse im Überblick

Die Ergebnisse für die verschiedenen Herkunftsbereiche für Deutschland sind im Überblick in Tabelle 5 dargestellt. Für Siedlungsabfälle sind die Ergebnisse aus dem Basisvergleich verwendet, für P&G- und B&A-Abfälle für 2030 die Ergebnisse der Szenarien 2, die auch für die EU27-Bilanzen verwendet wurden. In Summe ergibt sich für Deutschland für das Bilanzjahr

2017 ein gesamtes absolutes Nettoentlastungspotenzial von rund -38,6 Mio. Mg CO_2-Äquivalente. Für die gewählten Vergleichsszenarien für 2030 ergibt sich ein gesamtes absolutes Nettoentlastungspotenzial von rund -32,9 Mio. Mg CO_2-Äquivalente. Nach Systemräumen weisen alle Herkunftsbereiche ähnliche relevante Nettoentlastungspotenziale auf. Nach Abfallaufkommen liegt das der Siedlungsabfälle und der P&G-Abfälle ähnlich hoch (jeweils 26 %). Die B&A-Abfälle nehmen 48 % ein, bestehen aber zu 88 % aus mineralischen Abfällen (inkl. Asphalt), die nur geringe THG-Effekte beitragen.

Tabelle 5: Abfälle Deutschland – Mengen sowie absolute und spezifische Nettoergebnisse nach Herkunftsbereichen, 2030 ambitioniertere Szenarien

Bilanzraum	Aufkommen	THG absolut	THG absolut	spez. pro Kopf[1]	spez. pro Kopf[1]	spez. pro Tonne	spez. pro Tonne
		2017	**2030**	**2017**	**2030**	**2017**	**2030**
	Mio. Mg	Mio. Mg CO_2-Äq		kg CO_2-Äq/E		kg CO_2-Äq/Mg	
Siedlungsabfälle	49,2	-12,6	-10,9	-152	-131	-256	-221
P&G-Abfälle	49,8	-13,6	-10,3	-164	-124	-273	-207
B&A-Abfälle	90,2	-12,4	-11,8	-150	-142	-137	-131
Summe/Mittel	**189,2**	**-38,6**	**32,9**	**-466**	**-398**	**-204**	**-174**

1) berechnet mit Bevölkerungszahl von 82.792.351 in 2017 (Statistisches Bundesamt (Destatis) 2017)

Fazit und Empfehlungen

Die durchgeführte Studie ist eine umfassende Untersuchung sowohl hinsichtlich der Abfallströme als auch der THG-Bilanzierung. Die Daten der Abfallstatistik wurden mit Verbandsdaten und anderen Datenquellen abgeglichen. Die Bilanzierung erfolgte nach den einzelnen Abfallfraktionen für jeden der vier Bilanzräume. Zudem ist eine Vorgehensweise entwickelt und angewendet worden, wie die Vorbereitung zur Wiederverwendung und die Abfallvermeidung in die Ökobilanz der Abfallwirtschaft integriert werden können. Für die EU wurde eine gesonderte umfassende Studie durchgeführt. Insgesamt wurde eine Vielzahl von Szenarien und Sensitivitäten betrachtet. Allerdings bleiben auch für Deutschland relevante Datenunsicherheiten und die Ergebnisse insbesondere für Lebensmittelabfälle, P&G-Abfälle und B&A-Abfälle sind als orientierend zu verstehen. Ungeachtet dessen konnten wichtige Erkenntnisse gewonnen und die komplexen Zusammenhänge und gegensätzlichen Einflüsse für die THG-Bilanzierung analysiert werden. Relevante Erkenntnisse und Empfehlungen aus der Studie sind:

- Mit der Umsetzung der Energiewende und anderer Maßnahmen des Pariser Abkommens sinken die Klimaschutzpotenziale durch die Kreislaufwirtschaft notwendigerweise, da in Folge der Defossilisierung des Energiesektors auch die Substitutionspotenziale für Strom- und Wärmeerzeugung aus Abfall abnehmen. Dies zeigt sich für die Siedlungsabfälle bereits im geringeren Nettoentlastungspotenzial für 2017 verglichen mit der Vorgängerstudie und tritt in den Szenarien für das Jahr 2030 noch deutlicher zutage. Der Einfluss der Defossilisierung besteht auch bei der Primärherstellung von Produkten und dem damit einhergehenden Substitutionspotenzial für das Recycling (diese Studie Abschätzung für stromintensive Herstellung von Aluminium sowie von Holz- und Zellstoff).
- Die Studie zeigt, dass die Kreislaufwirtschaft durch Maßnahmen zur gesteigerten getrennten Erfassung von Wertstoffen, Steigerung des Recyclings und technische Optimierungen von

Anlagen trotzdem weiterhin wichtige zukünftige Klimaschutzbeiträge leisten kann. Deutlich wird dies in der Sensitivitätsbetrachtung „business as usual" für 2030 für Siedlungsabfälle. Ohne Maßnahmen würde sich der potenzielle Klimaschutzbeitrag gegenüber dem Basisjahr 2017 fast halbieren, gegenüber dem Leitszenario 2030 liegt der Beitrag um 40 % niedriger.

- Im Leitszenario 2030 für Siedlungsabfälle ist die Zielerreichung der rechtlich geforderten Recyclingquote von 60 % durch eine gesteigerte getrennte Erfassung berücksichtigt. Sowohl die Autorinnen und Autoren dieser Studie als auch Teilnehmende der beiden Online-Workshops mit Verbänden sehen diese Steigerung als sehr ambitioniert an. Hier ist die Politik gefordert gemeinsam mit den abfallwirtschaftlichen Akteuren flankierend unterstützende Maßnahmen zu identifizieren und umzusetzen.

- Insbesondere die Steigerung des Recyclings trockener Wertstoffe erzielt hohe Nettoentlastungspotenziale. Die Erreichung entsprechender Klimaschutzbeiträge kann nur gelingen, wenn die Datenlage und Kenntnis zu Mengenpotenzialen verbessert wird, z.B. durch Beauftragung von Analysen der Ist-Situation bei den trockenen Wertstoffen auf Kreisebene, Untersuchungen zur Optimierung der Sammelsysteme[16], Entwicklung eines Fahrplans für die weitere Steigerung der getrennten Erfassung unter der Prämisse guter Trennqualitäten, ökologisch begleitete Pilotprojekte, finanzielle Anreize für Akteure.

- Die Ergebnisse der Studie basieren gezwungenermaßen für bestimmte Abfallarten auf Annahmen oder eingeschränkt belastbaren Daten. Für eine bessere Einschätzung des Recyclings und dessen weitere Steigerungsmöglichkeit sollte die Zusammensetzung und Qualität der hausmüllähnlichen Gewerbeabfälle, des Sperrmülls und der gemischten Verpackungsabfälle (v. a. der nicht dem Recycling zugeführten Fraktionen) analysiert werden. Für LVP sollten für eine bessere Datenverfügbarkeit und Transparenz die bundesweiten Mengenstromdaten detailliert auf der Webseite der Stiftung Zentrale Stelle Verpackungsregister veröffentlicht werden.[17]

- Für Abfälle aus der Biotonne und GPF zeigt sich im Ergebnis, dass diese ebenfalls einen, wenn auch kleineren, Klimaschutzbeitrag leisten. Fossil-basierte kunststoffhaltige Fehlwürfe wirken sich nachteilig auf das Ergebnis aus. Zur Erreichung weiterer Klimaschutzbeiträge sind Maßnahmen nötig, damit bei der Steigerung der getrennten Erfassung von Organikabfällen, die Fehlwurfrate nicht noch ansteigt. Eine erfolgreiche Umsetzung benötigt z. B. die Kooperation der Bürgerinnen und Bürger. Vielfach bestehen noch Unsicherheiten was in die Biotonne darf, vielfach ist die Entsorgung noch kostenpflichtig. Hier sollte die Politik weiterhin ihre Unterstützung für eine bundesweite Harmonisierung und Intensivierung der Öffentlichkeitsarbeit anbieten.

- Der Klimaschutzbeitrag durch Abfälle aus der Biotonne ist bei einer Vergärung (kombinierte stoffliche und energetische Verwertung) höher. Um weitere Klimaschutzbeiträge zu erreichen muss deren Anteil gesteigert werden und müssen entsprechende Anlagen zugebaut werden. Planung und Aufbau der Infrastruktur benötigen organisatorische und finanzielle Unterstützung, auch sollten Fragen der Sektorenkopplung und Systemdienlichkeit für Biogas beachtet werden. Mit der Kommunalrichtlinie besteht ein Instrument zur Förderung emissionsarmer und effizienter Vergärungsanlagen, das weiter ausgebaut oder durch weitere Förderungen ergänzt werden könnte. Weitere wichtige Maßnahmen liegen in

[16] Z. B. flächendeckende Wertstofftonne, welche Infrastruktur ist nötig, welche Qualitätsvorgaben, welche Kontrollmechanismen.
[17] Mengenangaben für FKN, sonstige PPK-Verbunde, Weißblech, Aluminium, Folien, Mischkunststoffe, Kunststoffarten (idealerweise weiter untergliedert) und Angabe zu EBS-Mengen und Sortierresten.

der Verbesserung der Datenlage für die Vergärung durch weitere Messprogramme und Optimierungsmöglichkeiten zu THG-Emissionen.

- Der Klimaschutzbeitrag durch die Vergärung gewerblicher organischer Abfälle (Küchen-/-Kantinenabfälle, gewerbliche Speisereste, überlagerte Lebensmittelabfälle) kann nur orientierend ermittelt werden. Zur belastbaren Einschätzung bedarf es der Verbesserung der Datenlage durch Projekte zur Erhebung von Daten und THG-Emissionen bei den auf die Behandlung dieser Abfallarten spezialisierten Vergärungsanlagen. Entsprechende Projekte könnten auch helfen Möglichkeiten zur Lebensmittelabfallvermeidung besser einzuschätzen.
- Die Studie zeigt, dass auch die Restmüllbehandlung weiterhin einen Klimaschutzbeitrag leisten kann. Zur Erreichung dieser weiteren Klimaschutzbeiträge sind Optimierungsmaßnahmen unerlässlich. Für die thermische Abfallbehandlung betrifft dies die für 2030 angenommenen Steigerungen der Nutzungsgrade. Diese sind kein Selbstläufer. Sowohl für MVAs und EBS-Kraftwerke als auch für Biomassekraftwerke sind Möglichkeiten der Optimierung weiter zu prüfen und die Umsetzung zu unterstützen (v. a. Wärmenutzung). Die Mitverbrennung von Ersatzbrennstoffen in Zementwerken bietet einen relevanten – und gegenüber der Energierückgewinnung höheren – Klimaschutzbeitrag so lange noch Kohle als Regelbrennstoff eingesetzt werden darf, die durch EBS substituiert werden kann. Insofern gilt es auch MBAs in Optimierungsbemühungen weiter zu unterstützen.
- Die Einbindung der Abfallvermeidung und der Vorbereitung zur Wiederverwendung in die Ökobilanz der Abfallwirtschaft wurde in dieser Studie gezeigt. Das entwickelte Vorgehen kann auch für andere Abfallarten angewendet werden.
    - Bei der Abfallvermeidung ist die Voraussetzung dafür, dass die vermiedenen Produkte bekannt sind. Hierzu bedarf es analoger Daten wie für die Lebensmittelabfälle bezüglich der Zusammensetzung, der vermeidbaren Abfallmenge und deren THG-Belastung aus der Herstellung.
    - Für die Vorbereitung zur Wiederverwendung bedarf es einer Verbesserung der Datengrundlage. Für ein dauerhaftes Monitoring sollten Abfallmengenströme, die zur Vorbereitung zur Wiederverwendung geeignet sind (wie Möbel, Textilien, Elektro(alt)geräte), statistisch erfasst werden, um Potenziale besser erkennen und steuern zu können. Zudem werden zur besseren Einschätzung der tatsächlich möglichen Lebensdauerverlängerung weitergehende Untersuchungen benötigt.

Abschließend wird für künftige Untersuchungen empfohlen, neben den Klimaschutzpotenzialen auch die Ressourcenschonung zu berücksichtigen. Die Klimaschutzpotenziale in der Kreislaufwirtschaft sinken notwendigerweise mit zunehmender Umsetzung der Klimaschutzziele, die erreicht werden müssen, um die Klimakatastrophe abzuwenden. THG-Nettoentlastungspotenziale müssen für eine Klimaneutralität Null werden. Allerdings geht das Ziel der Klimaneutralität mit einem Rohstoffbedarf einher, insbesondere für Anlagen zur Erzeugung von Erneuerbaren Energien, den es im Blick zu behalten gilt. Der Aspekt der Ressourcenschonung ist wesentlich mit dem Beitrag der Kreislaufwirtschaft verbunden. In künftigen Vorhaben sollte zunächst ermittelt werden, welche Bereiche bzw. Ressourcen für eine Untersuchung der Ressourcenschonung relevant sind und wie diese zu bewerten sind.

1 Introduction and scope

This partial report Germany on the project "Climate Protection Potentials in the Circular Economy - Germany, EU"[18] documents the work and results for Germany. It describes the methodological procedure for the data collection, the basis for the balancing as well as the results and recommendations from the study. The results for the EU are published in a separate partial report ("Partial report EU").

Both partial reports examine the situation of waste management by the following types of waste:

- Municipal solid waste (MSW)
- Food waste (special balance)
- Commercial and industrial waste (C&I waste)
- Construction and demolition waste (C&D waste)

A separate quantity survey and greenhouse gas (GHG) balancing was carried out for each waste type. Methodologically, the balancing areas for MSW, C&I waste, and C&D waste are complementary areas, while food waste was investigated as a special balance area. This includes food waste from the MSW sector as well as from the C&I waste sector.

For the MSW and food waste, detailed GHG balances are presented, whereas rough assessments were made for the C&I and the C&D waste. For the MSW and food waste, the actual situation in the base year 2017 is analysed for Germany, for the current EU27, the previous EU28 (including the UK) and for two clusters defined from the EU member states. For the C&I and the C&D waste, the analysis is limited to Germany and the EU27. The future GHG emission savings potentials for the target year 2030 are also analysed more comprehensively for the MSW and the food waste with two scenarios for each: Germany, the EU27 and the two EU clusters. For the C&I and the C&D waste, there are two scenarios for Germany and one scenario for the EU27.

For the waste originating from C&I, C&D and the special balance area of food waste, there are some considerable data uncertainties. In many cases, the statistics – also the LoW-code in the German statistics – show waste types where the designation provides only vague clues about the type of waste. The assessment is particularly difficult in the case of C&I waste derived from Eurostat, as these sometimes include a large number of codes according to the European List of Waste (LoW-codes). Despite narrowing down and interpreting the German statistics on the basis of LoW-codes, there are still waste fractions that can only be estimated very roughly. However, assumptions also had to be made for the unmixed waste fractions such as metals and plastics. Also, for food waste, which is mainly fed to anaerobic digestion, characteristic data can sometimes only be roughly estimated. Therefore, the GHG results of C&I, C&D waste and the special balance of food waste (from C&I waste) are to be understood as orienting results.

18 Long title: Determining climate protection potentials in the circular economy for Germany and the EU as a contribution to achieving the goals of national and international climate protection commitments

2 Background and objectives

Climate protection is one of the greatest global challenges of the 21st century. With the Paris Agreement of December 2015, following the Kyoto Protocol, member states have again committed to reducing anthropogenic GHG emissions and limiting the global warming well below 2 °C compared to pre-industrial levels. This requires extensive efforts across all the climate relevant sectors and source groups, including the waste sector.

The waste sector is limited to direct and non-energy GHG emissions under the general reporting requirements of the Kyoto Protocol to avoid double reporting. As a result, the contribution of the waste sector is mainly represented by diversion from landfill. However, this does not include future GHG emissions from landfilling, nor the additional GHG emission savings potentials triggered by waste management that result from material recycling and energy recovery. The entirety of the contribution to climate protection that is achieved and achievable this way can be demonstrated with the help of the life cycle assessment (LCA) method of waste management, as has already been shown in previous studies (Dehoust et al. 2010; Vogt et al. 2015).

In this study, the waste management situation in 2017 is examined and the potential climate protection contribution of the circular economy for the target year 2030 is shown against the background of the further developed political and legal framework conditions. Additionally, possibilities of including preparation for re-use and waste prevention are considered.

The objective of the study is to demonstrate the potential contributions to climate protection by the waste sector and, in particular, to show how waste policy can further promote climate protection in the future. The project is intended to contribute to the fulfilment of the national and international climate protection commitments of Germany and the European Union.

3 Procedure for collecting data

3.1 Methodology and data sources

Four system areas are considered for the GHG balance: MSW, food waste, C&I waste, and C&D waste. For all waste types, only non-hazardous waste is accounted for; hazardous waste is excluded from this study.

The study refers as far as possible to data for the year 2017. The main source is the official German waste statistics (see Appendix A.1). Other sources such as associations, interviews with experts and relevant studies were used to evaluate the statistical data and to supplement it where necessary (see Appendix A.2).

Insofar as waste quantities per capita are mentioned in this study for 2017, the population level of 82,792,351 as of 31.12.2017 according to Destatis is used[19] .

3.2 Delimitation of the 4 waste balance areas

The delimitation of the waste quantities for the four system areas is described in detail in the "Partial report EU". For the balances of MSW and C&D waste, this is done by defining the relevant EWC-Stat code[20] . These and the LoW-codes assigned to them are described in chapters 5 and 8, respectively. There is no overlap of the system areas. For the balance of C&I waste, there would be overlaps with both the MSW and the C&D waste balance due to the LoW-codes contained in the EWC-Stat codes considered (see also partial report EU). The corresponding quantities are therefore deducted from the quantities to be taken into account for the production and commercial waste balance (see partial report EU and Chapter 7).

A special position applies to the food waste balance (Chapter 6). It contains both partial quantities from MSW (Chapter 5) as well as from C&I waste (Chapter 7). Since it became apparent in the course of the work that it is not possible to reliably calculate the corresponding portions, it was decided to consider the food waste balance as a "special balance area". This means that although it reflects the status of food waste disposal and recovery as well as possible, it cannot be taken into account additively to the balances of MSW and C&I waste. Otherwise, double counting would occur due to the overlapping of the balancing areas.

[19] https://www-genesis.destatis.de/genesis//online?operation=table&code=12411-0001&bypass=true&levelindex=0&levelid=1611656806242#abreadcrumb (last access 29.06.2021)

[20] In the case of C&D waste, all relevant codes are also fully allocated to NACE sector F in the statistics.

4 Basics of GHG balancing

4.1 Method

The determination of the climate protection potential of the circular economy is carried out using the life cycle assessment method of waste management based on ISO 14040/44. The method has already been applied many times in studies and described in detail (e. g. (Dehoust et al. 2010), (Vogt et al. 2015)). It allows a holistic view of the waste sector, since in addition to the direct emissions from waste treatment, the potentially avoided emissions from the substitution of primary products and conventionally generated energy are also included.

This type of sectoral consideration differs from the consideration of the waste sector under the general reporting requirements of the Kyoto Protocol. In the National Inventory Reports (NIR), the waste sector is limited to direct and non-energy GHG emissions to avoid double reporting. According to this, the contribution of the waste sector is mainly reflected by the diversion from landfilling. The GHG emission savings potentials that can be further identified with the LCA method of the waste management sector are to be understood in the context of the reporting obligations as potentially avoided emissions in the industry or energy sectors.

Another relevant difference between the LCA method and the NIR is the time horizon. In the NIR, the emissions occurring in the reporting year are reported, whereas in the LCA the functional unit is the quantity of waste considered. This means that all current and future debits and emission savings triggered by the disposal of a certain quantity of waste are assigned to this quantity of waste. This is particularly relevant in the case of landfilling, where methane emissions from the biological conversion of the deposited organic waste fraction are only released over decades. The LCA includes all future emissions from the landfilled waste under consideration, whereas the NIR reports the emissions calculated or measured for the reporting year that were caused by previously landfilled waste.

The essential rules of the balancing method to be considered as well as method conventions are described in the following subchapters.

4.1.1 Life cycle assessment of waste management

The LCA method of waste management is a sectoral consideration and deviates from a product LCA in the following points:

- Instead of "from the cradle to the grave", the balance area begins with waste generation (without debits) and ends with waste disposal or the products of waste treatment (energy, secondary raw materials).
- The main benefit is the disposal of a certain total amount of waste, which must be the same for all systems to be compared (requirement of equality of benefit).
- For additionally generated benefits (substitution potential for energy, secondary raw materials), the requirement of equality of benefits between systems to be compared is established by crediting emission savings potentials (credits, negative values).

The specification of equal total waste quantities also means that their composition must be the same. This means that material flow diversions within the total quantity - e.g. through increased separate collection of a waste fraction - can be investigated, but not waste quantity changes (e.g. increase due to more consumption). The comparison of systems with different amounts of waste requires the inclusion of the waste's previous life, its production (product life cycle assessment). The consideration of reusable systems also requires the examination of the total life cycle of products and thus a product life cycle assessment. In contrast, simple life-cycle extension can be included in the waste management LCA under certain circumstances. For corresponding wastes for preparation for re-use and for waste prevention, this study presents a methodological approach for the balance area of MSW (Chap. 5.3.4). Furthermore, waste prevention is considered in a scenario for the special balance area of food waste (Chap. 6.3.2). The procedure is described in the corresponding chapters.

Another relevant aspect for life cycle assessments of waste management is that the technical substitution potential is considered for material recycling and not the substitution potential according to the market mix. From a waste management perspective, it does not matter how high the share of secondary raw materials or products already is on the market. Since there are no other sources of origin for the secondary materials produced, it can be assumed that the production of functionally equivalent primary materials is avoided through the use of secondary materials. Conversely, an imputation according to market mix would lead to false statements for the waste management sector; more recycling with increasing secondary shares would lead to lower emission savings potentials.

In the case of co-incineration of waste in coal and cement plants, there is also a physical connection between fuel from waste and substituted regular fuel, as there are no other sources of origin here either. Accordingly, it is assumed for the co-incineration of waste in coal and cement plants that the use of coal as a standard fossil fuel is avoided on a calorific value equivalent basis.

When using waste in thermal treatment plants, which in addition to the main task of harmless waste disposal also generate energy, a differentiated consideration is necessary against the background of the energy transition. In (Dehoust et al. 2010) the marginal approach was used, according to which energy generated from waste marginally displaces fossil fuels from the energy generation system. With the further increase in the share of renewable energies in the electricity mix that has been achieved in the meantime, this interpretation with the marginal approach is no longer up-to-date. The substitution performance by energy from waste can only occupy a partial area alongside the substitution performance by electricity from renewable energy sources (biomass, wind power, solar energy), which account for a far higher share. If every alternative electricity generation were to claim the marginal approach for itself, the actual substitution potential would be overestimated. In addition, the marginal approach ignores the transformation of the energy system. Future scenarios can thus not show how the contributions to climate protection develop against the background of the decarbonisation of the electricity grid and the heat grid. For these reasons, the generation of electricity and heat from waste is credited by substituting average electricity and heat generation.

One exception is the possibility of flexible power generation. With increasing decarbonisation, the amount of electricity that can be fed into the grid decreases, and power plants can be flexibly ramped up and down to stabilise the grid. This function can only be partially taken over by electricity from biogas and biomass. Fossil-fuelled power plants will continue to be necessary for flexible electricity generation. This means that flexible electricity generation will have a special status in the future energy system. If electricity can be generated flexibly from waste, the substitution of flexible electricity generation from conventional fossil reserve power plants is credited for this.

4.1.2 Further boundary conditions, conventions

Emission factors electricity, heat

For the energy demand and the credit for the substitution of conventionally generated energy, average values are generally used. For the base year 2017, these are values for electricity according to the ifeu electricity generation/power plant model[21]. For heat, the emission factor for Germany corresponds to the weighted average for final energy consumption for households by energy source (AGEB 2019). For the EU, a corresponding value was derived from data for household heat from (TU Vienna 2017) derived. The values for 2030 are estimates or projections with assumptions on possible changes in the fuel and energy shares for the generation of electricity and heat.

For the balance area Germany, which is evaluated in detail in this study, the following national emission factors are used for the year 2017:

- Electricity mix DE 2017: 562 g CO_2eq/kWh
- Heat mix DE 2017: 256 g CO_2eq/kWh

For the EU balance areas that are also evaluated in this study, the emission factors for the EU27 are used uniformly. This also applies to the merging of the German balance with the EU27 (and EU28) balance area. For this purpose, the balances for Germany are also calculated with the EU27 emission factors. The differences in the results are presented for MSW (Chap. 5)[22] .

Furthermore, a sensitivity analysis is carried out for Germany for MSW using the UBA avoidance factors for renewable energy sources. This concerns energy from biogas, biomethane, biomass and the biogenic share in residual waste for the balance area of MSW in Germany. For electricity, the gross avoidance factors for 2018 are used. (UBA 2019)[23]. For the biogenic share in waste, this is 738 g CO_2eq/kWh of electricity, for the other energy sources relevant to this study it is 739 g CO_2eq/kWh of electricity. For heat, the gross avoidance factors are more differentiated (mainly solid biomass: individual furnaces, boilers, pellets, industry, district heating) and vary between 160 (liquid biomass) and 357 g CO_2eq/kWh (liquid biomass vegetable oil). For the biogenic share from waste, the value is 217 g CO_2eq/kWh[24]. For the sensitivity analysis, the heat avoidance factors are not included, as they cannot be clearly assigned for the balance. In addition, the emission factor for the heat mix Germany lies in the middle bandwidth of the avoidance factors, so that differences in the overall result would be small. For the energy recovery of residual waste, the biogenic waste share is assessed with the electricity avoidance factor. According to general convention in Germany, this is set at 50%. The non-biogenic share in residual waste is assessed with the emission factor for the 2017 electricity mix.

The avoidance factors as well as the emission factors for electricity and heat generally used in this study shows Table 6. For the scenarios with a time horizon of 2030, the factors are adjusted to a changed energy source mix. In addition, for a proportionate flexible electricity generation in 2030, the corresponding credit is applied according to (Dehoust et al. 2014) is applied. The possible share of flexible electricity generation at thermal waste treatment plants is set at 10%.

[21] https://www.ifeu.de/projekt/stromerzeugungkraftwerkspark-modell/

[22] In the partial report EU, sensitivity considerations are also carried out for the EU clusters with the regional emission factors for electricity.

[23] The values stated up to 2017 referred to the years 2012 and 2013 (UBA 2018a) and are no longer representative.

[24] The avoidance factor is based on the assumption that 100% of district heating generated from fossil energy sources is replaced. It is therefore assumed that the provision of heat from the biogenic fraction of waste does not provide any significant impetus for the expansion of heating networks. (UBA 2019)

Table 6 Emission factors electricity, heat in g CO_2eq/kWh final energy

	2017	2030
Electricity mix Germany	**562**	**218**
Heat mix Germany	**256**	**196**
Credit flexible power generation (Dehoust et al. 2014)		832
Sensitivity: Electricity avoidance factors according to (UBA 2019) - Avoidance factor biogas, biomethane, biomass - Avoidance factor electricity from residual waste (50% biogenic share)	 739 650	
Electricity mix EU27	429	179
Heat mix EU27	265	186
Electricity mix EU28	419	
Electricity mix EU Cluster 1	748	
Electricity mix EU Cluster 2	243	

Harmonised emission factors

The approach of using uniform harmonised emission factors in (Vogt et al. 2015) is basically continued in this study. Differences that arise for different waste origins are documented in each case. Harmonised emission factors make results more transparent and comparable. Regionally different assessments of substituted primary processes are standardised and the influence of the frequently given data uncertainties for the representation of substituted primary processes is defused. This procedure is advantageous for the given objective of this study, which is to show the climate protection potentials of the circular economy of different country units. In contrast, the procedure is not suitable for planning concrete decisions that are to be based on a climate protection contribution. This requires realistic emission factors.

In the present study, the uniform emission factors from Vogt et al. (2015) were updated and used as far as possible, especially for recycling (see Chapter 4.2.7). The harmonised factors are also largely used for the scenarios with a time horizon of 2030. An exception is the primary production of materials, which is characterised by electricity demand. For the production of pulp and aluminium, an estimate was made using the electricity emission factor for 2030. For other materials such as pig iron, glass, plastics, a significant change in GHG emissions from primary production will only occur in later years with technology changes (direct iron reduction instead of oxygen steel route, electric furnaces, PtX-based plastics).

Dealing with waste imports and exports

In the previous studies Dehoust et al. (2010) and Vogt et al. (2015) waste imports were automatically included, as they are included in the total quantities in the figures of the German waste statistic. Exports, on the other hand, were not considered. In this study, waste delivered to primary treatment plants from abroad was excluded from the comprehensive basic data collection and, conversely, exported waste quantities were included (see Chapter 5.1.3) in order to assess the waste generated in Germany (polluter-pays principle). This is consistent with the procedure for the EU balance areas (see partial report EU).

Potential carbon sink (C sink)

A C sink (long-term C storage, 100-year horizon) may be present in the landfilling of biogenic waste, in the application of composts (humus-C) or in the storage in very durable products (antique furniture, books). However, there are considerable uncertainties regarding the actual long-term storage of biogenic carbon. In the previous studies, the C sink was reported for information purposes. In this study, there is no further interest in knowledge about this; the C sink is not evaluated. Also, a possible C enrichment through wood conservation is not considered, as was the case in Dehoust et al. (2010). In Vogt et al. (2015) this had already been abandoned due to the high uncertainties.

4.1.3 Impact assessment global warming potential

For the evaluation of the greenhouse effect, the individual greenhouse gases of the life cycle inventory are summarised according to their effect equivalent to CO_2. The most important greenhouse gases and their CO_2 equivalent values used in this study according to IPCC (2013) for the 100-year horizon (GWP100) are listed in Table 7.

Table 7: Greenhouse gas potential of the most important greenhouse gases

Greenhouse gas	CO_2 equivalents (GWP100) in kg CO_2eq/kg
Carbon dioxide (CO_2), fossil	1
Methane (CH_4), fossil	30
Methane (CH_4), renewable	28
Nitrous oxide (N_2O)	265

Source: (IPCC 2013), Appendix 8.A

This distinguishes methane emissions according to their origin. Regenerative methane (from the conversion of organic matter) has a somewhat lower equivalence factor than fossil methane (from the conversion of fossil energy sources), as the regenerative carbon dioxide produced from the methane over time through air-chemical conversion (oxidation) is assessed as climate-neutral.

4.2 Balancing procedure

The procedure for balancing the various balancing areas is largely uniform with regard to the aspects described below. Specifics for individual types of waste or deviating assumptions for the balance areas MSW, C&I waste, C&D waste are explained in each case. Organic waste from MSW (kitchen/canteen waste, waste from the bio bin) and from C&I waste are shown separately for the special balance area food waste. The balancing is the same in each case even if the food shares are not 100%, as there is no reasonanble possibility of differentiation from the non-food waste shares.

4.2.1 Classification compared to previous studies

The balance area Germany was last investigated for the balance year 2006 exclusively for MSW. (Dehoust et al. 2010). An exception was waste wood, which was included from all sources, including commercial waste and construction and demolition waste. As in the previous study, the balance sheet for Germany was drawn up according to waste types. As far as possible, this has been implemented analogously for the EU balance areas.

The results of this study for MSW in Germany are compared with those from the previous study (see Appendix, Chapter B.4).

4.2.2 Collection and transport

In principle, the GHG impacts resulting from waste collection and transport are of minor importance in the overall life cycle of waste disposal (see e.g. results in (Dehoust et al. 2010)).

In the context of this study, GHG emissions from **collection are** not considered. This is mainly for reasons of consistency with the EU balance areas, as no information on collection distances and expenditures for collection is available for the various member states and cannot be collected in a representative manner within the scope of this study. In (Dehoust et al. 2010) the collection for the waste types considered was taken into account. For the comparison with the results of this study for MSW in Germany, the corresponding expenses were deducted from the results at that time.

Expenditures for **transport** from the primary treatment plant are included in the GHG balances. Although no representative individual data are available for this either, these transports are possibly the only relevant source of GHG emissions, especially for mineral waste. Based on the previous study (Dehoust et al. 2010) uniform transport distances were derived for all balance areas. Table 8 shows the estimated transport distances for MSW for the different output fractions from primary treatment plants. For the rough balances for C&I and C&D waste, a further simplified assumption on transport distances was made (Table 9). For the special balance area of food waste, transport distances are less relevant, as this is predominantly fed into composting or anaerobic digestion as primary treatment. For separated contaminants and secondary products, the transport distances derived for the MSW balance area are adopted. For fats and oils from other treatment plants for which transesterification into biodiesel is assumed, a transport distance of 200 km is applied analogously to transports to a material recycling facility.

The transport distances used for Germany are also used uniformly for the EU balance areas. There are no indications for justified deviations.

Table 8 Transport distances of MSW

Waste stream after primary treatment plant	Distance in km
Slag for processing	50
Contaminants, sorting and processing residues to waste incineration plants	100
RDF to thermal waste treatment	100
RDF, processing residues for co-incineration	200
Wood to biomass CHP	100
MBT residue to landfill	10
Minerals for landfill, other recycling	20
Metals for recycling	200
Wood processed for material recycling	200
Glass sorted for recycling	200

Waste stream after primary treatment plant	Distance in km
Paper sorted for recycling	200
Plastics sorted for recycling	200
Liquid beverage cartons, other composites for recycling	500

Table 9: Transport distances C&I and C&D waste

Waste stream after primary treatment plant	Distance in km
For backfilling	200
To the landfill	50
To thermal waste treatment	100
Mineral waste for recycling	50
(Recyclable) materials for recycling	200

4.2.3 Landfill

Landfilling no longer plays a role for Germany from a climate protection perspective. With the 2005 landfill ban, no more untreated waste is deposited. The mechanical-biological treatment (MBT) residues produced after mechanical-biological treatment have only a low landfill gas formation potential (see Chap. 4.2.5 on MBTs).

4.2.4 Thermal treatment

In Germany, thermal treatment is predominantly carried out as energy recovery. Only in the case of C&I waste, some waste is also treated partially thermally without energy generation (D10 process under the Waste Framework Directive, disposal by incineration on land, see Chap. 7.1.2).

Destatis distinguishes between "waste treatment plants" and "combustion plants" (see Chap. 5.1.5). The former includes waste incineration plants and hazardous waste incineration plants, while the latter includes refuse-derived fuel (RDF) power plants, biomass CHP plants, other power plants (e.g. coal-fired power plants) and plants for other production purposes (e.g. co-incineration in cement plants). This distinction is not helpful when considering the waste sector using the LCA method. What is important for the GHG balance is whether the plants are waste management plants (main purpose: waste treatment) or production or energy generation plants (coal-fired power plants, cement plants). In the latter, waste is co-incinerated instead of regular fuels. This means that differences result exclusively from differences in the fuels; process-related emissions are unaffected.

Fossil CO_2 emissions from waste incineration occur independently of the process and are determined by the fossil carbon content of the waste. Complete incineration is assumed[25] . Further debits and thus direct emissions arise in waste management plants from the use of auxiliary and operating materials such as fuel oil for auxiliary firing and substances such as hydrated lime, quicklime, hearth furnace coke, ammonia for flue gas cleaning. For the expenditures for auxiliary materials and operating supplies, the value from Dehoust et al. (2010)

[25] As a rule, almost complete combustion is technically achieved in Germany. The simplification considers the subsequent atmospheric oxidation of CO or VOC to CO_2.

in the amount of 30 kg CO_2eq/ton waste input, since the influence is small compared to the direct CO_2 emissions and, moreover, no relevant changes in the use of operating materials are assumed. In the case of co-incineration of waste, it is assumed that auxiliary and operating materials are used independently of the fuel, i.e. they would also be used anyway when operating with standard fuel.

The substitution potential of energy recovery also differs between co-incineration in production and energy generation plants and treatment in waste management plants (see Chap. 4.1). In the case of co-incineration, regular fuel is substituted in terms of calorific value equivalent. In the case of treatment in waste management plants, the substitution potential is determined by the externally usable energy generated (utilisation rates or net efficiencies) and by the substituted average energy production.

The relevant waste characteristics for thermal treatment, the calorific value and the fossil carbon content of the waste, are described in the chapters for the different waste balance areas. The utilisation rates of the different waste management facilities were taken from Flame et al. (2018) (Table 10).

Table 10 Efficiencies of thermal waste treatment and biomass CHP plants

System type	electric	thermal
Waste incineration plant	11.1%	33.5%
Refuse derived fuel power plant (RDF-CHP)	14.7%	45.4%
Hazardous waste incineration plant	-	56.6%
Biomass CHP plant	21.3%	15.0%

Source: (Flamme et al. 2018)

For the EU balance areas, the data from the EEA waste model according to Gibbs et al. (2014) were used. According to this, there is no distinction for thermal use in waste management plants according to the type of plant, but according to the type of energy generation. A distinction is made between plants that only generate electricity, plants that are operated in CHP and plants that only generate heat (Table 11).

Table 11: Efficiencies for incineration plants for the EU balance areas

Energy	Gross electrical efficiency	Thermal efficiency
Electricity only	25%	-
CHP	14%	42%
Heat only	-	80%

Source: (Gibbs et al. 2014)

This distinction can initially only be applied to MSW determined with the EEA waste model. Eurostat data only differentiate between thermal treatment with energy recovery[26] ("Energy Recovery") and incineration without energy generation[27] ("Incineration"). For MSW, weighted

[26] Recovery operation R1: Main use as fuel or other means of energy production or municipal solid waste incinerators if their energy efficiency is at least 0.6 (installations authorised before 01.01.2009) or 0.65 (installations authorised after 31.12.2008).

[27] Usually disposal method D10: Incineration on land.

efficiencies were calculated based on the efficiencies in Table 11. Weighted efficiencies were calculated for municipal solid waste based on the efficiencies in electricity generation, whereby a self-generated electricity requirement of 3 percentage points was assumed. A comparison of the calculated weighted efficiencies for Germany with the weighted efficiencies resulting from the values according to Flamme et al. (2018) for waste incineration plants and RDF cogeneration shows that the two sources provide similar results for Germany:

- Weighted utilisation rates for Germany according to EEA waste model: 11.6% electrical and 39.2% thermal
- Weighted utilisation rates for Germany for waste incineration plants and RDF cogeneration according to Flamme et al. (2018)11.3% electrical and 34.0% thermal

Waste incineration plants and RDF cogeneration plants are combined in this study under the term thermal waste treatment plants. The calculated values for Germany for all balancing areas are the values used for all balancing areas according to Flamme et al. (2018). For the balancing of the final destination of energy recovery, the weighted values for waste incineration plants and waste-to-energy plants are used for C&I waste and C&D waste, as a differentiated allocation for the approximate balancing is not possible in a representative manner.

Another component of the GHG balance is the processing of the slag produced and the **metal recovery from** it. For this study, the data according to (ITAD / IGAM 2019) were evaluated (see Chap. 5.1.7.1). The calculated values used for the GHG balance show Table 21. These values are used uniformly for the first use in a thermal waste treatment for all balance areas. Deviating EU-specific information is not available.

4.2.5 Mechanical biological treatment

Treatment in MBT plants is only relevant for MSW. For the approximate balancing of C&I waste and C&D waste, only the final destination can be evaluated. It is not known to what extent MBT plants play a role in these areas of origin. For food waste, MBT plants do not play a role.

In the German waste statistics (2019a) the waste streams for MBT plants are not further differentiated. For the breakdown by MBT types and the output from the plants, it was possible to use information from the UBA project on the further development of MBT plants, which was ongoing at the time of project processing (see Chap. 5.1.7.2). The metal yields for the separated ferrous and non-ferrous metal fractions are, according to Dehne et al. (2015) the metal yields for the separated ferrous and non-ferrous metal fractions are assumed to be 73% and 34%, respectively.

The technical parameters used for the GHG balance are shown in Table 12. The values were also provided from the UBA project on the further development of MBTs ((Ketelsen / Becker 2021), emission values (Ketelsen 2021b)). The TOC value corresponds to about 37% of the limit value of 55 g/t, the N_2O value to about 14% of the limit value of 100 g/t. The methane content was estimated at 60% from the TOC value and is calculated stoichiometrically as about 16 g CH_4/t. Characterised with the GWP according to IPCC (2013) the methane and nitrous oxide emissions result in a GHG emission value for the exhaust air from MBT plants of about 4 kg CO_2eq/t input.

Table 12: Technical parameters MBT plants

Parameter	Unit	Aerobic MBT	Anaerobic MBT	MPS	MBS	Medium
Electricity demand	kWh/t input	45.6	55.7	67.3	60.9	55.5
Natural gas demand	kWh/t input	32	40	174	25	48.0
Diesel demand	kWh/t input					8.0
TOC emissions	g/t input					20.6
N_2O emissions	g/t input					14.2

Source: (Ketelsen / Becker 2021), values updated according to (Ketelsen 19.11.21), (Ketelsen 2021b)

For anaerobic MBT, the biogas yield was calculated according to data in (Ketelsen / Becker 2021) as 40.6 m^3/t throughput[28]. This value is not technology-specific, but results as an average value over the various concepts implemented in practice, including partial and full flow anaerobic digestion. The methane content is assumed to be 60 vol%. 84.2% of the produced biogas (Ketelsen / Becker 2021) is used in the CHP unit. Of the remaining biogas, 2% is lost as flare losses, and the rest is used for own consumption (RTO, heat generator, other uses).

For the biogas CHP unit (as in Dehoust et al. (2010)), the gross efficiencies according to Vogt et al. (2015) were set at 37.5% electrical and 43% thermal. The gross electricity generated is fully accounted for, as the MBT plant's own energy and biogas requirements are calculated separately. Generated heat has not yet been used externally; the utilisation rate is set at zero.

The values reported in Flamme et al. (2018) for RDF are used uniformly as the characteristic data for the refuse-derived fuels produced:

- Calorific value: 13 MJ/kg
- Fossil C content: 15%

For co-combustion in coal-fired power and cement plants, the substitution of lignite is counted in calorific value equivalent. Although there is a proportionate co-combustion in hard coal-fired power plants in Germany (cf. Flamme et al. (2018)Table 3-7) and hard coal is also used in cement plants (cf. VDZ (2018)), but the difference in substitution potential is small. The supply and use of hard coal and lignite is associated with similarly high specific GHG emissions in terms of energy content, which are slightly above 400 g CO_2eq/kWh of coal. For the other EU countries (in the EU balance areas), the substitution of lignite is also assumed in each case. Information for a breakdown is not available.

The amount of MBT residue resulting from aerobic and anaerobic MBT was calculated with the assumption that the inert fraction in the landfill material is 4% (s. Table 22). The residual gas formation potential from the landfilling of the MBT residue was calculated as described in (Knappe et al. (2012)Chapter 4.3.3). With the GWP according to IPCC (2013)this results in a GHG emission value of 62.4 kg CO_2eq/t MBT residue.

4.2.6 "Mixed waste sorting"

Mixed waste sorting" refers to the treatment of mixed MSW in the facilities differentiated according to Destatis. (2019a) shredding plants and scrap shears", "sorting plants" and "other treatment plants". Summarised here are above all the LoW-codes "mixed municipal solid waste"

[28] Biogas volume in 2017 approx. 38 million m^3 and throughput of anaerobic MBT 936,579 t.

(20 03 01 00, 20 03 01 02) and "bulky waste" (20 03 07) (cf. Chap. 5.1.8 and 5.1.9). The waste statistics neither offer the possibility to classify the facilities according to their technology nor to map the output of these facilities. The plants can be mechanical treatment plants, commercial waste sorting plants or bulky waste sorting plants, all of which generally sort mainly RDF as the main product. Biological treatment is not provided at these plants. Accordingly, it can be assumed that the residual waste treated in these plants does not contain any significant organic fractions. Accordingly, no emissions from biological degradation are included in the GHG balance.

The "mixed waste sorting" relates exclusively to the balancing of MSW, as only the final destination can be considered for the rough balancing of C&I waste and C&D waste. Assumptions had to be made for the plant technology, the output and its destination. Due to the lack of a representative database, the simplified breakdown for the output from the "MBT 5" (basic sorting and energy generation) resulting from the EEA waste model for Germany was adopted:

- 92.5% RDF
- 2.5% Metals
- 2% paper, plastics
- 3% minerals

For the division of the metals into ferrous and non-ferrous metals, it was assumed that this corresponds to the average division of the MBT plants, according to which the proportions are 85% ferrous metals and 15% non-ferrous metals. For the yield from these sorting fractions, the same values were assumed as for the MBT plants according to Dehne et al. (2015): 73% for the ferrous metals and 34% for the non-ferrous metals.

For the destination of RDF, a corresponding assumption along the lines of the destination of RDF from MBTs is not plausible[29] . This aspect was exchanged with waste management associations in online workshops. There is no representative documentation on the destination of RDF, but information was kindly provided by the ASA for individual plants (Ketelsen 2021a). Based on this, the destination of RDF is determined as follows:

- 70% RDF-fired power plant
- 15% waste incineration plant
- 15% Co-combustion in the cement plant

The electricity requirement for sorting is estimated at 10 kWh/t waste input. As characteristic data for the RDF produced, the values for RDF according to Flamme et al. (2018) were used in a simplified and uniform manner:

- Calorific value 13 MJ/kg,
- fossil C content 15%.

For "mixed waste sorting" there are high data uncertainties both with regard to the composition of the input material (cf. also Chap. 5.2) as well as with regard to the quantity and quality of the RDF produced.

[29] The RDF from simple mechanical sorting is generally of lower quality and less suitable for co-incineration (feedback from online workshop on 30.09.2020).

4.2.7 Recycling dry recyclables

In this study, separately collected dry recyclables include the waste fractions paper, glass, metals and plastics. For MSW in Germany, this also includes the waste fraction of light packaging waste and non-packaging waste of the same material (in this study abbreviated as LWP), the balancing of which is described separately in Chapter 4.2.7.6. In other EU member states, LWP is not recorded separately or is not shown separately in the Eurostat data. Also, unlike according to Destatis, there is no separate reporting for packaging waste (LoW-code 15 01). For paper, plastics and metals, recycling may differ for packaging and non-packaging waste of the same material. This aspect is taken into account as far as possible for the transfer of the harmonised emission factors for the EU balances. The balancing for the recycling of dry recyclables is largely consistent with the balancing described in (Vogt et al. 2015) described above.

4.2.7.1 Glass

Waste glass is usually used in the glass melting process after sorting in glassworks. Sorting losses by mass are comparatively low (Table 15) and result from the separation of labels and closures. In the glass melting process, the use of waste glass cullet leads to a reduction in the energy required for melting and to a substitution of mineral raw materials (sand, soda, limestone, feldspar, dolomite). The latter determines the emission savings potential, whereby approximately half of the energy and mineral CO_2 emissions are avoided.

4.2.7.2 Paper

Sorting losses for separately collected paper are comparatively low by mass (Table 15). In addition to primary treatment via sorting facilities, relevant shares of paper are also shipped directly to paper mills. Since the latter do not have to be reported statistically, the Destatis figures do not match the association figures. A corresponding difference was estimated for the C&I waste balance area (see Chap. 7.1). Within the scope of the life cycle assessment (material flow balance), waste from paper recycling is necessarily included in the balance for paper. To avoid double accounting, paper sludge (in W032, W102) is not considered in the C&I waste.

For the destination of paper sludge or waste from paper recycling, the data according to (Destatis 2019a) for 2017 were used. The LoW-codes 03 03 05 (deinking sludge) and 03 03 07 (waste from the pulping of recovered paper) are decisive. On a weighted average, 85% of these are recycled for energy and 15% for materials. According to Destatis, the breakdown of energy recovery is only shown for about half of the waste quantities[30] . This results in a breakdown of energy recovery into 26% waste incineration plants, 46% RDF-fired power plants, 15% coal-fired power plants and 13% cement plants. Alternative information on the type of energy recovery is not available. Association data from a survey for 2016 (Bienert / Persin 2018) only show the share of energy recovery, which differs from the data according to Destatis[31]. According to the (VDP 2020) it is not possible to make a clear statement on the type of energy recovery; the destination depends on the situation. In this respect, the Destatis data are used for the balancing despite the data gap. The data on whereabouts are also used for the EU balances, as the data according to Eurostat do not offer sufficient differentiation[32] .

The substitution potential of paper recycling is credited at the fibre level. Waste paper fibres replace fibres made from wood pulp or cellulose. Data sets from ecoinvent V3.6 were used to

[30] Due to deinking sludge, only 5% of which is reported (presumably for data protection reasons).

[31] Destatis: 03 03 05 100% energy-related and 03 03 07 71%; survey: 03 03 05 40% energy-related and 03 03 07 90%.

[32] 03 03 05 is assigned to W032, which includes a total of 38 LoW-codes; 03 03 07 is assigned to W102, in which 77 LoW-codes are aggregated.

map the primary production of sulphate and wood pulp[33] . The fibre level interface corresponds to the technical substitution potential for recovered paper fibres. The approach defuses the regionally varying possibility of integrated paper production that can use renewable energies (steam generation from black liquor, biogenic CO_2 emissions) in the influence on the result with a pure focus on the greenhouse effect. For Germany, this approach is also applicable insofar as the demand for pulp is predominantly imported. In 2017, 67% cellulose and 33% wood pulp were used as virgin fibres in paper production in Germany. (VDP 2018). This split is maintained for the EU balances. This is partly in the sense of harmonised emission factors and partly because no differentiated data could be collected for the EU.

For beverage cartons and other composites, balancing is included in the LWP fraction (Chap. 4.2.7.6). For the EU balances, shares are derived according to association data; the share of total paper waste is low (see partial report EU).

The substitution potential or climate protection contribution for paper recycling is essentially determined by the electricity demand for the production of cellulose and wood pulp. As the GHG emission factor for electricity in 2030 is significantly lower than in 2017 due to decarbonisation (cf. Table 6), the GHG debits from primary production for cellulose were adjusted approximately in correlation to the electricity EF. For 2030, this results in a value reduced by about 60%.

4.2.7.3 Plastics

Little separate information is available for plastic waste - separated from plastic packaging waste in LWP. According to Destatis, 92% of the plastic waste in MSW is packaging waste. Accordingly, the processing is based on the available information for light packaging waste (see Chap. 4.2.7.6). Both the electricity requirement and the processing were carried out on the basis of LWP plastic waste (see Chap. 4.2.7.5).

The substitution potential is based on the data from (Conversio 2018). According to this, around 47% of recyclates from post-consumer plastic waste were used to substitute virgin plastic and otherwise mainly as a substitute for materials such as wood and concrete. This information was adopted for the balancing of plastic waste from MSW. For recyclates from plastic waste from the source areas C&I and C&D waste, the following was also taken into account on the basis of (Conversio 2018) a complete substitution of virgin plastics was assumed. The substitution of other materials is only given there by quantity for recyclates from post-consumer plastic waste. The substitution factor for virgin material in this study is assumed to be 0.8.

No information is available for the breakdown of plastic waste or the resulting recyclates by plastic type. Here, the market mix was simplified for Germany (Heinrich Böll Foundation 2019) and for the EU (PlasticsEurope 2018) and a substitution mix was calculated from this, whereby only the differentiated types of plastics were taken into account ("others" not classifiable). The resulting mix for each of these is shown in Table 13.

Table 13: Substitution mix of recycled plastic waste

Plastic type	Mix DE	Mix EU
Polypropylene (PP)	25%	26%
Polyethylene (LDPE/LLDPE)*	22%	24%
Polyethylene (HDPE)	19%	17%

[33] Allocation, cut-off by classification" database (system as ecoinvent 2): "ECF cellulose fibre production, RoW"; "TMP thermo-mechanical pulp production, RER".

Plastic type	Mix DE	Mix EU
PVC**	19%	14%
PET	9%	10%
PS/EPS	7%	9%

*) 50% LDPE and 50% LLDPE;
**) 88% S-PVC and 12% E-PVC

Weighted specific emission values for primary production were calculated on the basis of emission values for primary plastics (eco-profiles according to PlasticsEurope[34]). Since the market mix of recyclable plastic waste differs only slightly for Germany and the EU, the weighted specific emission values for primary production are almost identical for the substitution mix:

- Substitution mix Germany: 1,894 kg CO_2eq/t primary plastic
- EU substitution mix: 1,892 kg CO_2eq/t primary plastic

These substitution factors are used for recyclates from plastic waste, which replace virgin material depending on the substitution factor.

The described balancing is also adopted for the EU balances, for which no independent information is available. Due to the only proportional substitution of virgin material for the plastic waste from MSW, the results are in a comparable order of magnitude to the recycling of plastic packaging waste in the LWP fraction. There are high proportions of sorted mixed plastics (see Chap. 4.2.7.6), whose recyclates also replace only wood or concrete.

4.2.7.4 Metals

For metal waste from MSW (15 01 04 and 20 01 40), the statistics do not offer any further differentiation into ferrous and non-ferrous metals. Here, the breakdown was assumed based on the ratios for metals from slag, metals from MBT and the ratio of tinplate to aluminium for WEEE, which are each of a similar magnitude (adopted for EU balances). In the case of C&I waste and C&D waste, metals are each shown in the statistics as mixed metals (EWC-Stat code W063) and also separately as ferrous metals (W061) and non-ferrous metals (W062). Here, the breakdown for the mixed metal fraction was derived according to the ratio of the pure fractions. The respective breakdown for the different waste source areas shows Table 14.

Table 14: Breakdown of mixed metals into ferrous and non-ferrous metals

Waste type	MSW	C&I waste	C&D waste
Fe metals	85%	86%	93%
Non-ferrous metals	15%	14%	7%

For the balancing of metals, data sets from ecoinvent V3.6 from the database "Allocation, cut-off by classification" were used, which corresponds to the systematics of the previous version ecoinvent 2. For ferrous metals, the interface for balancing is the provision of pig iron, which is substituted by pure ferrous scrap on a mass-equivalent basis. For this purpose, the data set "pig iron production (RoW)" was evaluated from ecoinvent. The data set "iron scrap, sorted, pressed, RER" was used for processing. For aluminium, the interface for balancing is the provision of

[34] The reports and LCI datasets are published on the PlasticsEurope website (free registration required).

primary aluminium. The data set "aluminium production, primary, ingot (EU27)" was evaluated from ecoinvent for this purpose. Aluminium scrap is processed in a separate procedure and secondary aluminium is produced from it. The data set "treatment aluminium scrap, post-consumer, RER" was used for the processing.

For the packaging shares of metals in the EU, an estimate was made based on the packaging volume in Germany divided into private and commercial final consumption (see partial report EU). For the further breakdown into tinplate and aluminium packaging waste, the breakdown according to the LWP fraction was used as an approximation (Chap. 4.2.7.6).

In the case of metals, about half of the substitution potential or climate protection contribution for aluminium recycling is determined by the electricity required for production. Other GHG emissions are process-related (anode consumption) or result from natural gas demand. As the GHG emission factor for electricity in 2030 is significantly lower than in 2017 due to decarbonisation (cf. Table 6), the GHG impacts from the primary production of aluminium were approximately adjusted for the 50% electricity-related emissions in correlation to the electricity EF. For 2030, this results in a value reduced by about 30%. For pig iron production, the electricity demand is significantly less significant than the GHG emissions from coking coal. A relevant change in GHG debits from iron production will only occur after 2030 with a technology switch to direct iron reduction.

4.2.7.5 Electricity demand and processing yields

The electricity required for sorting and processing the dry recyclables differs according to the effort involved. The following are assumed:

- approx. 10 kWh/t for the simple sorting of glass and paper,
- 680 kWh/t for the processing of plastic waste following LWP plastic waste.

The yields from sorting and/or processing for the dry recyclables, which are generally used for balancing, are shown in Table 15. These yields largely apply uniformly to all source areas and balancing areas. Exceptions exist for some dry recyclables in the EU MSW balance areas (Table 15), for which the calculated values from the EEA waste model were used (see partial report EU). Further exceptions exist for C&I waste, which are also named accordingly in the table.

For the approximate accounting of C&I and C&D waste, for which only the final destination is reported, the sorting costs are related to the back-calculated input quantities. For plastic waste, on the other hand, processing residues are accounted for in relation to the reported quantity for recycling, as it is assumed that these quantities are not recorded in the final destination via the statistical data.

For plastic waste, a higher yield is assumed for C&I waste than for the other source sectors, because this does not arise from subsequent use but from production/manufacturing and is therefore assumed to be of a purer type. Higher yields are also assumed for metals in the case of C&I waste. These are predominantly metal chips. In the case of ferrous metals, impurities only exist in the amount of a maximum of 3% due to cooling liquid, because the waste must be "dry". For the non-ferrous metals from C&I waste, the yield was estimated based on the ferrous metals.

The contaminants separated during sorting are sent to waste incineration plants (paper sorting residues, glass labels and closures), to landfill or to other recycling (from glass and metal fractions). For the sorting residues, as in (Dehoust et al. 2010) simplified, the characteristic data for residual waste are used for the sorting residues. For the processing residues from plastic waste, the characteristic data for processing residues from LWP (see Table 18) have been adopted. A moisture loss of 20% is assumed for the residues from plastics processing. The destination of the residues is assumed to be analogous to the destination of the processing residues from LWP plastic packaging waste (98% cement plant, 2% waste incineration plant).

Table 15 Yields from processing of dry recyclable materials

Waste type	Germany	Exceptions EU-MSW
Paper	99%	95%
Glass	97%	95%
Ferrous metals	90%	
Ferrous metals, C&I waste	97%	
Non-ferrous metals	70%	
Non-ferrous metals, C&I waste	90%	
Plastics	70%	
Plastics, C&I waste	80%[35]	
Wood	98%	95%

4.2.7.6 LWP

The balancing of LWP is carried out analogously to the procedure in (Dehoust et al. 2016a). The breakdown of LWP waste given thereafter refers to the year 2014, which was adopted for 2017, as no significant changes are to be assumed in this period. It should be noted that (Dehoust et al. 2016a) refers to the LWP waste volumes of the Dual Systems with a total generation of 2,489,222 t. In this study, the LoW-codes shown in Table 16 are summarised under LWP. The quantities correspond to the quantities fed into " sorting plants for recyclables " (cf. Chap. 5.1.8 and 5.1.9). In total, the quantity amounts to about 4 million tons. No specific information is available for the difference of about 1.5 million tons of packaging waste, so that it is assumed for simplification that it is treated equally.

Table 16: LVP & StNVP to recyclables sorting plants, this study

LoW	Group	Quantity in 1000 tons	% share
15 01 05	Composite packaging	33.7	1%
15 01 06 00	Mixed packaging not differentiable	1,707.1	42%
15 01 06 01	Lightweight packaging (LWP)	1,952.8	48%
15 01 06 02	Mixed recyclables together with LWP	290.2	7%
20 01 99 01	Mixed recyclables without LWP	459	1%

Characteristics for LWP sorting and yields of further processing according to (Dehoust et al. 2016a) are listed in Table 17. For beverage and paper composites, further information is only

[35] The recycling share is presumably not the actual amount for final treatment, as Germany still reports according to the old method for the statistics in the period under consideration. This is not relevant for the GHG balance, which includes further processing after sorting.

partly available in (Dehoust et al. 2016a). Here, own calculations were carried out. For beverage composites, the breakdown from processing is 70% recovered paper pulp, 25% PE in the rejects, 3% aluminium in the rejects and 2% residues, for paper composites 70% recovered paper pulp, 7% PE in the rejects and 23% processing residues. The electricity requirement is set at around 322 kWh/t input in each case. A bauxite credit is allocated for separated aluminium. As with paper, a technical substitution factor of 0.95 is assumed for the recycling of recovered paper fibres. The substitution potential for recovered paper fibres also corresponds to the substitution potential used as a basis for paper (see Chap. 4.2.7.2).

Table 17 Characteristics for LVP sorting and yields Processing

Sorting fraction	Share in %	Electricity demand in kWh/t input	Yield of processing
Agglomerate slides	0.69%	362	0.686
Foils for regranulation	5.97%	1,100	0.7
Mixed plastics to agglomerates	0.80%	351	0.665
Mixed plastics to PO agglomerates	0.60%	573	0.45
Mixed plastics to regranulation	2.05%	580	0.46
PET to flakes	2.01%	500	0.7
PO for regranulation	5.74%	450	0.73
PS for regranulation	0.36%	450	0.872
EPS for regranulation	0.04%	833	0.98
Mixed plastics-RDF in blast furnace	2.81%	320	0.75
Mixed plastics-RDF in cement plant	24.99%	320	0.8
Beverage associations	5.57%		
Tinplate	11.47%	77.8	0.929
Aluminium	2.50%	74.5	0.31
Paper composites	2.19%		
RDF from LWP to the cement plant	1.83%	320	0.85
Sorting residues from LWP	30.36%	300	0.9

Source: (Dehoust et al. 2016a)

The whereabouts of the sorting and processing residues are taken from (Dehoust et al. 2016a) taken over. According to this, 22% of sorting residues go to waste incineration plants and 78% to cement plants for co-incineration. A moisture loss of 32.5% is given for LWP processing residues. 2% of the processing residues are used in waste incineration plants and 98% in cement plants. Deviating from this, 100% of the processing residues from aluminium pyrolysis are used in RDF cogeneration.

The characteristic data for the balancing of the energy recovered sorting residues, processing residues, RDF from LWP and mixed plastics as RDF are also taken from (Dehoust et al. 2016a)

(Table 18). For PE in the rejects from the processing of beverage compounds, the calorific value in this study is set at 37.82 MJ/kg and the fossil C content at 71.6%.

Table 18 Characteristics of fractions used for energy recovery

Group	Calorific value in MJ/kg wet weight	Fossil C content in % wet weight
Sorting residues from LWP	16.942	25.6%
Processing residues	16	26.0%
RDF from LWP	38	76.6%
Mixed plastics as RDF	33.97	68.9%

Source: (Dehoust et al. 2016a)

From the destination of the sorting fractions, a total of 60% of the LWP was sent for energy recovery and 40% for material recycling.. After deducting the processing residues from material recycling, 29.2% remain.

4.2.8 Recycling organic recyclables

For MSW, organic recyclables are to be classified according to the waste fractions (2019a) kitchen/canteen waste (20 01 08), waste from the bio bins (20 03 01 04) and garden waste (20 02 01). For the EU, maintaining this differentiation is also possible, as the EEA waste model distinguishes between the fractions of "food", "garden", "other waste". The waste from the bio bin is assigned to "other waste" (see partial report EU).

In the special balance area food waste, kitchen/canteen waste and waste from the bio bin (food waste fraction) are shown separately for Germany. For the EU, the source areas of MSW ("food waste" from the EEA waste model) and C&I waste could be evaluated separately. The balancing corresponds to that for MSW. Kitchen/canteen waste is fully included in the special balance (food waste share 100%). For waste from the bio bin, the food waste share was determined at 34% (see Chap. 6.1). This share is treated in the same way in the balance sheet, since there is no meaningful possibility of differentiating between the food waste and non-food waste shares in the bio bin. Food waste from C&I waste is accounted for and reported separately as far as possible. For Germany, an evaluation could be made according to LoW-codes, but this is not possible for the EU. Here, only the EWC-Stat codes W091 and W092 can be differentiated based on assumptions. The results of the food waste balance are used for the C&I waste balance area for the total item "animal and vegetable waste (W091, W092)" reported there. C&D waste does not generate any organic recyclables.

The basic procedure for balancing the biological treatment of organic recyclables from MSW is described below. For organic waste from the C&I waste source area, there are differences and further procedures, which are described in more detail in the chapter for the special balance area food waste.

4.2.8.1 Composting and anaerobic degestion of organic recyclables from MSW

Parameters and characteristics for biological treatment are summarised in Table 19. The treatment and separation of impurities is assumed to be uniform, also for the EU balance areas.

Table 19 **Parameters and characteristics of biological treatment**

Parameter	Unit	Calculated values	Source
Impurities			
Impurity content		5%	Assumption
Characteristics of impurities	Calorific value 12 MJ/kg; C_{fossil} 21%.		Calculated
Composting			(Knappe et al. 2012)
Diesel demand open composting	l Diesel/t Input	2.5	(Knappe et al. 2012)
Electricity demand open composting	kWh/t Input	0.5	(Knappe et al. 2012)
Electricity demand closed composting	kWh/t Input	50	(Knappe et al. 2019)
Share of open composting of waste from the bio bin		26%	(Knappe et al. 2019)
Share of open composting garden waste		88%	(Cuhls et al. 2015)
Methane emissions	g CH_4 /t Input	1,400	(Cuhls et al. 2015)
N_2O emissions	g N_2O/t Input	74	(Knappe et al. 2019)
Share of fresh compost from waste from the bio bin		39%	
Anaerobic digestion			(Knappe et al. 2012)
Average electricity demand anaerobic digestion	kWh/t Input	45	according to Vogt et al. (2008)
Methane emissions	g CH_4 /t Input	2,800	(Cuhls et al. 2015)
N_2O emissions	g N_2O/t Input	67	(Cuhls et al. 2015)
Gross efficiencies CHP	37.5% electric, 43% thermal		(Knappe et al. 2012)
Degree of utilisation of surplus heat		20%	(Knappe et al. 2012)
Average electricity demand processing to biomethane	kWh/m³ raw gas	0.3	according to Vogt et al. (2008)
Share of biomethane from waste from the bio bin and garden waste		19.5%	(Völler 2020)
Share of biomethane kitchen/canteen waste		14.1%	(Völler 2020)
Average methane slip processing to biomethane[1]		2%	according to Vogt et al. (2008)

1) Average value, requires exhaust air post-combustion to comply with the limit value of the GasNZV (max. 0.2%) for which complete oxidation to regenerative CO_2 is assumed.

The composition of the impurities is derived on the basis of (LUBW 2018) and is then calculated as follows:

- 33% Hygiene articles
- 25% Plastics (mainly packaging)
- 17% Organic
- 4% Metals
- 4% Glass

The characteristic data for the impurities are calculated on the basis of this composition and the standard values for waste fractions (Table 24). The emission factors for composting and anaerobic digestion correspond to the median values in (Cuhls et al. 2015). These factors are used uniformly in national reporting for all organic waste (cf. UBA NIR (2019)) and are therefore also applied uniformly for this study[36] . Overall, this allows a consistent approach also for the EU balance areas, as corresponding factors are available via the NIR reports of the EU member states that were evaluated. Applying the characterisation factors according to IPCC (2013), the median values for methane and N_2O emissions listed in Table 19 result in the following values for Germany:

- Composting: 59 kg CO_2eq/t input
- Anaerobic digestion: 96 kg CO_2eq/t Input

For biogas production, values from the Faustzahlen Biogas were used, for waste from the bio bin and kitchen/canteen waste (food leftovers) the values from the 3rd edition (KTBL 2013), for park waste approximate values for "grass, fresh" from the 1st edition (KTBL 2007). The characteristic data and on this basis calculated biogas or methane yield per ton of input are shown Table 20.

Table 20 Biogas production characteristics

Parameters	Unit	Waste from the bio bin	Garden waste	Kitchen/canteen waste
Dry matter	% wet weight	40	18	16
Organic substance (OS)	% dry weight	50	91	87
Biogas	l/kg OS	615	600	680
Methane content	Vol%	60	54	60
Biogas yield, calculated	m³/t input	123	98	95
Methane yield, calculated	m³/t input	74	53	57

4.2.8.2 Composting products and application

Compost production and application was assessed according to the results in Knappe et al. (2012). The share of fresh compost from the composting of waste from the bio bin is set at 39% according to (Knappe et al. 2019). Garden waste compost is assumed to be 100% finished compost, analogous to Knappe et al. (2012). Composted digestate was also generally assumed for anaerobic digestion. According to Knappe et al. (2012) the following product quantities are generated per ton of waste input for mixtures of organic and green waste in biological treatment:

[36] For individual case studies, the differentiated values from (Cuhls et al. 2015) should be used.

- Fresh compost: 0.421 kg/kg input
- Finished compost: 0.442 kg/kg input
- Composted digestate: 0.388 kg/kg input

The values were also used for food waste (kitchen/canteen waste). For the composting of kitchen/canteen waste, this should be approximately correct. No corresponding data are available for the anaerobic digestion of leftovers and overstocked food waste. In this case, however, it can be assumed that the digestate is usually not post-composted, but used directly in agriculture. However, since the median values according to (Cuhls et al. 2015) are applied uniformly on the emissions side, analogous to the procedure for the national reporting (NIR DE 2019), which places the anaerobic digestion of kitchen waste without post-digester in a worse position[37], the compost application and the resulting substitution potentials are also adopted as for biowaste.

For composted digestate, the share used in agriculture is assumed to be 46% as assumed in Knappe et al. (2012). According to IPCC (2006) N_2O-N emissions of 1% in relation to the nitrogen applied are attributed for use in agriculture. The emission savings effects for agricultural application result from the nutrient contents and the humus reproduction potential according to Knappe et al. (2012). For the application of composted digestate in horticulture, the substitution of peat and bark humus is taken into account in equal parts, analogous to aerobic composts.

4.2.9 Waste wood

For waste wood, the balancing for MSW is carried out in a more differentiated manner according to the data in Destatis (2019a). For the approximate consideration of the balance areas for C&I waste and C&D waste, the final destination is accounted for. Energy recovery and material recycling are balanced uniformly for all balancing areas.

For MSW, the evaluation according to Destatis (2019a) and Destatis (2019b) results in primary treatment in biomass CHP plants (14%), a proportionate treatment of a smaller quantity in garden waste composting (0.6%) and a larger partial stream that is initially treated in sorting plants (85%) (cf. Chap. 5.1.9). The composted portion is neglected for the balancing (cut-off criterion < 1%).

For treatment in waste wood processing plants, an electricity demand of 20 kWh/t input is assumed. The output from waste wood treatment is balanced according to the results in Flamme et al. (2018, Figure 10). This results in the following breakdown for the output from waste wood processing:

- 75% Energy recovery
- 23% Material recycling
- 2% Elimination

No information is available for the type of disposal; this sub-stream is not considered further. For recycling, the emission factors are used according to Prognos et al. (2008) for chipboard recycling in a humid environment. The corresponding specific emission factors are:

- Debit: 366 kg CO_2eq/t waste wood
- Credit: 431 kg CO_2eq/t waste wood

[37] Emissions only anaerobic digestion (VA): 460 g CH_4 /t waste, 9.7 g N_2O/t waste.

The energy recovery in biomass CHP plant can be calculated on the basis of the degrees of utilisation (Table 10) according to Flamme et al. (2018). The characteristic data - calorific value and fossil C content - are also taken from the data of Flamme et al. (2018):

- Calorific value: 16 MJ/kg
- Fossil C content: 2.3%

In the absence of country-specific data, the balancing described for the material (recycling) and energy recovery of waste wood is also carried out analogously for the EU balancing areas.

5 Municipal solid waste

5.1 Waste generation and destination

5.1.1 Introduction

According to the waste balance (Destatis 2019c), the total amount of MSW generated in Germany in 2017 was 51.79 million tons, of which 51.125 million tons was non-hazardous waste. The recovery rate was 98%, the recycling rate 67%[38] .

From the data in Table 1.1, FS19, R1, the "total input" for waste chapters 15 01 and 20 is calculated to be 52,642,500 t, of which 51,961,800 t is non-hazardous waste, of which 1,072,900 t was delivered from abroad. The difference of 50,888,900 t of non-hazardous domestic MSW forms the starting point for the MSW to be considered in this study plus export quantities.

Chapters 5.1.2 - 5.1.7 present the first evaluation of the raw data used as well as parameters used for further modelling. The further processing and allocation of the data with regard to the balancing are carried out in Chapter 5.1.9. An informative presentation of quantities for home composting as well as the description of selected new treatment processes not yet included in the balance are presented in Chapters. 5.1.10 and 5.1.11, respectively.

5.1.2 Amount according to Destatis (2019b)

The amount of MSW is first determined from Table 1.1 of FS19, R1 Destatis (2019b). All reported waste delivered to treatment facilities is listed there. For each waste code, the following are listed:

- The number of facilities that accepted the respective waste
- The total input into these plants, as well as the proportion of each that is
  - from their own operation,
  - from within the country or
  - was delivered from abroad.

The focus of this study is on all domestic waste quantities, including those from own operations, but does not take into account quantities delivered from abroad. Exports are added. The German Environment Agency's list of transboundary shipments of waste requiring consent is used as the source for exports by waste type. (UBA 2017). Exports of waste not subject to notification that are exported directly, i.e. without prior treatment in Germany, are not taken into account, as they are not clearly covered by either the transboundary shipment of waste or the waste statistics. Data calculated for this purpose by the German Environment Agency from the foreign trade statistics of the Federal Statistical Office of Germany (Umweltbundesamt 2021)do not relate to MSW for the most part. Furthermore, it cannot be clarified whether the waste was exported before or after delivery to a primary treatment facility. In the latter case, the exported quantities would be recorded twice.

According to the Destatis definition, all waste listed under the LoW-codes 20 and 15 01 is classified as MSW. In total, this was around 40.5 million t for 2017 under LoW-code 20, of which 634,400 t came from abroad, so that the initial quantity for this study is around 39.85 million t. In addition, there are around 12.2 million t under LoW-code 15 01 (packaging waste), of which

[38] Recycling rate according to "old" calculation method.

472,800 t were delivered from abroad, leaving an initial value of around 11.68 million t, or a total of around 51.5 million t for MSW with LoW-code 20.

Further restrictions are made for this study. On the one hand, the connectivity to the previous studies should be ensured, so that waste streams that were already excluded in the previous studies are also excluded for the present study. On the other hand, the representability and connectivity to the EU balance areas, which are also considered in this study and are derived on the basis of Eurostat data, must be maintained. Therefore, the following were excluded in principle:

- Hazardous waste, i.e. all waste marked as such with an * in the LoW-code. This is a total of 680,700 t for the LoW-codes 15 01 and 20, of which 34,300 t were delivered from abroad, so that the initial quantity is reduced by 646,400 t.
- Textiles in any form (15 01 09, 20 01 10, 20 01 11). In total, this amounts to 247,300 t or 235,700 t without the waste delivered from abroad.
- Edible oils and fats (20 01 25), paints, printing inks, adhesives and synthetic resins other than those mentioned in 20 01 27 (20 01 28), detergents other than those mentioned in 20 01 29 (20 01 30), pharmaceuticals other than those mentioned in 20 01 31 (20 01 32). In total, this amounts to 96,600 t or 83,000 t without the waste delivered from abroad.
- Batteries and accumulators other than those mentioned in 20 01 33 (20 01 34), used electrical and electronic equipment other than those mentioned in 20 01 21, 20 01 23 and 20 01 35 (20 01 36). In total, this amounts to 130,900 t or 129,200 t without the waste delivered from abroad.
- Soil and stones (20 02 02), street sweepings (20 03 03). In total, this amounts to 798,300 t or 793,300 t without the waste delivered from abroad.
- Other fractions (not otherwise specified), not differentiable (20 01 99 00), MSW (not otherwise specified) (20 03 99), faecal sludge (20 03 04) and waste from sewer cleaning (20 03 06). In total, this amounts to 175,500 t; no quantities were delivered from abroad.

After deducting the quantities of the excluded waste types, a total volume of 49.47 million t of MSW remains.

5.1.3 Exported quantities according to Destatis (2019b)

The exported quantities are reported in the FS19, R1 only by waste chapter in Table 20.1. According to this, a total of 49,000 t were exported under the LoW-code 15 and a total of 213,000 t under the LoW-code 20.

A breakdown by waste type can be found for transboundary movements of waste requiring consent in UBA (2017). The resulting exported 38,536 t for the LoW-code 15 01 (miscellaneous packaging waste) and 179,928 t for LoW-code 20 (mixed MSW and components of MSW) were added to the MSW quantity derived in Chapter 5.1.2 which results in approximately 49.7 million tons.

5.1.4 Amount according to individual tables from FS19, R1 (Destatis 2019b)

The destiantion of MSW in the individual treatment pathways is described in tables of FS19, R1 (Destatis 2019b). As with the total volume, waste delivered from abroad was not considered, while exports were added (see Chap. 5.1.3).

The individual tables on the waste treatment plants were evaluated for the waste types listed in Chapter 5.1.2. Waste treatment plants (e.g. sewage sludge composting plants or WEEE dismantling plants) that typically treat wastes outside the scope of this study were not considered. As a result, waste quantities that are actually within the scope of this study and are shipped to these facilities cannot be taken into account further on. In total, the amount of waste excluded amounts to 231,900 t.

For many types of waste, the sum of waste differentiated by treatment facilities is lower than the total volume. It is assumed that this difference is due to data protection reasons, as Destatis only reports values if more than three individual facilities are included in the data set. In this respect, the difference in quantities must have been shipped to facilities other than those indicated. The deviation across all waste types amounts to a total of 1.352 million t or 2.7%.

Plausible assumptions are made for the three largest differential quantities. The input quantity of domestic waste from Table 1.1 of FS19 results in 2,060,900 t for glass packaging. For the difference in quantity to the total of waste differentiated by treatment facilities of 641,400 t for glass packaging, it is assumed that the glass waste is used for direct shipment to glassworks via transshipment/intermediate facilities. In principle, the destination of this quantity can be allocated to sorting plants and is added there. For household waste and commercial waste similar to household waste (20 03 01 01), the difference is 252,700 t (with an input quantity of domestic waste from Table 1.1 of FS19 of 8,465,400 t). This difference quantity is also not included in the exempted treatment facilities (see above). It is assumed that they are reported in the statistics as input for the combustion plants (no numerical entry there). Therefore, they are added there in the following. For the additional 144,700 t of waste from the bio bin, it is assumed that they were reported in the statistics under sewage sludge composting and other biological treatment. However, these plants are not considered further (see above).

The further breakdown of the quantities going to waste incineration plants, combustion plants and biological treatment plants is possible using the extra tables purchased from Destatis (Destatis 2019b) and is described in the following chapter.

5.1.5 Evaluation of the special tables (Destatis 2019b)

The additionally acquired special tables (Destatis 2019b) differentiate the input for plant types, which is only shown in aggregate in FS19, R1. However, the input quantities in the extra tables include quantities delivered from abroad, which are not considered in the context of this study. In detail, a case-by-case decision is made as to whether quantities from the extra tables or the tables from FS19, R1 are used (see Appendix A.1).

5.1.5.1 Thermal waste treatment plants

Inputs to thermal waste treatment plants are reported in FS19, R1 in Table 3.1. The input quantity of the waste types considered in this study amounts to 13,175,100 t. In chap. 5.1.4 159,576 t of exported waste are added to this quantity (=total 13,334,676 t) (see Chap. 5.1.3).

In the special table for thermal waste treatment plants from Destatis, the waste types considered in LoW 15 01 and 20 are reported as input exclusively under waste incineration plants and special waste incineration plants. The sum of the waste types considered in this study amounts to 13,628,800 t for input to waste incineration plants and 2,000 t for input to hazardous waste incineration plants. In total, this quantity is about 0.5 t higher than the 13,175,100 t mentioned above. Since the quantity of waste to waste incineration plants is 99.99%, the quantities in the extra table (incl. quantities from abroad) are not used, but the quantities derived from Table 3.1 of FS19, R1 are retained and assigned to 100% waste incineration plants.

5.1.5.2 Combustion plants

Inputs to combustion plants are reported in FS19, R1 in Table 4.1. The input quantity of waste types considered in this study amounts to 645,000 t.

In the special table for combustion plants, the input of the considered waste types of LoW 15 01 and 20 amounts to 158,900 t for RDF power plants, 254,700 t for biomass CHP plants, 12,900 t for heating plants and 9,600 t for co-incineration. The total quantity is around 209,000 t lower than the above-mentioned quantity from Table 4.1 of FS19, R1. For this reason, the quantities in the extra table are not used here either, but the input quantity derived from Table 4.1 of FS19, R1. This is divided in a simplified manner only between RDF cogeneration and biomass CHP (95% of the total quantity in the special table). The breakdown is by waste type. The quantities of wood packaging (15 01 03), wood (20 01 38) and biodegradable waste (20 02 01) are allocated to the biomass CHP and the remaining quantities are allocated in a simplified way to RDF power plants.

5.1.5.3 Biological treatment plants

Inputs to biological treatment plants are reported in FS19, R1 in Table 7.1. The input quantity of waste types considered amounts to 9,992,100 t.

In the extra table for biological treatment plants (Destatis 2019c), the input of the considered waste types of LoW 15 01 and 20 amounts to 3,376,000 t for biowaste composting plants, 3,365,700 t for green waste composting plants, 1,681,500 t for biogas and anaerobic digestion plants and 1,296,400 t for combined composting and anaerobic digestion plants. Quantities delivered to sewage sludge composting plants and other biological treatment plants (biodegradable waste, LoW 20 02 01) are excluded (see Chap. 5.1.4). In total, this results in a waste quantity of 9,719,600 t. Since, on the one hand, the quantities delivered from abroad in Table 7.1 of FS19, R1 are proportionately low at 11,700 t and, on the other hand, the difference to the quantity of domestic waste is largely covered by the quantities to sewage sludge composting plants and other biological treatment plants that were not considered, the values from the extra table are adopted in this case.

5.1.6 Packaging waste

Packaging waste quantities are reported by waste type in FS19, R1 by Destatis under LoW 15 01. (Destatis 2019a). This is done in Table 1.1 for the total input to treatment facilities and in the other tables for the individual facility types. On the other hand, in tables 21 and 22 of FS19, R1, the results of a separate survey by the statistical offices of the states of Germany on the collection of dual systems and sectoral solutions:

- Sales packaging at private final consumers (input in table 22.1) and
- Transport and secondary packaging at commercial and industrial end users (input in Tab 21.1)

Another source for packaging waste in Germany is the survey “Generation and recovery of packaging waste in Germany"(Aufkommen und Verwertung von Verpackungsabfällen in Deutschland), which is conducted annually by the Association for Packaging Market Research (Gesellschaft für Verpackungsmarktforschung (GVM)) on behalf of the German Environment Agency (UBA). For the year 2017, the survey by GVM (2019) reports almost consistently higher packaging quantities than occur according to FS19, R1 (Destatis 2019a). The difference totals almost 5 million t and is particularly noticeable for packaging made of paper, followed by wood, plastic and tinplate packaging. The differences in sales packaging are relatively small at 0.42 million t, while the large differences are due to the data for transport and secondary packaging from the commercial sector (GVM 2019). A comparison of the data and explanations of deviations can be found in the Appendix. A.3.

It is not possible to compare the two data sources (Destatis (2019b) and GVM (2019)) with each other, as they are based on different definitional boundaries. Paper packaging waste, for example, can also be reported separately under the LoW-codes for MSW (LoW 20 01) due to a different allocation between printed products and packaging from separate collection via the waste paper collection (blue bin). Since the presentation in Tables 21 and 22 according to Destatis (2019b) is based on a separate survey and does not differentiate between LoW 15 01 and 20 01, these shares cannot be broken down. A simple substitution of the packaging quantities reported under LoW 15 01 by the higher quantities according to GVM (2019) can therefore lead to double counting, whereby the effect of this multiple counting is not quantifiable. For consistency reasons, therefore, the quantities reported by Destatis (2019b) are also used for packaging waste for this study, as they are based on the input quantities for treatment in Chapter 5.1.4 and 5.1.5 are presented. In addition to the generation, the destination can thus also be evaluated in a consistent manner for the balance sheet (see chapter 5.1.9). In comparison with data from the Association of German Paper Mills (Der Verband Deutscher Papierfabriken, cf. VDP 2019) a clear underestimation of the volume of paper according to the Destatis (2019b) becomes clear. These quantities are therefore taken into account in the balance sheet by means of an additional estimate. According to (ARGUS et al. 2019) these differences are due to recovered paper flows that are taken directly for recycling and are therefore not recorded in treatment plants. It is assumed that this mainly concerns paper quantities from trade and industry (ARGUS et al. 2019). These additional quantities are therefore taken into account as part of the balancing of production and commercial waste (see Chapter 7). No quantitative indications of a similar nature are available for other waste fractions, so that no estimates or changes are made here.

5.1.7 Output treatment plants

In this chapter, the output from treatment plants is analysed and essential conclusions are derived. For this purpose, the additionally acquired special tables from Destatis (2019c) were evaluated as well as other data sources, which are described in detail below.

5.1.7.1 Thermal waste treatment

In this chapter, output data from waste incineration plants and RDF cogeneration plants are analysed. On the one hand, corresponding data are available from the Destatis special tables (Destatis 2019c)(see appendix A.1), on the other hand there is a joint publication on the "Processing of slags from MSW incinerators" by the Interest Group of Waste Incineration Slag Processors (die Interessengemeinschaft der Aufbereiter für Müllverbrennungsschlacken (IGAM)) and the Interest Group of Thermal Waste Treatment Plants in Germany (Interessengemeinschaft der Thermischen Abfallbehandlungsanlagen in Deutschland e. V. (ITAD)) (ITAD / IGAM 2019).

From the special tables of Destatis, the data for the respective total output of the waste incineration plants and the RDF cogeneration plants are first placed in relation to the corresponding total input. The aim is to determine the distribution of the residues in order to be able to apply them to the quantities considered in this study. For the correct relations, the total input and total output are decisive, even if this includes all types of waste and not only those considered in this study in the balance area of MSW. For the sake of simplicity, it is assumed that the additional commercial waste treated in the plants leads to the same quantities of ash, flue dust, flue gas cleaning residues and enables the same metal yields in ash processing as the treated MSW. The Destatis special tables (Destatis 2019c) show an input of 21.6 million t and an output of 6.5 million t for waste incineration plants and an input of 4.7 million t and an output of 1.3 million t for RDF power plants (total for waste incineration plants + RDF power plants: total input 26.3 million t and total output 7.8 million t).

In the output data, the final processing of bottom ash and boiler ash is only taken into account if this took place directly in the plant. The further processing, in which in particular the further separation of metals represents a non-negligible factor for the GHG balance, cannot be clearly derived from the Destatis data.

In contrast, the publication of ITAD / IGAM (2019) offers a more comprehensive picture.

IGAM and ITAD do not give a total input quantity to which the slag and metal quantities can be related. The output quantity of 6,258,000 t for bottom ash and boiler ash reported by Destatis compared to the fresh slag according to ITAD / IGAM (2019) of 5,670,727 t, shows a difference of 587,273 t. If the IGAM/ITAD quantity is related to the total input of 26.3 million t from Destatis, the share of ash quantities in the total input would be 21.6%. In its annual report for 2018, ITAD states that in 2017, 23.6 million t of waste was treated in 78 thermal waste treatment plants that are members of ITAD (ITAD (2019)). According to Dehoust / Alwast (2019) and Flamme et al. (2018), 66 waste incineration plants and 32 RDF cogeneration plants, i.e. a total of 98 thermal waste treatment plants, are currently in operation in Germany, while the survey of Destatis (2019b) includes 84 waste incineration plants and 33 RDF cogeneration plants.

In comparison with the values from Destatis (2019c), IGAM/ITAD show remarkebly higher metal yields. This indicates that slags are predominantly processed in external plants for metal recovery. Since the Destatis values therefore only represent a smaller part of the output, the IGAM/ITAD data for the output from waste incineration plants and RDF cogeneration plants are used for this study.

For the balance sheet, we assume that the unburned fractions are returned to the plants. The distribution between ferrous and non-ferrous metal fractions from processing, including the adhering ash particles, is 72.3% for iron and 27.7% for non-ferrous metals. Since the pure metal yield of 92% for iron is significantly higher than that of about 66% for non-ferrous metals, the share of iron in the distribution of pure metal fractions increases to 78.6%. The metal fractions separated before processing the ashes are usually larger components, which explains the high metal yield of 95% from the separated fraction. A distribution according to ferrous and non-ferrous fractions is not given. Simplified, we assume the same distribution between ferrous and non-ferrous metals as is found in the processed slag for the processing fractions and the "pure" metal fractions. The resulting calculated values for metals from incineration residues are shown Table 21.

For Germany, but also for the EU member states as a whole, it can be assumed that slag is generally processed. In the BREF (Neuwahl et al. (2019)3.4.3), slag treatment and separation of ferrous metals is specified for all plants, and for non-ferrous metals for most of them as well. The amount of slag produced is not specified. According to information for individual plants in Germany, about 20-30% of the waste incinerated is processed slag. In CEWEP (2019), the amount of slag in relation to the incinerated waste is given as about 20%. For the calculation, 20% of processed slag was assumed and the amount of fresh slag was recalculated on this basis (i.e. plus separated metals).

Table 21 Calculation values for metals from incineration residues

Group	Unit	Value
Proportion of slag preparation	% Slag attack	100%
Fresh slag	% Amount of waste incinerated	22%
Ferrous metals from slag	% Slag	7.14%
of which pure ferrous metals	% Fe metal fraction	93%
Non-ferrous metals from slag	% Slag	2.73%
of which pure non-ferrous metals	% Non-ferrous metal fraction	66%

Sources: (BREF et al. 2019), CEWEP (2019), (ITAD / IGAM 2019)

5.1.7.2 Mechanical biological waste treatment

Inputs to mechanical (biological) waste treatment plants are reported in FS19, R1 in Table 8.1. According to this, in 2017 a total of 52 Mechanical (-biological) waste treatment plants were supplied with a total of 3.79 million t of waste - from domestic sources and those generated in their own operations - and with 29,500 t from abroad. Of this, a total of 2.92 million t was MSW (LoW 20) and 56,900 t was packaging waste and similar (LoW 15). In addition, 652,600 t of waste were delivered from waste treatment plants, the remaining 160,800 t came from industry and commerce and to a very small extent from agriculture.

Only the selected waste types and quantities are relevant for the balancing, which amount to a total of 2,911,500 t. Added to this are the allocated export quantities (see Chap. 5.1.3), resulting in an input quantity of 2,970,400 t. A distribution by MBT type cannot be determined from the Destatis data.

For the balancing, the input quantity derived from Destatis (2019b) derived input quantity in MBTs is retained, for the distribution among MBT types and the output from the plants, information is provided according to Ketelsen / Becker (2019) and Ketelsen (2020) is used, which allows for a better level of detail[39] . Both sources give data on the number and capacity (and throughput) by different plant types. In total, both sources record a number of 36 MBT plants, but in Ketelsen / Becker (2019) seven plants that have already been converted to purely mechanical plants and three plants that only treat biowaste in the biological part of the plants are not taken into account. According to Ketelsen (2020) the 36 MBT plants had a throughput of 3.733 million t and a capacity of 4.796 million t in 2017.

This results in the following distribution split according to MBT types:

- 32% Treatment in aerobic MBT
- 25% Treatment in anaerobic MBT
- 31% Treatment in MBS
- 12% Treatment in MPS

The distribution of the output and its destinatione by Ketelsen (2020) for the different MBT types is shown in Table 22 shown. In the case of energy recovery, the quantities for "further processing" are added to the co-incineration in the cement plant in the GHG balance. The very

[39] Interim report and averages from the ongoing UBA project on the further development of MBTs.

small quantities of "other" under material recovery are neglected in the balance for the sake of simplicity. The landfill fraction from MPS and MBS is usually inert material. For aerobic and anaerobic MBT, an inert fraction of a similar magnitude is assumed; the remaining quantity is accounted for in the GHG balance as MBT residue (largely stabilised material with a low residual methane formation rate). For the "other residues", according to information from (Ketelsen 2019) ("predominantly waste incineration"), energy recovery in waste incineration plants is balanced.

Table 22 Estimate of whereabouts in 2017 according to MBT types

Figures in %	Aerobic MBT	Anaerobic MBT	MPS	MBS
Energy recovery	46.9%	50.4%	66.8%	64.8%
RDF power plant	31.6%	25.6%	4.8%	40.7%
Cement plant	4.4%	0.7%	19.8%	12.1%
Coal-fired CHP	1.8%	2.0%	40.7%	10.9%
Biomass CHP	1.1%	1.0%	0	0.4%
Waste incineration plant	7.7%	19.6%	1.4%	0.4%
Further processing	0.3%	1.4%	0.2%	0.3%
Recycling (metals)	2.3%	2.3%	5.0%	3.6%
Ferrous metals[40]	2.1%	2.2%	4.0%	3.2%
Non-ferrous metals[41]	0.2%	0.1%	1.0%	0.5%
Other	0.025%	0	0	0.006%
Biogas	0.003%	5.0%	0	0
Landfill	30.6%	23.6%	5.2%	4.3%
Other destination	1.5%	0.8%	0	0
Composting losses	18.7%	17.8%	23.0%	27.3%

Source: Ketelsen (2020), values updated according to (Ketelsen 19.11.2021)

5.1.8 Other treatment plants

In Destatis (2019b) the input of waste in shredding plants and scrap shears, in sorting plants and other treatment plants is also reported. These are summarised for the present balance depending on the waste types reported for primary treatment (LoW-code):

- "Mixed waste sorting plants" for mixed MSW
- "Recyclables sorting facilities" for separately collected dry recyclables.

The waste statistics do not offer the possibility to map the output of these facilities. The balancing of material flows is based on expert knowledge, publications and assumptions (see Chap. 4.2.6 and 4.2.7).

40 Incl. foreign substances

41 Incl. foreign substances

5.1.9 Quantity and destination for the balancing

The summarised results derived and explained in the previous sections are presented in the following Figure 5 figure below. Here, the 641,400 t of glass waste, whose destinations are not explicitly documented in Destatis (2019b), were assigned to the "glass packaging" (LoW 15 01 07) (see Chap. 5.1.4). For household waste and commercial waste similar to household waste (LoW 20 03 01 01), the input-output difference of 252,700 t was allocated to RDF power plant (see Chap. 5.1.4, in Figure 5, light yellow). Figure 5 does not yet include the breakdown of the input quantity in MBT by MBT type (see Chap. 5.1.7.2).

Figure 5 Analysis of Destatis data (in 1,000 t)

LoW-code	Waste type	from Table 1.1 Total input (incl. export quantities)	from Table 2.1 Input landfill	from Table 3.1 Input waste incineration	from Table 4.1 Input combustion plants - RDF plants	from Table 4.1 Input combustion plants - Biomass CHP	from Table 7.1. Input biol.treatment - Biowaste compost	from Table 7.1. Input biol.treatment -Green waste compost	aus Tab 7.1. Input biol.treatment - Biogas plant	aus Tab 7.1. Input biol.treatment - Biogas plant (cascade)	from Table 8.1 - Input M(B)T plants	from Table 10.1 Input shredder plants and scrap shears	Input Sorting plant	from Table 13.1 Input other treatment plants
150101	Paper and cardboard packaging	3,238.9		1.0	5.4							102.4	2,774.6	355.5
150102	Plastic packaging	1,056.4		2.9	4.9						4.6	91.9	427.4	524.7
150103	Wood packaging	722.6		0.4		95.8					35.3	351.6	144.0	95.5
150104	Metal packaging	34.8		0.1								16.6	10.6	7.5
150105	Composite packaging	39.0		5.1							0.2	2.4	12.8	18.5
15010600	Mixed packaging non-differentiable	2,266.8		469.4	35.1						55.2	26.4	1,322.2	358.5
15010601	Light weight packaging (LWP)	1,952.8											1,952.8	
15010602	Mixed recyclables with LWP	290.2											290.2	
150107	Glass packaging	2,060.9	0.3	1.1	0.0								1,622.0	437.5
200101	Paper and cardboard	4,562.3		4.8	0.2						0.1	494.5	4,001.5	61.2
200102	Glass packaging	515.4	2.4										417.7	95.3
200108	Biodegradable kitchen and canteen waste	993.8		7.3			53.7	1.5	505.7	51.3	4.2			370.1
200138	Wood other than that falling under 200137	679.2		0.4		100.6		8.4				413.5	96.7	59.6
200139	Plastics	102.9		5.5	3.1						1.6	24.7	40.3	27.7
200140	Metals	337.3		0.3								303.1	22.1	11.8
20019901	Mixed recyclables without LWP	45.9											45.9	
200201	Biodegradable waste	5,712.2		7.3		75.6	934.9	3,245.6	223.3	216.3	23.4	290.3	481.5	214.0
200203	Other non-biodegradable waste	16.1		14.4							0.1		1.3	0.3
20030100	Mixed MSW non-differentiable	7,091.1	5.1	4,663.2	180.5		99.6			66.4	491.2	40.8	927.3	617.1
20030101	Household waste, household-like commercial waste collected together via the public waste collection system	8,465.4		6,157.8	252.7						2,012.4		42.5	0.0
20030102	Household-like commercial waste, delivered or collected separately from household waste	2,044.1		1,087.8	115.4						131.3	10.6	678.3	20.7
20030104	Biowaste from bio bin	4,321.4					2,277.7	108.3	909.0	958.2			68.2	0.0
200302	Market waste	85.8		9.5			10.1	1.9	43.5	4.2	3.4		0.8	12.4
200307	Bulky waste	2,597.1		896.4	28.4						207.4	145.7	1,037.5	281.7
	Sum	**49,232.5**	**7.8**	**13,334.7**	**625.7**	**272.0**	**3,376.0**	**3,365.7**	**1,681.5**	**1,296.4**	**2,970.4**	**2,314.5**	**16,418.2**	**3,569.6**

The total volume of MSW considered is 49,232,464 t. The colour markings in Figure 5 refer, among other things, to further allocation steps for the derivation of a basic table on generation and destination for balancing.

The following classifications are made for the waste types under consideration:

- The various residual waste fractions (20 03 01 00, 20 03 01, 20 03 01 02) are grouped together under the term "residual waste".
- The quantities of separately collected waste types (organic or dry recyclables) as well as bulky waste sent to residual waste treatment plants (waste incineration, MBT, RDF power plants) are also summarised under "residual waste" (light blue in Figure 5).
- In total, this amounts to 1,503,000 t for waste incineration plants and RDF incinerators and 335,533 t for mechanical-biological treatment plants, which are mainly determined by the amount of bulky waste and mixed, non-differentiable packaging. Bulky waste cannot be shown separately for the EU balance areas and was also subsumed under "residual waste" in the previous studies.
- Conversely, residual waste fractions (in this case 20 03 01 00, green in Figure 5) that go to biological treatment plants are assigned to the waste from the bio bin (20 03 01 04). This simplification concerns 99,600 t of waste that goes to composting of waste from organic waste bins and another 66,400 t that is treated in combined composting and anaerobic digestion plants. This simplification can be justified because the quantities involved are small and there may have been a mistake in waste reports in allocating these wastes to the non-differentiable mixed MSW.
- The two waste types "other non-biodegradable waste" (20 02 03) and "market waste" (20 03 02) are also not presentable for the EU and were not included in previous studies. They are allocated according to the type of treatment: biological treatments lead to an addition to waste from the bio bin (only concerns market waste). Residual waste in residual waste treatment plants is assigned to "residual waste" (light blue in Figure 5).
- The treatment of waste in sorting, shredding and other treatment facilities is summarised as follows:

  The sum of the separately collected dry recyclables ends up in "recyclables sorting plants" (approx. 17 million tons, beige in Figure 5). The output is mapped in the GHG balance on a waste type-specific basis according to empirical values. For the sorting of composite packaging, mixed lightweight packaging and non-material-equivalent packaging (LoW 15 01 05, 15 01 06 & 20 01 99 01), an allocation to recyclable material fractions according to (Dehoust et al. 2016a) (see Chapter 5.1.8).

  - The quantities of "mixed MSW" (20 03 01), "market waste" (20 03 02), "other non-biodegradable waste" (20 02 03) and "bulky waste" (20 03 07) are added up as input of a "mixed waste sorting plant" (approx. 3.9 million tons, blue-grey in Figure 5. This can be a mechanical processing plant, a commercial waste sorting plant or a bulky waste sorting plant, all of which generally sort mainly RDF as the main product. The balancing of this mixed fraction is described in Chapter 4.2.6.
  - For kitchen waste (LoW 20 01 08) going to other treatment plants (370,100 t), it is assumed that these are upstream or transfer plants. For further use, the quantity is allocated to biogas and anaerobic digestion plants.

- For "biodegradable waste" (20 02 01), where quantities are reported for all three sorting plant types, the assumption is made that these are upstream plants that separate this garden waste into woody, digestible and compostable components. For the material flow separation of the total 985,800 t of "biodegradable waste", a division into 25% woody waste, 25% digestible and 50% compostable is assumed according to empirical values. The woody waste is assigned to biomass CHP, the digestible waste to anaerobic digestion and the compostable waste to green waste composting.

The resulting basic table for the generation and destination of MSW for the GHG balance shows Table 23.

Table 23 Basic table: quantity and destination for the Germany balance (in 1,000 t)

LoW-code	Waste type	Quantity	Input LF	Input INC	Input RDF power plant	Input Biomass CHP	Input Composting Waste from bio bin	Input Green waste composting	Input AD plant	Input combined comp. / AD. plant	Input Aerobic MBT	Input Anaerobic MBT	Input MBS	Input MPS	Input "sorting plant for recyclables"	Input "mixed-waste sorting plant"
	Residual waste	20,821	5	13,335	626						947	745	921	357		3,885
150101	Paper and cardboard packaging	3,233													3,233	
150102	Plastic packaging	1,044													1,044	
150103	Wooden packaging	687				96									591	
150104	Metal packaging	35													35	
150105, 15010600, 15010601, 15010602, 20019901	LWP[42]	4,030													4,030	
150107	Glass packaging	2,060	0.3												2,060	
200101	Paper and cardboard	4,557													4,557	

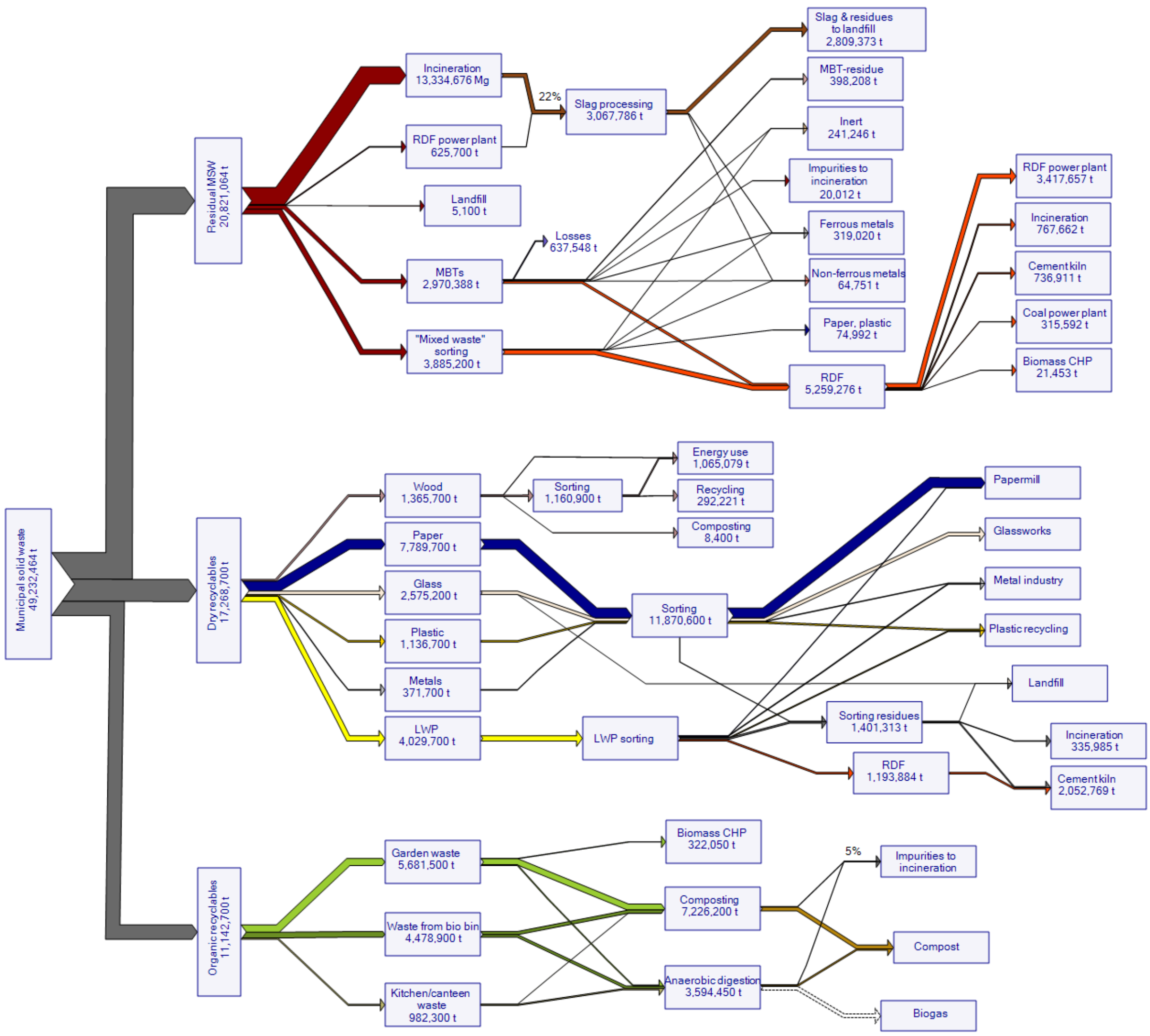
[42] Breakdown according to DSD ((Dehoust et al. 2016a) for ref. year 2014)

LoW-code	Waste type	Quantity	Input LF	Input INC	Input RDF power plant	Input Biomass CHP	Input Composting Waste from bio bin	Input Green waste composting	Input AD plant	Input combined comp. / AD. plant	Input Aerobic MBT	Input Anaerobic MBT	Input MBS	Input MPS	Input "sorting plant for recyclables"	Input "mixed-waste sorting plant"
200102	Glass	515	2												513	
200108	Biodegradable kitchen and canteen waste	982					54	2	876	51						
200138	Wood other than that falling under 200137	679				101		8							570	
200139	Plastics	93													93	
200140	Metals	337													337	
200201	Biodegradable waste	5,682				322	935	3,739	470	216						
20030104	Waste from the bio bin	4,479					2,387	110	953	1,029						
Total		**49,232**	**8**	**13,335**	**626**	**518**	**3,376**	**3,859**	**2,298**	**1,296**	**2,970**				**17,061**	**3,885**

The result of the basic data survey on waste generation and its destination for MSW in Germany 2017 is shown in Figure 6 as a material flow diagram. Figure 7 shows the volume of primary treatment as a bar chart by waste type. In addition to the waste stream "residual waste", this also includes the separately collected organic waste (waste from the bio bins, garden waste, kitchen/canteen waste), which is treated using the same processes due to the waste characteristics.

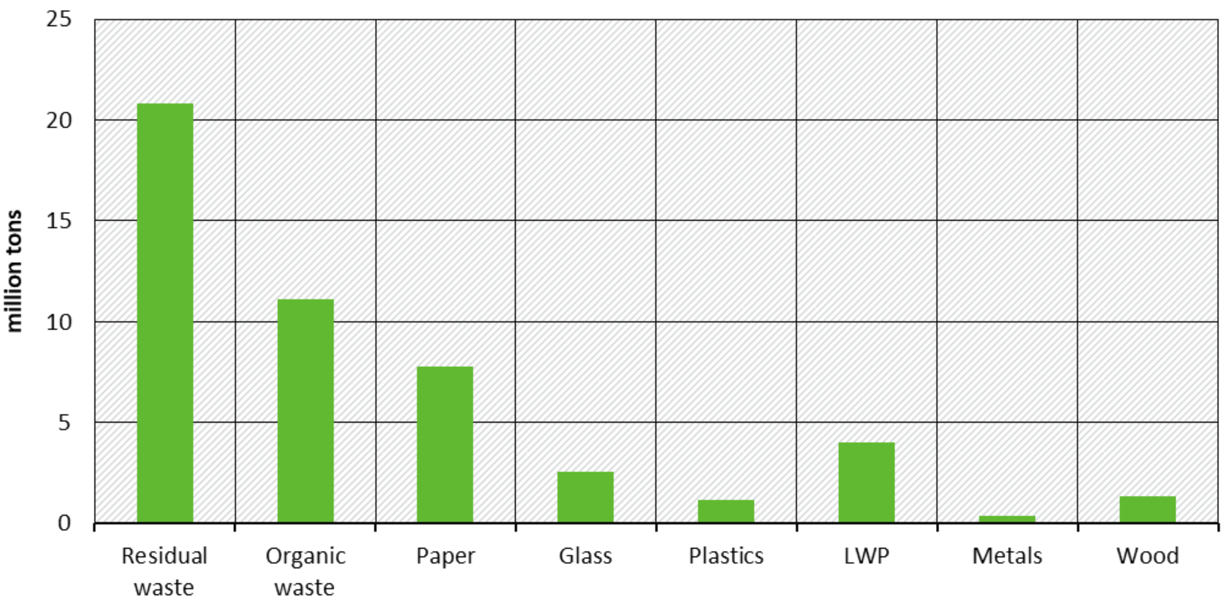
Both diagrams visualise that comprehensive separate collection is already established in Germany. Separately collected dry recyclables (incl. wood) account for 35% of the total volume and separately collected organic waste for 23%. This leaves a residual waste stream of 42%, which is mainly fed into thermal waste treatment plants (waste incineration plants, RDF cogeneration plants) for initial treatment (67%).

Figure 6: Sankey diagram MSW Germany 2017



Source: own representation, ifeu

Figure 7: MSW generation Germany 2017 by waste type



5.1.10 Home composting

Home composting is defined as the composting of organic and green waste in private households without the involvement of a waste management company. It is therefore inaccessible to statistical recording and systematically collected quantities are not available.[43] It is also difficult to evaluate home composting, as domestic practice can vary greatly and it is not possible to assess the quality of compost heaps/composters operated by private households.

Home composting is therefore not taken into account in the MSW balance in the baseline comparison. However, a scenario analysis is carried out in which home composting is counted towards the RC rate (cf. Chap. 5.3). There are considerable data uncertainties with regard to both the amount of home composting and its GHG assessment, which are briefly discussed below and described in more detail in the appendix (Chap. A.4).

For an estimate of the possible home composting quantities, the study of the German Environment Agency on high-quality recycling options for biowaste (Bulach et al. 2021) is used as a current source containing a detailed overview of the situation of home composting in Germany

In order to determine the amount of home composting, in Bulach et al. (2021) the garden and kitchen waste potentials are first determined. From this, the shares of garden and kitchen waste in the statistically recorded green waste, biowaste and residual waste volumes, as well as the quantities disposed of via other routes (e.g. sewers, bonfires, illegal disposal), are deducted and the home composted quantities are calculated.

Accordingly, based on studies (Krause et al. 2014) for the reference year 2010, of a total amount of 177 kg of garden waste and 81 kg of kitchen waste per capita, 82 kg of garden waste and 13 kg of kitchen waste were fed into home composting or recycling in private households[44] . Other

[43] At EU level, it is also possible to count quantities from home composting towards the recycling quota, for which a defined calculation method has been established (see partial report EU). However, Germany has not yet made use of this option, so that the German MSW data at European level do not include any quantities from home composting.

[44] Recycling in private households could also include feeding to pets. For kitchen waste (food waste), it was estimated at 4.3 kg/(E*a) in Thünen (2019a).

studies mentioned support the order of magnitude of the total quantities for home composting with figures of 80 kg/(E*a) and 100 kg/(E*a) (Bulach et al. 2021).

Based on Bulach et al. (2021) the amount of home composting was then derived as described below. The starting point is the data for 2010, according to which a total of 95 kg/(E*a) was composted. Various approaches can be used for extrapolation to the year 2017:

- Option 1: The per capita amount of home composting remained constant at 95 kg/(E*a)→ Home composting amount = 7.9 million tons.
- Option 2: The total per capita volume of biowaste and green waste remained constant, the per capita volume for home composting was reduced by the shift to separate collection to 65 kg/(E*a)→ Volume for home composting = 5.4 million tons.
- Option 3: The total per capita volume of organic and green waste increased proportionally and thus the per capita volume for home composting increased to 113 kg/(E*a)→ Volume for home composting = 9.3 million tons.

Option 1 was chosen for the scenario with home composting in the RC rate. The assumption of a constant amount of home composted waste per capita is plausible in itself, even if it means that the total amount of native-organic waste from households would have increased in 2017 compared to 2010. The options were also discussed in the online workshops (see Chap. B.2). The amount under option 1 was estimated to be probably too high. For this study, it was used as it offers good relevance for the scenario with home composting in the RC rate additionally investigated in this study (s. ch. 5.3).

5.1.11 New procedures

As part of the collection of material flow data for balancing, framework conditions for waste treatment processes were to be researched and compiled that have not yet been mapped in the GHG balance models. For this purpose, three processes - pyrolysis, hydrothermal carbonisation (HTC) and conversion of waste with the soldier fly larvae - were selected in the course of the project, as they are suitable for the utilisation of biogenic residues and waste materials. They are described in this chapter.

In addition to the selected processes, the "chemical recycling" of polymers and the separation of CO_2 from flue gases of thermal waste treatment for use as a carbon source for synthetic hydrocarbons in the context of power-to-X processes (carbon capture and usage, CCU) were also discussed. However, the consideration of chemical recycling was excluded due to the narrow focus on plastic waste as a starting point. The pyrolysis included in the consideration represents a possibility for the (thermo-)chemical recycling of plastics, whereby a pyrolysis oil is produced as a product at the level of (synthetic) crude oil, which must be further refined (see e.g. Lechleitner et al. 2019). The combination of thermal waste treatment with CCU was also not considered. On the one hand, a much more detailed consideration of this option is being carried out in the project of the German Environment Agency that has just been commissioned, "Uses and potentials in waste treatment plants for sector coupling" (FKZ 3719 31 302 0). On the other hand, PtX processes require largely renewable electricity generation in order to achieve advantages over conventional processes in terms of GHG emissions. The origin of the CO_2 in the flue gas (biogenic/fossil) is also relevant. The time horizon of 2030 is too short in view of the degree of decarbonisation to be expected by then.

Within the framework of the project of the German Environment Agency "Determination of criteria for high-quality alternative recycling options for biowaste (Bulach et al. 2021), the treatment of biogenic residues and waste materials by means of pyrolysis, hydrothermal carbonisation (HTC) and soldier fly larvae was investigated in detail. The detailed profiles contained therein present the processes based on various available sources, from which characteristic data for the life cycle assessment were derived. The corresponding characteristic data are used for the balancing within the scope of this project. In the following, the technologies of pyrolysis, HTC and soldier fly larvae are briefly described and data for the life cycle assessment, which were compiled in Bulach et al. (2021) are presented. The LCA data are adopted for the GHG balancing in this study. For further details, please refer to Bulach et al. (2021). In addition, pyrolysis and HTC were examined in detail as alternative thermal treatment processes within the framework of the project of the German Environment Agency on the status of alternative processes for the thermal disposal of waste (Quicker et al. 2017).

5.1.11.1 Pyrolysis of biogenic residual and waste materials

Pyrolysis is a process in which organic material, in this study limited to biomass, is thermo-chemically converted to so-called biochar and one or more liquid phases (pyrolysis oils, tars). The process takes place anaerobically and usually at temperatures between 200 and 600 °C. Possible substrates for pyrolysis are often woody biomasses as well as biogenic residues and waste materials, other wastes such as used tyres have also been used. (Lechleitner et al. 2019, Quicker et al. 2017). The proportions and types of products depend significantly on the process duration and temperature as well as the input used.

Flash pyrolysis is used to maximise the yield of pyrolysis oils. In medium-fast pyrolysis, an increased proportion of pyrolysis oils can be produced. In contrast, the target product of charring (complete slow pyrolysis) is charcoal. Torrefaction (incomplete slow pyrolysis) predominantly produces a lignite-like solid.

While slow pyrolysis has been used to produce charcoal for thousands of years, the fast process variants have only been researched for about 30 years. Therefore, they are still mostly in the pilot or demonstration phase today. On its own homepage, Pyreg describes itself as the market leader for medium-fast pyrolysis and sells decentralised container plants that are suitable for the use of various biogenic residues and waste materials (e.g. green waste, pre-treated sewage sludge, digestate).

For the life cycle assessment , the average pyrolysis yield determined in Bulach et al. (2021) for the Pyreg process of 126 kg of biochar per ton of woody biomass. For the biochar, it is assumed that 20% is used as stable litter (replacement of wood chips, as well as use as a soil conditioner), 30% as activated carbon (replacement of charcoal) and 50% (plus 20% from the subsequent use of the stable litter) as a soil conditioner (replacement of peat). (Bulach et al. 2021). The use of biochar as a food supplement for animals has also been described, but no provable data existed. In addition, heat is extracted from the process, which can be credited if used productively. Pyrolysis oils were not considered as a product.

Pyrolysis oils are mixtures of various organic components (including alcohols, furans, aldehydes, phenols and acids) that can be used energetically (e.g. as a substitute for heavy heating oil) and materially (e.g. as a binder for chipboard, surfactants or for the production of phenol-formaldehyde resins). In addition, there are applications in the food industry (smoke flavouring) and in agriculture (as a long-term fertiliser after conversion with nitrogenous compounds).

GHG emission values

For the GHG balance, the data were taken from (Bulach et al. 2021). The emission value for the emission savings potential is adopted 1:1. The expenditures were recalculated for this study. For the pyrolysis of wood, the characteristic data used in this study were applied for the purpose of equal treatment (Table 88). Due to the proportionate fossil C content in wood waste, higher debits result than in (Bulach et al. 2021). The specific net emission savings potential is calculated as -73 kg CO_2eq/t.

5.1.11.2 Hydrothermal carbonisation (HTC) of biogenic residues and waste materials

Hydrothermal carbonisation is also a thermo-chemical process to convert biomass into biochar, so-called HTC carbon. The process takes place at 180 to 260 °C and pressures between 150 and 240 bar and is particularly suitable for aqueous substrates such as liquid manure, green waste or dogestate due to the hydrothermal conditions. It has also already been tested for plastics (Shen 2020). After mechanical preparation of the substrate and addition of water, the solution is heated and the pressure in the reaction tank is increased. After 0.2 to 16 hours, the pressure is released and the carbon sludge can be cooled, dewatered and dried. Two types of HTC coal are produced. The primary coke can be used as a solid fuel. Its use as a soil improver is questionable in terms of its environmental impact and depends on the substrate used and the process control, as no pollutant removal is provided for in the process and pollutant development can take place during the process. Heavy metal-contaminated source streams, e.g. in the case of sewage sludge, are not suitable. Secondary coke is suitable for use in industrial carbon black, electrodes, as an adsorbent, and also as a solid fuel. In addition to coal, very large quantities of wastewater are produced that are heavily contaminated with organic substances. Some of these can be recycled in the process, but a large part must be treated at great expense before disposal is possible.

HTC plants are located in several industrialised countries (including Germany (HTCycle, Artec, SunCoal) and Spain (Ingelia S.L.)). The largest plants currently have theoretical capacities of about 10,000 tons/year. In Germany, none of the plants is operated continuously throughout the year. Moreover, the focus is mostly on carbonisation and dewatering, without treatment of the resulting wastewater and exhaust air.

For the life cycle assessment, the average mass-based yield of 23.2% to HTC coal according to Bulach et al. (2021) is used. As a substituted product, woodchips are used is in Bulach et al. (2021). In principle, lignite can also be substituted, but it loses its relevance with regard to future scenarios.

GHG emission values

For the GHG balance, the data were taken from (Bulach et al. 2021). The emission value for the emission savings potential is adopted 1:1. The expenditures have been recalculated for this study. For the treatment of waste from bio bins, the 5% share of impurities used in this study was taken into account for the purpose of equal treatment. Due to the lower emission factors for energy in 2030, the specific net debit of 31 kg CO_2eq/t is somewhat lower than in (Bulach et al. 2021).

5.1.11.3 Soldier fly larvae for the treatment of biogenic residual and waste materials

The soldier fly larvae is a tropical feeding insect that can be used to treat organic residues and waste. Kitchen waste, food leftovers or residual materials from agriculture or industry are used as substrate after shredding and adjusting the water content. The young larvae are placed on the biomass and, under aerobic conditions, transform it into a special compost, so-called "larval fertiliser", within about 12 days. During this time, the larvae grow up to the pre-pupal stage. They are then separated from the rest of the substrate and can either be used directly as live food or further processed into meal and oil. The protein-rich larvae meal can replace fish meal for feeding, for example. The larval fertiliser can be used in agriculture because of the improved nutrient availability due to the enzymatic digestion by the larvae, if necessary after post-composting.

With regard to product marketing for animal feed, the European feed law, which was influenced by the BSE scandal, does not yet allow for the economic breeding of soldier fly larvae for waste treatment. Thus, only small-scale plants exist today that sell the larvae regionally or offer larvae-based animal feed for pets. In South Africa and Canada, there is one company in each that uses soldier fly larvae on an industrial scale for a capacity of 36,000 and 91,000 tonsof substrate annually, respectively.

Despite the restrictions imposed by feed legislation, the life cycle assessment of the use according to Bulach et al. (2021) assumed that the 126 kg of larvae meal resulting from the use of 1 ton of organic residue replace protein feed. In addition, 667 kg of larval fertiliser are produced, which substitutes fertiliser and soil conditioner in the same way as compost.

GHG emission values

For the GHG balance, the data were taken from (Bulach et al. 2021) were used. The emission value for the emission savings potential is adopted 1:1. The expenses have been recalculated for this study. For the treatment of waste from bio bins, the 5% share of impurities used in this study was taken into account for the purpose of equal treatment. Due to the lower emission factors for energy in 2030, the specific net debit of 550 kg CO_2eq/t is lower than in (Bulach et al. 2021).

5.2 Waste composition of residual waste and characteristics

As in the previous study, the GHG balancing is carried out according to waste types. For the residual waste fraction, the characteristic data of calorific value and fossil C content are required for the balancing of thermal use. Individual values are available in the literature for this. E.g. according to (Flamme et al. 2018) the calorific value for "mixed municipal solid waste" is given as 10 MJ/kg. For the C-content, the National Inventory Report (NIR DE 2019) gives an emission factor[45]. In (Ketelsen / Becker 2021) a calorific value of 8.8 MJ/kg is given for the weighted average of the residual waste input in MBT plants and a fossil C content of 7.8%.

In the absence of representative measured values for the total residual waste fractions generated, for this study - analogous to the procedure in Dehoust et al. (2010) - the characteristic data are calculated on the basis of the waste composition with the help of the standard values shown in Table 24.

The residual waste volume derived for this study (cf. Chap. 5.1.9) of approximately 20.8 million tons comprises the following waste quantities:

- approx. 6.9 million tons of mixed MSW cannot be differentiated (20 03 01 00),
- approx. 8.5 million tons of household waste, household-like commercial waste collected jointly via waste collection (20 03 01 01),
- approx. 2 million tons household-like commercial waste collected separately from household waste (20 03 01 02),
- approx. 2.6 million tons of bulky waste (20 03 07)
- approx. 0.8 million tons other according to the derivation of the volume flows from Destatis.

[45] (NIR EN 2019), Table 522: 91.5 t CO_2 /TJ household waste, municipal solid waste, biogenic share 50%; from this, the fossil C content is calculated at 12.5% wet weight.

Table 24 Default values for waste fractions

Substance group	C total in % wet weight	C biogenic in % C total	Calorific value in MJ/kg waste
Paper and cardboard	37%	100%	13.02
Glass	0%	0%	0
Plastics	68%	0%	30.481
Metals	0%	0%	0
Organic and green waste	16%	100%	4.62
Wood	38%	100%	13.25
Textiles, leather, rubber	39%	56%	15.02
Composites	43%	49%	18.017
Fine waste < 8 mm	13%	65%	5.133
Other waste	21%	53%	7.8
Inert	0%	0%	0
Nappies	18%	75%	4.447

Source: (Dehoust et al. 2010)

The waste composition for household waste was determined in Dornbusch et al. (2020) representative for Germany. It refers to a per capita generation of 128.2 kg/(E*a). For the balance year 2017, with a population of 82,792,351, the absolute amount of household waste in Germany is calculated as 10,605,700 tons (Federal Statistical Office (Destatis) 2017). Compared to the quantity according to Destatis for the LoW-code 20 03 01 01, this also includes proportionate quantities that could not be allocated in the statistics (20 03 01 00). No representative data are available for the composition of bulky waste and commercial waste similar to household waste.

The extent to which the household waste composition can also be transferred to other shares of the household waste and commercial waste similar to household waste collected jointly via waste collection was discussed controversially in the online workshops with waste management associations and experts. Basically, there is both the opinion that the total amount collected via waste collection is comparable in its composition, and the opinion that this is not the case, since the waste types household waste and business waste differ significantly, especially in their organic content. There are also different quantities for waste collection[46] . For the composition of commercial waste, Dehne et al. (2015) an older source for the years 2007/2008 and "current, although not representative data material" was evaluated. The recyclable material contents described therein are considered too high against the background of initial findings from the evaluation of the Commercial Waste Ordinance.

[46] Destatis (2019c) 14,108,000 tons "household waste, household-like commercial waste collected jointly via public waste collection" (corresponds to a share from 20 03 01 00 of 81% collected via waste collection); according to waste balances of the German states approx. 12.9 million tons.

For this study, in the absence of representative current data for household-like commercial waste, an average value was taken as an approximation from the household waste composition according to Dornbusch et al. (2020) and the composition for household-like commercial waste from Dehne et al. (2015) is formed. This acknowledges both the fact that, according to expert opinion, the organic content of the household waste composition is too high for household-like commercial waste and, conversely, that the recyclable material content is too high. Both are levelled out by averaging.

The composition for bulky waste is approximated by the composition surveyed in Dornbusch et al. (2020) for orientation purposes. The following simplified allocation was made:

- Wooden furniture, other wood to "wood",
- Upholstered, composite furniture 50% to wood, 50% to "textiles",
- Mattresses, carpets to "textiles",
- Other bulky waste to "other waste".

Table 25 shows the resulting waste compositions by fraction as well as the weighted composition for residual waste 2017.

Based on the determined residual waste composition, the following characteristic data for residual waste are calculated, which are used in this study for the balance year 2017:

- Calorific value: 9.2 MJ/kg
- Fossil C content: 9.4%
- Biogenic C content: 15.7%

Characteristic data for other waste fractions or sorting fractions are listed in overview in Table 88 in the Appendix.

Table 25 Waste composition of residual waste fractions and calculated composition of residual waste 2017 this study

Substance group	Household waste[1]	Household-like business waste[2]	Bulky waste[1]	Weighted composition of residual waste
Paper and cardboard	5.2%	14.6%		7.7%
Glass	4.5%	6.8%		4.7%
Plastics	6.7%	13.4%	4.7%	8.7%
Metals	2.0%	3.0%	6.9%	3.0%
Organic	39.3%	25.7%		296%
Wood	1.2%	1.6%	56.5%	8.5%
Textiles, leather, rubber	3.5%	3.3%	27.2%	6.5%
Composites	4.3%	4.6%		3.9%
Fine waste	6.3%	10.7%		7.0%
Other waste	8.9%	7.4%	4.7%	7.9%

Substance group	Household waste[1]	Household-like business waste[2]	Bulky waste[1]	Weighted composition of residual waste
Inert	3.9%	2.0%		2.7%
Hygiene products	13.5%	6.8%		9.5%
Problem substances and pollutants	0.5%	0.3%	-	0.4%

1) Composition from (Dornbusch et al. 2020)

2) Calculated mean values of household waste from (Dornbusch et al. 2020) and commercial waste according to (Dehne et al. 2015)

5.3 Description of the GHG balance scenarios 2030

For the balance area of MSW in Germany, the balance year 2017 is compared with scenarios for the target year 2030. The future scenarios to be developed must be based on legal requirements and political framework conditions. The consideration of an increase in waste quantities or waste prevention cannot be regarded as an integral part of the LCA of waste management (see Chap. 4.1). However, the topic of waste prevention is considered separately (see Chap. 5.3.4).

The most important quantitative legal target for MSW is the recycling quota of 60% by 2030, as stipulated in Article 11 of the Waste Framework Directive or in § 14 of the Circular Economy Act (Kreislaufwirtschaftsgesetz, KrWG). The most important lever for achieving this RC quota lies in an increase in the separate collection of recyclable materials by removing them from the residual waste.

Explanation: Recycling quota - Recycling rate

In the context of this study, not all statistically reported municipal solid waste is considered (cf. Chap. 5.1). In addition, this study is based on the volume of primary treatment plants according to Destatis. The material flow balancing (quantity and destination of the output) is based on the analysis of further data bases and on expert reports[47] .

Consequently, the recycling quantities determined in this study and the percentages of recycling calculated from them should not be confused with the official recycling quota. To distinguish between the two, the recycled percentage in this study is referred to as the **"recycling rate"** (RC rate).

The interfaces used in this study to determine the recycling rate basically correspond to the calculation points specified at European level according to (EU 2019). In the case of separately collected biological MSW, the quantities actually fed into aerobic or anaerobic treatment are included; in the case of dry recyclables, the quantities that are not subjected to any further processing before being fed into a glass furnace, melting furnace, pulper or e.g. extrusion process are included. In this respect, the recycling rate determined in this study provides an orientation with regard to the official recycling rate.

For the base year 2017, the recycling rate for the MSW considered in this study is calculated at 48%. In order to increase this to 60%, around 6 million tons of recyclables would have to be removed from residual waste by 2030 (corresponds to 29% of the residual waste volume for

[47] It is not possible to allocate the output shown in the waste statistics to specific input quantities.

2017). Even if an increase in separate collection compared to 2017 can be assumed at the current status in 2021, the mathematically required increase in separate collection by 2030 is very ambitious. Both the feasibility and the achievable qualities of recyclable separately collected fractions are in question.

Since a less ambitious scenario would fail to meet the legal targets, the following two approaches, which were also discussed in the online workshops (see Appendix), are pursued for the model-theoretical consideration of the future 2030 scenarios:

1. **Baseline comparison: Comparison of** the base year 2017 with a lead scenario 2030, which refers to a comparatively valid data basis but is very ambitious.
2. **Comparison with home composting in the RC rate**: The home composting quantity is added to the base year 2017, which is adopted identically for the 2030 scenario; this lowers the ambition level of separate collection, although there are very high data uncertainties regarding home composting.

Counting the amount of home composting towards the official recycling quota is explicitly allowed under the Waste Framework Directive. It can also be assumed that this option is used by some EU member states. However, at the current state of knowledge, the actual amount of home composting in Germany is not known (cf. Chap. 5.1.10). A legally compliant determination of the home composting quota according to the calculation described in (EU 2019) Appendix II) is not feasible within the scope of this study.[48]

Another disadvantage of including home composting is that no reliable GHG assessment is possible for it. Neither the benefits of home composting nor the methane and nitrous oxide emissions resulting from the treatment can be validly named. The tendency is to expect a net debit (see Appendix, Chap. A.4). In this study, home composting is assessed as zero in order to keep the influence on the GHG balance as neutral as possible and thus have as little impact as possible on the actual question of the scenario.

The home composting volume is set in such a way that a significantly lower ambition level for the increased separate collection results. The purpose of the scenario with crediting of the home composting volume to the RC rate is to show and discuss the range of different ambition levels for increased separate collection. A direct comparison between the lead scenario and the scenario with home composting is not possible due to the different total waste quantities. The results of the scenarios are discussed comparatively at the level of specific values.

The following subchapters describe the waste volume diversions for the lead scenario and the scenario with home composting. In both cases, these must be model-theoretical assumptions; reliable forecasts are not possible.

In addition to the basic comparison described and the scenario with home composting, further scenarios and sensitivities are considered. An overview is shown in Table 26. A more detailed description follows in the subchapters.

[48] A corresponding project on "Determining a data basis for calculating the influence of home composting on biowaste recycling" is included in the departmental research plan 2021.

Table 26 Overview of scenarios and sensitivities for MSW in Germany

2017	2030
1. Base scenario	1. Lead scenario (sensitivity BAU scenario)
2. Scenario with home composting in the RC rate	2. Scenario with home composting in the RC rate
3. Base scenario with EU27 emission factors for electricity and heat for the EU balances[1]	3. Lead scenario with EU27 emission factors for electricity and heat for the EU balances[1]
4. Sensitivity of the base scenario with avoidance factors for electricity from biogenic waste (cf. Chap. 4.1.2)	
	5. Sensitivity Lead scenario with proportional consideration of re-use/ waste prevention

1) For the balances for Germany, national emission factors for electricity and heat are generally used, whereas for the EU balances the emission factors for electricity and heat for the EU27 are uniformly used, also for Germany (cf. Chap. 4.1.2).

5.3.1 Lead scenario 2030

In the lead scenario 2030, the target RC rate of 60% for 2030 is achieved on the basis of the volume flows collected from the statistics for 2017 through a model-theoretical increase in separate collection. The total comparatively considered waste quantity corresponds to the MSW quantity derived from the statistics of 49,232,464 tons.

5.3.1.1 Assumptions on increased separate collection and recycling of recyclables

As a starting point for increased separate collection of recyclables, the compositions for household waste, bulky waste and household-like commercial waste from Chapter 5.2 are used. For the household waste amount of around 10.6 million tons according to Dornbusch et al. (2020), the theoretically usable potential can be reliably calculated from the data in Dornbusch et al. (2020) at around 5.1 million tons. A similar estimate is not possible for bulky waste and household-like commercial waste, as the compositions are not representative and no information on qualities is available.

The approx. 5.1 million tons of theoretically usable potential in household waste derived for this study primarily includes native-organic waste and also packaging waste as well as other products made of paper, glass, metals and plastics. In each case, the quantities of the sorting categories "10-40 mm" are not taken into account. Composites are also not considered, as they are partly electrical appliances which are excluded from this study and are otherwise not differentiated by material and thus cannot be assigned. In the case of native-organic waste, kitchen and garden waste are included, but not packaged food waste[49] and other organics, which are considered to have no usable potential. The other sorting fractions fine waste, other waste, inert material, hygiene products, as well as, problem substances and pollutants offer no usable potential. Used textiles are excluded from this study. For the lead scenario 2030, it is assumed that 70% of the theoretically usable potential is collected and recycled separately[50] .

For bulky waste, the composition according to Dornbusch et al. (2020) primarily shows a theoretically usable potential for wood. Used textiles are not considered in this study and other

[49] Would have to be unpacked first, are also classified in Dornbusch et al. (2020) as non-utilisable potential.

[50] Corresponds to approx. 3.6 million tons of household waste or 34% of the reference quantity for household waste of approx. 10.6 million tons (see also Table 22).

fractions are downstream in terms of quantity. For the lead scenario 2030, it is assumed that 20% of the wood volume in bulky waste can be collected separately and recycled. For commercial waste, it is not possible to estimate a theoretically usable potential due to a lack of information and data uncertainties. For the lead scenario 2030, a simplified assumption was made that 50% of the recyclable fractions can be collected and recycled separately.

The calculated quantities of recyclable materials removed from household waste, bulky waste and commercial waste similar to household waste are shown in Table 27. These unmixed fractions are assigned to the corresponding fractions according to Destatis (unmixed recyclables and packaging fractions) for the volume flow diversion in the 2030 scenario. The volume of light packaging waste determined for 2017 is kept constant, as no suitable allocation to the sub-fractions is possible. In the lead scenario 2030, LWP is accounted for as in Scenario 1 in Dehoust et al. (2016b) (see also Table 31). This considers both optimised sorting and an increase in recycling.

Table 27 Quantities for increased separate collection in the lead scenario 2030

Substance group	From household waste	From bulky waste	From household-like commercial waste	Total
Waste paper packaging	167,292			167,292
Waste glass packaging	264,824			264,824
Plastic packaging	297,551			297,551
Metal packaging	73,613			73,613
Waste paper	186,903		497,696	684,600
Waste glass	50,472		230,950	281,422
Plastics	174,942		456,062	631,004
Metals	57,782		102,940	160,722
Native organic waste	2,322,127		876,566	3,198,693
Wood/Cork		293,246		293,246
Total	**3,595,506**	**293,246**	**2,164,214**	**6,052,966**
Share of reference quantities	*34%*	*11%*	*32%*	*29%*

Overall, the mass flow diversion through increased separate collection in the lead scenario 2030 results in around 6 million tons and thus 29% of the residual waste volume in 2017. The main share for the increase in separate collection is the fraction of native-organic waste. Under the assumptions described above, the volume of residual waste in the lead scenario 2030 is reduced from 20,821,064 tons to 14,768,098 tons. The resulting change in the composition of residual waste is presented in Table 28.

Table 28 **Composition of residual waste 2017 and 2030 in baseline comparison**

Substance group	2017	Lead scenario 2030
Waste paper	7.7%	4.9%
Waste glass	4.7%	2.8%
Plastics	8.7%	5.9%
Metals	3.0%	2.6%
Native organic waste	29.6%	19.5%
Wood/Cork	8.5%	10.1%
Waste textiles	6.5%	9.3%
Composites	3.9%	5.5%
Fine waste (0-10 mm)	7.0%	10.0%
Other waste	7.9%	11.3%
Inert material	2.7%	3.9%
Hygiene products	9.5%	13.5%
Problem substances and pollutants	0.4%	0.5%

For this waste composition, the characteristic data calorific value and fossil carbon content are again calculated according to the procedure described in Chapter 5.2. The resulting values are only slightly changed compared to those of the base year:

- Calorific value: 9.1 MJ/kg
- Fossil C content: 8.9%
- Biogenic C content: 15.9%

5.3.1.2 Assumptions for primary treatment in the lead scenario 2030

In addition to increased separate collection, the lead scenario 2030 includes assumptions on primary treatment. In part, mass flow diversions were also assumed here. In addition, the lead scenario 2030 includes new processes for certain types of waste (cf. Chap. 5.1.11). Overall, the following assumptions are made:

1. Primary treatment of residual waste:

For the reduced residual waste quantity, an equal distribution of the reduction is assumed via the primary treatment via mechanical and biological treatment and "mixed waste sorting". No statements can be made about how the calculated reduction in residual waste could actually be distributed. In principle, there are indications in (Flamme et al. 2018) where the input quantity in MBT plants was forecasted at -10% for 2030. However, there are no analogous forecasts for the input quantity in thermal waste treatment or for "mixed waste sorting" and, above all, the described quantity changes by 2030 in (Flamme et al. 2018) are significantly lower than the residual waste quantity reduced in the 2030 lead scenario of this study to achieve a target RC rate of 60%. The breakdown within thermal waste treatment plants is unchanged compared to

2017 (96% waste incineration, 4% RDF power plant). For the distribution within the MBT plants, it is taken into account that a shift in treatment towards MBS plants can generally be assumed. For example, the RESCUE project (Dittrich et al. 2020) assumes a complete conversion to MBS by 2050, but with constant input. With the significantly reduced amount of residual waste in the 2030 lead scenario, it is assumed in this study that the input quantity in MBS is not reduced and the percentage share in MPS plants remains constant. The difference is equally distributed and deducted from the aerobic and anaerobic MBT.

2. Native-organic waste:

At just under 30%, native-organic waste has the largest share in residual waste (Table 28) and accordingly, at around 3.2 million tons, form the largest volume stream in the increased separate collection derived for the lead scenario 2030. The amount of this quantity is also due to the incomplete implementation of the nationwide separate collection prescribed by the Circular Economy Act (KrWG) since 2015. Despite the enforcement deficit, even according to the assessment of experts, implementation of the assumption in the 2030 lead scenario is not realistic. At the very least, it would have to be assumed that the qualities collected would deteriorate in the short time remaining. This aspect is examined as a sensitivity. In principle, the increased separate collection via the bio bin is assumed in the lead scenario 2030. Existing plant capacities cannot absorb these quantities. It is assumed here that anaerobic digestion plants with combined energy and material recovery are added for treatment. This assumption is also very ambitious. For example, with an average plant capacity of 30,000 t/year, around 100 anaerobic digestion plants would have to be added by 2030.

In addition to the assumption that the additional separately collected quantity is treated via anaerobic digestion plants, the new or alternative processes HTC and treatment with soldier fly larvae are also considered for smaller quantities (cf. Chap. 5.1.11). The expansion potential is assumed to be 25,000 ton for HTC and 50,000 tons for treatment with soldier fly larvae. From a climate protection perspective, according to the results in (Bulach et al. 2021) both processes are currently disadvantageous due to low efficiency and/or high energy demand. However, both have potential for optimisation, which will be briefly discussed.

For the other native-organic recyclables, a diversion from composting to anaerobic digestion is assumed:

- for garden waste, a redirection of 10% of the previously composted quantities towards anaerobic digestion takes place,
- Kitchen/canteen waste is no longer composted in the 2030 scenario, but exclusively anaerobically digested.

Overall, this results in an increase in the share of anaerobic digestion compared to composting of organic waste from 33% to 52%.

3. Wood waste:

For a small part of the wood waste, a diversion from energy recovery to a new recovery through pyrolysis is considered. The potential for expansion is assumed to be 100,000 tons. Pyrolysis is classified as material recovery[51] . The diversion of the relatively small quantity has no influence on the RC rate.

4. Secondary waste:

[51] According to (Bulach et al. 2021) 70% of the biochar produced is ultimately used as a soil conditioner (black earth) in agriculture to substitute peat.

Quantities co-combusted in coal-fired power plants to date (mainly RDF and rejects from paper recycling) are used in thermal waste treatment.

The overall resulting volume changes from the baseline comparison for the lead scenario 2030 in primary treatment can be seen in Table 29.

Table 29: Primary treatment amounts 2017 and 2030 in baseline comparison

Waste for primary treatment	Base 2017 [t]	Lead scenario 2030 [t]	Difference [%]
Residual waste to landfill	5,100	0	-100%
Residual waste to thermal treatment	13,960,376	9,904,331	-29%
Residual waste to MBTs	2,970,388	2,107,372	-29%
"Mixed waste sorting"	3,885,200	2,756,395	-29%
Waste from the bio bin	4,478,900	7,677,593	71%
thereof composting	2,497,600	2,497,600	0%
thereof anaerobic digestion	1,981,300	5,104,993	158%
thereof new procedures		75,000	
Garden waste	5,681,500	5,681,500	0%
thereof composting	4,673,400	4,206,060	-10%
thereof anaerobic digestion	686,050	1,153,390	68%
of which biomass CHP	322,050	322,050	0%
Kitchen/canteen waste	982,300	982,300	0%
thereof composting	55,200	0	-100%
thereof anaerobic digestion	927,100	982,300	6%
Paper	7,789,700	8,641,592	11%
Glass	2,575,200	3,121,446	21%
Plastics	1,136,700	2,065,254	82%
LWP	4,029,700	4,029,700	0%
Metals	371,700	606,035	63%
Wood	1,365,700	1,658,946	21%
thereof pyrolysis		100,000	
Total	**49,232,464**	**49,232,464**	**0%**

5.3.1.3 Assumptions on technical optimisations

In addition to the flow diversions, technical optimisations are assumed in the lead scenario 2030:

- Increasing the efficiency of thermal plants,
- Increasing yields in the processing of dry recyclables,
- Increasing metal yields from residual waste treatment,
- Increasing the proportionate production of biomethane.

The utilisation rates for thermal plants applied in the lead scenario 2030 are listed in Table 30. These are based on the assumptions of the previous study. (Dehoust et al. 2010). For waste incineration plants, an increase in efficiency to14% electrical and 45% thermal was assumed for the target year 2020. In this study, on the other hand, somewhat higher values are assumed for the year 2030. The assumed utilisation rates for biomass CHP plant correspond to those already assumed in (Dehoust et al. 2010) assumed for 2020. With the given climate protection targets, high heat utilisation rates play an important role.

Table 30 Optimisation of utilisation rates of thermal plants in the Lead Scenario 2030

	2017	Scenario 2030
Waste incineration		
Electric	11.1%	16%
Thermal	33.5%	46%
RDF power plant		
Electric	14.7%	16%
Thermal	45.4%	46%
Biomass CHP		
electric	21.3%	18%
thermal	15.0%	40%

For LWP, for which scenario 1 from Dehoust et al. (2016b) technical optimisations are included to the extent that sorting success increases and, for example, plastic waste is increasingly recycled (Table 31).

Table 31: Breakdown of sorting fractions LVP sorting

Sorting fraction	2017	Scenario 2030
Foils for agglomeration	0,69%	0,80%
Foils for regranulation	5,97%	8,11%
Mixed plastics for agglomeration	0,80%	2,01%
Mixed plastics for PO agglomeration	0,60%	2,81%

Sorting fraction	2017	Scenario 2030
Mixed plastics for regranulation	2.05%	2.81%
PET to flakes	2.01%	6.03%
PO for regranulation	5.74%	8.03%
PS for regranulation	036%	0.36%
EPS for regranulation	0.04%	0.04%
Mixed plastics-RDF in blast furnace	2.81%	0.00%
Mixed plastics-RDF in cement plant	24.99%	15.06%
Beverage associations	5.57%	5.62%
Tinplate	11.47%	10.85%
Aluminium	2.50%	2.41%
Paper composite	2.19%	2.41%
RDF from LWP to the cement plant	1.83%	0.00%
Sorting residues from LWP	30.36%	32.63%

Source: (Dehoust et al. 2016a); Actual situation for 2017 and scenario 1 for 2030

For the qualities of the yields, no optimisation is assumed for plastic waste (incl. that from LWP) for the lead scenario 2030. However, this would be an important aspect from a climate protection perspective if recycled plastics were to increasingly replace virgin plastics instead of applications made of wood and concrete (Chap. 4.2.7.3).

The further assumptions on optimised sorting success or increasing the processing to biomethane are shown Table 32. In the case of dry recyclables there are already largely high sorting successes in Germany, so that no further increase is assumed for glass, paper and ferrous metals. In contrast, technical optimisation potential is seen for plastics and non-ferrous metals[52].

Table 32: Optimisation yields in the 2030 Lead Scenario

	2017	Scenario 2030
Yield of plastics	70%	80%
Yield of non-ferrous metals	70%	75%
Share of output from LWP sorting plant for recycling (Scenario 1) (Dehoust et al. 2016b))	40%	67%
Increase factor for metal yields from residual waste treatment	1	1,2
Increase factor for processing to biomethane	1	1,1

[52] For the EU27 excluding Germany or the EU balances for MSW, no increase in yields for dry recyclables is assumed for the actual situation due to the already given data uncertainties regarding data transferability.

Further optimisations are assumed for the metal yields from residual waste treatment. Since the increased separate collection and reverse reduction of residual waste affects primary treatment via mechanical-biological treatment, mechanical-biological treatment and "mixed waste sorting" equally, the proportion of metal remaining in the residual waste does not change in relation to the primary treatment processes. Here, an increase in metal yield of 20% is uniformly assumed.

The production of biomethane as of 2017 is described in Chap. 4.2.8. In the lead scenario 2030, it is assumed that this share will increase by 10%. The background to this assumption is, on the one hand, that the market conditions for biomethane as a fuel will improve (fuel quota). On the other hand, this assumption is advantageous from a climate protection perspective, as defossilisation in the mobility sector is progressing more slowly than in the energy sector.

5.3.2 Scenario with home composting in the RC rate

The purpose of the scenario with home composting in the RC rate in this study is to contrast the high level of ambition for achieving the RC rate of 60% in the lead scenario 2030 with a model variant that enables a less ambitious increase in separate collection by counting the home composting quantity towards the RC rate. For this purpose, the home composting quantity is set in such a way that a significantly lower level of ambition for the increased separate collection results, in order to be able to discuss the range of different ambition levels. Although the specified home composting volume of 7.9 million tons can be derived from studies, it is probably too high for Germany (Chap. 5.1.10). However, the underlying assumption of a constant per capita quantity for home composting fits well with the assumption of equal waste volumes in comparative scenarios, which is necessary for balancing. Within the scope of this study, it is neither intended nor possible to discuss potential interactions between separate collection of native-organic waste and home composting.

For the scenario with home composting in the RC rate, a separate comparison of the balance years 2017 and 2030 is necessary, as the total waste quantity is higher than in the baseline comparison by the assumed home composting volume of 7.9 million tons in each case. The total amount of waste considered for comparison in this scenario thus amounts to 57,132,464 tons.

Since home composting is (allowed to be) counted towards the RC rate, the RC rate in the scenario with home composting in 2017 is arithmetically 55%. Accordingly, the RC rate target of 60% for 2030 can be achieved through a lower model-theoretical increase in separate collection. The additional quantity to be separately collected for this scenario is calculated at around 2.7 million tons and is more than half lower than in the baseline comparison of the lead scenario.

The baseline for increased separate collection - the theoretically usable potential - corresponds to that for the lead scenario 2030 (Chap. 5.3.1.1). To achieve the additional 2.7 million tons to be separately collected, it is assumed that 35% of the usable potential of household waste is exploited (instead of 70% in the Lead Scenario). For bulky waste, it is assumed that 5% of the wood volume in bulky waste is collected separately and recycled (instead of 20% in the lead scenario). For household-like commercial waste, it is assumed that 20% of the recyclable fractions contained are collected and recycled separately (instead of 50% in the lead scenario). The resulting quantities of recyclable materials taken from household waste, bulky waste, and household-like commercial waste are listed in Table 33.

Under the assumptions described above, the residual waste volume in the 2030 scenario with home composting is reduced in the RC rate from 20,821,064 tons to 18,084,314 tons. The resulting change in the composition of the residual waste is shown in Table 34. For this waste composition, the characteristic data of calorific value and fossil carbon content are again calculated according to the procedure described in Chapter 5.2. The resulting values are only slightly changed compared to those of the actual situation:

- Calorific value: 9.2 MJ/kg
- fossil C content: 9,2%
- Biogenic C content: 15.8%

Table 33 Quantities for increased separate collection in the 2030 scenario with home composting in the RC rate

Substance group	From household waste	From bulky waste	from household-like commercial waste	Total
Waste paper packaging	83,646			83,646
Waste glass packaging	132,412			132,412
Plastic packaging	148,775			148,775
Metal packaging	36,807			36,807
Waste paper	93,452		199,079	292,530
Waste glass	25,236		92,380	117,616
Plastics	87,471		182,425	269,896
Metals	28,891		41,176	70,067
Native organic waste	1,161,063		350,626	1,511,690
Wood/Cork		73,312		73,312
Total	**1,797,753**	**73,312**	**865,686**	**2,736,750**
Share of reference quantities	*17%*	*3%*	*13%*	*13%*

Table 34: Composition of residual waste 2017 and 2030 in the scenario with home composting in the RC rate (scenario HC 2030)

Substance group	2017[1]	Scenario EC 2030
Waste paper	7.7%	6.7%
Waste glass	4.7%	4.0%
Plastics	8.7%	7.7%
Metals	3.0%	2.9%
Native organic waste	29.6%	25.5%
Wood/Cork	8.5%	9.5%
Old textiles	6.5%	7.5%

Substance group	2017[1]	Scenario EC 2030
Connected	3.9%	4.5%
Fine waste (0-10 mm)	7.0%	8.1%
Other waste	7.9%	9.1%
Inert material	2.7%	3.2%
Hygiene products	9.5%	10.9%
Problem and pollutants	0.4%	0.4%

1) Corresponds to the residual waste composition of the 2017 baseline assessment

The assumptions on primary treatment - as well as the assumptions on technical optimisations - are adopted unchanged compared to the lead scenario 2030. For the quantities, only the percentage shares of a shift change. Table 35 shows the changes in quantities resulting in the 2030 scenario with home composting in the RC rate for the volume for primary treatment.

For the year 2017, the only difference compared to the 2017 baseline balance is that the defined home composting volume is added, which is also set unchanged for 2030. The most significant difference in the 2030 scenario with home composting in the RC rate can be seen in the native-organic waste. Here, only about 1.5 million tons must be collected separately via the organic waste bin. This quantity still requires an expansion of the existing treatment capacities, but can also be considered realistic according to estimates by associations and experts (online workshops). With the example assumption of an average plant capacity of 30,000 t/year, around 50 anaerobic digestion plants would have to be added by 2030 (instead of around 100 in the lead scenario 2030, see Chap. 5.3.1).

Table 35: Volume of primary treatment in 2017 and 2030 in the scenario with home composting in the RC rate (scenario HC 2030)

Waste for primary treatment	2017 [t]	Scenario HC 2030 [t]	Difference
Residual waste to landfill	5,100	0	-100%
Residual waste to thermal treatment	13,960,376	12,128,375	-13%
Residual waste to MBT plants	2,970,388	2,580,588	-13%
"Mixed waste sorting"	3,885,200	3,375,351	-13%
Waste from the bio bin	4,478,900	5,990,590	34%
thereof composting	2,497,600	2,497,600	0%
thereof anaerobic digestion	1,981,300	3,417,990	73%
thereof new procedures		75,000	
Garden waste	5,681,500	5,681,500	0%
thereof composting	4,673,400	4,206,060	-10%
thereof anaerobic digestion	686,050	1,153,390	68%

Waste for primary treatment	2017 [t]	Scenario HC 2030 [t]	Difference
of which Biomass CHP	322,050	322,050	0%
Kitchen/canteen waste	982,300	982,300	0%
thereof composting	55,200	0	-100%
thereof anaerobic digestion	927,100	982,300	6%
Paper	7,789,700	8,165,876	5%
Glass	2,575,200	2,825,228	11%
Plastics	1,136,700	1,555,371	37%
LWP	4,029,700	4,029,700	0%
Metals	371,700	478,574	29%
Wood	1,365,700	1,439,012	5%
thereof pyrolysis		100,000	
Home composting	7,900,000	7,900,000	0%
Total	**57,132,464**	**57,132,464**	**0%**

5.3.3 Scenarios, sensitivity emission factors for electricity and heat

1. Scenarios with EU27 emission factors for electricity and heat

Originally, it was planned for this study, in which both Germany and the EU are considered, to use the EU27 emission factors for electricity and heat uniformly for all balancing areas. This was to avoid that different energy systems in the different balancing areas influence the results. This applies above all to the substitution potential through energy from waste. In countries or country clusters with a high GHG emission factor, especially for electricity[53] , the energy recovery of one and the same type of waste achieves higher GHG emission savings potentials than in countries with a low GHG emission factor. The reason for this is not measures in the circular economy, but in the energy sector. Since the climate protection potentials of the circular economy of the EU balance areas are to be examined comparatively, a uniform emission factor is indispensable in order to be able to recognise the differences as well as the advantages and disadvantages of the waste management measures. The emission factors for electricity vary considerably depending on whether Germany, the EU27, or clusters 1 or 2 are considered (see Chap. 4.1.2).

On the other hand, considered individually, the national electricity mix is certainly relevant for the consideration of the circular economy sector from a climate protection perspective. Particularly in countries that on the one hand still have difficulties establishing higher recycling shares and on the other hand still have a long way to go to defossilise their electricity generation, waste-to-energy can make a relevant contribution to climate protection. In addition, it was critically noted in the online workshops that national emission factors should be used for Germany as a separately considered balance area.

[53] The GHG emission factor for heat is usually lower and alsodiffers less between countries.

In order to take these aspects into account, national emission factors for electricity and heat are used uniformly for the GHG balances for Germany in this partial report. Conversely, in order not to generate a bias for the EU balances, the GHG balances for Germany are also calculated with the EU27 emission factors for electricity and heat. Only the results from this are included in the GHG balances for the EU, which are described in the partial report EU. For the EU balances for MSW, sensitivities are also calculated with the regional electricity emission factors. The differences that result for Germany from the balances with national and EU27 emission factors are described in the chapter for results (5.4.2.3).

2. Sensitivity with avoidance factors for electricity from biogenic waste

The emission factors for electricity and heat used for the balance areas are also used for the crediting of substitution potentials through the generation of electricity and heat from waste. The only exception is the potential for flexible electricity generation. The previous valuation according to the marginal approach for energy from waste as it was done in (Dehoust et al. 2010) is no longer up-to-date (cf. Chap. 4.1.1).

The German Environment Agency publishes annual avoidance factors for renewable energy sources. Retrospectively, substitution factors are determined for various renewable energy sources. For the biogenic share of waste, biogas, biomethane, biomass, sewage gas, landfill gas and others, avoidance factors for electricity were uniformly updated until 2017 on the basis of a study for 2012 and 2013[54] . The calculation methodology was updated for 2018 (UBA 2019). The substitution factors for electricity are now determined with the help of a simulation of the European electricity market. The real electricity market is compared with a fictitious European electricity market without German renewable energy production. As a result, for 2018, 67.6% of electricity from hard coal, 30.3% of electricity from gas and 1.5% of electricity from lignite was substituted by electricity generation from the biogenic share of MSW, which is reflected in the gross avoidance factor of 738 g CO_2eq/kWh electricity. The substitution factors and correspondingly the gross avoidance factor apply almost identically to the other renewable energy sources mentioned above[55] . The gross avoidance factors refer to displacement mechanisms for the European electricity market and not to national electricity generation.

For this study, the gross avoidance factors for electricity from biogenic waste are considered as part of a sensitivity for the balance year 2017. For the biogenic share in MSW, the avoidance factor is credited at 50%. Heat avoidance factors are not considered (cf. Chap. 4.1.2). An analogous consideration is not possible for the balance year 2030, as the values are determined retrospectively and no forecasts are possible. Corresponding values cannot be researched for the EU member states or the EU balancing areas, so that no analogous sensitivity analysis is carried out for the EU balancing areas.

The differences that result for Germany from the sensitivity analysis are described in the chapter for results (5.4.2.3).

5.3.4 Methodological approach to integrate preparation for re-use and waste prevention

Preparation for re-use and waste prevention had not been considered in LCAs of waste management so far. The main reason for this is the difficult data situation. The determination of substitution potentials for re-use and waste prevention was or is hardly possible or difficult

[54] (UBA 2018a), Chapter 2.2.6.

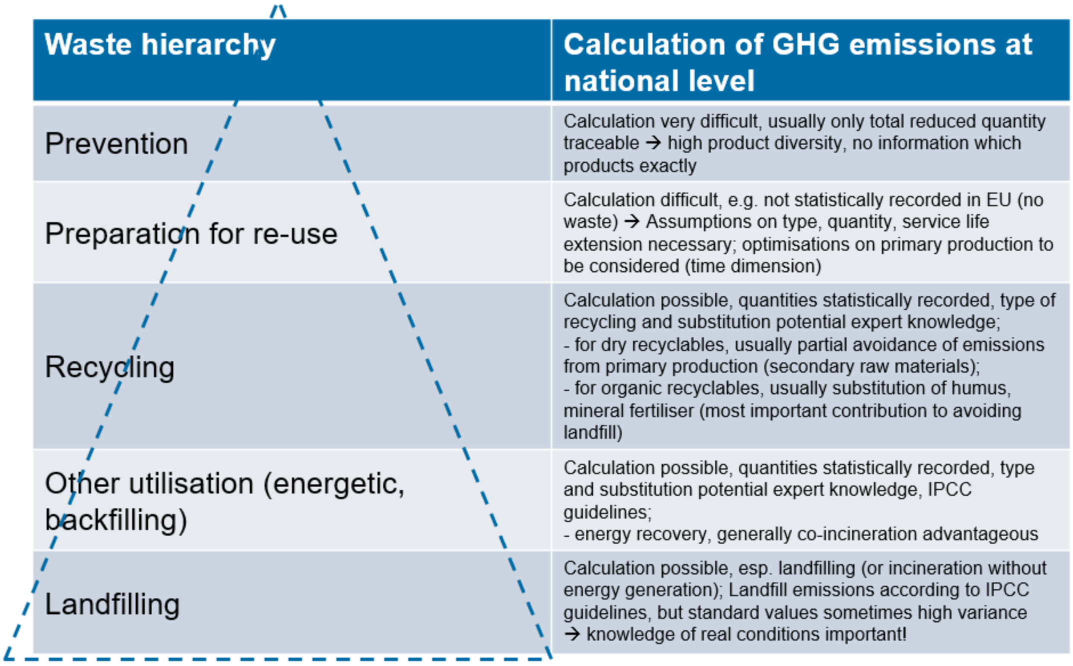
[55] The substitution factor for electricity from gas is partly given as 30.7%, the gross avoidance factor as 739 g CO_2 -eq/kWh electricity.

insofar as the re-used or prevented quantities can hardly be reliably quantified and moreover hardly or no representative information is available for the concretely prevented goods.

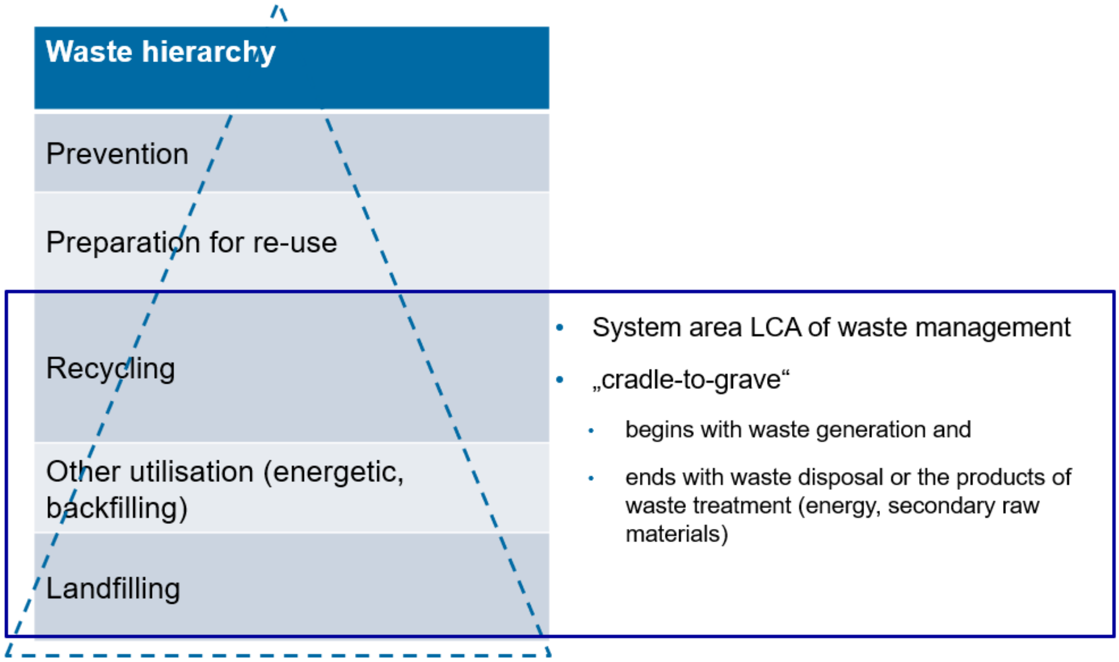
In principle, it would be desirable to be able to consider all five levels of the waste hierarchy. The hurdles and difficulties in doing so and the reasons why life cycle assessments of waste management have so far been limited to recycling, other recovery and disposal are illustrated in Figure 8 below. The figure shows two slides that were presented at a German-Russian online conference on the topic of GHG emissions from the waste and circular economy (Vogt 2021).

Figure 8: Life cycle assessment of waste management in the context of the waste hierarchy

Problems of calculating GHG emissions for waste hierarchy levels



Resulting framework for life cycle assessments of waste management commonly used to date



Source: (Vogt 2021)

Problem of quantity data

For waste prevention, it is difficult to determine the quantities actually avoided on the basis of statistical data. A change in specific waste generation per capita (or per value added in the respective sector) alone cannot necessarily be directly classified as waste prevention. Reasons for changes in quantities may also be due to a change in the reporting system, for example if waste is initially recorded as household-like commercial waste (MSW) and then in the comparison year as sectoral commercial waste (production waste). It is also unclear to what extent waste prevention is an achievement of the circular economy or can be attributed to it.

So far, no representative data are available for preparation for re-use. Since it is not waste in the legal sense, the re-used quantities are not recorded statistically. Quantitative data are partly available from individual studies on social and second-hand department stores, which are used in the context of this study. In contrast, data on second-hand goods traded privately or through online trade is even more difficult to access. For example, there is hardly any reasonable evaluation possibility for trade via online platforms without special access and the support of the platform operators. In this study, online trade is not considered. This is not only due to the data situation, but also because online trade, which has so far been organised mainly by the private sector, is outside the scope of waste management. This means that, as a rule, there is no possibility for public waste management authorities to exert any influence.

Methodology Life Cycle Assessment of Waste Management

In principle, preparation for re-use and waste prevention can be methodically included in the life cycle assessment of waste management. Analogous to the crediting of emission savings potentials through recycling or energy recovery, the emission savings potential for goods that are used longer through re-use or for waste that is avoided altogether can also be credited. Here, too, it is important to note that the total amount of waste must be the same in comparative considerations. In the case of preparation for re-use, it also applies that in this way - under certain boundary conditions to be observed - only simple re-use or service life extension can be included, but not cascade use. The consideration of re-usable systems requires the examination of the entire life cycle of products including the cycles through multiple use and thus a product life cycle assessment.

A methodological approach to integrating preparation for re-use is, for example, published in (Vogt / Ludmann 2019). An essential boundary condition to be considered with regard to the substitution potential lies in the time delay due to an extension of the service life of goods. Here it must be examined whether primary production has changed in the period of the service life extension. If, for example, significantly more efficient products are manufactured within this period or the production process itself becomes more environmentally friendly, this "lost advantage" through re-use must be taken into account in the balance sheet. This aspect is particularly relevant for electronics and electrical appliances (see (Vogt / Ludmann 2019)), which are excluded from this study.

For waste prevention, a fundamental difficulty in GHG assessment is that it is generally not known which wastes are actually prevented and, accordingly, no avoided products can be assigned. This applies in particular to waste mixtures such as waste from bio bins, household waste, bulky waste and household-like commercial waste. For this reason, at the beginning of the project it was examined to what extent published data could be used. On the one hand, this was the data of the shopping basket from a study by the Öko-Institut for the year 2005. (Öko-Institut 2007 p.). These are 800 individual data sets. However, these are no longer up to date and updating them would be too time-consuming, especially since, despite the large number of data sets, it would only be possible to make orienting statements on waste prevention. As a further approach, the possibility of using key figures from consumption models such as CO_2 calculators or economic calculation models was examined. Here, however, the degree of differentiation is very overriding. According to consumption or need fields (housing, food, mobility, other consumption), food or clothing would be very roughly assignable headings. Textiles are excluded from this study and the allocation of a GHG indicator from "other consumption" would be very imprecise.

However, after further research and thanks to ongoing or now completed projects, it is possible to estimate the waste composition and potentially avoided waste for some areas representatively or at least better. These include the sorting analysis for MSW (Dornbusch et al. 2020), a study on food waste (Jepsen et al. 2016), the update of the waste prevention programme (Wilts et al. 2020), the study about GHGs of food stuffs (Reinhardt et al. 2020), and the assessment of re-use (Vogt / Ludmann 2019). The procedure in this study to integrate preparation for re-use and waste prevention is described in the following chapters.

5.3.4.1 Integration Preparation for re-use

The quantification of quantities for re-use is divided into two steps. The first step is the quantification of the amount re-used per capita. The second step is to characterise the composition of the re-used goods.

For the quantification of the re-used quantity per capita, various sources were consulted and plausibility checked. The first source is the social department store Stilbruch, which published information on product groups, their share, the number of items and the price. (Bernhard 2017). Their data is processed and supplemented by further data to enable a balancing of greenhouse gas emissions. The given product groups are assigned to different clusters for which average weights have already been determined from previous projects. For certain clusters, an average value is calculated from the existing weights (e.g. upholstered furniture) or own assumptions are made (e.g. beds/slatted frames) in order to be able to assign weights to all existing product groups. The result is shown in the following table.

Table 36: Data on the product groups for the products sold at the Sozialkaufhaus Stilbruch in Hamburg in 2015

Product group	Quantity/ Number of pieces	Assignment	Weight in kg	Total mass	Mass fraction
Glass/porcelain	91,997	Small household items	0.4	33,119	1.9%
Books	53,202	Small household items	0.4	19,153	1.1%
Small furniture	17,063	Tables, shelves, cupboards	20	341,260	2.,1%
Upholstered furniture	3,380	Mixture of upholstered furniture	32	108,160	6.4%
Images	10,013	Small household items	0.4	3,605	0.2%
Tables	4,968	Tables, shelves, cupboards	20	99,360	5.8%
Chairs	11,095	Chairs	6	67,698	4.0%
Toys	27,759	Small household items	0.4	9,993	0.6%

Product group	Quantity/ Number of pieces	Assignment	Weight in kg	Total mass	Mass fraction
Antique furniture	1,870	Shelves, cupboards up to 1.5 m wide	50	93,500	5.5%
Large furniture	1,352	Living room cabinet(wall)	300	405,600	23.9%
Sport goods	5,946	Small household items	0.4	2,141	0.1%
Beds/slatted frames	1,753	Own assumption	15	26,295	1.5%
Garden/Home	6,439	Own assumption	2	12,878	0.8%
Office furniture	3,327	Mix of wood-based furniture	35	116,445	6.9%
Seasonal articles	8,543	Own assumption	0.1	854	0.1%
Textiles	59,437	Outerwear	0.4	23,775	1.4%
Electrical appliances.	33,236	Mix of small electrical appliances and hoovers	5.0	165,040	9.7%
CD/LP/DVD	31,432	Own assumption	0.1	3,143	0.2%
Bicycles	2,924	Bicycle	17	49,708	2.9%
Carpets	709	own assumption	10	7,090	0.4%
Losses				110,452	6.5%
Total				1,699,269	100%

Source: own evaluation based on (Bernhard 2017)

The total (1,699,269 kg) of this bottom-up approach is divided by the population of Hamburg in 2015 (1,787,408) (Statistical Office for Hamburg and Schleswig-Holstein 2016). This results in a per capita quantity of 0.95 kg. This quantity is compared with the mass figure for the Stilbruch department stores' of 2.67 million kg, which is shown in (Wilts et al. 2020). This results in a per capita quantity of 1.49 kg. This quantity is made plausible in dialogue with experts. In 2015, the district of Herford had a per capita quantity of 3.2 kg (Arbeitskreis Recycling e.V. 2020) and represents the best case in Germany due to its infrastructure. The experts (Working Group Recycling e.V. 2020) estimate that in Germany on average about half of this amount, i.e. 1.6 kg/capita, is achieved. Since this figure fits well with the calculated amount in Hamburg of 1.49 kg, the 1.6 kg per capita is used for quantification. Multiplied by the population of Germany in 2017 (Federal Statistical Office (Destatis) 2017) of 82,792,351, this results in a mass of 132,467,762 kg of re-used goods in Germany.

For the characterisation of the composition of the recycled goods, the two aforementioned sources (Bernhard 2017) and (Arbeitskreis Recycling e.V. 2020) are used. The rough composition is shown in the following table for both sources.

Table 37: Composition of re-used goods in Hamburg and in the district of Herford

	Electric	PC	Textile	Household contents	Bicycle	Furniture	Books	Garden and home
Hamburg	10%	-	2%	3%	3%	74%	1%	1%
Herford	14%	1%	16%	6%	1%	57%	5%	-

Source: Compilation based on (Bernhard 2017) and (Arbeitskreis Recycling e.V. 2020)

After an exchange with various experts, the data from Herford was seen as more representative. The high furniture share in Hamburg is not representative and is due to the structure of the acquisition. Nevertheless, the data from Hamburg are valuable as they provide a higher resolution for the furniture fraction. The data presented in Table 36 are evaluated for the furniture fractions and result in the key shown in the following Table 38, adjusted to the accounting data.

Table 38 Composition of the furniture fraction

Furniture group	Share
Tables, shelves, cupboards	40%
Shelves, cupboards up to 1.5 m wide	12%
Living room cabinet(wall)	32%
1-seater (armchair)	4%
2-seater (sofa)	3%
3-seater (sofa)	2%
Beds	2%
Chairs	5%

Source: Compilation based on (Bernhard 2017)

With the total mass in Germany of re-used goods shown above and the composition of the re-used goods as well as the breakdown of the furniture fraction, the masses shown in the following table result.

Table 39: Re-used goods by type and mass

Type of goods	Mass in kg
Electric	18,019,675
PC	1,818,302
Textile	20,854,732
Household contents	8,581,059
Bicycle	1,808,737
Books	6,417,815

Type of goods	Mass in kg
Total furniture	74,967,441
of which tables, shelves, cupboards	29,719,789
of which shelves, cupboards up to 1.5 m wide	9,039,247
of which living room cupboard(wall)	24,164,634
thereof 1-seater (armchair)	3,221,951
thereof 2-seater (sofa)	1,933,171
thereof 3-seater (sofa)	1,288,780
thereof beds	1,566,590
thereof chairs	4,033,277

Source: Own calculation

The categories electrical, PC and textile are outside the scope of consideration and are not included in the balancing.

The derivation and classification by types of goods described above is based on the possibilities to assess their GHG avoidance potential. As part of the 2018 material flow, climate gas and environmental balance for the state of Berlin, a tool for social and used goods was developed (Vogt / Ludmann 2019) together with the operators to present the waste prevention performance or the GHG prevention potential. In a first step, a harmonised list of articles was agreed upon, which was used as a basis for the derivation of the types of goods considered here. Together with the stakeholders, further required parameters such as weight, material components, age, technical service life and, above all, the expected service life extension for the used goods were then agreed upon or attempted to be determined.

In order to illustrate the GHG avoidance performance through re-use, GHG emission factors (GHG-EF) were determined for the production of corresponding new goods. As far as possible, literature sources were used or own calculations were carried out. The actual service life extension is decisive for the GHG emission savings potential. There are hardly any reliable data on this. The existing estimates are based on information or assumptions about the technical service life of products and the age of second-hand goods sold (initial service life). It is not possible to say whether the technical service life is actually exhausted via a second or subsequent use. However, since this is precisely what determines the result, and due to the overall data uncertainties, the calculated emission savings potentials are to be understood as orienting values. The overall (Vogt / Ludmann 2019) data used for the GHG assessment of the preparation for re-use is shown in Table 40.

This does not include household good, which are not considered for this study because they include a large number of different small items such as dishes, baking pans, flower pots, decorations, clothes hangers, ladders, roller blinds, juice squeezers, umbrellas, etc., for which only assumptions were possible for the GHG assessment in (Vogt / Ludmann 2019). Furthermore, beds are not assessed, which could also not be mapped in (Vogt / Ludmann 2019). In total, the **quantity considered** for preparation for **re-use is 75,210 tons**.

The data on the service life extension of 50% are set assumptions, as no reliable information is available on this. The GHG emission factors for wood-based furniture (shelves, cabinets) are own calculations in (Vogt / Ludmann 2019). The data on upholstered furniture (armchairs, sofas, couches) are taken from (Behrendt et al. 2011). The GHG-EF for chairs is the average of six environmental product declarations for chairs of different materials. The GHG emission factor for bicycles is the mean value for bicycles with aluminium and steel frames according to (Mottschall 2012).

Table 40 Key data for the GHG assessment of re-use

Type of goods	Weight in kg	Technical life	Lifetime extension after first use	GHG-EF Production
	kg	Years	% Technical life	kg CO_2eq/ pieces
Bicycle	17	10	50%	-111
Tables, shelves, cupboards	20	15	50%	-16
Shelves, cupboards up to 1.5 m wide	50	15	50%	-39
Living room cabinet(wall)	300	15	50%	-234
1-seater (armchair)	25	20	80%	-57
2-seater (sofa)	35	20	80%	-80
3-seater (sofa)	45	20	80%	-102
Chairs	6	15	50%	-10

Source: derived from (Vogt / Ludmann 2019)

The GHG prevention performance for the considered quantity of 75,210 tons is calculated to a total of 45,899 tons CO_2eq. The resulting weighted specific value of around – **610 kg CO_2eq/ton used goods** is included in the sensitivity analysis for the lead scenario with proportional re-use and waste prevention. The re-used goods quantities are deducted from the residual waste with the assumption that these quantities are removed from the bulky waste. The amount of preparation for re-use is low for the goods considered. As a rule, the goods are of good quality, so that the expenses are limited to transport and energy requirements for the sales rooms or warehouses, which are also basically given when trading with primary goods.

5.3.4.2 Integration of waste prevention

The integration of waste prevention would be simple in principle, insofar as the products that do not need to be produced through waste prevention are known. In the context of this study this can be shown for food waste and is described in the Chapter 6.3.2. For the MSW balance sheet for Germany, the results from this are integrated in the sensitivity to waste prevention.

For other types of waste, there is currently no possibility to estimate waste prevention by quantity for specific goods. At this point, however, possible approaches are mentioned that could be relevant for future studies.

Plastic products in particular are currently the focus of legal and/or strategic targets. For example, in (Wilts et al. 2020) plastic carrier bags < 50 µm were considered for which there is a political target at European level to reduce the quantities to 40 bags per capita and year. In

2017, Germany had already fallen far short of this target with 29 carrier bags per capita. For other EU member states, this avoidance performance could still be relevant. The GHG avoidance performance according to (Wilts et al. 2020) around -1.6 kg CO_2eq/kg PE carrier bag[56] .

Another potentially interesting aspect with regard to waste prevention lies in the regulations on single-use plastic (initiative from the European Green Deal). Since July 3rd 2021, certain single-use plastic products have been banned in the EU. These include drinking straws, stirrers, disposable tableware, to-go cups and disposable polystyrene containers. According to the Germanl Ministry for the Environment, the amount of waste from disposable tableware and to-go packaging in 2017 was more than 346,000 tons[57] . These quantities should theoretically be avoided in the future. In order to be able to include them in the context of a life cycle assessment of waste management, further investigations are required. A differentiation of the quantity by plastic type, an allocation to LoW-codes and the avoided GHG impact from their production would have to be researched in detail.

The voluntary agreement of the European Plastic Pact also focuses on the prevention of plastic waste[58] . The European Plastic Pact has committed itself to reducing the production of new plastic products by 20% by 2025. 10% absolute reduction through refill systems and 10% reduction through increased recycling. The former would be one aspect of waste prevention potential through re-use. However, this can only be included in the life cycle assessment of waste management if it is a simple secondary use. A cascade use methodologically requires a product life cycle assessment.

Further waste prevention potentials for packaging waste in general exist through the targets of the European Green Deal and the New Circular Economy Action Plan. (EU Commission 2019). (EU Commission 2020). In addition to quantitative targets for re-use and recycling, the New Circular Economy Action Plan in particular announces targets for waste prevention of packaging waste: For the reduction of (over)packaging and packaging waste, targets and waste prevention measures are to be named in 2021/2022.

5.4 Results GHG balances

In the following chapter (5.4.1) the result of the GHG balance for the baseline comparison - the comparison of the 2017 baseline balance with the 2030 Lead Scenario - is presented. Chapter 5.4.2 describes scenarios and sensitivity considerations for the MSW balance for Germany (see overview in Chap. 5.3).

The results are summarised by waste type. For residual waste, the result includes the GHG balancing across the different treatment pathways, which are shown in the Sankey diagram in Figure 6. Similarly, the treatment paths for the organic recyclable waste from the bio bin, garden waste and kitchen/canteen waste are summarised under "Organic waste". The results for the separately collected dry recyclables are listed individually by waste type. These differ significantly from each other in terms of their characteristics and have little/no in common when it comes to recycling.

The task of this study was also to maintain or show the connectivity to the previous study. Climate protection potentials of waste management for MSW in Germany were last examined in Dehoust et al. (2010) for the balance year 2006. The comparison in the time series is - for

[56] Roughly calculated according to data in Table 24 in (Wilts et al. 2020).

[57] https://www.bundesregierung.de/breg-de/themen/nachhaltigkeitspolitik/einwegplastik-wird-verboten-1763390 (23.08.2021)

[58] https://europeanplasticspact.org/targets/ (13.06.2021)

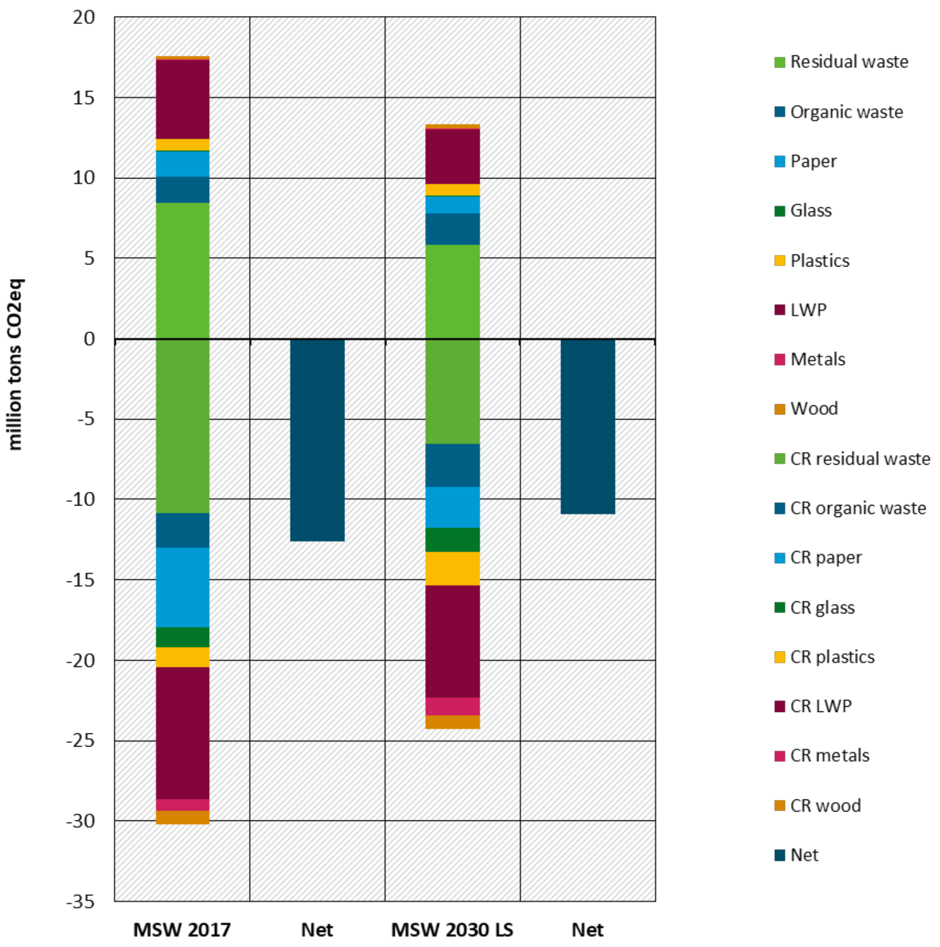
methodological reasons - only possible to a limited extent. To understand the development, a corresponding comparison can be found in the Appendix, Chapter B.4.

5.4.1 Base comparison

In the baseline comparison, the GHG results for the actual situation for Germany in 2017 (Chapter 5.1.9) are compared with those of the lead scenario in 2030 described in Chapter 5.3.1. The following designations are used for the figures:

- Base 2017: "MSW 2017" (municipal solid waste 2017)
- Lead scenario 2030: "SiAbf 2030 LS" (municipal solid waste 2030 lead scenario)

Figure 9: Baseline comparison MSW Germany



GS: Credit or emission savings potential

Figure 9 shows the absolute results according to the credits and debits of the waste fractions as well as the total net result in a year-on-year comparison. For the **base year 2017**, there is an **absolute net emission savings potential of around -12.6 million t CO_2 eq.** The underlying debits amount to around 17.6 million t CO_2 eq and the emission savings potential to around -30.2 million t CO_2 eq. The absolute debits are mainly caused by the residual waste and LWP fractions. In total, these two fractions account for 76% of the debits. The absolute emission savings potentials are also primarily formed by the waste fractions residual waste and LWP, and then by paper (74% in total). By mass, the fractions account for 50% and with paper for 66%.

In contrast, the **Lead Scenario 2030** shows lower debits, but also lower emission savings potentials. The **absolute net emission savings potential is around - 10.9 million t CO_2 eq.** The debits are around 13.3 million t CO_2 equivalents and the emission savings potential is around -24.2 million t CO_2 equivalents. The main contributions to the absolute debits continue to be made by the residual waste and LWP fractions with 69% (with a mass share of 38%). Together with paper, the three fractions still account for 66% of the emission savings potential (with a mass share of 56%).

The differences in the result - the overall 1.7 million t CO_2eq lower net emission savings potential - is mainly due to the defossilisation of the energy system. On the one hand, the GHG debits from energy demand decrease, but on the other hand, the substitution potentials for energy and primary products, the production of which is associated with a relevant electricity demand (aluminium, paper, see Chap. 4.2.7). This is countered by the optimisations in the lead scenario, the increased separate collection and technical optimisations.

The following table shows the overall GHG net results for MSW by waste fraction in absolute values as well as specific per capita and per ton in the base year 2017 and in the lead scenario 2030 (2030 LS).

Table 41 Absolute and specific net results by waste fraction - baseline comparison MSW Germany: base year 2017 and lead scenario 2030

Waste fraction	absolute	absolute	spec. per capita[1]	spec. per capita[1]	spec. per ton	spec. per ton
MSW	**2017**	**2030 LS**	**2017**	**2030 LS**	**2017**	**2030 LS**
	million t CO_2eq		kg CO_2eq/cap		kg CO_2eq/t	
Residual waste	-2.37	-0.71	-28.6	-8.6	-114	-48
Organic waste	-0.60	-0.72	-7.3	-8.3	-54	-50
Paper	-3.35	-1.48	-40.4	-17.9	-430	-171
Glass	-1.20	-1.43	-14.4	-17.3	-464	-460
Plastics	-0.49	-1.43	-5.9	-17.3	-431	-692
LWP	-3.31	-3.57	-39.9	-43.1	-820	-886
Metals	-0.66	-0.98	-7.9	-11.8	-1,769	-1,616
Wood	-0.65	-0.59	-7.8	-7.2	-474	-358
Sum/average	**-12.6**	**-10.9**	**-152**	**-132**	**-256**	**-222**

1) calculated with a population of 82,792,351 in 2017 (Federal Statistical Office (Destatis) 2017)

Based on the **specific net results by waste fraction per ton of waste,** the differences in results can be explained:

At the specific level per ton, the **metals in particular** show high net emission savings potentials. The production of pig iron and aluminium is associated with comparatively high GHG emissions. In the lead scenario 2030, this specific net emission savings decreases, as a reduced GHG impact is estimated for the electricity-intensive primary production of aluminium (Chap. 4.2.7.4).

Furthermore, the disposal of **plastic waste and LWP** shows high specific net emission savings. In the Lead Scenario 2030, the net emission savings for plastic waste increases more significantly than for LWP. This is due to the lower GHG debit for electricity demand (more clearly for pure plastic waste than for the LWP mixture). The emission savings potentials are little changed. For LWP, they are about 20% lower due to the lower emission savings potentials for aluminium packaging waste and paper (estimated reduced GHG debit for electricity-intensive primary production, Chap. 4.2.7.2). Increases in the emission savings potentials could be achieved primarily through better qualities and the resulting greater substitution of virgin plastics instead of applications as wood and concrete substitutes.

The net emission savings potentials per ton for **paper, glass and wood are** roughly similar in the base year 2017. For paper and glass, these are characterised by material recycling, for wood by energy recovery. Chipboard recycling of wood is associated with a comparatively low specific net emission savings (see Chap. 4.2.9). In the lead scenario 2030, the specific net emission savings potential for paper decreases. The main reason is the estimated reduced GHG impact due to the electricity demand in the primary production of wood and pulp (Chap. 4.2.7.2). Reduced emission savings potentials from the energy recovery of rejects also play a role. In 2017, these went proportionately to coal-fired power plants for co-incineration. In contrast, the diversion for treatment in thermal waste treatment in 2030 is associated with lower emission savings potentials. The lower emission savings for electricity and heat from waste is partly compensated by the higher utilisation rates for thermal waste treatment assumed for 2030. The specific net result for glass waste is almost unchanged; electricity demand or energy recovery from processing residues only play a minor role. For wood waste, the reduced specific net emission savings potential is mainly due to the lower electricity and heat credits (defossilisation), which are only partly compensated by the higher heat utilisation efficiency assumed for 2030. The smaller quantity for which pyrolysis is assumed has hardly any influence. With higher volume shares, the net emission savings would decrease. Although peat credits are awarded for 70% of the biochar produced (Chap. 5.1.11.1), the specific net emission savings of this process is lower by a factor of 5-7 than the energy use in the lead scenario 2030.

For **organic waste**, there is a specific net emission savings in the base year 2017, which is mainly achieved through proportional anaerobic digestion and biogas utilisation. For green waste (garden waste), the proportionate energy recovery in Biomass CHP also plays a role. In the previous study (Dehoust et al. 2010), there were still specific net debits for the GHG balances for waste from bio bin and garden waste. In the lead scenario 2030, the specific net debit for organic waste is somewhat lower. By individual waste fraction, the specific net emission savings for waste from bio bin is slightly improved due to the additional anaerobic digestion of the quantities from the increased separate collection. The specific result for composting is largely unchanged in the lead scenario 2030. The new processes additionally considered for waste from bio bin have hardly any influence on the result with the small quantities. With higher quantities, there would be a deterioration. Both the HTC process and the treatment with soldier fly larvae have, according to Bulach et al. (2021) a net impact (see Chap. 5.1.11). In the case of soldier fly larvae, this is mainly due to the high heat requirement, which would be less relevant in southern countries. The method is considered accordingly for selected EU Member States in the EU balances (see partial report EU). In the individual analysis for garden waste and kitchen/canteen waste, the specific net emission savings is somewhat reduced in each case. Composting is also largely unchanged for garden waste. For energy from Biomass CHP (garden waste) and energy from biogas or biomethane from anaerobic digestion, there is lower emission savings potential in the lead scenario 2030 (defossilisation).

The disposal of **residual waste in** the base year 2017 is also associated with specific net emission savings potentials. The specific emission savings is higher if the RDF produced is also co-incinerated in coal and cement plants and replaces fossil fuels. For the result for residual waste, there are high data uncertainties for the share treated via "mixed waste sorting plants" (19%). There is a lack of information both on the composition of the input material and on the quantity, quality and destination of the RDF produced. Assumptions had to be made here and the proportionate net emission savings due to the high RDF shares may be overestimated (cf. Chap. 4.2.6). Another limitation to the results is that this study had to work with national average values for RDF. Here the values according to (Flamme et al. 2018) were used (Table 88). More detailed investigations for individual treatment pathways and RDF qualities are reserved for other specific projects, such as the parallel project on M(B)T plants (Ketelsen / Becker 2021) in which process-specific RDF qualities are differentiated[59] . In the lead scenario 2030, the net emission savings potential of residual waste treatment is reduced. The background to this is, on the one hand, the reduced emission savings potential from electricity and heat generation from waste (defossilisation, see emission factors for electricity and heat in Table 6). On the other hand, the diversion of RDF from co-incineration in coal-fired power plants to treatment via thermal waste treatment plants also plays a role. On average, this affects 10% of the RDF. This is counteracted by the higher utilisation rates for thermal waste treatment assumed for the 2030 scenario. The changed composition of residual waste due to the increased separate collection has hardly any influence on the result. The calculated characteristic data differ only slightly (Table 88).

5.4.2 Comparisons with scenarios and sensitivities

The following subchapters describe scenarios and sensitivity considerations for the MSW balance for Germany (see overview in Chap. 5.3):

- The sensitivity analysis of a "business as usual" waste management development allows a better assessment of the climate protection contribution of MSW treatment in the lead scenario 2030, especially in the context of the energy transition.
- The scenario with home composting in the RC rate allows consideration at a reduced ambition level of separate collection, although there are very high data uncertainties regarding home composting.
- The scenario with EU27 emission factors for energy is needed to merge the results for Germany with the EU balance. It shows the influence of regional energy systems.
- Sensitivity with the electricity avoidance factor shows the influence of the avoidance effect for energy from biogenic waste (UBA 2019) estimated avoidance effect for energy from biogenic waste.

[59] The mean calorific value used in this study and the overall results on average for residual waste that is first treated via MBT plants are comparable to those of this study. Deviations are possible for the fossil carbon content.

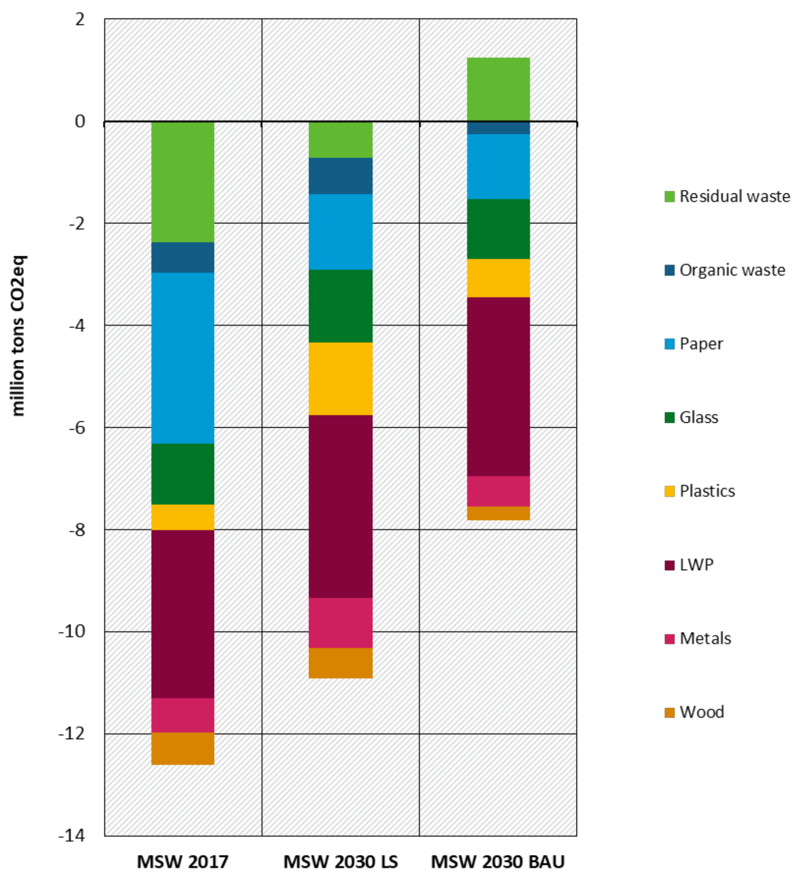
- Sensitivity with preparation for re-use and waste prevention shows a methodological approach developed in this study to integrate these aspects into the LCA of waste management.

5.4.2.1 Sensitivity "business as usual

The sensitivity "business as usual" in the circular economy ("SiAbf 2030 BAU") shows the development in the GHG balance for the case that no waste management measures are undertaken until 2030. The increase in the separate collection of recyclables and the technical optimisations are omitted (cf. Chap. 5.3.1.3). Both the generation and destination MSW and the state of technology correspond to those of the base year 2017. On the emission savings potential side, the emission factors for electricity and heat and thus also the estimated emission factors for energy-intensive primary production (aluminium, paper) correspond to those in the Lead Scenario 2030. Under these circumstances, the treatment of MSW in Germany would achieve a **reduced absolute net emission savings potential of around -6.5 million t CO_2eq in** 2030. This means that without waste management measures, the potential climate protection contribution would be almost halved compared to the base year 2017, and compared to the lead scenario 2030, the contribution would be 40% lower.

Figure 10 shows the sensitivity results compared to the baseline results as absolute net results by waste fraction.

Figure 10 Sensitivity "business as usual" MSW Germany - absolute net results by waste fraction



The figure clearly shows that residual waste treatment in a situation without waste management measures, but with a permanent transformation of the energy system, would no longer lead to net emission savings in 2030. In principle, this applies to all treatment paths, since the co-incineration of RDF in coal-fired power plants no longer applies and cannot be compensated for by technical optimisations such as increasing utilisation rates at thermal waste treatment or a proportionate flexible electricity generation, as in the lead scenario 2030[60] . In the net results for organic waste, the emission savings potential is reduced by the lack of diversion to anaerobic diversion and the flexible electricity generation from biogas, which is also not considered. A narrow net emission savings potential remains. In the case of dry recyclables, the absolute net emission savings potential is also reduced by the lack of an increase in separate collection and also the lack of an increase in the utilisation rates for energy recovery (wood, processing residues) as well as the lack of an increase in yields (above all metals).

The sensitivity "business as usual" clearly shows that the legal requirements implemented in the lead scenario 2030 via the assumptions made also result in a relevant climate protection contribution. The correlation of measures in the different sectors also becomes clear. The climate protection targets must be met, and the transformation of the energy system in Germany must be implemented accordingly. The emission factors for electricity and heat for 2030 used in this study do not claim to be correct, but they are indicative. Without measures, the climate protection contribution from the circular economy would decrease faster. The waste management measures on which the lead scenario 2030 is based, provide a relevant further climate protection contribution, even if the net emission savings potential is lower compared to the base year 2017.

5.4.2.2 Scenario with home composting in the RC rate

In this study, the scenario with home composting in the RC rate serves the sole purpose of being able to discuss a significantly lower level of ambition for increased separate collection without formally missing legal targets. In this context, the home composting rate is defined in such a way that it has a good relevance for the scenario analysis. Technical optimisation potentials and other boundary conditions are unchanged compared to the lead scenario 2030. For further explanations on the scenario with home composting in the RC rate, please refer to Chapter 5.3 and the Subchapter 5.3.2 for further explanations on the scenario with home composting in the RC rate.

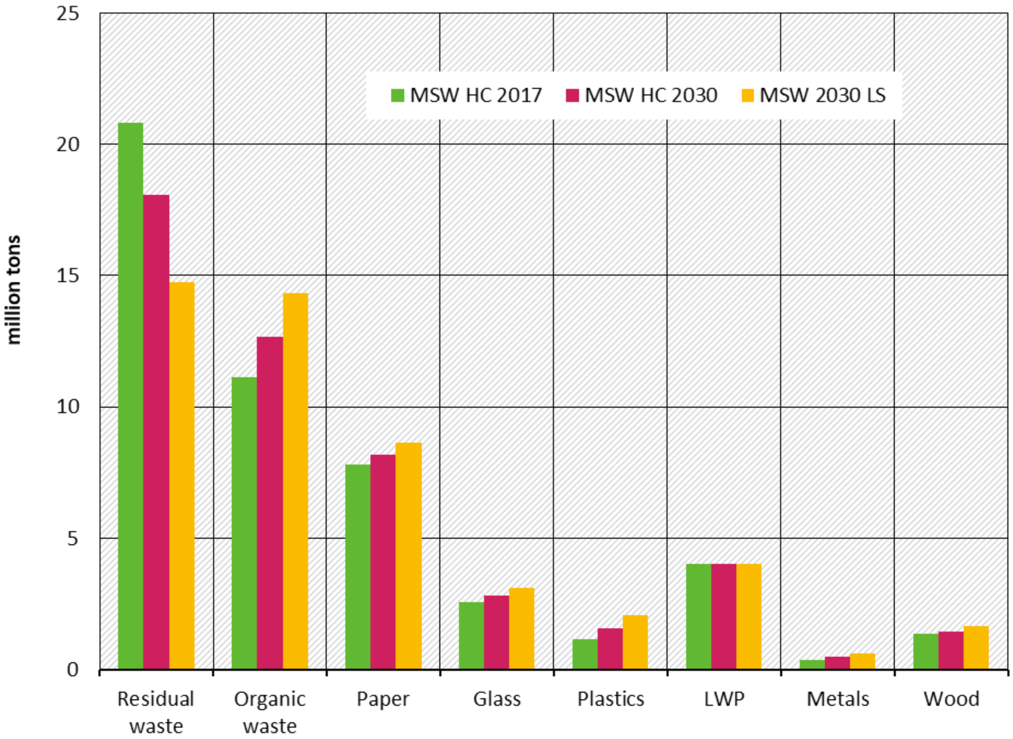
The following (further[61]) designations are used for the illustrations in this scenario:

- Scenario with home composting in the RC rate 2017: "MSW HC 2017"
- Scenario with home composting in the RC rate 2030: "MSW HC 2030"

Figure 11 shows the differences in the RC rate for primary treatment in the scenario with home composting compared to the baseline comparison. For reasons of clarity, the amount of home composting is not shown. Without the home composting, the volume in the 2017 baseline scenario is the same as that shown in the figure for the scenario with home composting in the RC rate for 2017 and is not listed separately. The figure illustrates that the ambition level for increased separate collection is approximately halved by the defined home composting quantity and its inclusion in the RC rate.

[60] At the specific level, net emission savings potentials remain insofar as RDF is treated in RDF power plants whose utilisation rates in 2017 are already almost at the level of the utilisation rates assumed for the lead scenario (cf. Table 30).
[61] For comparison, the lead scenario 2030 is shown "MSW 2030 LS".

Figure 11 Scenario with home composting in the RC rate for MSW in Germany - comparison of primary treatment volumes with the lead scenario 2030



For reasons of clarity, the volume for home composting of 7.9 million tons is not shown.

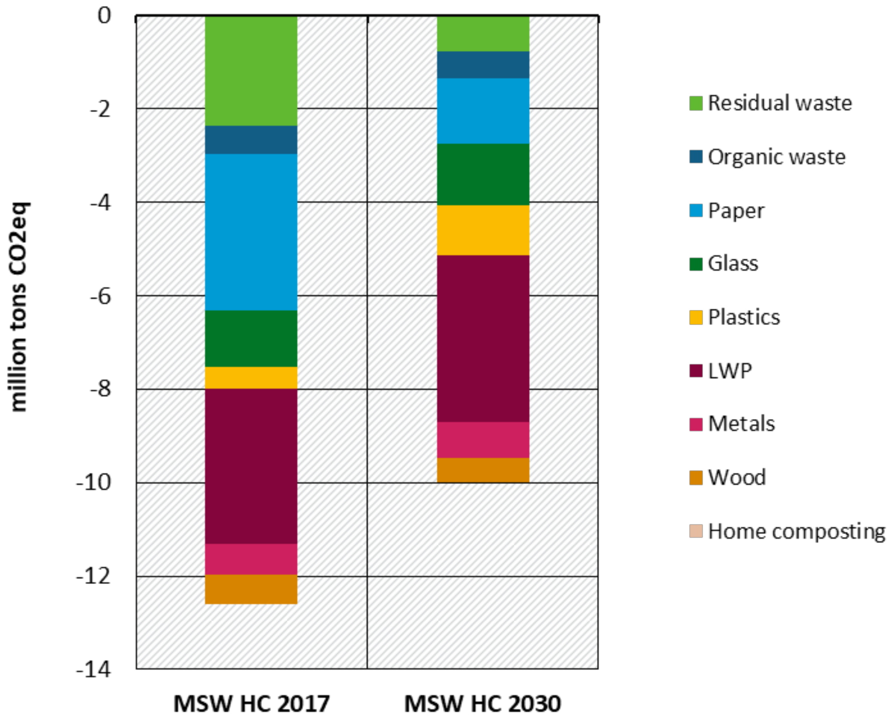
The scenario with home composting in the RC rate results in an absolute net emission savings potential of around -12.6 million tons CO_2 equivalents for the balance year 2017. A comparison at the absolute level with the baseline comparison is generally not methodologically permissible due to the different total waste quantities - 49.2 million tons in the baseline comparison and 57.1 million tons in the scenario with home composting in the RC rate. However, since home composting itself is valued at zero in the GHG balance, there is no difference in the absolute result for 2017 compared to the result of the 2017 baseline balance.

For the year 2030, the scenario with home composting in the RC rate results in an absolute net emission savings potential of just under -10 million tons CO_2 equivalents. Again, a comparison with the baseline comparison, the lead scenario 2030, at the absolute level is fundamentally methodologically not permissible. If it were correct that home composting is quasi-neutral and thus has no influence on the climate gas balance, it could however be stated that a scenario with a lower level of ambition for increased separate collection than the lead scenario 2030 **leads to a net emission savings potential of around** 1 million tons CO_2 equivalents**.**

Figure 12 shows the result for the scenario with home composting in the RC rate as absolute net results by waste fraction. The representation corresponds to the representation in Figure 10. The results for 2017 are the same (since home composting is valued at zero). For 2030, the qualitative comparison with the baseline comparison shows that the recycling of dry recyclables in particular achieves lower absolute net emission savings potentials, due to the reduced separately collected quantities. Conversely, there is only a minor influence in the treatment of the quantities remaining in residual waste.

The fact that the absolute net emission savings potential is not significantly lower than in the lead scenario 2030 is due to the fact that the main part of the increased separate collection is in organic waste. At around 30%, organic waste is the largest fraction of residual waste and accounts for about half of the increased separate collection. For the year 2017, there are net emission savings potentials for organic waste, which are, however, small in comparison to the emission savings potentials of the recycling of dry recyclables (Table 41).

Figure 12: Scenario with home composting in the RC rate MSW Germany - absolute net results by waste fraction



At the specific level per ton of waste, the results can be compared quantitatively. Differences to the baseline comparison in the specific result by waste type only exist for 2030 and only for the waste fractions residual waste and organic waste (waste from the bio bin). For residual waste, the specific net emission savings is somewhat lower. This is due on the one hand to other characteristic data for calorific value and fossil C content for thermal treatment (different residual waste composition in 2030) and on the other hand because the redistribution to MBS by quantity assumed for 2030 is less effective (thus lower RDF yield). In the case of organic waste, the specific net emission savings for waste from the bio bin is slightly lower, as the additional quantities for anaerobic digestion are lower than in the lead scenario 2030. For all other fractions, the specific net result is unchanged compared to the lead scenario 2030. The clearest difference at the specific level arises in relation to the total waste quantities. The specific **net emission savings potentials** are significantly lower **overall**, as the results refer to around 57 million tons (including the 7.9 million tons of home composting).

- Specific net result "MSW HC 2017": -221 kg CO_2eq/t MSW (14% lower than baseline balance 2017)
- Specific net result "MSW HC 2030": -175 kg CO_2eq/t MSW (21% lower than lead scenario 2030)

The values apply to the assessment of home composting with zero, which is assumed here in order to keep the influence on the GHG balance as low as possible. In general, however, net impacts are to be expected from home composting (cf. Appendix, Chap. A.4).

In the overall view of the scenario with home composting in the RC rate, it is to be noted that net emission savings potentials are lost primarily due to the reduced separate collection of dry recyclables. The reduced separate collection of organic recyclables has only little influence on the result of the GHG balance. In addition, its net emission savings potential could deteriorate if the very ambitious increase in the separate collection of organic recyclables in the lead scenario 2030 of 3.2 million tons were to be associated with a significant increase in the content of impurities. With the average composition of the contaminants determined in this study (Chap. 4.2.8.1), an increase in the proportion of contaminants from 5% to 15% in the baseline comparison would be accompanied by a loss in absolute net emission savings potential of around 0.5 million tons CO_2eq. due to the fossil CO_2 emissions from the combustion of the contaminants, which outweigh the emission savings potential from energy generation.

On the one hand, however, it should be noted here that the observations in this study are scenario observations. They are necessarily based on average values and assumptions. The amount of home composting itself is a determination; reliable data is still lacking. On the other hand, the increased separate collection and treatment of organic waste is an important component of a circular economy with a view to resource protection. The potential for optimising biological treatment through low-emission and efficient anaerobic digestion plants should also be investigated more closely. The measured values for GHG emissions used for national reporting, and accordingly also in this study, date back several year. (Cuhls et al. 2015). The measurements refer to biowaste anaerobic digestion plants[62] and the number of cases for concepts with post-digestion were 3 (open post-digestion) and 6 (closed post-digestion). According to (Knappe et al. 2019) there were already 80 anaerobic digestion plants in 2016 that treat mainly biowaste. In addition, the technology of plant concepts has advanced in the meantime. There are low-emission, efficient biowaste anaerobic digestion plants in operation for which GHG emissions have been measured (Vogt / Reinhardt 2015) lower than the median values used in the NIR.

5.4.2.3 Scenarios, sensitivity emission factors for electricity and heat

This chapter describes the results for the scenarios with EU27 emission factors for electricity and heat, which are required for the EU balances. Furthermore, the results of the sensitivity analysis are shown, in which the avoidance factor according to the German Environment Agency is taken into account for electricity from biogenic waste. Explanations of the background for the scenarios, the sensitivity can be found in Chapter 5.3.3 and the respective emission factors for electricity and heat in Table 6.

1. Scenarios with EU27 emission factors for electricity and heat

All scenarios for Germany that are also required for the EU balances are also calculated with the EU27 emission factors for electricity and heat. This applies to all balancing areas. The differences in the results are described in more detail here using the example of MSW. The following terms are used for the results in the baseline comparison with the EU27 emission factors:

- Base year 2017 for EU: "MSW 2017 for EU"
- Lead scenario 2030 for EU: "MSW 2030 LS for EU"

Compared to the baseline comparison with the German emission factors for electricity and heat, the absolute total net emission savings potentials are reduced by 3% for both 2017 and 2030.

[62] In the NIR, the values are equally used for the anaerobic digestion of food waste, superimposed food waste, about whose plant concepts there is little public information.

For the individual waste fractions, the regionally different emission factors for electricity and heat have different effects (Table 42).

Table 42: Regional emission factors in baseline comparison for MSW: Absolute net results with emission factors EU27 and DE for electricity and heat

MSW	2017 for EU	2030 LS for EU	2017	2030 LS
t CO_2eq				
Residual waste	-1.74	-0.33	-2.37	-0.71
Organic waste	-0.50	-0.66	-0.60	-0.72
Paper	-3.57	-1.53	-3.35	-1.48
Glass	-1.19	-1.43	-1.20	-1.43
Plastics	-0.59	-1.48	-0.49	-1.43
LWP	-3.44	-3.60	-3.31	-3.57
Metals	-0.66	-0.98	-0.66	-0.98
Wood	-0.52	-0.54	-0.65	-0.59
Total	**-12.2**	**-10.6**	**-12.6**	**-10.9**

Waste fractions with a high electricity demand for waste treatment, and where treatment residues are mainly co-incinerated (especially in cement plants), show lower debits with the lower EU27 emission factor for electricity and sometimes show higher net emission savings potentials than in the result with the German emission factors for electricity and heat (plastics, LWP, paper). For most waste fractions, however, the net emission savings potentials are reduced by assessing energy from waste with the lower EU27 emission factors. This is particularly evident for residual waste in 2030.

2. Sensitivity avoidance factors for electricity from biogenic waste

Sensitivity with the avoidance factors of the German Environment Agency for electricity from biogenic waste examines the difference in the base year 2017 to the generally applied average values for electricity from waste. Table 43 shows the absolute net results by waste fraction in comparison. If the avoidance factors for electricity from biogenic waste were taken into account, the absolute total net emission savings potential for 2017 would be 8% higher.

As in the previously shown scenarios with the EU27 emission factors for electricity and heat, the effects for the individual waste fractions are different. As the sensitivity refers exclusively to the credit for electricity from waste, it has hardly any impact on the result for dry recyclables, as these are characterised by recycling and energy recovered processing residues are predominantly co-incinerated. There are clearer differences for residual waste, organic waste and wood. In the case of residual waste, the net emission savings potential is 23% higher and primarily concerns thermal treatment (incl. RDF, residues) with electricity and heat generation. For organic waste, the differences in the individual fractions are all the higher (20% to 40%), the higher the proportion of anaerobic digestion and thus the generation of electricity from biogas. In the case of wood, the difference is 27%; here, there is also a proportionate material recycling, on which the sensitivity has no influence.

Table 43: **Sensitivity avoidance factors for electricity from biogenic waste in the base year 2017**

MSW	2017 Sensitivity avoidance factors	2017
t CO_2eq		
Residual waste	-2.92	-2.37
Organic waste	-0.78	-0.60
Paper	-3.40	-3.35
Glass	-1.20	-1.20
Plastics	-0.49	-0.49
LWP	-3.32	-3.31
Metals	-0.66	-0.66
Wood	-0.82	-0.65
Total	**-13.6**	**-12.6**

5.4.2.4 Sensitivity with preparation for re-use and waste prevention

Sensitivity with preparation for re-use and waste prevention shows a methodical approach to integrating these aspects into the LCA of waste management. A description of the problems that make it difficult to integrate these aspects and why they have not been integrated or have hardly been integrated at all to date can be found in Chapter 5.3.4. In Chapter 5.3.4.1 the derivation of the considered quantities and prevention potentials for preparation for re-use is described. Waste prevention is shown in this study using the example of food waste prevention. The procedure for calculating the prevention potentials is described in Chapter 6.3.2.

Again, in order to compare the results on an absolute level, the total amount of waste must be the same. The sensitivity with preparation for re-use and waste prevention ("MSW 2030 P") is based on the lead scenario 2030 ("MSW 2030 LS"). The total amount of waste considered corresponds to that of the baseline comparison (49.2 million tons). Figure 13 shows the generation by waste fraction from the baseline comparison compared to the scenario with re-use and waste prevention. The avoided waste quantities identified in this study are also shown in the figure (dotted bars): "Re-used residual waste" (75,210 tons) corresponds to the amount that will be avoided in 2030 through life-cycle extension (second-hand goods that would otherwise mainly accumulate in bulky waste), "prevented food waste" (1,258,669 tons) corresponds to the amount of food waste that will no longer accumulate in 2030. These quantities are deducted from organic waste, and a small proportion (0.5%) is also deducted from residual waste ("food waste to waste incineration plant").

Figure 13: Sensitivity re-use and waste prevention - MSW generation Germany

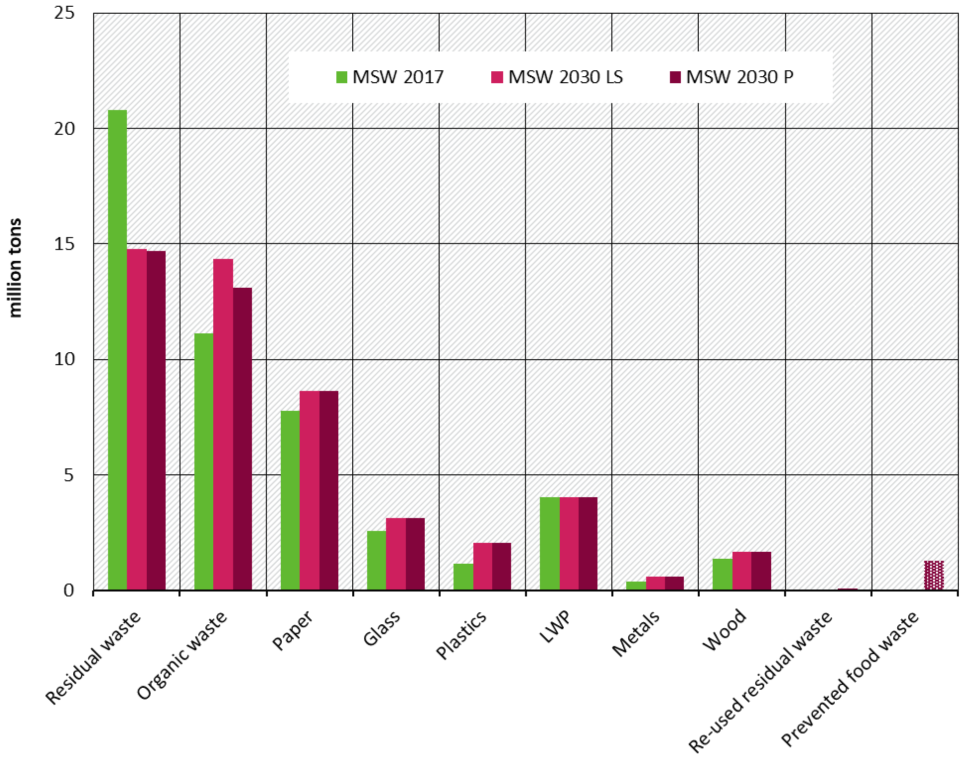
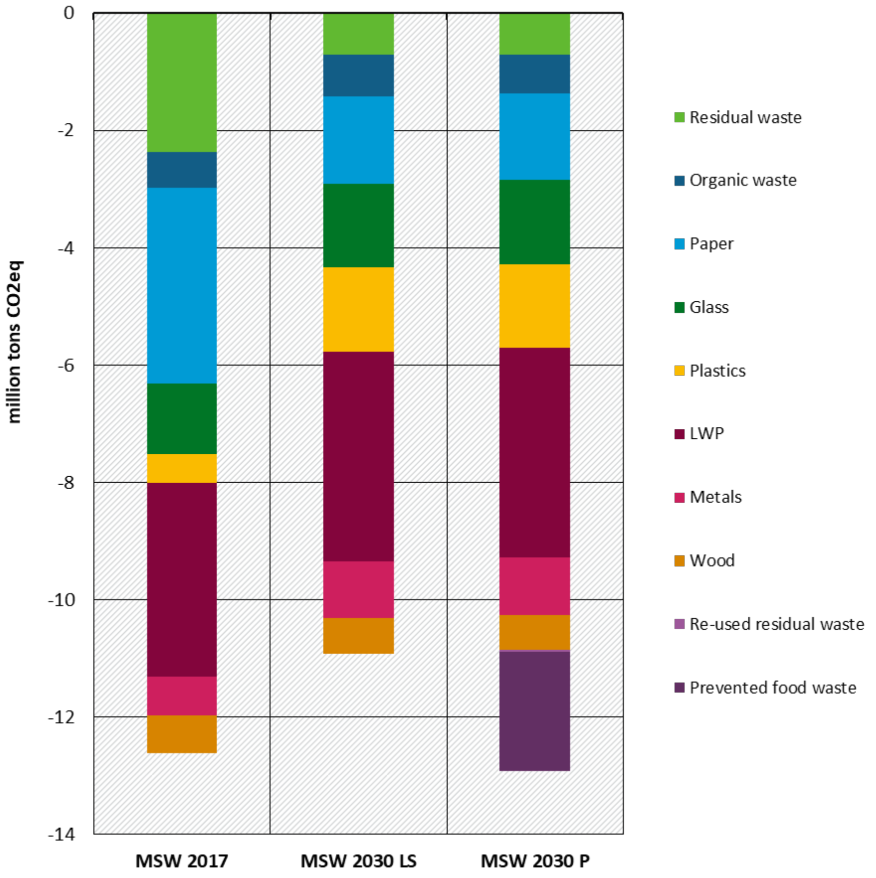


Figure 14 shows the absolute net results by waste fraction for the baseline comparison with "MSW 2030 P". For the balance year 2030, the sensitivity with re-use and waste prevention results in an **absolute net emission savings potential of around -13 million tons CO_2 equivalents** (+18% compared to MSW 2030 LS). The increase compared to the lead scenario 2030 is mainly characterised by the amount of prevented food waste, the avoidance of which is calculated with a specific GHG avoidance factor of -1.61 kg CO_2eq/kg food waste. The contribution of preparation for re-use is less visible on an absolute level. This is mainly because a significantly lower amount was identified for second-hand goods. The specific GHG prevention factor for simple life extension is -0.61 kg CO_2eq/kg second-hand goods. The result for re-use and waste prevention is favourable. The lower net emission savings contributions for residual waste and organic waste due to the lower quantities to be treated in "MSW 2030 P" are hardly visible in the figure compared to "MSW 2030 LS".

Figure 14: Sensitivity re-use and waste prevention MSW Germany - absolute net results by waste fraction



6 Special balance room food waste

The special balance area food waste includes the food content in the organic waste of MSW and C&I waste. The areas of origin were differentiated in the collection of the basic data and an attempt was made to obtain a differentiation according to this, especially for the EU (see partial report EU). For the EU, only the EWC-Stat code W091+W092 (animal and mixed food waste; vegetal waste) is reported. Differentiation by W091, W092 for the EU is based on expert knowledge. For the balancing of the EU balance areas, the German statistics were evaluated in more detail in order to be able to make plausible assumptions for the EU based on them.

6.1 Waste generation and destination

6.1.1 Introduction

Food waste has been in the spotlight for several years. The European Commission and the United Nations call for the reduction of food waste along the entire value chain. In 2015, the United Nations adopted the "2030 Agenda for Sustainable Development". It sets out 17 Sustainable Development Goals (SDGs), to which a total of 169 targets are assigned. In Goal 12 on ensuring sustainable consumption and production patterns, Target 12.3 calls for an overall reduction in global food waste and a halving of food waste at the retail and consumer level by 2030 (Thünen 2019a) (FAO 2019)[63].

In order to clarify open questions regarding target 12.3 and to define comprehensible rules for compliance with the SDGs, a committee called Champions 12.3 was formed, which concretised:

- The target of halving food waste should also apply to losses,
- In addition to the edible parts of the food, non-edible parts (such as peels, seeds and bones) are also addressed, since the target is assigned to Goal 12 and not to Goal 2, the fight against hunger.
- The use of food as animal feed or for processing into industrial products (bioplastics, soaps, biodiesel or cosmetics) is not counted as food waste or loss. However, all other types of recovery such as anaerobic digestion, composting, incineration, etc. are included.
- The recommended indicators are food loss and waste per capita, measured in kg/cap*year. This should be reported in two parts.
- The Food Loss Index (FLI), from primary production to retail and
- The Food Waste Index (FWI), looks at waste at the retail and consumer level.

Sources (Thünen 2019a); (FAO 2019).

Globally, the FWI was 14% in 2016. The loss rates in Europe and North America were 15.7%. In determining the percentage of food losses, the actual losses were divided by the quantities produced. Economic weighting allows for international comparison and higher value foods are lost more than lower value foods. High losses are observed for roots, tubers and oleaginous fruits (25.3 per cent) and fruits and vegetables (21.6 per cent), meat and animal products (11.9 per cent), cereals and pulses (8.6 per cent). Corresponding estimates for the FWI are still pending from the UN Environment Programme. (FAO 2019)

[63] https://www.fao.org/documents/card/en/c/I9549EN

In the EU Waste Framework Directive[64] the definition for food waste is:

"'Food waste' means any food, as defined in Article 2 of Regulation (EC) No 178/2002 of the European Parliament and of the Council, that has become waste."

In accordance with Article 2 of Regulation (EC) No 178/2002:

" ..... "Food" means any substance or product intended to be, or reasonably expected to be ingested by humans in a processed, partially processed or unprocessed state.

Foodstuffs" also include beverages, chewing gum and any substance, including water, intentionally added to food during its manufacture or processing. Water shall be included without prejudice to the requirements of Directives 80/778/EEC and 98/83/EC from the point of compliance within the meaning of Article 6 of Directive 98/83/EC.

Not included in "food":

a. Feed,
b. Live animals, unless they have been prepared for placing on the market for human consumption,
c. Plants before harvesting,
d. Medicinal products within the meaning of Council Directives 65/65/EEC (1) and 92/73/EEC (2),
e. Cosmetic products within the meaning of Council Directive 76/768/EEC (3),
f. Tobacco and tobacco products as defined in Council Directive 89/622/EEC (4),
g. Narcotics and psychotropic substances as defined in the United Nations Single Convention on Narcotic Drugs, 1961, and the United Nations Convention on Psychotropic Substances, 1971,
h. Residues and contaminants
i. Medical devices within the meaning of Regulation (EU) 2017/745 of the European Parliament and of the Council."

In addition to the fact that it must be a foodstuff, it is therefore essential for food waste to fulfil the waste characteristic. Thus, food waste should also be recorded in the waste regime and assigned a waste code. A distinction from the further processing of former foodstuffs into animal feed is described in the Appendix, Chapter A.9.

The material flows determined for the food waste balance for Germany are presented in this chapter. They include both partial quantities from MSW (Chapter 5) as well as from commercial and industrial waste (Chapter 7). Since it became apparent in the course of the work that it is not possible to reliably calculate the corresponding shares, it was decided to consider the food waste balance as a "special balance area". This means that although it reflects the status of food waste disposal and recovery as well as possible, it cannot be taken into account additively to the balances of MSW and C&I waste. Otherwise, double counting would occur due to the overlapping of the balancing areas

6.1.2 Material flows in Germany

The data situation on actual quantities of food waste and on its composition and nature is insufficient. Recent research projects on the collection of food waste data, especially as a

[64] Current version as of 05.07.2018; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02008L0098-20180705, last access: 03.06.2020

baseline for monitoring compliance with the prevention targets, now provide some basis for reasoned estimates of the quantity and the most important sources. The most important data source, which was also used to check the plausibility of the data used for this study, is the 2015 baseline study presented by the Thünen Institute together with the University of Stuttgart in 2019 (Thuenen 2019a).

Since this study focuses on waste management, the destination of the waste in the disposal or recovery facilities is a crucial piece of information in addition to the quantity of waste generated. Thünen (2019a) only contains incomplete information on the destination of waste. For this study, information on the generation and destination of food waste is therefore consistently derived from the German waste statistics, where waste generation and destination are reported for relevant LoW-codes (Destatis 2019a). However, there is the restriction that food waste are not explicitly reported, but may be included in the relevant LoW-codes. The approach and results of the evaluation are described in the following Chapter 6.1.2.1. A comparison of the waste volume derived from Destatis with the figures according to Thünen (2019a) is given in Chapter 6.1.2.2.

6.1.2.1 Waste generation and destination according to Destatis

The evaluation was carried out in the following steps:

1. Consideration of all LoW-codes that may contain food waste.
   At the level of European statistics, this includes all LoW-codes that fall under the EWC-Stat codes W091, W092 and W101. These three EWC-Stat codes were adopted for consideration at the German level.
2. Deduction of waste quantities from primary production
   Since food waste from primary production is not taken into account, the share of waste allocated according to Destatis (2020) NACE A (agriculture, forestry and fisheries sector) was deducted from the total reported generation[65] . The information on the sectoral origin was last available for the reference year 2016. It was assumed approximately that it can be applied in the same way for the reference year 2017.
3. Consideration of the share of food waste
   The waste codes of the European Waste Catalogue usually do not allow for an explicit differentiation between food waste or other wastes reported under the same LoW-code. Therefore, the proportion that can be attributed to food waste must be determined for each code. Since there are hardly any reliable data for this, estimates were made at the European level for the present study (see partial report EU). These were also used as a basis for the evaluation of Germany (cf. A.5), with the following exceptions:

a) Waste from bio bin (LoW 20 03 01 04): The value reported by Thünen (2019a) is used here. The estimate that approx. 1/3 of the waste in the bio bin is kitchen waste was confirmed by Kern (2020). For the LoW-code 20 02 01 (biodegradable waste from garden, park and cemetery waste), a food waste share of 0% was applied. On average, this results in a value of 14.5% for both items, which shows good consistency with the value used at European level (13%).[66]

b) For the quantities of Destatis (2019a) the quantities of household waste and household-like commercial waste that are collected together via public waste

[65] For this study, the quantities reported under Destatis (2019b) Table 1.1 were taken into account as the total reported volume (total input from domestic plants).

[66] In European statistics, the organic waste bin is reported together with biodegradable waste under LoW 20 02 01.

collection, the proportions of native organics in the residual waste and food waste in the native organics according to Table 20 in (Dornbusch et al. 2020) are used. Residual waste is incinerated to 70% and the remaining 30% is treated in MBT plant. For accounting reasons (incineration of a pure food waste stream with a high water content is difficult to model plausibly and does not correspond to the real treatment of the waste mixture), the food waste stream in the residual waste is therefore not considered.

c) For the quantities of Destatis (2019a) the quantities of household-like commercial waste that are delivered or collected separately from household waste, the native organic fraction according to Dehne et al. (2015) was checked against the proportion of food waste in the native organics according to (Dornbusch et al. 2020) checked. On the authors' advice that a direct transfer of the data from (Dornbusch et al. 2020) to this stream is not possible, however, this approach was discarded.

d) For market waste, a food waste share of 50% was estimated by the experts of the Öko-Institut.

e) No relevant contribution to food waste is expected from the other LoW-codes included under W101 MSW (street sweepings, bulky waste, and MSW not mentioned elsewhere).

4. Evaluation of the destination under the assumption that the distribution by Destatis (2019b and c) remains constant for the subset under consideration.

This means that of the MSW only the following streams are considered for the special balance area food waste: Waste from bio bins (20 03 01 04), market waste (20 03 02) and kitchen waste (20 01 08).

A complete list of the LoW-codes used and the corresponding food waste shares can be found in Appendix A.5.

The **evaluation of the quantity**[67] is shown in Table 44. All LoW-codes of the EWC-Stat codes W091 and W092 are assigned to the C&I waste except for kitchen/canteen waste (LoW 20 01 08) and waste from the bio bin (LoW 20 03 01 04). These are shown under "W091, W092" as MSW. Municipal solid waste under W101 includes residual waste (LoW 20 03 01 00, 20 03 01 01, 20 03 01 02) and market waste (LoW 20 03 02).

A differentiated list according to LoW-code can be found in Appendix A.6.

Table 44: Overview of food waste generation

in 1,000 tons	Waste, total	Commercial & industrial waste			Municipal solid waste		
		total	W091, W092	W101	total	W091, W092	W101
Total organic waste generation	32,432	9,274	9.274	0	23,157	5,469	17,688

[67] For this study, the total domestically generated input in waste treatment plants shown in Destatis (2019b) Table 1.1 was considered as the volume for the relevant LoW-code in each case.

in 1,000 tons	Waste, total	Commercial & industrial waste			Municipal solid waste		
Food waste amount (incl. food waste share in residual waste, excl. NACE A)	9,115	1,645	1,645	0	7,469	2,504	4,966
Food waste amount without food waste in residual waste	**4,193**	**1,645**	**1,645**	**0**	**2,547**	**2,504**	**44**

Source: own evaluation based on Destatis (2019a and b)

For the further **analysis of the destination** for primary treatment, the food waste volume without residual waste is considered, which totals a good 4 million tons. Furthermore, the evaluation has shown that food waste is mainly treated in the following four types of facilities: Thermal treatment plants, incineration plants, biological treatment plants and other treatment plants. All other facilities[68] are neglected for further evaluation due to their respective share of < 1%.[69] A comparison of the reported generation[70] with the destination in the plants taken into account confirms that all flows are covered for the relevant LoW-codes. Only for the LoW-code 02 01 02[71] there is a coverage gap, as no information on the whereabouts is available. For the further evaluation, it is assumed that the destination is distributed in the same percentage as for LoW 02 02 02[72] , under which waste from animal tissue is also reported (to a significantly greater extent than under LoW 02 01 02).[73] Overall, this results in a coverage of 98.7% for the flows considered in the further analysis of the destination compared to the reported generation.

Exports were not taken into account. In particular, no exports subject to notification are shown for LoW Chapter 02 (Destatis 2019a). For LoW Chapter 20, the total quantity reported for 2017 is approx. 0.2 million tons, the total residual waste quantity is 17.6 million tons. Even if small amounts of residual waste were exported, they are therefore of a negligible magnitude.

Over the total quantities treated, there is a clear tendency towards recovery in biological plants followed by treatment in other plants (Table 45).

[68] Chemical-physical treatment plants, soil treatment plants, mechanical and mechanical-biological treatment plants, shredders/scrap shears, sorting plants

[69] Neglecting the physio-chemical treatment would result in a neglect of approx. 20% of the reported destination for LoW 20 01 25 (edible oils and fats) (see also Appendix A.4). Since this is non-hazardous edible waste, it is assumed here that it could be a case of transesterification to biodiesel, which is reported as a chemical treatment. This is therefore assumed for the present evaluation. For the LoW-codes under which fats and oils are reported, this was also assumed for the quantities for other treatment based on expert opinion. In addition, Destatis (2019b) reports quantities in anaerobic digestion plants.

[70] For this study, the total domestically generated input in waste treatment plants shown in Destatis (2019b) Table 1.1 was considered as the volume for the relevant LoW-code in each case.

[71] Animal tissue waste from agriculture, horticulture, aquaculture, forestry and fisheries

[72] Animal tissue wastes from the preparation and processing of meat, fish and other food of animal origin.

[73] Information is also missing for LoW 02 02 01 in the whereabouts; since negligible quantities are involved, it is excluded from further consideration.

Table 45: Distribution of food waste destination

Facility	Share	Quantity (1,000 t)
Thermal waste treatment plants	2.4%	101
Combustion plants	3.3%	140
Biological treatment plants	71%	2.995
Other treatment plants	21%	890
Other	1.4%	59
Total	**100%**	**4,193**

Source: own evaluation based on Destatis (2019b, 2020)

The four types of treatment facilities were analysed in more detail below, based on the additional information available on their whereabouts (Destatis 2019c).

Thermal treatment plants

Here we are dealing exclusively with waste incineration plants. The contributions of the relevant LoW-codes are shown in Table 46. The waste is predominantly animal tissue/meat waste.

Table 46: Food waste for incineration

LoW-code	Waste type	Shares
02 01 02, 02 02 02, 02 02 03	Animal origin, meat, etc.	76%
02 03 04	Plant origin	9%
02 05 01	Dairy	1%
02 06 01	Baked goods	2%
20 01 08	Kitchen & Canteen Waste	7%
20 03 02	Market waste	5%

Source: own evaluation based on Destatis (2019b, 2019c, 2020)

For subsequent balancing, an average calorific value and average energy extraction values are assumed for the food waste incinerated in the overall waste in the waste incineration plant. This simplified approach seems justified in view of the comparatively small quantities (2.4% of the foos waste waste). Formally, the waste incineration plant corresponds to an energy recovery plant (R1), since waste incineration plants in Germany generally have R1 status and no quantities are reported under hazardous waste incineration plants.

Combustion plants

In the case of combustion plants, the main inputs also consist of waste from meat processing and animal tissue. Vegetable waste is utilised to a lesser extent, mainly in biomass power plants (see Table 47).

Table 47: Food waste for recovery in combustion plants

LoW-code	Waste type	Share	Type of combustion plant
02 01 02, 02 02 02	animal tissue	29%	No details on the type of plant
02 01 03	plant tissue	4%	Biomass power plant
02 02 03	Unsuitable for consumption/processing (meat etc.)	50%	Plant for other production purposes
02 03 04	Unsuitable for consumption/processing (fruit and vegetables)	18%	Details incomplete; mainly in biomass power plant

Source: own evaluation based on Destatis (2019b, 2019c, 2020)

For meat waste not suitable for consumption/processing (LoW-code 02 02 03), Destatis (2019c) shows the destination in "plants for other production purposes". For this study, it is assumed that these are cement plants. According to VDZ (2018) cement plants received "animal meals and fats" in 2017 in quantities of 150,000 tons/year. The reported total[74] of LoW 02 02 03 is 118,000 tons/year plus 17,000 tons/year of imports. For animal tissue (LoW 02 01 02, 02 02 02), no detailed information is given in Destatis (2019c). For the balancing in this study, it is assumed for simplification that these quantities also go to cement plants. The input is thus slightly overestimated compared to the quantities reported by VDZ (185,000 tons instead of 150,000 tons after VDZ (2018)).

Biological treatment plants

In the case of biological treatment plants, commercial waste is predominantly anaerobically digested in biogas plants.[75] For MSW (bio bin, kitchen and canteen waste), composting and combined composting and anaerobic digestion plants are also reported to a relevant extent (see. Table 48).

Table 48: Food waste for biological treatment

LoW-code	Waste type	Anaerobic digestion	Combined systems[1]	Composting
02 01 02, 02 02 02, 02 02 03	Animal origin, meat, etc.	7%	-	-
02 01 03, 02 03 01, 02 03 04, 02 05 01, 02 06 01, 02 07 01, 02 07 02, 02 07 04	Plant origin, dairy, bakery, beverages	18%	-	1%
19 08 09, 20 01 25	Oils and fats	1%	-	-

[74] Without deduction of non-food waste and NACE A sector

[75] Relevant quantities of sludges are also recycled (LoW 02 03 01 "Sludges from washing, cleaning, peeling, centrifuging and separation processes"); as these are sludges, it is assumed that they have a particularly high water content, which does not lead to any yields in the biogas plant. To simplify matters, the water content was estimated at 50% and deducted from the input quantities of this key with regard to GHG balancing.

20 01 08, 20 03 01 04	Kitchen & canteen waste, organic waste bin	27%	13%	30%
20 03 02	Market waste	1%	-	-

1) "Combined composting and anaerobic digestion plants".

Source: own evaluation based on Destatis (2019b, 2019c, 2020)

A small stream of packaging residues also goes from biogas plants to waste incineration plants for disposal. Due to the small amount[76] , the contribution is neglected for this study.

Other treatment plants

For the evaluation of the quantities reported under "Other treatment plants", it was assumed that these are mainly facilities that mechanically unpack packaged food in a first step and then feed the contents to recovery processes. With regard to the relevant codes, it is assumed that the recovery generally takes place in an anaerobic digestion plant (see "Other treatment plants", Table 49).[77] An exception are the quantities of edible oils and fats (20 01 25). Here, transesterification into biodiesel is assumed. [78] In the case of bakery products, further processing into animal feed could also be considered. However, due to the lack of data, a reliable quantification of the quantities is not possible and animal feed is only considered for information purposes in this study (see Chapter A.9).

Assumptions must also be made for the packaging volume. According to BFaN (2020), packaged former foodstuffs processed into animal feed have a packaging share of 1 - 2%. According to Core (2020) the packaging share for foodstuffs is max. 10 - 20%. According to a BGK study (BGK, Bundesgütegemeinschaft Kompost 2018) the weight share is approximately between 8% for plastic and 30% for glass packaging. For reasons of consistency with the EU balances, the same value is used for this study as for the 5% share of impurities in organic waste.[79]

Table 49 Food waste for other treatment

LoW-code	Waste type	Share	Final destination	Packing (1.000 t)
02 01 02, 02 02 02, 02 02 03	Animal origin, meat, etc.	10%	Anaerobic digestion	5
02 01 03, 02 03 01, 02 03 04, 02 05 01, 02 07 02, 02 07 04	Plant origin, dairy, beverages	15%	Anaerobic digestion	7
02 06 01	Baked goods	21%	Anaerobic digestion	10
19 08 09	Grease and oil mixtures from oil separators	5%	Anaerobic digestion	0

[76] According to expert assessment approx. 2

[77] For the sludges (LoW 02 03 01) with the assumed approx. 50% water content (see footnote 75), no packaging is assumed; the other treatment here could, for example, consist of pre-drying.

[78] The stated value also includes the amount reported under "chemical-physical treatment", which, however, only accounts for a good 10%.

[79] For the EU balance areas, neither other treatment nor individual waste types can be distinguished, and thus no packaging fractions of impurity fractions can be distinguished.

LoW-code	Waste type	Share	Final destination	Packing (1.000 t)
20 01 25	Edible oils and fats	5%	Transesterification	0
20 01 08	Kitchen & canteen Waste	39%	Anaerobic digestion	18
20 03 02	Market waste	0.7%	Anaerobic digestion	0.3

Source: own evaluation based on Destatis (2019b, 2019c, 2020)

The overall derivation steps described and the assumptions made regarding generation and destination are systematically applied uniformly to food waste from MSW and from C&I waste. In this context, cut-off criteria such as "deduction of waste quantities from primary production" (NACE Code Agriculture, Forestry) or neglect of facilities with treatment quantities < 1% lead to the total generation of food waste from MSW in the special balancing area being about 2% lower than in the balancing area MSW.[80] The overall view of the treatment options for food waste results in the distribution to the final destination shown in Table 50.

Table 50 Overview of the final destination of food waste (1,000 t)

Origin	LoW-code	Composting	AD	Transesterification (biodiesel)	Combustion[1]	Other (neglected)	Total income
C&I waste	relevant 02 xx xx, 19 08 09, 20 01 25	30	1,241	53	230	91	1,645
MSW	20 01 08, 20 03 01 0 4, 20 03 02	907	1,599		12	30	2,547

Source: own evaluation based on Destatis (2019b, 2019c, 2020)

1) Thermal waste treatment and combustion plants

The differentiated breakdown according to LoW-codes for the reported destinations according to (Destatis 2019a) is shown in Appendix A.7.

6.1.2.2 Data basis Destatis and Thünen (2019a)

For food waste, the study of Thünen (2019a) provides central data. For this reason, it was investigated whether these data are suitable for the preparation of this special balance area. The main difference between the data basis of Thünen (2019a) and Destatis is that in Thünen (2019a) NACE codes are used for the origin, whereas Destatis uses data from associations in addition to its statistical surveys, which are difficult to reconcile. A detailed comparison between the two sources can be found in Appendix A.8. This also shows that Destatis was still used in this balance area for reasons of consistency.

80 This can be seen in the comparison of the amount of kitchen/canteen waste, whose food waste share is set at 100%.

6.1.3 Quantity and destination for the balancing

In the final basic table for the GHG balance (Table 51), the LoW-codes are summarised for which similarity is assumed. The order of the listed waste types corresponds to their assignment to EWC-Stat codes W091 and W092. The first entries up to used fats are wastes of animal origin (W091), the entries below are wastes of vegetable origin (W092). The waste from bio bin is assigned to vegetable waste according to Eurostat specifications. For this study, the market waste (W101) has also been added. The individual types of waste from the C&I waste are often non-identifiable waste. 66% of food waste from C&I waste is "unsuitable for consumption or processing". The table also shows the respective shares of food waste from MSW and from C&I waste. Here, the quantities from MSW predominate with 62%.

Table 51: Base table: food waste production and destination for the 2017 German balance sheet

Waste type	Waste INC plant	Biomass CHP	Cement plant	AD	Composting	Other treat-ment	Amount
Quantities in t							
Animal waste (02 01 02, 02 02 02, 02 02 03)	76,841		109,930	203,367		91,952	482,091
Dairy waste (02 05 01)	900			37,700		32,900	71,500
Grease separator contents (19 08 09)				19,152		43,563	62,715
Kitchen waste (20 01 08)	7,124			544,631	53,974	361,173	966,903
Used fats (20 01 25)				7,019		53,186	60,205
Vegetable waste (02 01 03, 02 03 01, 02 03 04)	9,538	30,235		295,171	29,647	87,326	451,918
Baking waste (02 06 01)	2,300			72,300		200,200	274,800
Waste from beverage production (02 07 01, 02 07 02, 02 07 04)				128,120		22,408	150,528
Waste from bio bin (incl. market waste) (20 03 01 04, 20 03 02)	4,735			686,846	852,672	6,181	1,550,435
Total	**101,439**	**30,235**	**109,930**	**1,994,307**	**936,294**	**898,890**	**4,071,094**
Sum W091	**84,865**	**0**	**109,930**	**811,869**	**53,974**	**582,775**	**1,643,414**

Waste type	Waste INC plant	Biomass CHP	Cement plant	AD	Composting	Other treat-ment	Amount
Sum W092	**16,573**	**30,235**	**0**	**1,182,438**	**882,320**	**316,115**	**2,427,681**
Total MSW	**11,859**	**0**	**0**	**1,231,477**	**906,647**	**367,354**	**2,517,337**
Total C&I waste	**89,579**	**30,235**	**109,930**	**762,829**	**29,647**	**531,536**	**1,553,757**

Figure 15 shows the food waste material flows derived for the balance as a Sankey diagram. In Figure 16 the waste volume calculated for this study is shown by waste type. From both figures it is again clear that food waste from MSW takes up the main share of total food waste.

Figure 15: Sankey diagram food waste Germany 2017

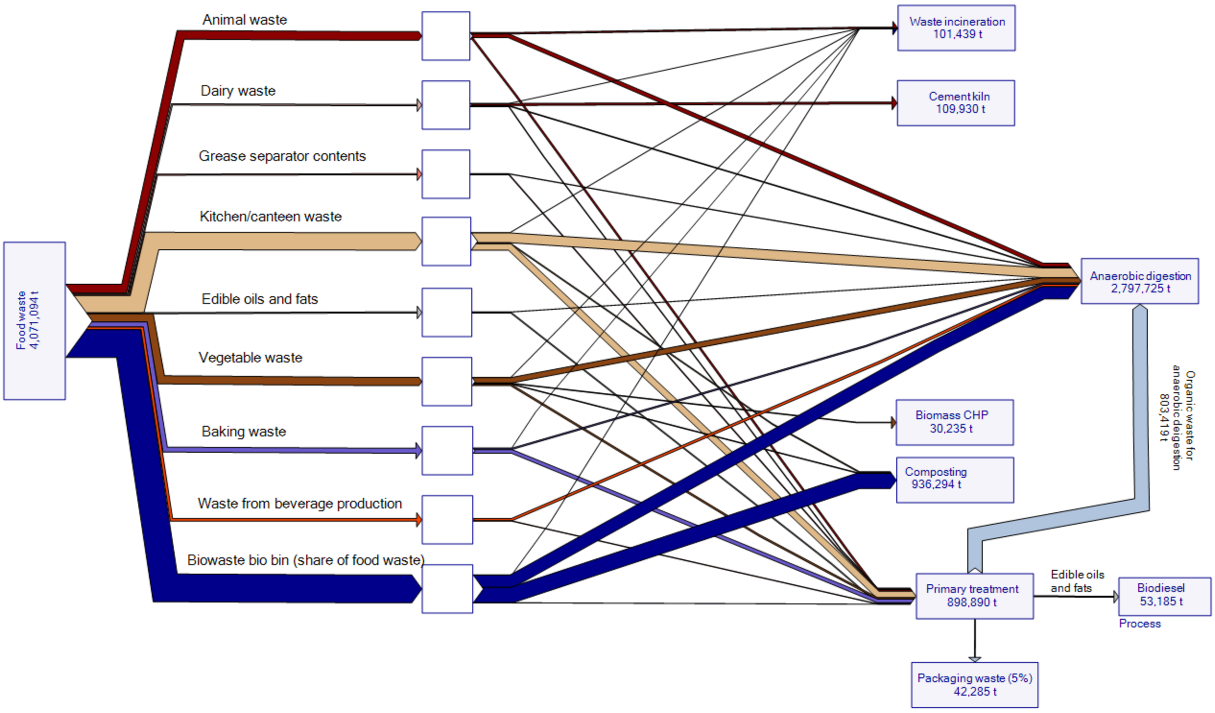
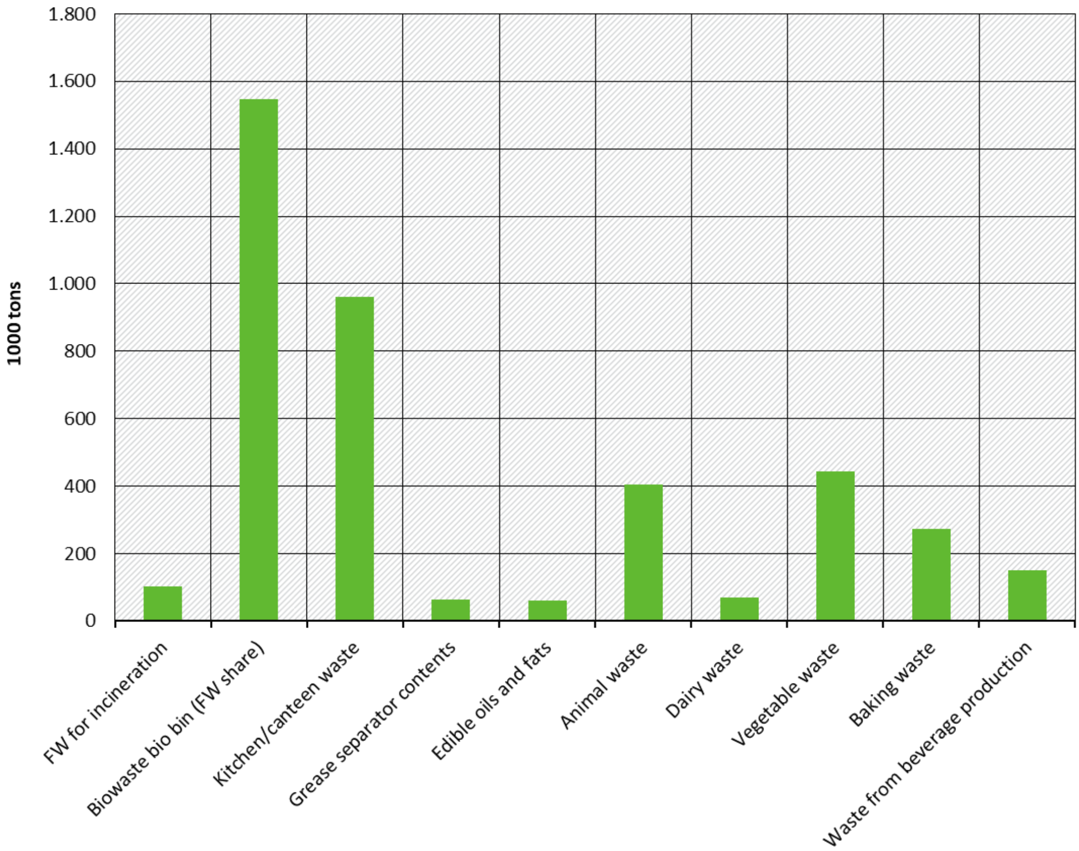


Figure 16: Quantity of initial treatment of food waste in Germany 2017



6.2 Procedure of balancing and characteristics of waste fractions

Food waste is balanced for Germany according to in Table 51 derived waste types[81] and the stated destinations. For the balancing of food waste from C&I waste, the results determined here are adopted for the C&I balancing area. The procedure for balancing is described below according to the different areas.

Food waste to the waste incineration

The small quantities of food waste that are submitted to thermal treatment in waste incineration plants are assessed with a uniform calorific value. A calorific value for the main quantity LoW 02 02 02 ("waste from animal tissue") is used as a proxy. The average value from the waste analysis database of the state of North Rhine-Westphalia was used. (ABANDA n.d.):

- Calorific value: 20388.33 kJ/kg
- Fossil C content: 0% (assumption, organic waste)

Kitchen/canteen waste and waste from the bio bin (food waste from MSW)

The balancing for kitchen/canteen waste and for biowaste from bio bin is the same as for MSW. For kitchen/canteen waste, this is clear, as the food waste share is assumed to be 100%. For the waste from the bio bin, the assumed food waste share is 34% (Appendix A.5). In this case, there is no representative and meaningful way to separate the food waste fraction from the non-food waste fraction for the purposes of balancing the biowaste bio bin.

[81] For the EU, according to the information available, a distinction can only be made between food waste from MSW ("food waste" from the EEA waste model) and W091, W092 from C&I waste.

The specific GHG results for kitchen/canteen waste and biowaste from bio bin are the same in both balance areas. Small differences may result from rounding inaccuracies from the allocation of the destination and the slight volume deviation.

Food waste from C&I waste

Most of the food waste from the C&I waste is anaerobically digested (Table 51). This waste is often waste that cannot be further identified. For example, the statistics or data collection do not provide any more detailed information on the type of waste "unfit for consumption or processing", which accounts for 66% of the total. However, with the given predominant destination to anaerobic digestion, it is assumed that this waste is suitable for anaerobic digestion and that it is not e.g. bones or non-organic components.

For these wastes, characteristic data for anaerobic digestion were estimated for the waste fractions listed in Table 51 were estimated for these wastes. Due to the given uncertainties with regard to the type of waste, the GHG results are to be understood as orienting results.

The characteristic data used for the **anaerobic digestion** is shown in Table 52. Most of the data was taken from the biogas yield database of the LfL Bayern. (2020). For vegetable and baking waste, the data sets were taken directly. For waste from beverage production, an averaged data set was derived approximately from fresh spent grains, fresh potato stillage and apple fruit pomace. For grease separator contents, the data set for flotation fat was used and for edible oils and fats the data set for frying fat was used. Data sets for dairy products are also available in the database. However, these differed significantly by product, especially in the dry matter content (5% - 100%), which determines the total gas yield. Here it was assumed that the substances unsuitable for consumption or processing are centrifugate residues and the dry matter content was estimated at 80%.

Table 52 Key characteristics for anaerobic digestion

Waste type	Dry matter	Organic dry matter	N content	Gas yield	Gas yield	Methane content
	% wet weight	% dry weight	% dry weight	l/kg organic dry matter	m³/t	Vol%
Animal waste	29%	89%	8.1%	792	205	70
Dairy waste	80%	90%	3.7%	700	504	55
Grease separator contents	7%	90%	3.7%	1.000	63	68
Edible oils and fats	95%	92%	3.7%	1.000	874	68
Vegetable scraps	15%	76%	1.3%	500	57	56
Baking waste	88%	97%	1.3%	764	651	53
Waste beverage production	17%	93%	3.4%	575	93	56

For the other characteristics, approximate mean values from the data sets of LfL Bayern (2020) were used. For animal waste, no suitable data set according to LfL Bayern (2020) is available (only for oils and fats) and further research did not yield a data set for meat. Since animal waste consists less of fat and more of protein, a data set for fish waste was used as an approximation (Bücker et al. 2020). For the nutrient content of substrates such as nitrogen, there is no data in (LfL Bavaria 2020). These values were taken from own studies (e.g. Vogt & Ludmann (2019) for grease separator contents) and otherwise estimated. The values are needed to estimate the benefits (mineral fertiliser substitution) from the application of digestate.

The methane contents listed roughly correspond to methane contents according to the Buswell formula for carbohydrates, proteins and fats. According to this formula, biogas from carbohydrates achieves a methane content of 50 vol%, from proteins of 70 vol% and from fats of 67 vol%. The listed gas yields approximately match theoretical gas yields for carbohydrates, proteins and fats, which are highest for fats (1,200 m^3 gas/t organic dry matter) and similar for carbohydrates and proteins (700 – 800 m^3 gas/t organic dry matter).

For the balancing of the anaerobic digestion of food waste from C&I waste, a different procedure was chosen than for food waste from MSW. For these wastes, it is not assumed that they are subjected to post-digestion to produce finished compost after digestion. On the contrary, it is assumed that the digestate is usually spread on agricultural land, possibly after solid-liquid separation. In this respect, an assessment of the GHG emissions from biological treatment on the basis of the median values according to (Cuhls et al. 2015) (cf. Chap. 4.2.8) is not expedient[82] , as these are mainly characterised by the post-composting process.

No data on GHG emissions from treatment are available for balancing food waste from C&I waste and no analogous measurements are known as for the anaerobic digestion of waste from organic waste bins. As an approximation, the assessment is carried out analogously to the knowledge of agricultural anaerobic digestion plants. It is assumed that, similar to agriculture, mainly concrete or steel containers with membrane covers are used as process technology. It can also be assumed that gas-tight digestate storage and a gas-tight retention time of 150 days are not standard in this sector, which generally does not receive renewable energy subsidies for biogas production. According to individual findings (Vogt / Ludmann 2019), gas-tight post-digester with a retention time of about 8 days are used for food residues or grease separator contents.

Against this background, the following assumptions were made for the balancing of anaerobic digestion, which are described, for example, in (Vogt et al. 2008):

- diffuse methane losses from digester 1% of methane produced,
- Flare losses 2%,
- Assumed proportion of plants with post-digester 70%, rest open digestate storing,
- Methane losses from storage in plants with post-digester (and subsequent open storage) 1.5%,
- Methane losses from open digestate stores 2.5%.

For biogas use, use in biomass CHP plants was assumed. The efficiencies were assumed to be the same as for MSW (see Table 19). However, the degree of utilisation for surplus heat was assumed to be zero, since the plants are usually located outside and no connection to local or district heating networks can be assumed.

A mass loss of 10% due to anaerobic degradation is assumed for the digestate produced, and a loss of 10% for the nitrogen contained. For the application of the digestate in agriculture, here too, N_2O emissions of 1% in relation to the nitrogen content were uniformly assumed according

[82] For kitchen/canteen waste, this was implemented for consistency reasons, as these are assessed in the National Inventory Report using these unit factors.

to the IPCC (2006). Emission savings effects of the application are taken into account through mineral fertiliser substitution.

For the treatment via **other treatment facilities it** is assumed as described in Chapter 6.1.2.1 that this is packaged food waste, which is unpackaged and then anaerobically digested (packaging share 5%). For the separated packaging, thermal treatment via waste incineration plants is accounted for. The characteristic data are uniformly adopted as for the fraction of contaminants in organic MSW (Table 19).

Further treatment processes concern vegetable waste, animal waste and edible oils and fats. For the proportional composting of vegetable waste, the balancing is analogous to the procedure described for garden waste for MSW (Chap. 4.2.8). Thermal utilisation takes place in biomass power plants. The degrees of utilisation for biomass power plants are set uniformly as for MSW (Table 10). The calorific value for this plant waste is assumed to be 5 MJ/kg, based on biowaste, and the fossil C content is set to zero, since it is organic material for which no other impurities are assumed.

For the thermal treatment of animal waste, it is assumed that this is co-incinerated in cement plants. Typically, such co-incineration takes place for animal meal. According to VDZ(2018), the calorific value is set at 18 MJ/kg for the year 2017. No impurity contents are assumed, and the fossil C content is set to zero. The emission savings potential results from the calorific value-equivalent substitution of the regular fuel coal.

For edible oils and fats, the treatment into used grease methyl ester is balanced for the quantities treated via other treatment plants and chemical-physical treatment plants. For the treatment via other treatment plants, a separation of impurities of 5% is also uniformly assumed here. The transesterification process is balanced according to ifeu's own characteristic data. In a first step, 1% of the process-interfering substances are separated. The electricity requirement for processing is set at 30kWh/t dry matter input. The transesterification itself requires further energy input with an electricity demand of about 40 kWh/t input and a heat demand of 323 kWh/t input. Methanol is used as an additive at an average of 110 g/t crude fat. The yield for waste fat methyl ester is 97%. The calorific value used to calculate the calorific value equivalent of the substitution of diesel fuel is 37.2MJ/kg.

6.3 Description of the GHG balance scenarios 2030

For Germany, two future scenarios are developed for the target year 2030, which are based on legal requirements and political framework conditions. In line with the procedure for MSW, changes in waste flows are considered first, followed by possible technical optimisations. The assumptions made for food waste from MSW are adopted or transferred.

For food waste from C&I waste, there is little scope for waste stream diversion. This also applies to the EU balance areas for which the destination is estimated from the German data. The majority of the waste is already anaerobically digested as Table 53 shows. In Germany, only 2% of this waste is still composted. Half of the 15% energy recovery comes from animal waste that is co-incinerated in cement plants (animal fats/animal meal) and the rest from predominantly animal waste that is treated in waste incineration plants. A material flow diversion to anaerobic digestion would not necessarily lead to a GHG benefit. Animal feed is an established substitute fuel for the cement industry, replacing coal on a calorific value equivalent basis. With the quantities used in waste incineration plants, the suitability for anaerobic digestion cannot be assessed.

Table 53: Overview of the final use of food waste from C&I waste in the different balance areas

Final destination	Compost ing	AD/Trans-esterification[1]	Energy recovery (R1)	Combustion (D10)	Landfill	Other disposal
Cluster 1	19%	74%	4%	1%	2%	0%
Cluster 2	19%	74%	4%	1%	2%	0%
EU27 (without DE)	19%	74%	4%	1%	2%	0%
Germany	**2%**	**83%**	**15%**	**0%**	**0%**	**0%**
EU27	17%	75%	5%	1%	2%	0%

1) Transesterification only (processing to waste fat methyl ester) 3 percentage points

Against this background, a lead scenario for 2030 is first considered for food waste, in which - similar to the lead scenario for MSW- both waste volume flow diversions and technical optimisations are examined. For the second scenario, waste prevention is also considered. This allows legal requirements to be taken into account, which in the case of food waste focus on reducing food waste. The two scenarios are described as follows:

- "Food waste 2030 LS" for the lead scenario, which provides for material flow shifts and technology improvements.
- "Food waste 2030 P" for the scenario that also provides for the prevention of food waste from the MSW sector.

6.3.1 Lead scenario "Food waste 2030 LS

A material flow redirection of food waste within MSW can only be carried out consistently in both areas of consideration. The assumptions for the treatment of food waste correspond to the assumptions in the MSW balance area:

- Kitchen/canteen waste will no longer be composted in 2030, but exclusively anaerobically digested.
- The increased share of biowaste from the bio bin for anaerobic digestion is taken into account; in 2030, 22% more waste will be anaerobically digested at the expense of composting (share of anaerobic digestion in the bio bin in 2017 44% increases to 66% in 2030).

For food waste from C&I waste, the following assumptions are added:

- Quantities still composted will also be anaerobically digested in 2030 (only concerns vegetable waste).
- Edible oils and fats that have been anaerobically digested up to now will be processed into waste fat methyl ester (diesel substitute) in 2030.

6.3.2 Scenario with waste prevention "Food waste 2030 V

The inclusion of waste prevention is only possible for the LCA method of waste management if the prevented products are known and their prevented production can be credited (cf. Chap. 5.3.4). For food waste, this means that only consumption products can be considered. No original products can be identified for sludges, slops, peeling residues, etc. or the "substances unsuitable for consumption or processing" that predominate in C&I waste. Accordingly, waste prevention considerations are only made for the food waste portions of the two waste fractions biowaste from the bio bin and kitchen/canteen waste.

According to the National Strategy to Reduce Food Waste, food waste should be halved by 2030[83] . According to Thünen (2019a) this is only possible with several actors and not only by private households alone. Households alone can, according to Thünen (2019a) 44%, while processing has 55%, out-of-home consumption 72% and trade even 84% prevention potential.

In the context of this study, the extent to which the sectoral prevention potentials can be assigned to the two waste fractions considered here was questioned in a technical exchange with the German Environment Agency. According to the given data situation, this is not possible, since the data of the sectoral consideration cannot be directly assigned to the waste codes and their flows. For this reason, the 50% avoidance is applied as a lump sum:

- 483,451 tons for kitchen/canteen waste
- 775,217 tons for biowaste from bio bins (incl. market waste).

The total preventable quantity considered here thus amounts to 1,258,669 tons. In the assessment, this quantity is divided into food waste from households (biowaste from bio bin incl. market waste) and food waste from out-of-home consumption (kitchen/canteen waste), because the composition of the food waste differs here. In the following table, the prevention is broken down into different foodstuffs for both material flows (breakdown according to Jepsen et al. 2016):

Table 54: Distribution of prevention among various foodstuffs for households and out-of-home consumption

Waste type	Households		Out-of-home consumption	
Quantities in tons	**Prevented quantities**	**Percentage share**	**Prevented quantities**	**Percentage share**
Bread and cereal products	118.445	15,3%	197.023	40,8%
Rice	877	0,1%	5.010	1,0%
Bread/Baked Goods	109.142	14,1%	143.786	29,7%
Pasta/other cereal products	8.425	1,1%	48.206	10,0%
Meat/meat products	91.792	11,8%	68.370	14,1%
Beef & Veal	15,821	2.0%	18,854	3.9%
Pork	15,790	2.0%	18,813	3.9%
Poultry meat	11,955	1.5%	14,239	2.9%

[83] https://www.bundesregierung.de/breg-de/aktuelles/lebensmittelabfaelle-halbieren-1581854 (02.08.2021)

Waste type	Households		Out-of-home consumption	
Meat & Sausages	48,227	6.2%	16,464	3.4%
Fish/Fish products	12,128	1.6%	7,234	1.5%
Dairy products and eggs	139,488	18.0%	55,024	11.4%
Milk	118,669	15.3%	39,330	8.1%
Cheese	9,853	1.3%	5,363	1.1%
Cream	4,070	0.5%	1,538	0.3%
Butter	4,121	0.5%	1,372	0.3%
Eggs	2,774	0.4%	7,421	1.5%
Edible fats and oils	2,550	0.3%	48,539	10.0%
Fruit	153,799	19.8%	17,004	3.5%
Citrus fruits	29,273	3.8%	2,827	0.6%
Bananas	8,149	1.1%	4,137	0.9%
Apples	4,275	0.6%	9,396	1.9%
Canned fruits/frozen fruits	29	0.0%	644	0.1%
Vegetables/Potatoes	**254,853**	**32.9%**	**88,949**	**18.4%**
Tomatoes	64,771	8.4%	14,011	2.9%
Fresh vegetables, salad	98,493	12.7%	21,307	4.4%
Dry, deep frozen, preserved vegetables	4,662	0.6%	31,056	6.4%
Potatoes	86,926	11.2%	22,596	4.7%
Sugar	2,162	0.3%	1,310	0.3%
Total	**775,217**	**100.0%**	**483,452**	**100.0%**

The quantity breakdowns shown in the table form the basis for the balancing.

GHG emission values for food waste prevention

GHG emission values for food production are evaluated to account for food waste prevention. (Reinhardt et al. 2020) provide a comprehensive study on CO_2 footprints of different foods, which are used as a basis for determining emission values. The breakdown of foods according to (Jepsen et al. 2016) corresponds in part to the product categories in (Reinhardt et al. 2020) (e.g. rice, bananas). These values can be used directly as emission values for the respective products. For products with many different variations (e.g. apples depending on season or origin), an average value given by the authors was used - as far as available.

In some cases, however, the categories of (Reinhardt et al. 2020) are more detailed. For the application to the product categories of (Jepsen et al. 2016) GHG emission values were summarised by averaging. The mean value was chosen because the range or individual values per kilogram within most product categories are relatively small[84] . Higher specific GHG emission values and thus more relevant deviations exist within the categories "fish" and "meat and sausage products". These include values for different animal species (beef, poultry, pork) or different origins or qualities (fish: mass-produced, frozen). From the trade statistics data, it was not possible to determine market shares specifically for these categories in order to generate a weighted average value. Therefore, the simple mean was used in these cases as well. For the task in this study of showing a methodological approach to integrating waste prevention into the LCA of waste management, this procedure is sufficiently accurate.

For the product categories meat and meat products and meat and sausage products, the designations have been recast, as the emission values differ primarily according to the animal species. "Pork", "poultry meat" and "meat and sausage products" are combined under the category "other meat", while the category "beef and veal" remains unchanged. The emission value of the category "Other meat" is formed by the mean value of the three combined product groups. Table 55 shows the mean values derived in this way. These form the basis for calculating the weighted emission values for food waste from households and food waste from out-of-home consumption.

Table 55 GHG emission values for food

	kg CO_2eq/kg food	Number of products with averaging
Bread and cereal products		
Rice	3.1	
Bread/Baked Goods	0.9	n=4
Pasta/other cereal products	0.7	n=6
Meat/meat products		
Beef & Veal	13.6	
Other meat	4.9	n=3
Fish/Fish products	6.8	n=5
Dairy products and eggs		
Milk	1.3	n=5
Cheese	5.7	
Cream	4.2	n=3
Butter	10.3	n=2
Eggs	3.0	
Edible fats and oils	2.7	n=8

[84] For example, for fresh vegetables, the range for 24 types of vegetables is from 0.1 kg CO_2eq/kg for carrots or white cabbage to 1.3 kg CO_2eq/kg for mushrooms.

	kg CO_2eq/kg food	Number of products with averaging
Fruit		
Citrus fruits	0.3	
Bananas	0.6	
Apples	0.3	
Canned fruits/frozen fruits	1.4	n=3
Vegetables/Potatoes		
Tomatoes	0.8	
Fresh vegetables, salad	0.3	n=24
Dry, deep frozen, preserved vegetables	1.4	n=20
Potatoes	0.2	
Sugar	0.8	n=4

For the GHG balance, the sum product results in the following emission values for food waste prevention:

- for food waste from households and thus in this study for prevented biowaste from the bio bin -1.42 kg CO_2eq/kg food,
- for waste from out-of-home consumption and thus in this study for prevented kitchen/canteen waste -1.91 kg CO_2eq/kg food.

Based on the avoided quantities for 2030 derived above for this study, the **weighted average for food waste prevention is -1.61 kg CO_2eq/kg food**. This value is also used in the MSW balance for the sensitivity of waste prevention.

6.4 Results GHG balances

In the following, the results for the baseline comparison are first described - the actual situation in 2017 and the lead scenario in 2030. In the next chapter, the result for the scenario with waste prevention is also presented. In general, due to data uncertainties and data gaps, the results should be understood as orientational (cf. Chap. **Fehler! Verweisquelle konnte nicht gefunden werden.**).

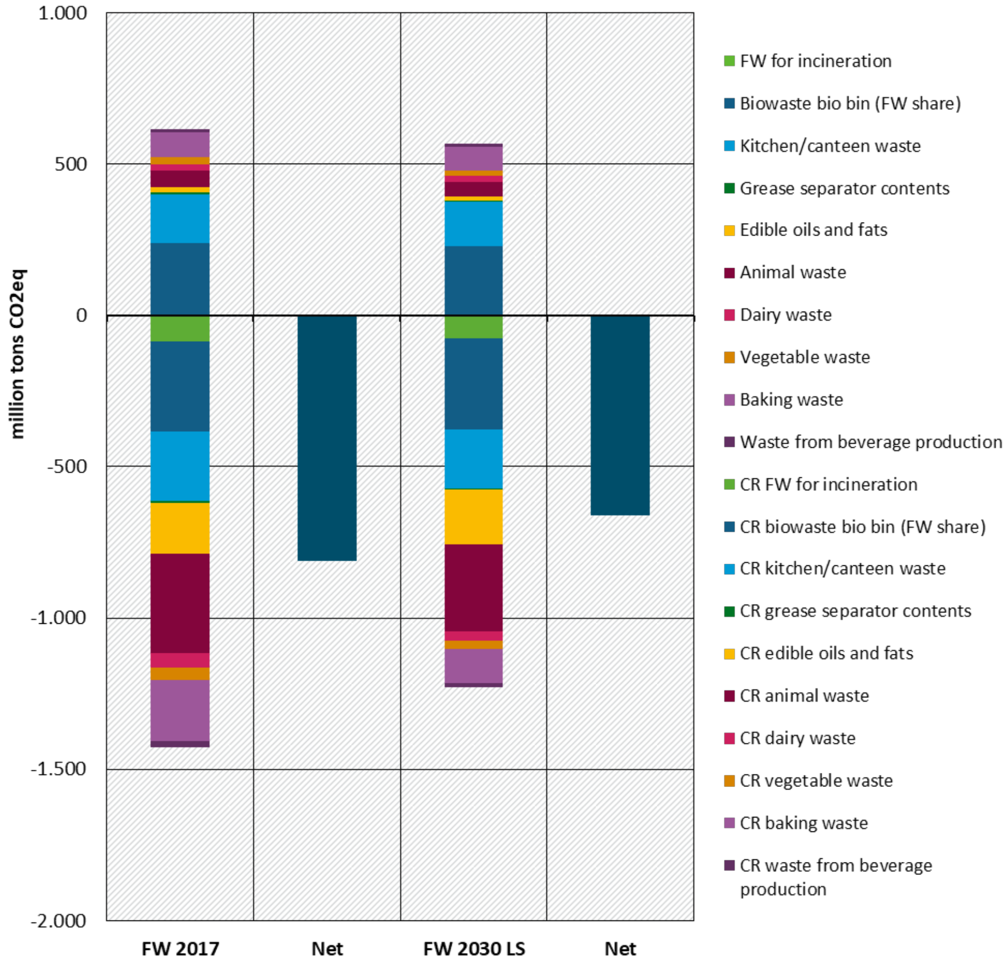
6.4.1 Base comparison

In the baseline comparison, the GHG results for the material flows derived in Chapter 6.1.2 are compared for the actual situation for Germany in 2017 with those of the lead scenario 2030 described in Chapter 6.3.1. The following designations are used for the figures:

- Actual situation 2017: "FW 2017" (Food waste 2017)
- Lead scenario 2030: "FW 2030 LS" (Food Waste 2030)

Figure 17 shows the absolute results according to the debits and credits of the waste fractions as well as the total net result in a year-on-year comparison. For the **actual situation in 2017, there is an absolute net emission savings potential of around -0.8 million tons CO_2 eq.** The underlying debits amount to around 0.6 million tons CO_2eq and the emission savings potential to around -1.4 million tons CO_2eq. The figure clearly shows the contribution of food waste from MSW, whose debit and emission savings are at a similar level. In addition, there are clear contributions, especially to the emission savings potential of edible oils and fats and animal waste.

Figure 17 Baseline comparison of food waste in Germany



GS: Credit or emission savings potential

For the **lead scenario 2030**, the comparison shows somewhat lower debits and lower emission savings potentials. The **absolute net emission savings potential is around - 0.7 million tons CO_2eq.** The debits are around 0.6 million tons CO_2eq and the emission savings potential is around -1.2 million tons CO_2eq. The differences in the result - the overall somewhat low net emission savings potential - is mainly due to the defossilisation of the energy system. On the one hand, the GHG debits from energy demand decrease, on the other hand, above all the substitution potential for energy from biogas. This is countered by the optimisations in the lead scenario 2030, the increased anaerobic digestion instead of composting and the complete processing of edible oils and fats into waste fat methyl ester.

The overall view of the net GHG results for food waste by waste fraction in absolute values as well as specific per capita and per ton for the actual situation in 2017 and in the lead scenario 2030 (2030 LS) are shown Table 56.

Table 56 Absolute and specific net results by waste fraction - food waste Germany actual situation 2017 and lead scenario 2030

Waste fraction	absolute	absolute	spec. per capita[1]	spec. per capita[1]	spec. per ton	spec. per ton
Food waste	**2017**	**2030 LS**	**2017**	**2030 LS**	**2017**	**2030 LS**
	1.000 tCO_2eq		kg CO_2eq/cap		kg CO_2eq/t	
FW for incineration	-82	-74	-1.0	-0.9	-810	-728
Biowaste bio bin (FW share)	-63	-77	-0.8	-0.9	-41	-50
Kitchen/canteen waste	-66	-46	-0.8	-0.6	-68	-48
Grease separator contents	-2	0	0.0	0.0	-33	-2
Edible oils and fats	-151	-167	-1.8	-2.0	-2.514	-2.771
Animal waste	-273	-240	-3.3	-2.9	-675	-593
Dairy waste	-29	-11	-0.3	-0.1	-408	-160
Vegetable waste	-18	-9	-0.2	-0.1	-41	-19
Baking waste	-117	-34	-1.4	-0.4	-429	-124
Waste fro beverage production	-10	-4	-0.1	0.0	-65	-26
Sum/average	**-811**	**-662**	**-9.8**	**-8.0**	**-199**	**-163**

2) calculated with a population of 82,792,351 in 2017 (Federal Statistical Office (Destatis) 2017)

Based on the **specific net results by waste fraction per ton of waste,** the differences in results can be explained:

The high specific net emission savings potential for edible oils and fats results from its suitability for processing into a substitute for diesel fuel, which achieves a comparatively high GHG emission savings potential. In the lead scenario 2030, this is done exclusively, whereas in 2017, 33% was anaerobically digested on a pro rata basis. Furthermore, higher net emission savings potentials result for animal waste due to its proportionate co-incineration in the cement plant. In the lead scenario 2030, this leads to a lower impact through defossilisation than for other waste fractions, which are predominantly anaerobically digested. The thermal use of food waste also shows higher specific net emission savings potentials. However, this is only representative if the comparatively high calorific value of 20.4 MJ/kg with a simultaneous 0% fossil C content approximately applies in practice. In the 2030 lead scenario, the optimised increased utilisation rates of waste incineration counteract defossilisation, so that the specific net emission savings potential only decreases slightly. In contrast, no change in the utilisation rates is assumed for biogas utilisation in CHP plants. The specific net results of the other types of waste are mainly influenced by anaerobic digestion and whether the material has a high or low water content. Low water content (dairy waste, baking waste) results in higher gas yields and correspondingly higher net emission savings potential.

6.4.2 Scenario Emission factors electricity and heat EU27

This chapter presents the results for the scenarios with EU27 emission factors for electricity and heat needed for the EU balance (cf. Chap. 5.3.3 and Table 6). The absolute result values by waste fraction show Table 57. Compared to the results with emission factors for Germany, the absolute net emission savings potentials are 13% lower in total for 2017 and 5% lower for 2030.

Table 57: Absolute net results for food waste with EU27 emission factors for electricity and heat

Waste fraction	2017	2030 LS
in 1,000 t CO_2eq		
FW for incineration	-75	-68
Biowaste bio bin (FW share)	-52	-71
Kitchen/canteen waste	-51	-41
Grease separator contents	-1	0
Edible fats and oils	-150	-167
Animal waste	-257	-236
Dairy waste	-20	-9
Vegetable scraps	-13	-7
Baking waste	-77	-23
Waste from beverage production	-7	-3
Total	**-704**	**-626**

6.4.3 Scenario with waste prevention

The scenario with waste prevention shows a methodical approach to integrating this aspect into the LCA of waste management. A description of the problems that make it difficult to integrate this aspect, and why it has not or hardly been done so far, can be found in Chapter 5.3.4. The procedure for calculating the prevention potentials for food waste is described in Chapter 6.3.2. As is generally the case, the total amount of waste must be the same for a comparison of the results at the absolute level. The scenario with waste prevention ("FW 2030 P") corresponds to the lead scenario 2030 ("FW 2030 LS") except that it is additionally assumed that 50% of the waste from bio bin and 50% of the kitchen/canteen waste can be prevented. In total, this is around 1.26 million tons of food waste or around 31% of the total waste volume considered (as in the baseline comparison, around 4.1 million tons).

Figure 18 shows the generation by waste fraction from the baseline comparison compared to the scenario with waste prevention. The avoided waste quantities are shown in the figure as dotted bars and reduced accordingly for the waste from the bio bin and the kitchen/canteen waste.

Figure 18 Food waste prevention scenario - generation in Germany

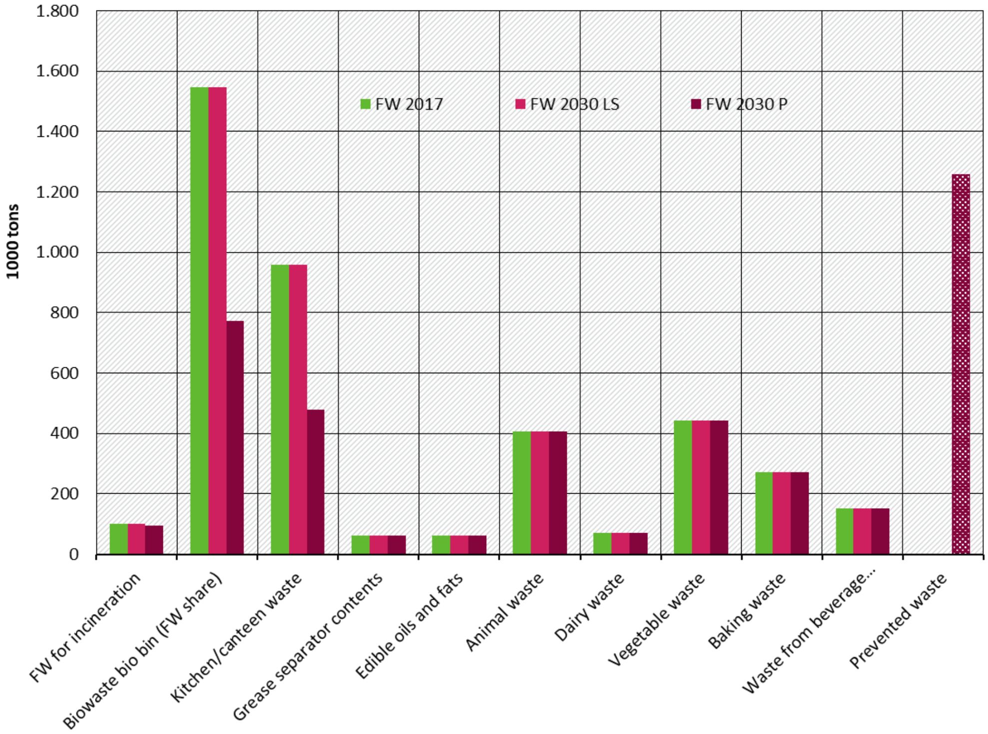
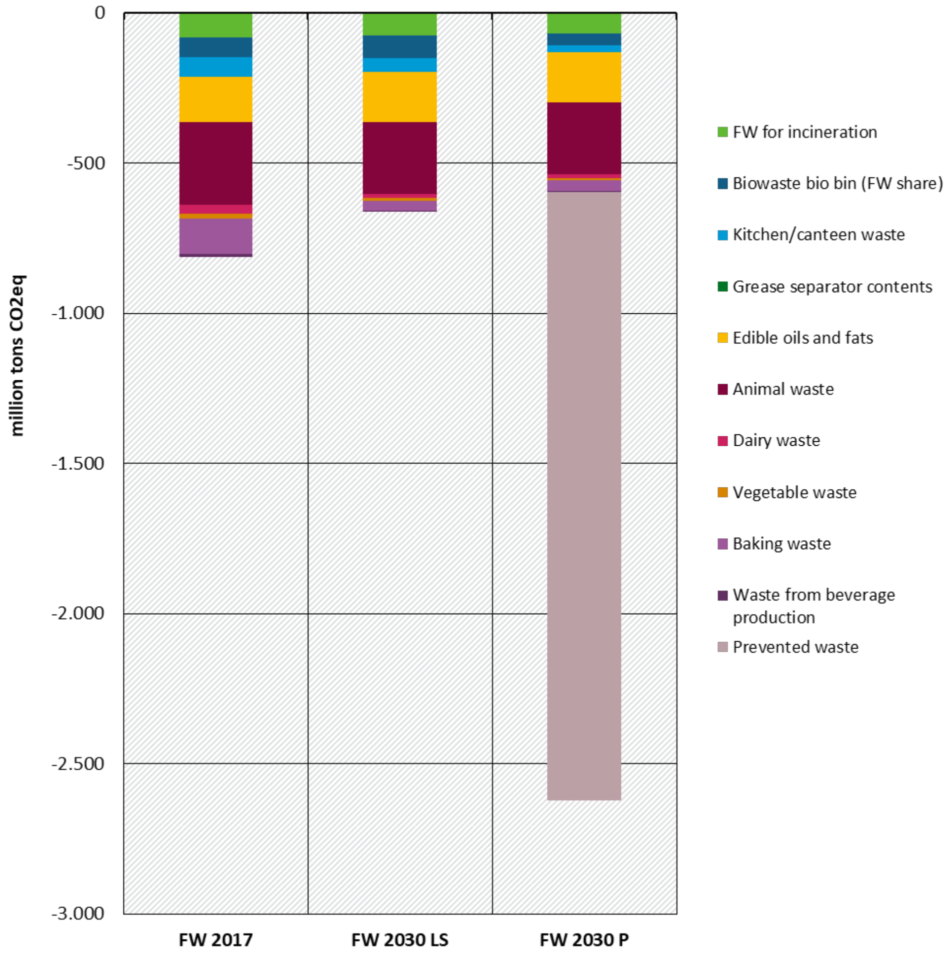


Figure 19 shows the absolute net results by waste fraction for the baseline comparison with "Food waste 2030 P". For the scenario with waste prevention, the **absolute net emission savings potential for** the balance year 2030 is **around -2.6 million tons CO_2eq** (almost a factor of 4 compared to FW 2030 LS). The significantly higher net emission savings potential results from the relevance of food waste prevention. On the one hand, this is set for 31% of the total food waste. On the other hand, the specific net emission savings potential of - 1.61 kg CO_2eq/kg food waste is comparatively high.

Figure 19 **Scenario with waste prevention FW Germany - absolute net results of waste fractions**



7 Commercial and industrial waste

7.1 Waste generation and destination

Commercial and industrial waste (C&I waste) originates from a very broad spectrum of different sectors and thus contains very different waste streams. Thus, possible contributions are distributed across all chapters of the European waste statistics. The collection of the quantities for the subsequent balancing of the GHG emissions associated with their disposal is only carried out for orientation purposes. In the first step, the EWC-Stat codes to be analysed are determined for this purpose, as well as the sectors of origin relevant for the balancing (via NACE categorisation). This analysis is carried out for all EU member states and is described in the partial report EU. In a second step, an analysis is carried out for Germany at the level of the LoW-codes within the considered EWC-Stat codes.

The more detailed analysis of the German data serves the following objectives:

1. Better assessment of GHG impacts associated with the streams through more detailed information on the type of waste (at the LoW-code level, instead of higher-level EWC-Stat code).
2. If necessary, adjust the destinations reported at European level for an EWC-Stat code if only a subset of an EWC-Sat code is taken into account due to the demarcation to other balance areas described in Chapter 7.1.1 and/or the restriction with regard to the NACE origin, only a subordinate subset of an EWC-Stat key is taken into account.
3. Allocation of waste quantities that were derived from the MSW balance sheet (see Chapter 5), but were not reported in the NACE sectors households and/or commerce based on the comparison with the European statistics (see also description of the approach to the delimitation to the MSW balance in the partial report EU).

The approach to the survey of the quantities and treatment routes to be considered for the C&I waste balance for Germany is described in Chapter 7.1.1. Chapter 7.1.2 provides an overview of the results for each of the EWC-Stat codes considered.

7.1.1 Approach

In order **to narrow down the relevant EWC-Stat codes**, the following basic specifications were taken into account (see also partial report EU).

- Explicitly excluded from this study are chapters W033 (sludges and liquid wastes from waste treatment), W103 (sorting residues) and W128 (mineral wastes from waste treatment and stabilised wastes) with exclusive reference to secondary waste, as well as chapters W13 (used oils) and W08 (discarded appliances). Discarded equipment includes used appliances, end-of-life vehicles and batteries. However, used tyres, which are reported under the code W073 (rubber waste), are not excluded. Waste water treatment is also not considered in this study. Chapter W11 (common sludges) is therefore also excluded, as these are almost exclusively flows from wastewater treatment. An overview of the EWC-Stat codes taken into account for the C&I waste balance and the LoW-codes contained therein by definition can be found in Appendix A.10.

- C&I waste that is recorded as MSW is fully attributed to the material flow "MSW" (see Chapter 5) and are therefore excluded from the C&I waste balance.

- Regardless of its origin, textile waste is generally exempted, as is the case with MSW.

- Construction and demolition waste is also taken into account in a separate balance sheet (see Chapter 8) and are therefore not considered here. Thus, W121 is completely excluded, as well as all codes included in the balance sheet for construction and demolition waste (LoW-code 17). The LoW-codes from Chapter 17 already excluded in Chapter 8, especially soil and stones (LoW 17 05 04) and dredged material (LoW 17 05 06) are also not considered here.
- The EWC-Stat codes W091 (animal and mixed food waste), W092 (vegetable waste) and W101 (household and similar waste) are in principle to be considered first. Although they are also considered in the food waste balance (see Chapter 6) they are also considered. However, due to difficulties in delimiting the balance areas, this cannot be considered as additive to the other balance areas and is therefore placed as a special balance area next to the result of the other balances. In addition, the food waste balance only takes into account the shares of food waste, whereas the C&I waste balance includes the entire quantities.
- Only waste classified as "non-hazardous" is collected.

As a result, the following EWC-Stat codes are analysed for the C&I waste balance: W012, W02A[85] , W032, W05, W06, W071, W072, W073, W074, W075, W091, W092, W101, W102, W124, W12B[86] . If adjustments are necessary to the generation to be taken into account for the C&I waste balance, this is explained in Chapter 7.1.2.1.

As a **further delimiting characteristic,** the analysis includes the **NACE origin.** For W091, W092 and W101, all sectors except agriculture (NACE A) are taken into account. For all other EWC-Stat codes, only the sectors NACE C and G-U are considered for simplification, since the most relevant quantities are to be expected there with regard to C&I waste. NACE F is already covered by the balance of construction and demolition waste and, in addition to agriculture, the mining sector (NACE B) was also excluded as agreed. The exclusion of NACE E reflects the limitation of the balance to primary waste (see also partial report EU).

As with the other balances, the German waste statistics serves as the basis for the extended **analysis of German waste generation at the LoW-code level.** (Destatis 2019b). With regard to the delimitation of the NACE origin, the additional calculations of the Federal Statistical Office of Germany are also available for W091, W092 and W101, differentiated according to LoW-codes. (Destatis 2020). They refer to the reference year 2016 and were adopted for the orientation balance sheet for the reference year 2017. For all other EWC-Stat codes considered, no differentiated information is publicly available for Germany at the LoW-code level. In the first step, a qualitative classification was used: if the name of an LoW-code indicated that it came from NACE C or G-U, it was taken into account at 100% for the sake of simplicity. If the code number suggested a different estimate of the origin, the corresponding LoW-code was completely assigned to another NACE sector.[87] The obtained quantities thus to be taken into account were compared for each EWC-Stat code with the values obtained from the analysis of the European data:

[85] The aggregate W02A "Chemical wastes" contains the EWC-Stat codes W014 Spent chemical catalysts, W02 Wastes of chemical preparations and W031 Chemical deposits and residues.

[86] The aggregate W12B "Other mineral wastes" contains the EWC-Stat codes W122 Asbestos wastes (without exception classified as hazardous), W123 Wastes of naturally occurring materials and W125 Miscellaneous mineral wastes.

[87] For example, LoW-codes from LoW Chapters 06, 07 and 08 were 100% classified as NACE C and G-U, whereas waste from LoW chapter 10 01 (waste from power plants and other combustion facilities) was 100% classified as NACE D.

- If quantities were derived from the MSW balance that could no longer originate from the household and commercial sectors in the reconciliation with the European statistics,[88] it was examined whether there is an improved correspondence between the quantities derived from Destatis (2019b) or Eurostat for the C&I waste balance.
- In case of otherwise strong discrepancies, adjustments were made where possible to improve compliance.

Where applicable, both are described at the appropriate places in the presentation of the results in Chapter 7.1.2.

In general, when comparing the waste quantities according to Destatis (2019b) and Eurostat (see partial report EU) it must be taken into account that the data from Destatis (2019b) refer directly to the reference year 2017, whereas the European values were extrapolated from the data available for 2016 to the reference year 2017 (see partial report EU).

In addition, the **destination for the relevant LoW-codes** was analysed based on Destatis (2019b and c). On the one hand, this verified whether, even in cases where the share of waste taken into account for the C&I waste balance is significantly lower than the total waste quantity of the EWC-Stat key, the distribution shown according to Eurostat for the total EWC-Stat code remains valid at Final treatment options .89 In those cases where for the NACE C and G-U share according to the Destatis (2019b) based estimation, adjusted values have been derived. Where applicable, these are also documented at the appropriate places in Chapter 7.1.2 documented. In Chapter 7.1.2.2 the reported Destatis (2019b) reported destination in the primary treatment plants is also discussed in order to obtain a deeper understanding of the type of treatment with regard to GHG accounting.

7.1.2 Results according to EWC-Stat code

In the following, the results derived on the basis of the approach described in Chapter 7.1.1 the results derived for each EWC-Stat code are presented. The conclusions with regard to a possibly necessary adjustment of the values derived at European level are highlighted.

In Chapter 7.1.2.1 first presents the overview of generation and destination in final treatment options as it is also used at European level for Germany.

A more in-depth discussion for each EWC-Stat code is given in the Chapter 7.1.2.2. Here, the relevant LoW-codes are also presented and their destinations (also with regard to primary treatment) are discussed. EWC-Stat codes that have already been excluded in Chapter 7.1.2.1 are no longer considered in the Chapter 7.1.2.2.

When interpreting the results, it must be kept in mind that **hazardous waste** is in principle **excluded** from the balance.

In addition, it must be taken into account that due to the large number of LoW-codes included, this is an **orientational evaluation.**

[88] (as the quantities from the MSW balance were larger than the quantities reported for households and commerce in this EWC-Stat key, see partial report EU).

[89] If only a subset of the total EWC-Stat key is taken into account, it is possible that a different allocation than the one reported by Eurostat applies to it (if the destination known by Eurostat is determined by quantity flows that were excluded for the C&I waste balance or are only taken into account to a small extent in it).

7.1.2.1 Overview of quantity and destinations

Table 58 and Table 59 show an overview of the generation and destination of C&I waste (see also partial report EU). The figures are mainly based on the data from Eurostat per EWC-Stat code for the economic sectors NACE C and G&U.

In those cases where according to Destatis (2019b) identified **total quantities for the generation** of the respective EWC-Stat code differ from the values extrapolated at European level to the year 2017, no adjustment was made. On the one hand, this is to ensure a consistent approach (application of the extrapolation) for all member states. On the other hand, there would also be uncertainties in adjusting the German quantities to the values actually reported for 2017, as the breakdown by NACE origin would have to be applied to the reference year 2017 from the shares known at European level (reference year 2016). In addition, the deviations are generally within an acceptable range within the scope of accuracy. There are significant deviations in the EWC-Stat codes W032 and W11, where sludges are reported. They are due to the consideration of water fractions in Destatis (2019b) which are not included in the European data.

Adjustments with regard to the generation to be taken into account for the C&I waste balance as well as with regard to the final destination are listed in Table 58 and Table 59.

Table 58: Generation of production and commercial waste by EWC-Stat category and economic sector, 2017, in 1000 tons

EWC-Stat Key		C10-C12	C13-C15	C16	C17_C18	C19	C20-C22	C23	C24_C25	C26-C30	C31-C33	G-U (excl. G46.77)	A, B, D, E, G46.77	P& G total
	Description	Production of food products, beverages and tobacco	Production of textiles, apparel, leather, leather goods and footwear	Production of articles of wood and of products of wood and cork, except furniture	Production of paper and paperboard and of articles thereof; printing; ...	Coking plant and mineral oil processing	Production of chemicals, pharmaceuticals, rubber and plastic products	Production of glass and glass products, ceramics, processing of stones and earths	Metal production and processing, manufacture of metal products	Production of computer, electronic and optical products, ...	Production of furniture, jewellery, musical instruments, sports equipment, toys and other products	Services (excluding wholesale of used and residual materials)	Other areas	Commercial and industrial waste
W012	Acids, alkalis or salts	18.3	0	0	9.5	0.8	176.7	17.9	21.0	21.9	0.1	5.2	n. a	272
W02A	Chemical waste	11.0	4.3	5.5	38.3	11.2	94.2	5.1	81.7	32.7	10.6	53.0	n. a	348
W032	Sludges from industrial waste water	n. a.	n. a	n. a	730.0	n. a	n. a	n. a	n. a	n. a	n. a	n. a	n. a	730
W05	Medical and biological waste	0	0	0	0	0	2.7	0	0	0	0	357.6	n. a	360
W061	Ferrous metals	2.4	2.5	8.8	18.3	0.3	12.1	26.5	1.247.3	746.6	102.3	217.3	n. a	2,384
W062	Non-ferrous metals	0.1	0.4	0.4	1.0	0.1	5.2	1.9	144.4	153.0	11.8	72.5	n. a	391
W063	Mixed metals	6.6	0.9	0.6	3.7	0	5.6	0.1	9.0	2.0	0.9	18.7	n. a	48
W071	Glass waste	183.3	0.0	5.9	3.2	0.0	23.2	152.6	19.6	5.2	14.3	0	n. a	407

EWC-Stat Key		C10-C12	C13-C15	C16	C17_C18	C19	C20-C22	C23	C24_C25	C26-C30	C31-C33	G-U (excl. G46.77)	A, B, D, E, G46.77	P& G total
W072	Paper and cardboard waste	0	0	0	0	0	0	0	0	0	0	0	n. a	0
W073	Rubber waste	0.2	0	0.3	0.5	0.2	141.9	2.4	73.3	8.2	11.2	332.0	n. a	570
W074	Plastic waste	92.8	11.5	7.1	44.3	5.2	172.5	56.6	40.3	75.3	23.7	0	n. a	529
W075	Wood waste	19.5	3.7	2,619.4	270.5	0.2	66.1	74.6	91.1	220.1	262.0	0	n. a	3,627
W091, W092	Animal and mixed food waste (excl. manure and slurry)	1,720.4	2.0	42.4	6.9	0.2	436.5	1.8	6.5	20.2	79.2	804.2	427.9	3,548
W101	Household and similar waste	0	0	0	0	0	0	0	0	0	0	0	0	0
W102	Mixed and undifferentiated substances	525.1	16.8	67.8	1.529.2	1.5	271.4	29.1	143.0	168.5	56.6	49.4	n. a.	2,858
W124	Combustion residues	45.7	0.3	64.3	203.1	38.4	146.0	136.2	3.105.2	30.9	7.8	192.8	n. a.	3,971
W12B	Other mineral waste	11.0	1.0	0.5	8.6	1.0	24,211.9	236.9	2,102.2	165.5	37.4	256.9	n. a.	27,033
Total		**2,636.4**	**43.4**	**2,823**	**2,867.1**	**59.1**	**25,766**	**741.7**	**7,084.6**	**1,650.1**	**617.9**	**2,359.6**	**427.9**	**47,077**

n. a.: not applicable, as the waste does not fall under the balance of production and commercial waste (see definition of balance areas).

1) Excluding waste from NACE A

Table 59: Final treatment of C&I waste, 2017, in 1 000 tons

EWC-Stat code	Description	Recycling	Backfilling	Energy recovery (R1)	Combustion (D10)	Landfill	Other disposal	Total final treatment
W012	Acids, alkalis or salts	118	0	23	0	131	0	272

EWC-Stat code	Description	Recycling	Backfilling	Energy recovery (R1)	Combustion (D10)	Landfill	Other disposal	Total final treatment
W02A	Chemical waste	195	8	92	24	29	0	348
W032	Sludges from industrial waste water	0	0	730	0	0	0	730
W05	Medical and biological waste	0	0	315	45	0	0	360
W061	Ferrous metals	2,357	0	21	0	6	0	2,384
W062	Non-ferrous metals	391	0	0	0	0	0	391
W063	Mixed metals	47	0	1	0	0	0	48
W071	Glass waste	402	0.5	0.5	0.5	5	0	407
W072	Paper and cardboard waste	0	0	0	0	0	0	0
W073	Rubber waste	385	0	185	0	0	0	570
W074	Plastic waste	421	0	106	1	0.5	0	529
W075	Wood waste	0	0	3,627	0	0	0	3,627
W091, W092	Animal and mixed food waste	2,768	0	781	0	0	0	3,549
W101	Household and similar waste	0	0	0	0	0	0	0
W102	Mixed and undifferentiated substances	800	0	2,058	0	0	0	2,826

EWC-Stat code	Description	Recycling	Backfilling	Energy recovery (R1)	Combustion (D10)	Landfill	Other disposal	Total final treatment
W124	Combustion residues	632	808	96	0.5	2,435	0	3,971
W12B	Other mineral waste	1,275	1,195	179	0	24,384	0	27,033
Total		**9,847**	**2,013**	**8,328**	**134**	**26,992**	**1**	**47,280**

Adjustments to the quantity to be considered for the C&I waste balance (Table 58) were made in the following cases:

- **W012** (acids, alkalis or salts) is completely excluded from the C&I waste balance. An attempt was made to carry out a balance on the basis of ecoinvent data records. However, there are only approximately suitable data sets here, so that due to the poor data situation (there is no concrete information on the waste) the results for the GHG emissions contain a great deal of uncertainty. It therefore also remains unclear whether the results would be directionally reliable.
- **W02A** (chemical waste) is completely excluded from the C&I waste balance. Here, too, an attempt was made to carry out a balance using ecoinvent data sets. However, there are only approximate matching data sets, so that due to the poor data situation, the results for the GHG emissions contain a great deal of uncertainty. It therefore remains unclear whether the results would be directionally reliable.
- **W032** (sludges from industrial waste water): The two main streams in this category originate from the paper industry (see also para. 7.1.2.2 on W032). The other flows are mainly from wastewater treatment, which is not considered in this study. Since an additional amount of paper is estimated in W072, the two flows from the paper industry are also omitted from W032 to avoid double counting. In addition, it cannot be said for the EU statistics whether the allocation of W032 for Germany is transferable to the EU27. Thus, W032 is completely disregarded in the C&I waste balance.
- **W071, W074** (glass waste, plastic waste): Delimitation to the MSW balance area: the waste quantities that were taken into account in the MSW balance and can no longer come from NACE EP_HH and G-U in the reconciliation with the European statistics, are assigned 100% to NACE C. The quantity to be considered for the C&I waste balance is reduced accordingly.[90]
- **W072** (paper and cardboard waste): the statistically reported quantities are considered within MSW, as all LoW-codes are already included in the MSW balance or represent secondary waste. However, in comparison with association data on the use of domestic recovered paper quantities in paper mills (VDP 2019), a relevant statistical coverage gap seems to exist (see Chapter 7.1.2.2, W072). This quantity of approx. 7.2 million tons in 2017 is taken into account in the C&I waste balance.
- **W101** (household and similar waste) is completely excluded from the C&I waste balance, as all relevant LoW-codes are already included in the MSW balance.
- **W102** (Mixed and undifferentiated materials) is completely excluded from the balance of C&I waste, as similar to W032 it is mainly waste from paper production. Since an additional amount of paper is considered in W072, W102 is omitted from the C&I waste balance to avoid double counting.

The distribution on final treatment options (s. Table 59) was adjusted for the following categories:

- **W073** (Rubber waste): This refers exclusively to used tyres. For used tyres, Eurostat reports 68% of the generation as recycling, the values for incineration without energy recovery (D10) and with energy recovery (R1) are marked as confidential. According to association data (VDZ 2018 and WDK 2018) approx. 200,000 tons are burned in cement plants. This

[90] Subtraction simplistically equally distributed from each NACE C subcategory.

corresponds well to the 32% (185,000 tons) not reported according to Eurostat. Consequently, a distribution of 68% recycling and 32% R1 (incineration in the cement plant) is used as a basis for the balancing. This distribution corresponds well with the data according to Destatis (2019b), according to which 71% goes to recycling and 29% to combustion plants. According to WDK (2018) however, only 229,000 tons of used tyres are recycled into granulate/rubber powder, a further approx. 73,000 tons are retreaded, and approx. 75,000 tons are re-used (both domestic+export). However, quantities for retreading and re-use should not actually be included in the waste regime, so that the quantity for recycling reported by Eurostat and Destatis (2019b) at approx. 400,000 tons appears to be too high, and the value from WDK (2018) too low.

- **W075** (wood waste): For waste wood, Eurostat reports 71% of the generation as incineration with energy recovery (R1). Further information on the destination is missing due to confidentiality. According to Destatis (2019b), 80% is directly recovered for energy and 17% is first processed. Overall, a 100% recovery of the flows relevant for the C&I waste balance can be assumed in a simplified manner in combustion plants if the distribution split applied for the treatment of waste wood from intermediate treatment plants (construction and demolition waste, 80% R1 and 20% recycling) is also applied for C&I waste.
- **W091, W092** (Animal and mixed food waste): Eurostat reports a distribution of 87% recycling and 13% incineration with energy recovery (R1) for these two EWC-Stat codes. The comparison with Destatis (2019b) leads to a distribution of 78% recycling and 22% incineration with energy recovery (R1) for the categories to be considered in the C&I waste balance (based on the same end-use assumptions as in the food waste balance, for a detailed description see Chapter 6). The distribution is therefore adjusted accordingly.

7.1.2.2 Analysis of the relevant LoW-codes and the destinations

For each of the EWC-Stat codes considered for the C&I waste balance, the following is a comparative discussion of the values available from Eurostat and Destatis (2019b) available values. The previously excluded categories W012, W02A, W032, W101, W102 and W11 are not considered here. In addition, the dominant LoW-codes in each case are highlighted and their whereabouts discussed.

W05 Medical and biological waste

The volume in this category is around 350,000 tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is -2%[91] . Only waste to be included in the C&I waste balance is included. Therefore, the breakdown to the final destination according to Eurostat is taken over unchanged (s. Table 59).

In total, the category contains 5 LoW-codes. It is by far dominated by one LoW-code:

Table 60: Overview of the most important LoW-codes of the EWC-Stat code W05

LW-code	Designation	Origin	Share[92]
18 01 04	Waste whose collection and disposal is not subject to special requirements from an infection prevention point of	Waste from obstetrics, diagnosis, treatment or prevention of human disease	98%

[91] Values < 0% mean that the extrapolation based on Eurostat is lower than Destatis (2019b).

[92] The percentage refers to the share of electricity used in the C&I waste balance sheet.

	view (e.g. wound and plaster dressings, linen, disposable clothing, nappies).		

Also according to the data from Destatis (2019b) this waste is disposed of almost exclusively in incineration plants. However, thermal waste treatment plants also usually have R1 status in Germany. Information on whether some of the hospital waste is also disposed of in hazardous waste incineration plants (with D10 status) was (Destatis 2019b) not available. In the GHG balance, the destination is implemented according to Eurostat data.

W06 Metallic waste

The volume in this category is around 12 million tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is +3%. This category includes ferrous metals (W061, 84%), non-ferrous metals (W062, 11%) and mixed metals (W063, 5%). This includes relevant quantities from the MSW balance as well as from the construction and demolition waste balance (see Chapters 5 and 0) as well as secondary waste. The lump-sum qualitative classification of the NACE origins gives a good agreement, within the limits of accuracy, between the quantities derived from Destatis (2019b) and the quantities derived from Eurostat for the C&I waste balance (2.1 and 2.8 million tons, respectively). For reasons of consistency, the value derived from the European statistics will be used for the balance in the following (cf. Table 58).

In total, the category contains 25 LoW-codes. The main contributions come from the following LoW-codess:

Table 61: Overview of the most important LoW-codes of the EWC-Stat code W06

LoW-code	Designation	Origin	Share[93]
10 02 10	Mill scale	Waste from the iron and steel industry	14%
12 01 01	Iron filings and turnings	Wastes from shaping and physical and mechanical surface treatment of metals and plastics	30%
12 01 02	Iron dust and parts	Wastes from shaping and physical and mechanical surface treatment of metals and plastics	46%
12 01 03	Non-ferrous metal filings and turnings	Wastes from shaping and physical and mechanical surface treatment of metals and plastics	4%
12 01 04	Non-ferrous metal dust and particles	Wastes from shaping and physical and mechanical surface treatment of metals and plastics	5%
Total			**99%**

The analysis of the destination for the relevant LoW-codes shows that only minor shares are sent to landfill and combustion plants. The majority goes to intermediate treatment facilities

[93] The percentage refers to the share of electricity used in the C&I waste balance sheet.

(28% shredders/scrap shears, 17% sorting facilities, 50% other treatment facilities). Assuming that these quantities are ultimately returned to recycling, the breakdown by final destination according to Eurostat can be adopted. A smaller share of quantities (approx. 2%) to combustion plants is not considered further. In the GHG balancing, it must be considered that the metal chips in question are fine and only adhere to the cooling liquid (max. 3%), so that higher yields are assumed for recycling than for metals from MSW or C&D waste.

W071 Glass waste

The volume in this category is around 3.4 million tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is -2%. This includes relevant quantities from both the MSW balance and the construction and demolition waste balance (see Chapters 5 and 0) as well as secondary waste are included. Only one key is fully allocated to NACE sector C.

This means that the quantities to be taken into account according to Destatis (2019b) for the C&I balance sheet are initially significantly lower than the value derived according to Eurostat. The following plausible assumptions are made for reconciliation:

1. The quantities derived from the MSW balance, which could no longer originate from the household and commercial sectors in the comparison with the European statistics, are completely allocated to NACE sector C. For the orienting balance, this "excess quantity" is subtracted from the quantities of all NACE C subsectors to be taken into account in the C&I waste balance in a simplified, equally distributed manner.
2. The quantities reported as secondary waste with LoW 19 12 05 were reconciled with the quantities reported from NACE E 38 (waste collection, treatment). The reconciliation showed that almost half of the quantity according to Destatis is reported by sectors other than NACE E 38. This share was also completely assigned to NACE sector C and thus taken into account in the volume evaluation according to Destatis (2019b) taken into account.

With these assumptions, a very good agreement was achieved between the quantities derived based on Destatis (2019b) and Eurostat for inclusion in the C&I waste balance (approx. 400,000 t, deviation 1%).

Accordingly, two of a total of 6 LoW-codes are taken into account in the balance of C&I waste in this category:

Table 62: Overview of the most important LoW-codes of the EWC-Stat code W071

LoW-code	Designation	Origin	Share[94]
10 11 12	Glass waste other than that mentioned in 10 11 11	Wastes from the manufacture of glass and glass products	68%
19 12 05	Glass (as a share not reported by NACE E 38)	Wastes from mechanical treatment of waste (e.g. sorting, shredding, compacting, pelletising), not otherwise specified	32%
Total			**100%**

[94] The percentage refers to the share of electricity used in the C&I waste balance sheet.

The breakdown by final destination according to Eurostat can be adopted unchanged for the sake of simplicity (cf. Table 59). Almost complete recycling is probable as the final destination for the waste from glass production.[95] For the glass waste assigned to the secondary waste code, it also seems plausible after mechanical pre-treatment that it will be recycled.[96]

W072 Paper and cardboard waste

The volume in this category is around 7.9 million tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is 2%.[97] . In total, three LoW-codes are included, but these are fully covered by the MSW balance (15 01 01, 20 01 01) or represent a secondary waste (19 12 01). Therefore, this category is not considered for the balancing of C&I waste.

In contrast to the Destatis (2019b) reported volumes of approximately 7.9 million tons of paper waste per year, the Association of German Paper Mills (VDP) reports a volume of 15.2 million tons of recovered paper purchased from the domestic market or exported in 2017 (VDP 2019). It is concluded from this that in the case of paper, relevant waste quantities are not recorded statistically because they are not delivered to waste treatment plants but directly to paper mills (see also ARGUS et al. 2019). Taking into account 1% sorting losses in the quantities delivered to intermediate treatment plants and statistically recorded in W072, and additionally taking into account a small quantity of statistically recorded paper composites resulting as output from LWP sorting (approx. 300,000 tons, see Chapter 5), the coverage gap between the figures from Destatis (2019b) and VDP (2019) amounts to around 7.2 million tons in 2017.

For the purposes of the indicative balance sheet, it is assumed that these quantities delivered directly to paper mills can be completely assigned to NACE sectors C and G-U for simplification. Quantities could also be delivered from agriculture or the construction industry (NACE A and F), but the volume is classified as low for these origins. Accordingly, the entire 7.2 million tons of waste paper are included in the C&I waste balance.

W073 Rubber waste

The category W073 includes used tyres as the only LoW-code. The volume amounts to approx. 600,000 tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is -6%.[92] Based on the analysis of the Eurostat data, 96% of the waste amount can be allocated to the C and G-U sectors. However, Eurostat only reports 68% of the waste as recycled; the values for incineration without energy recovery (D10) and with energy recovery (R1) are marked as confidential. The comparison with association data (VDZ 2018, WDK 2018) shows that approx. 200,000 tons are incinerated in cement plants. This corresponds well to the missing reported destination of 32% (see Chapter. 7.1.2.1, Table 59). When balancing the recycling, it should also be taken into account that Destatis (2019b) and Eurostat report just under 400,000 tons, but (WDK 2018) only 231,000 tons are mentioned for recycling as granulates and rubber powder (other quantities for re-use and retreading). An explanation for this cannot be found. The quantities allocated to re-use/retreading in Germany are used tyres, not scrap tyres.

W074 Plastic waste

The volume in this category is around 2.8 million tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is 2%.[92] This includes relevant quantities from

[95] According to Destatis (2019b) 97% goes to intermediate treatment plants (shredders/scrap shears, sorting plants, other treatment), and a further just under 2% to landfill.

[96] No information on destinations available from Destatis (2019b).

[97] The percentage refers to the share of electricity used in the C&I waste balance sheet.

the MSW balance as well as from the construction and demolition waste balance (see Chapter 8) as well as secondary waste. Only two of the total of eight LoW-codes are completely assigned to NACE sector C.

This means that the quantities to be taken into account according to Destatis (2019b) for the C&I balance sheet are initially significantly lower than the value derived according to Eurostat. The following plausible assumptions are made for reconciliation:

1. The quantities derived from the MSW balance sheet, which could no longer come from the household and commercial sectors in the reconciliation with European statistics,[88] are completely assigned to NACE sector C. For the orienting balance, this "excess quantity" is subtracted from the quantities of all NACE C subsectors to be taken into account in the C&I waste balance in a simplified, equally distributed manner.
2. The quantities reported as secondary waste with LoW-code 19 12 04 were reconciled with the quantities reported from NACE E 38. The reconciliation showed that a small share of the quantity according to Destatis is reported by sectors other than NACE E 38. This share was also completely assigned to NACE sector C and thus taken into account in the quantity evaluation according to Destatis (2019b).

However, the value determined on the basis of Eurostat is still approx. 100,000 tons (19%) higher than the value estimated from Eurostat. Destatis (2019b). An explanation for the deviation is offered by extrapolating the total volume according to Eurostat to the year 2017. The resulting value is approx. 70,000 tons higher than that reported by Destatis (2019b) reported. For the balance of C&I waste, the value derived from the European statistics is used in the following to increase consistency with the approach for the other countries.

Accordingly, three out of eight LoW-codes are considered in this category, which is dominated by one LoW-code from manufacturing and processing of plastics:

Table 63: Overview of the most important LoW-codes of the EWC-Stat code W074

LoW-code	Designation	Origin	Share[98]
07 02 13	Plastic waste	Waste from the MFSU of plastics, synthetic rubber and synthetic fibres	77%
19 12 04	Plastics and rubber (as a share not reported by NACE E 38)	Wastes from mechanical treatment of waste (e.g. sorting, shredding, compacting, pelletising), not otherwise specified	15%
12 01 05	Plastic chips and turnings	Wastes from shaping and physical and mechanical surface treatment of metals and plastics	8%
Total			**100%**

The breakdown by final destination according to Eurostat can be adopted unchanged for the sake of simplicity (see Table 59) if it is assumed that approx. 90% of the quantities from the intermediate treatment plants (shredders/scrap shears, sorting plants, other treatment plants) go to recycling. This seems possible especially for waste from manufacturing and processing.

[98] The percentage refers to the share of electricity used in the C&I waste balance sheet.

W075 Wood waste

The volume in this category is approx. 11.5 million tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is 5%. This includes relevant quantities from both the MSW balance and the C&D waste balance (see Chapters 5 and 0) as well as secondary waste. Three of the total of seven LoW-codes are fully assigned to NACE C and G-U. In addition, the share of LoW-code 19 12 07 that was not reported under NACE E 38 is also considered as NACE C and G-U. In this way, a good correspondence of the quantities derived based on Destatis (2019b) or Eurostat for consideration in the C&I waste balance (deviation 5%). Thus, 30% of the waste has to be considered in the C&I waste balance:

Table 64: Overview of the most important LoW-codes of the EWC-Stat code W075

LoW-code	Designation	Origin	Share[99]
03 01 05	Sawdust, shavings, cuttings, wood, chipboard and veneer with the exception of those which fall under 03 01 04	Waste from wood processing and the production of panels and furniture	59%
03 01 01, 03 03 01	Bark and cork waste, wood waste	Wood processing & protection	18%
19 12 07	Wood other than that mentioned in 19 12 06 (as a fraction not reported by NACE E 38)	Wastes from mechanical treatment of waste (e.g. sorting, shredding, compacting, pelletising), not otherwise specified	22%
Total			**100%**

If the quantities that go to Destatis (2019b) to intermediate treatment plants (shredders/scrap shears, sorting plants, other treatment plants) are divided between recycling and energy recovery with the same split as used in the C&D waste balance (80% incineration (R1), 20% recycling, cf. Chapter 8.1.2.2, Table 75), this results in a total allocation of 94% to energy recovery. 3% is recycled and 2% goes to biological treatment.

In view of the orientational character of the C&I waste balance, a complete allocation to energy recovery is assumed for the final destination of wood waste for simplification purposes. The European statistics show 71% of the entire category as energy recovery. For the remaining quantity, there is no information on the destination due to confidentiality. In Table 59, 100% incineration with energy recovery is therefore shown for category W075, which is used as a basis for the subsequent balancing of GHG emissions. The evaluation of the additional tables (Destatis 2019b) shows that of the quantities delivered directly to combustion plants, approx. 60% are burnt in Biomass CHP plants and approx. 40% in heating plants.

W091 Animal and mixed food waste, W092 Vegetable waste

The total volume in categories W091 and W092 is approx. 10.5 million tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is 3%.[100] A total of 22 LoW-codes are included in these categories. Two of them are already fully included in the

[99] The percentage refers to the share of electricity used in the C&I waste balance sheet.

[100] The waste from the bio bin was deducted from the Eurostat value. For the European statistics, this is reported under LoW-code 20 02 01 and thus in W092. In the evaluation based on Destatis (2019b), this quantity would be included under LoW-code 20 03 01 and thus in W101.

MSW balance (LoW-code 20 01 08, 20 02 01), so they may no longer be included in the C&I waste balance. For all other LoW-codes, all source sectors except agriculture (NACE A) were taken into account as agreed. The corresponding shares were appliedd according to Destatis (2020). This means that the shares calculated according to Destatis (2019b and 2020) to be taken into account for the C&I balance are thus initially 16% lower than the value derived according to Eurostat. No explanation could be found for the deviation, except that the extrapolation of the quantities to the year 2017 at the European level possibly leads to an overestimation in some places. In any case, approx. 30% of the total waste volume must be taken into account for the C&I waste balance.

The main contributions are relatively strongly distributed in categories W091 and W092.

For W091 they come from the following LoW-codes:

Table 65: Overview of the most important LoW-codes of the EWC-Stat code W091

LoW-code	Designation	Origin	Share[101]
02 02 02, 02 01 02	Animal tissue waste	Waste from the preparation and processing of meat, fish and other food of animal origin	23%
02 02 03	Substances unsuitable for consumption or processing	Waste from the preparation and processing of meat, fish and other food of animal origin	54%
02 05 01	Substances unsuitable for consumption or processing	Waste from the dairy products industry	7%
19 08 09, 20 01 25	Fats and oils	from grease/oil separators and edible oils/fats	13%
Total			**98%**

In W092 the following LoW-codes are relevant:

Table 66: Overview of the most important LoW-codes of the EWC-Stat code W092

LoW-code	Designation	Origin	Share[102]
02 01 03	Vegetable tissue waste	Waste from agriculture, horticulture, aquaculture, forestry, hunting and fishing	13%
02 01 07	Waste from forestry	Waste from agriculture, horticulture, aquaculture, forestry, hunting and fishing	18%
02 03 01	Sludges from washing, cleaning, peeling, centrifuging and separation processes	Wastes from fruit, vegetable, Grain, edible oil, cocoa, coffee, tea and tobacco preparation and processing; canning; yeast and yeast extract	11%

[101] The percentage refers to the share of electricity used in the C&I waste balance sheet.

[102] The percentage refers to the share of electricity used in the C&I waste balance sheet.

		production, molasses preparation and fermentation	
02 03 04	Substances unsuitable for consumption or processing	Wastes from fruit, vegetable, Grain, edible oil, cocoa, coffee, tea and tobacco preparation and processing; canning; yeast and yeast extract production, molasses preparation and fermentation	27%
02 06 01	Substances unsuitable for consumption or processing	Waste from the baking and confectionery industry	14%
02 07 02	Waste from alcohol distillation	Wastes from the production of alcoholic and non-alcoholic beverages (except coffee, tea and cocoa)	15%
Total			**97%**

The same approach was used to analyse the destination as for the food waste balance sheet (see Chapter 6). [103] This results in a final destination of 78% for recycling (anaerobic digestion, composting, transesterification) and 22% for energy recovery (cement plant or biomass power plant) for the main contributions. The breakdown of the final destination derived from the European statistics is adjusted accordingly (see Table 59).

W124 Combustion residues

Under incineration residues, slag, ash, dust, dross and scum and other solid residues are reported. The generation in this category is around 16 million tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is +5%.[104] A total of 50 LoW-codes are included in these categories. In the lump-sum qualitative classification, waste from power plants and other incineration plants (LoW 10 01 xx) was completely assigned to NACE D. All other LoW-codes were fully classified as NACE C and G-U. This leaves after Destatis (2019b) approx. 3.3 million tons to be considered for the C&I waste balance. The evaluation of the European statistics results in approx. 4 million tons The relatively high deviation is presumably due to the lump-sum qualitative classification of the NACE origin for the data of Destatis (2019b). For the rest of the work, therefore, the value determined from the European statistics is taken as a basis (cf. Table 58).

The main contributions come from the following LoW-codes:

Table 67: Overview of the most important LoW-codes of the EWC-Stat code W124

LoW-code	Designation	Origin	Share [105]
10 02 01	Waste from the processing of slag	Waste from the iron and steel industry	18%

[103] Packaging shares were neglected for the orienting balancing of C&I waste.

[104] The percentage refers to the share of electricity used in the C&I waste balance sheet.
105 The percentage refers to the share of electricity used in the C&I waste balance sheet.

10 02 02	Unprocessed slag	Waste from the iron and steel industry	38%
10 02 08	solid wastes from waste gas treatment other than those mentioned in 10 02 07	Waste from the iron and steel industry	12%
10 05 01	Slags (first and second smelting)	Waste from thermal zinc metallurgy	7%
10 09 03	Furnace slag	Wastes from the casting of iron parts	9%
Total			**83%**

For the primary destination, Destatis (2019b) mainly shows quantities for landfilling (42%). Deliveries for other treatment (25%) and to construction waste processing plants (5%) as well as for landfill construction (11%) are also relevant. A clear allocation to the end destination cannot be concluded from this. The allocation to final destination according to Eurostat is therefore largely adopted for the sake of simplicity. The smaller share of quantities (approx. 2%) for combustion plants is not taken into account (see "Waste to energy"). Table 59).

W12B Other mineral wastes (W123, W125)[106]

The total volume in this category is approx. 30 million tons in 2017. The deviation between Destatis (2019b) and the extrapolation based on Eurostat is -10%.[107] In total, this category comprises 48 LoW-codes, 14 of which originate from LoW Chapter 01. However, since based on the analysis of European statistics only a very small part can be assigned to NACE B (4%), these were also classified as NACE C and G-U on a flat-rate basis. Three LoW-codes were excluded as secondary waste. One code of minor importance in terms of volume is already fully considered in the MSW balance. Thus, the lump-sum qualitative classification results in a 19% higher quantity for consideration in the C&I waste balance than derived from the European statistics. In addition to the larger total volume identified, this reflects the uncertainty in the classification of waste, especially from LoW Chapter 01, and must be kept in mind when assessing the main contributions.

By far the largest amount comes from waste from mineral mining. Two other LoW-codes provide additional noticeable shares:

Table 68: Overview of the most important LoW-codes of the EWC-Stat code W12B

LoW-code	Designation	Origin	Share[108]
01 01 02	Wastes from the extraction of non-metallic mineral resources	Waste from mineral extraction	83%
10 09 08	Casting moulds and sands after casting other than those mentioned in 10 09 07 fall	Wastes from the casting of iron parts	5%

[106] W122 Asbestos waste is also included in W12B by definition, but is not part of this consideration as all asbestos waste is classified as hazardous.

[107] The percentage refers to the share of electricity used in the C&I waste balance sheet.
[108] The percentage refers to the share of electricity used in the C&I waste balance sheet.

01 04 11	wastes from the processing of potash and rock salt other than those mentioned in 01 04 07	Wastes from the physical and chemical processing of non-metallic minerals	4%
Total			**92%**

The quantities from LoW 01 01 02 are reported by Destatis (2019b) almost completely reported under "Disposal of mining waste" (Table 14.1). If this type of disposal is classified as landfilling, the final destination reported according to the European statistics can be retained for simplification (cf. Table 59).

With regard to the GHG balance, it must be taken into account that although very high quantities[109] are generated in this category, this mainly involves the landfilling of mineral waste. The specific climate relevance of the treatment is therefore very low. For the GHG balance, the transports are also estimated in order to see whether this results in a relevant contribution to the emissions due to the high quantities.

7.1.3 Quantity and destination for the balancing

The derivation described above leads to the quantities shown in Table 69 for the generation and destination of the C&I waste considered in this study. For the destination, very small quantities are not considered in the GHG balance (cut-off criterion < 1%). The quantities shown correspond to the quantities resulting from the documented and considered destination. The volume considered in this way is 0.7% lower than that shown in Table 59 reported. The volume shown in Table 69 is higher overall because it includes the estimated paper quantity.

[109] More than 50% of all flows to be considered for the C&I waste balance.

Table 69: Basic table: final treatment of C&I waste, 2017 Germany in tons

	Recycling	Backfilling	R1 energy recovery	D10 combustion	Landfill	Other disposal	Total final treatment
Hospital waste (W05)	0	0	315,000	45,000	0	0	360,000
Ferrous metals (W061)	2,357,000	0	0	0	0	0	2,357,000
Non-ferrous metals (W062)	391,000	0	0	0	0	0	391,000
Mixed metals (W063)	47,000	0	0	0	0	0	47,000
Glass waste (W071)	402,000	0	0	0	5,000	0	407,000
Paper (W072)	7,200,000						7,200,000
Used tyres (W073)	385,000	0	185,000	0	0	0	570,000
Plastic waste (W074)	421,000	0	106,000	0	0	0	527,000
Wood waste (W075)	0	0	3,627,000	0	0	0	3,627,000
Organic waste (W091, W092)	2,768,000	0	781,000	0	0	0	3,549,000
Combustionwaste (W124)	632,000	808,000	0	0	2,435,000	0	3,875,000
Other mineral wastes (W12B)	1,275,000	1,195,000	0	0	24,384,000	0	26,854,000
Total	**15,878,000**	**2,003,000**	**5,014,000**	**45,000**	**26,824,000**	**0**	**49,764,000**

Figure 20 shows the material flows considered for C&I waste as a Sankey diagram. In Figure 21 the amount of the waste types for final treatment is shown as a bar chart. Both diagrams visualise that C&I waste by mass is dominated by "other mineral waste" (W12B). This waste fraction takes up more than 50% of the total quantity. It is followed by the estimated paper waste quantity with a mass share of 14%. Among the other waste fractions, ferrous metals, wood, organic waste and incineration residues account for between 5% and 7% of the total quantity. The percentage share of the remaining waste fractions is around or < 1% in each case.

Figure 20: Sankey diagram C&I waste Germany 2017

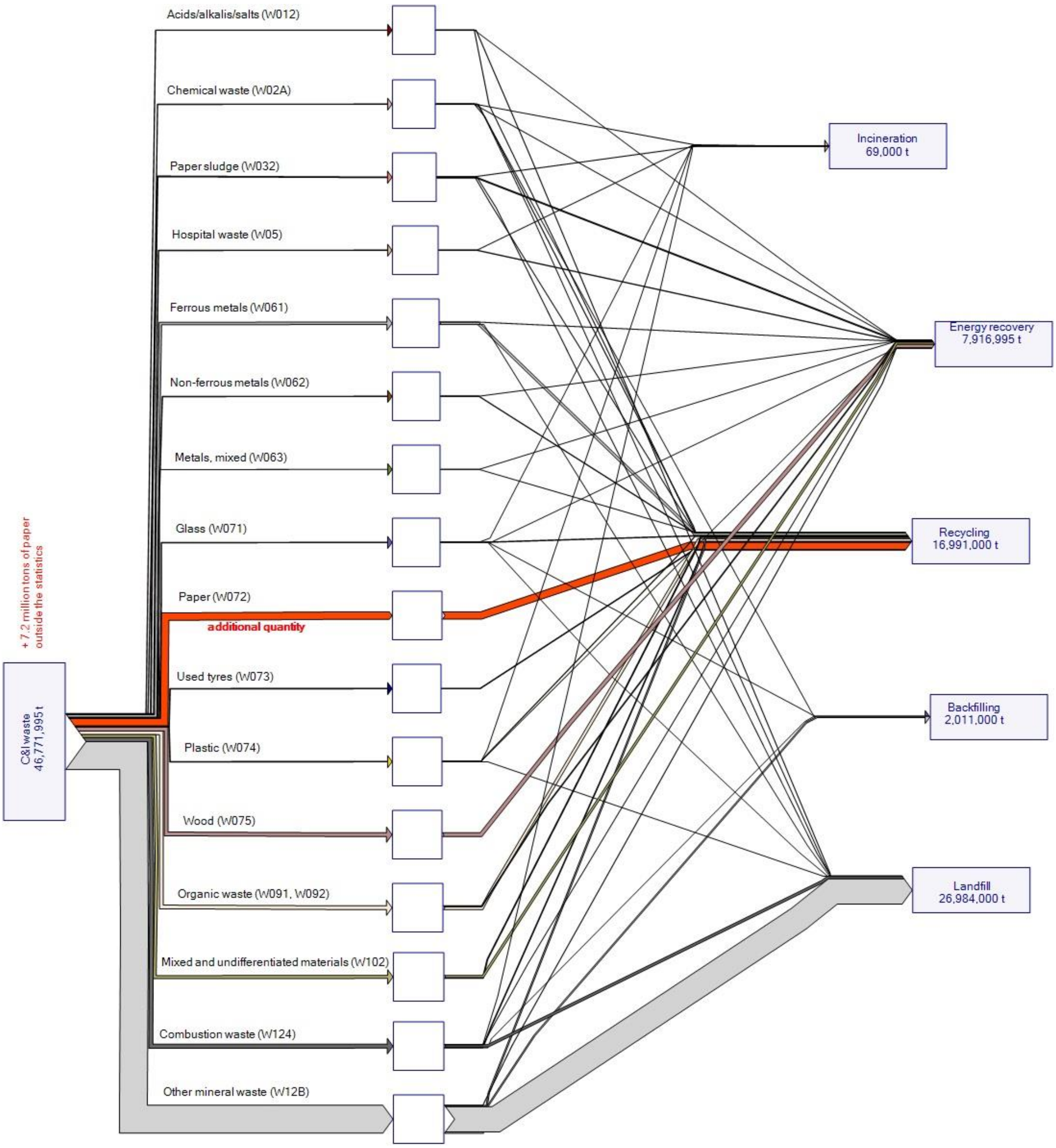
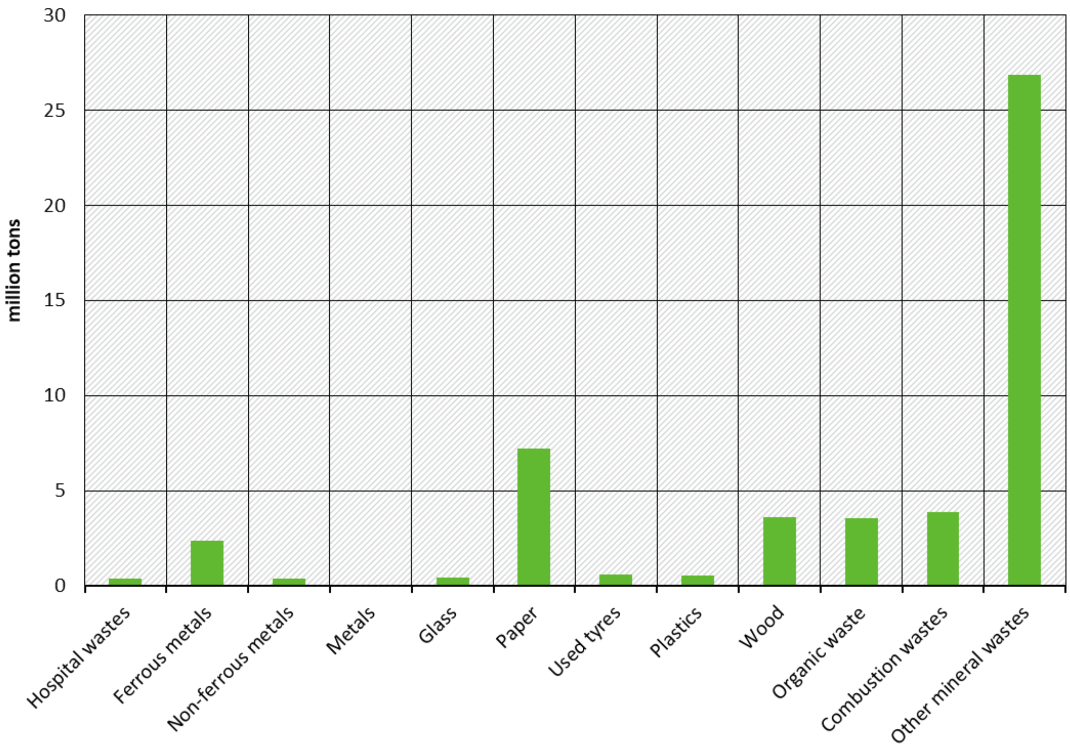


Figure 21: Quantity of final treatment C&I waste Germany 2017



7.2 Procedure of balancing and characteristics of waste fractions

C&I waste is accounted for according to the waste fractions and the final treatment specified in the previous chapter. Insofar as sorting expenditures from primary treatment are relevant and can be mapped, as in the case of dry recyclables, input quantities for these are recalculated in the balance on the basis of sorting losses. The procedure for balancing is described below according to the different waste fractions.

Dry recyclables (W061, W062, W063, W071, W072, W074)

The dry recyclables from the C&I waste - the metals, glass, paper and plastics - are almost exclusively assigned to recycling after final treatment. An exception is a smaller amount of glass waste, which is landfilled, and about 20% of the plastics, which are assigned to energy recovery.

The balancing of the recycling of dry recyclables is basically carried out in the same way as the balancing of the dry recyclables in MSW as described in Chapter 4.2.7. For individual types of waste, such as metals and plastics, higher recycling yields are assumed (Table 15). The division of mixed metals into ferrous and non-ferrous metals is based on the division of the pure fractions and results in 86% ferrous metals and 14% non-ferrous metals for the metals from C&I waste (Table 14). These differences also result in slightly different specific emission values, which are shown in Table 89.

No GHG emissions are generated for the landfilling of glass waste. For the proportional energy recovery of plastics, the characteristic data - calorific value and fossil C content - were calculated according to the market mix for plastics in Germany (Table 13). For the individual types of plastic waste, the corresponding values according to IPCC (2006Volume 5, Chapter 2). The calculated characteristic data result in:

- ► Calorific value: 34.2 MJ/kg
- ► Fossil C content: 69.9%

The balancing of energy production in thermal waste treatment corresponds to the procedure described in Chapter 4.2.4. The average values resulting from the data according to Flamme et al. (2018) (11.3% electrical, 34.0%thermal) are used as utilisation rates..

Wood (W075)

Wood waste from C&I waste in Germany in 2017 was exclusively sent to energy recovery for final treatment. The accounting corresponds to the procedure described in Chapter 4.2.9 for use in biomass CHP plant.

Used tyres (W073)

In 2017, 68% of used tyres in Germany were recycled and 32% were co-incinerated in cement plants. For co-incineration, the calorific value was set at 28MJ/kg. This value corresponds to the data in VDZ (2018) for used tyres, which has been reported unchanged since 2008 and is considered representative for Germany[110] . The fossil C content for used tyres is set at 52.8% in accordance with the data in Flamme et al. (2018). According to Vogt & Ludmann et al. (2019) the calorific value is assessed at 26 MJ/kg and the fossil C-content at 51.6%, so that the combination of calorific value and fossil C-content chosen for this study is considered representative. In addition to the calorific value-equivalent substitution of the standard fuel coal, the steel content in the used tyre is also taken into account for the co-combustion of used tyres in cement plants, which, as in Schmidt et al. (2009) is set at 18% (range 15% - 20%). The steel content substitutes iron oxide, which is otherwise used for the production of cement clinker. In fact, this corresponds to downcycling; pig iron can be replaced in the recycling of steel.

The modelling for the recycling of used tyres follows the knowledge from e.g. Schmidt et al. (2009). Used tyres are usually first shredded in several stages (pre-shredding, granulation, fine grinding) and separated into the fractions steel, textile cord and rubber granulate. The steel is recycled in the steel industry (substitution of pig iron). The textile fraction is burnt in cement plants (calorific value 28.3 MJ/kg, fossil C content 28.6%) and replaces the standard fuel coal there. A smaller inert fraction, which is also separated, is landfilled. The main fraction, rubber granulate, can be produced in different grain sizes and qualities. The possible applications are manifold and differ significantly according to their substitution potential:

- Floor coverings (replacement of PVC, PP),
- Rubber-modified asphalt (substitute of styrene-butadiene-styrene and bitumen),
- Waste tyre granulate artificial turf (substitute of thermoplastic polymers (EPDM, TPE)),
- Sand pitches, equestrian surface (r substitute of sand),
- Building material (substitute of concrete, gravel, partly polyethylene),
- Rubber dust in new tyres (theoretically possible between 2-20%, according to the German Rubber Association (wdk) not suitable for quality tyres and reduces mileage and safety).

Information on the actual use of rubber granulate is not available. For this study, it was uniformly assumed for Germany and the EU that 50% fine rubber granulate is used in high-value applications such as asphalt or infill in artificial turf, thereby replacing fossil-based thermoplastics. For the other 50%, an application as a building material or for sand pitches was assumed, whereby mineral materials are replaced. In the first case, there is a comparatively high GHG avoidance performance, in the second case only a low one, as the provision of the inert primary raw materials is hardly associated with GHG debits.

[110] The calorific value of 30 MJ/kg given in Flamme et al. (2018) was not adopted.

Organic waste (W091, W092)

In 2017, organic waste in Germany was mainly recycled and 22% was recovered for energy. For energy recovery, the calorific value was roughly estimated at 15 MJ/kg; the fossil C content is set to zero, consistent with the procedure for food waste. The balancing of the energy generation in thermal waste treatment corresponds to the procedure described in Chapter 4.2.4. The average values resulting from the data according to Flamme et al. (2018) (11.3% electrical, 34.0% thermal) are uniformly used as utilisation rates..

The balancing of recycling for organic waste was derived from the balancing for food waste. For this purpose, volume-weighted specific emission values were calculated from the results for food waste from C&I waste (without the separately balanced incineration). These result in:

- Specific debit: 146 kg CO_2 eq/t Input
- Specific emission savings: -556 kg CO_2eq/t input
- Specific net emission savings potential: -410 kg CO_2eq/t input

Combustion residues (W124)

In 2017, 63% of incineration residues in Germany were landfilled, 21% were backfilled and 16% were recycled. For recycling, use in road and path construction was assumed. As the ashes and slags are inert, non-biologically active material, their disposal is not associated with any GHG emissions. Pollution is only caused by transport, the influence of which is of minor importance.

Other mineral waste (W12B)

Other mineral waste, which makes up the main mass of C&I waste, was landfilled to 91%, backfilled to 4% and recycled to 5% in Germany in 2017. For recycling, use in road and path construction was assumed. Since this waste fraction is inert material, its disposal is not associated with any GHG emissions. Expenditure is only caused by transport, the influence of which is of minor importance despite the comparatively high mass share.

Hospital waste (W05)

In 2017, 87.5% of hospital waste in Germany was recycled for energy in thermal waste treatment plants and 12.5% was thermally treated without energy generation. The characteristic data for incineration were taken from (Vogt / Ludmann 2019):

- Calorific value 14.9 MJ/kg
- fossil C content: 19%

The balancing of energy production in thermal waste treatment plants corresponds to the procedure described in Chapter 4.2.4. As utilisation rates, the average values resulting from the data according to Flamme et al. (2018) (11.3% electrical, 34.0% thermal) were used. For thermal treatment without energy generation, there is no emission savings potential.

7.3 Description of the scenarios

For C&I waste, two scenarios are designed that differ in their ambitions and consider both material flow diversions and optimisation potentials. The ambitious scenario 2 uses the potentials here within a technically feasible framework, while scenario 1 is based on the same assumptions, but assumes significantly lower improvements.

The following wastes have no optimisation potential in either scenario:

- Hospital waste (W05)

- Ferrous metals (W061)
- Non-ferrous metals (W062)
- Mixed metals (W063)
- Glass waste (W071)
- Combustion residues (W124)
- Other mineral wastes (W12B)

The following table provides an overview of the shifts in the waste streams assumed in both scenarios.

Table 70: Percentage shifts between the utilisation endpoints for scenarios 1 and 2

	Scenario 1		Scenario 2	
Waste stream	**Energy recovery**	**Recycling**	**Energy recovery**	**Recycling**
Used tyres	- 2%	+ 2%	- 5%	+ 5%
Plastic	- 5%	+ 5%	- 10%	+ 10%
Wood	- 5%	+ 5%	- 10%	+ 10%
Organic waste	- 2%	+ 2%	- 7%	+ 7%

For plastic waste, an increase in yield from 80% to 85% is also assumed as a technical optimisation.

7.3.1 Scenario 1 "C&I 2030 SC1

The following assumptions are made for the individual waste streams in Scenario 1:

Used tyres (W073)

The recycling rate is 68% and an optimisation potential of 2% is conservatively seen. This is justified by the ongoing trend of increasing material recycling of used tyres (increase in recycling of around 0.5% per year).

Plastic (W074)

The recycling rate is 80% and an optimisation potential of 5% is conservatively seen. This is justified by technological progress, which means that previously non-recyclable plastic waste (e.g. punching waste from multilayer material) can be recycled in the future (e.g. via the newcycling process), and better sorting leads to increased recycling.

Wood (W075)

Wood waste is 100% recycled for energy[111] . Conservatively, a shift potential of 5% towards material recycling (chipboard production) is seen here. This is justified by the fact that material recycling is already possible today in chipboard (e.g. 90% waste wood share in Italy). For economic reasons, however, this is not carried out, as energy recovery brings more money.

Organic waste (W091, W092)

[111] Simplification, see Chapter 7.1.2.1

The recycling rate is 78% and an optimisation potential of 2% is conservatively seen. This is justified by the potential for the recycling of oils and fats, which can be fully used in biodiesel production, as well as a shift towards anaerobic digestion.

These assumptions result in the following changes:

For used tyres (W073), 11,400 tons are shifted from energy recovery (R1) to recycling. For plastics (W074), 26,350 tons are shifted from energy recovery (R1) to recycling. For wood (W075), 181,350 tons are shifted from energy recovery (R1) to recycling. For organic waste (W091, W092), 70,980 tons are shifted from energy recovery (R1) to recycling.

7.3.2 Scenario 2 "C&I 2030 SC2“

The following assumptions are made for the individual waste streams in Scenario 2:

Used tyres (W073)

The recycling rate is 68% and an optimisation potential of 5% is seen. This is justified by the ongoing trend of increasing material recycling of used tyres (increase in recycling of around 0.5% per year).

Plastic (W074)

The recycling rate is 80% and an optimisation potential of 10% is seen. This is justified by technological progress, which means that previously non-recyclable plastic waste (e.g. punching waste from multilayer material) can be recycled in the future (e.g. via the newcycling process).

Wood (W075)

Wood waste is 100% energetically utilised[111]. A shift potential of 10% towards material recycling (chipboard production) is seen here. This is justified by the fact that material recycling is already possible today in chipboard (e.g. 90% waste wood share in Italy). For economic reasons, however, this is not carried out, as energy recovery brings more money.

Organic waste (W091, W092)

The recycling rate is 78% and an optimisation potential of 7% is seen. This is justified by the potential for recycling oils and fats, which can be fully used in biodiesel production, and by a shift towards anaerobic digestion.

These assumptions result in the following changes:

For used tyres (W073), 28,500 tons are shifted from energy recovery (R1) to recycling. For plastics (W074), 52,700 tons are shifted from energy recovery (R1) to recycling. For wood (W075), 362,700 tons are shifted from energy recovery (R1) to recycling. For organic waste (W091, W092), 248,430 tons are shifted from energy recovery (R1) to recycling.

7.4 Results GHG balances

This chapter presents the results of the GHG balance of the actual situation (Table 69) in comparison with the two scenarios described above for the year 2030. In principle, the results are to be understood as orientational due to data uncertainties and data gaps (cf. Chap. **Fehler! Verweisquelle konnte nicht gefunden werden.**). The following designations are used for the figures:

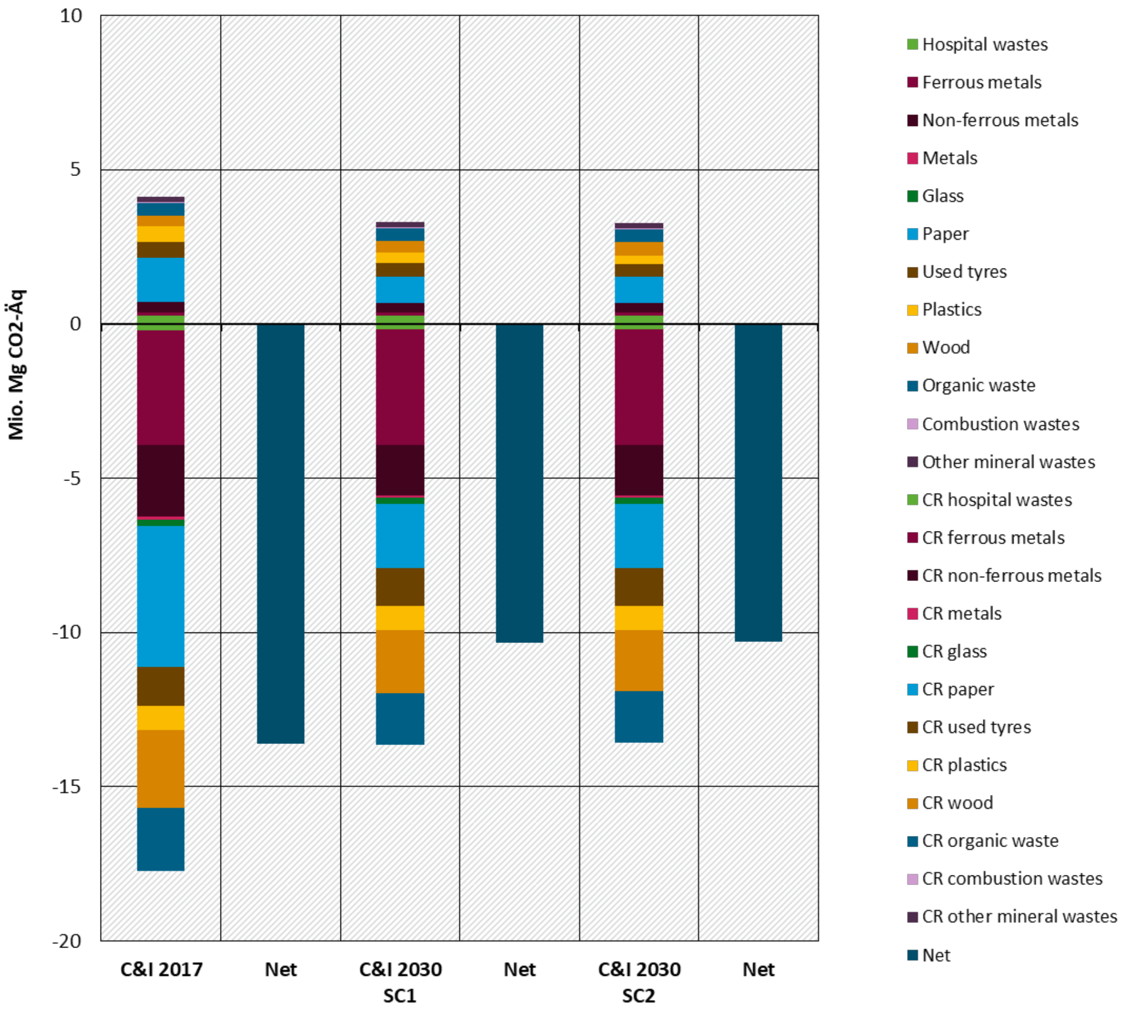
- Actual situation 2017: "C&I 2017"
- Scenario 1 2030: "C&I 2030 SC1"

- Scenario 2 2030: "C&I 2030 SC2"

Figure 22 shows the absolute results according to the debits and credits of the waste fractions as well as the total net result in a year-on-year comparison. For the **actual situation in 2017, there is an absolute net emission savings potential of around -13.6 million tons CO_2eq.** The underlying debits amount to around 4 million tons CO_2eq and the emission savings potential to around -18 million tons CO_2eq. The figure clearly shows that it is primarily the dry recyclables that make a significant contribution to the result, with a total share of 22%. The main masses of the other mineral wastes and also the incineration residues have no influence on the result due to their inert character. The transports taken into account for these types of waste are of minor importance in the overall result despite the high mass shares. In addition to the dry recyclables, the disposal of wood and organic waste also makes a visible contribution to reducing the debit.

The **comparative scenarios for 2030** show reduced debits and lower emission savings potentials. The two scenarios 1 and 2 differ only slightly in absolute terms. On the one hand, differences are only assumed for four waste types. On the other hand, the percentage shift shares for these overall and between the two scenarios are moderate at 2 - 5% (Scenario 1) and 5 - 10% (Scenario 2). For both comparison scenarios in 2030, the rounded **absolute net emission savings potential is -10.3 million tons CO_2eq**. The debits in both scenarios are around 3.3 million tons CO_2eq and the emission savings potential around - 13.6 million tons CO_2eq. The differences in the result - the overall somewhat low net emission savings potential compared to the actual situation - is mainly due to the defossilisation of the energy system. On the one hand, the GHG debits from energy demand decrease, but on the other hand, the substitution potentials for energy and primary products, the production of which is associated with a relevant electricity demand (paper, aluminium, see Chap. 4.2.7). This is countered by the optimisations for 2030, the above-mentioned shifts from energy recovery to recycling.

Figure 22: Scenario comparison C&I waste Germany



GS: Credit or emission savings potential

The overall GHG net results for C&I waste by waste fraction in absolute values as well as specific per capita and per ton for the actual situation in 2017 and for the comparative scenarios in 2030 (2030 SC1, 2030 SC2) are shown in Table 71.

For the EU balance, no separate balance is required for C&I waste for Germany with the emission factors for electricity and heat of the EU27. Since all quantity data - those for the EU27 and those for Germany - are derived from European statistics using the same procedure. For the EU27 balance, only the quantities for the EU27 without Germany are merged with those for Germany. For the 2030 scenario, scenario 2 is used for the EU balance, for which only one scenario is to be calculated.

Table 71 Absolute and specific net results by waste fraction – C&I waste Germany - actual situation 2017 and comparative scenarios 2030

Waste fraction	absolute	absolute	absolute	spec. per capita[1]	spec. per capita[1]	spec. per capita[1]	spec. per ton	spec. per ton	spec. per ton
C&I waste	**2017**	**2030 SC1**	**2030 SC2**	**2017**	**2030 SC1**	**2030 SC2**	**2017**	**2030 SC1**	**2030 SC2**
	t CO_2eq			kg CO_2eq/cap			kg CO_2eq/t		
Hospital waste	0.06	0.09	0.09	0.8	1.0	1.0	180	241	241
Ferrous metals	-3.63	-3.63	-3.63	-43.8	-43.8	-43.8	-1,538	-1,538	-1,538
Non-ferrous metals	-1.97	-1.33	-1.33	-23.8	-16.0	-16.0	-5,029	-3,398	-3,398
Metals	-0.10	-0.08	-0.08	-1.2	-1.0	-1.0	-2,035	-1,803	-1,803
Glass	-0.19	-0.19	-0.19	-2.3	-2.3	-2.3	-464	-459	-459
Paper	-3.16	-1.25	-1.25	-38.1	-15.1	-15.1	-438	-174	-174
Used tyres	-0.75	-0.79	-0.79	-9.0	-9.6	-9.6	-1,311	-1,389	-1,393
Plastics	-0.27	-0.44	-0.50	-3.3	-5.3	-6.1	-515	-831	-958
Wood	-2.21	-1.64	-1.56	-26.6	-19.8	-18.8	-608	-451	-429
Organic waste	-1.60	-1.28	-1.24	-19.3	-15.4	-15.0	-451	-360	-349
Combustion waste	0.04	0.04	0.04	0.4	0.4	0.4	9	9	9
Other mineral waste	0.17	0.17	0.17	2.1	2.1	2.1	6	6	6
Sum/average	**-13.59**	**-10.33**	**-10.28**	**-164.1**	**-124.8**	**-124.2**	**-273**	**-208**	**-207**

1) calculated with a population of 82,792,351 in 2017 (Federal Statistical Office (Destatis) 2017)

Based on the **specific net results by waste fraction per ton of waste,** the differences in results can be explained:

Non-ferrous metals in particular, and subsequently ferrous and mixed metals (86% ferrous metals), show high specific net emission savings potentials. This result was already evident in the case of MSW. The production of pig iron and aluminium is associated with comparatively high GHG emissions. However, it cannot be ruled out that the assumed yields for metals (Table 15) are overestimated. The net emission savings potential for used tyres is similarly high as for ferrous metals. The higher emission savings share is achieved here through material recycling, although only 50% of a high-quality application with substitution of fossil thermoplastics is assumed. The other waste fractions mostly show net emission savings potentials of a similar amount. An exception is hospital waste, which shows a debit in the net result. The results for the inert fractions incineration residues and mineral waste include the transport costs, which have a comparatively low significance despite a high mass share.

In the comparative scenarios 2030, the specific net results are changed since they are affected by defossilisation and/or assumed optimisations. The changes due to the defossilisation of the energy system for the dry recyclables are described in more detail for MSW (cf. Chap. 5.4.1). The impact on ferrous metals and glass is small. For non-ferrous metals, which are accounted for as aluminium, the specific net emission savings is lower due to the estimated reduced GHG impact of electricity-intensive primary production. This applies analogously to paper (Chap. 4.2.7.2). In the case of plastic waste, there is an increase in the specific net emission savings potential primarily due to the lower GHG debit for the electricity required for processing (defossilisation) and also due to the redirection of energy recovery (R1) to recycling (reduction of fossil CO_2 emissions from incineration). The specific emission savings potential is only slightly changed by the assumed increase in yield.

In the case of wood, the reduced specific net emission savings potential is primarily due to the lower credits for generated energy (defossilisation), which are only partially compensated for by the higher heat utilisation efficiency assumed for 2030. In addition, the proportionate diversion to recycling results in a reduced net emission savings, as chipboard recycling is associated with a lower specific net emission savings (see Chap. 4.2.9). For organic waste from C&I waste, the changes for recycling and energy recovery correspond to those described in the chapter on food waste. Recycling (predominantly anaerobic digestion) achieves somewhat lower net emission savings potentials than the energy recovery of this biogenic waste, since an increase in the utilisation rates is assumed for thermal waste treatment, but not for biogas utilisation in CHPs[112]. In the case of used tyres, the shift to recycling results in a somewhat higher specific net emission savings potential. Proportionate co-incineration in the cement plant is unaffected by defossilisation; in the case of recycling, the GHG debits from electricity demand decrease.

For incineration residues and other mineral waste, the specific net result does not change (no optimisation potential, comparatively low GHG impacts from transport). For hospital waste, the specific net impact increases due to lower credits for generated energy (defossilisation).

[112] In principle, the possibility of increasing the use of heat depends on the possibility of feeding it into local or district heating networks.

8 Construction and demolition waste

8.1 Waste generation and destination

Construction and demolition (C&D) waste is defined in the context of this study as all non-hazardous streams of Chapter 17 of the European Waste List, with the exception of the codes for "soil and stones" (LoW 17 05 04) and "dredged material" (LoW 17 05 06). The LoW-codes taken into account and the allocation to the EWC-Stat codes of the European waste statistics are listed in Table 72. For these codes, the information from the German waste statistics on the generation[113] and destination in the various treatment facilities in Germany was evaluated (Destatis 2019b), see also Appendix A.1. Quantities delivered from abroad were not considered in accordance with the defined scope of the balance. The reported exports of C&D waste in (Destatis 2019b) (Table 20.1) amount to a total of just under 1.3 million tons and thus amount to 1.4% of the identified domestic generation. Due to the small share, they were not analysed further and neglected in the balance.[114]

Since data for construction waste processing plants and asphalt mixing plants are collected every two years, no data are available for the reference year 2017, which is why the data basis of 2016 is used for this purpose.

8.1.1 Generation of construction and demolition waste

The generation of C&D waste in Germany is shown in Table 72. The breakdown for the EWC-Stat codes with more than one relevant LoW-code is shown Figure 23.

Table 72: Generation of construction and demolition waste in Germany (Destatis (2019b))

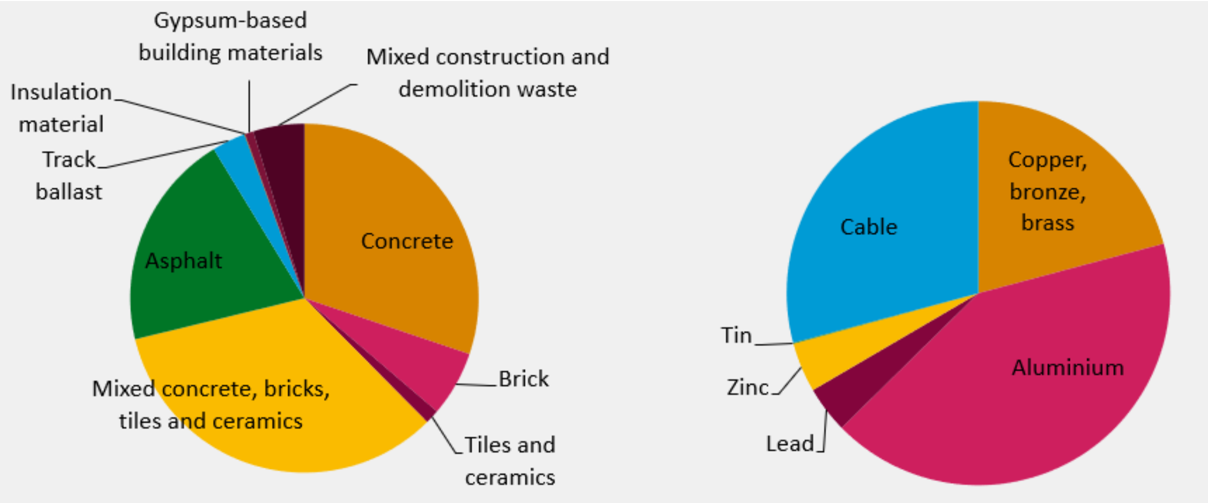
Designation	EWC-Stat code	LoW-code	Quantity (1,000 t))
Mineral waste	W121_without asphalt	17 01 01, 17 01 02, 17 01 03, 17 01 07, 17 05 08, 17 06 04, 17 08 02, 17 09 04	64,940
Asphalt	W121_asphalt	17 03 02	16,306
Ferrous metals	W061	17 04 05	6,395
Non-ferrous metals	W062	17 04 01, 17 04 02, 17 04 03, 17 04 04, 17 04 06, 17 04 11	456
Mixed metals	W063	17 04 07	184
Glass	W071	17 02 02	258
Plastic	W074	17 02 03	110
Wood	W075	17 02 01	3,020
		Total	91,669

[113] The volume is defined as the sum of all waste streams delivered from within Germany to waste treatment plants in Germany in the reference period (total input from within Germany, Tab 1.1 Destatis 2019b). Waste streams that are directly re-used in production plants or directly exported abroad are thus not covered by the statistics.

[114] The exports according to Table 20.1 (Destatis 2019a) are not further broken down by LoW-codes. As the waste is subject to notification, it is also assumed that hazardous waste plays a role among them, which is excluded for this study.

The total amount of C&D waste is around 92 million tons. The waste volume is dominated by mineral waste (excluding asphalt) with a around 70%, followed by asphalt (just under 20%), ferrous metals (7%) and wood (3%). These four streams account for 99% of the total waste.

Figure 23 Allocation of mineral waste (W121) and non-ferrous metals (W062) to LoW-codes



a) Mineral waste (W121) b) Non-ferrous metals (W062)

Source: own presentation based on Destatis (2019b)

Mineral waste is dominated by concrete (LoW 17 01 01) and mixtures of concrete, bricks, tiles and ceramics (LoW 17 01 07). The smallest share is accounted for by gypsum-based building materials. For non-ferrous metals, aluminium (LoW 17 04 02) and copper (LoW 17 04 01, 17 04 11) are particularly relevant. Although many recyclable materials are reported as individual materials, they are usually not pure, but may contain foreign materials/adhesions (e.g. steel reinforcement in concrete, cable sheathing in copper cables, etc.).

8.1.2 Destination of construction and demolition waste

Table 73 shows the result for the relevant plant types (input for treatment).[115]

The facilities cover almost 100% of the waste. The coverage is at least 95% for almost all codes and thus at a level sufficient for the accuracy of the analysis. The only exception is gypsum-based building materials (LoW 17 08 02) with only 81% coverage. However, since gypsum-based building materials represent a very small quantity compared to the total volume (less than 1%) and the major part is disposed of in landfills (approx. 70% according to Destatis (2019b), 55% according to (Circular economy construction 2018)), this deviation is neglected.

In order to be able to assess the climate effect of the destination of the waste, the entire treatment path up to the final destination in the disposal and recovery facilities is relevant. Therefore, an evaluation was carried out below and the flows were assigned to the categories "recycling", "incineration", "landfilling" or "backfilling" analogously to the European data (see partial report EU). The result (see Table 76) also forms the interface for the presentation of the German volume data at EU level.

[115] Small quantities also go to other types of treatment. However, they account for significantly less than 0.1% per plant type in all cases and were therefore not considered further in the evaluation.

A clear allocation is made for the quantities delivered to landfills and for deposit in surface quarries, as these already represent the end use. Incineration also represents an end use, whereby it was assumed that all waste incineration plants in Germany are also classified as R1 ("energy recovery"). However, there are different efficiencies or substituted processes compared to incineration plants, which is why the two options are discussed separately at the relevant points. For the sake of simplicity, the quantities in landfill construction measures are assigned to recycling, even if the definition situation here is not entirely clear. As a consequence, the results for the glass and asphalt waste streams would be slightly overestimated in terms of their GHG emission savings effect, as their recycling substitutes the production of primary glass or bitumen in asphalt, which is not the case when used as a landfill construction measure. For the GHG balance, the corresponding quantities are shown separately (see also Table 73), so that this overestimation is avoided. The quantities are assessed analogously to the backfilling or landfilling of mineral waste. For the other types of waste, there are no corresponding climate gas-relevant differences in the assessment.

An overview of the result of the allocation to the final destination described in the following is given in Table 76 in Chapter 8.1.3.

Table 73: Destination of C&D waste in the facility types in 1000 tons

Destatis (2019b)		LF	LF con-struction mea-sures	Waste INC	Com-bustion plants	Ground handling	Shredder /scrap shears	Sorting plants	Other handling	Surface storage	Con-struction waste processing	Asphalt mixing plants	Sum plants	Cove-rage
FS 19, R1	Table	Tbl. 2.1	Tbl. 2.4	Tbl 3.1	Tbl 4.1	Tbl 6.1	Tbl 10.1	Tbl 11.1	Tbl 13.1	Tbl. 16.1	Tbl 17.1	Tbl 18.1		
Mineral waste	W121 excl. asphalt	4,502	1,085	481	24	605	77	3,959	789	5,793	47,312	2	64,629	98%
Concrete	170101	253	49	0	0	32	0	204	92	721	23,167	2	24,519	100%
Brick	170102	80	68	0	0	1	0	99	54	616	3,999	0	4,917	100%
Tiles and ceramics	170103	59	25	0	0	0	0	34	8	364	574	0	1,065	100%
Mixed concrete, bricks, tiles and ceramics	170107	3,322	814	0	0	255	0	933	316	3,963	17,693	0	27,295	100%
Track ballast	170508	60	115	0	0	316	0	186	137	12	1,630	0	2,456	97%
Insulation material	170604	15		2	0	0	2	10	26	0	0	0	54	95%
Gypsum-based building materials	170802	351	5	0	0	3	0	69	15	41	29	0	512	81%
Mixed construction and	170904	362	9	479	24	0	76	2,425	141	75	221	0	3,810	99%

Destatis (2019b)		LF	LF construction measures	Waste INC	Combustion plants	Ground handling	Shredder /scrap shears	Sorting plants	Other handling	Surface storage	Construction waste processing	Asphalt mixing plants	Sum plants	Coverage
demolition waste														
Asphalt	170302	315	426	13	0	36	3	75	84	119	10,805	4,429	16,305	100%
Iron and steel	W061	0		0	0	0	5,001	639	748	0	2	0	6,390	100%
Non-ferrous metals	W062	0		0	0	0	108	92	251	0	0	0	451	99%
Common metals	W063	0		0	0	0	66	60	56	0	0	0	182	99%
Glass	W071	12	0.5	0	0	0	0	163	69	0	1	0	246	95%
Plastic	W074	0		5	0	0	1	16	87	0	0	0	109	98%
Wood	W075	0		2	238	0	1,738	652	309	0	44	0	2,983	99%
Total plant type		**4,828**	**1,512**	**500**	**262**	**642**	**6,994**	**5,657**	**2,392**	**5,911**	**58,165**	**4,431**	**91,293**	**100%**

8.1.2.1 Mineral waste

For mineral waste, the further classification is made in particular by additionally evaluating the outputs of construction waste processing plants[116] , which receive 90% of the waste that goes into intermediate treatment. Although waste from LoW Chapters 10, 19 and 20 is also reported as input in construction waste processing plants, 99% of the input comes from Chapter 17, which is relevant for C&D waste. For simplification, it was therefore assumed that the entire output of construction waste processing plants can be assigned to C&Dwaste.

The most relevant output streams from construction waste processing plants in terms of quantity are products for use in road and path construction (LoW 19 12 09 01), products for use in other earthworks (including backfilling) (LoW 19 12 09 02), products for use in asphalt mixing plants (LoW 19 12 09 04) and products for other uses (e.g. landfill construction, sports ground construction, noise barriers) (LoW 19 12 09 05). In addition, there are other mineral output streams as well as separated recyclable material streams (especially ferrous metals, to a lesser extent also non-ferrous metals)[117] .

For **asphalt** (LoW 17 03 02, bitumen mixtures), a breakdown of the final destination was published in Kreislaufwirtschaft Bau (2018). For the reference year 2016, 95.4% of 16 million tons were recycled, 2.5% were used in landfill construction and backfilling, and 2.1% were landfilled. Since this information refers specifically only to the LoW-code key 17 03 02, it was adopted for this evaluation. An extrapolation to the reference year 2017 was not made, as the deviation of the accumulation is small[118] and the main plants to which bitumen mixtures are delivered, are only available for the reference year 2016 according to Destatis (2019b)[119].

In addition, the analysis of the construction waste processing plants ((Destatis 2019b),Table 17.2) show that of the input of approx. 11 million tons of bitumen mixtures (LoW 17 03 02), at most approx. 6 million tons are delivered to asphalt mixing plants (LoW 19 12 09 04)[120]. It is possible that the remaining quantity will go to unbound recycling (e.g. road and path construction or other use).

In contrast, asphalt mixing plants report an input of 10.3 million tons with Low-code 19 12 09 04. Where the remaining quantity comes from is not traceable from the analysis by Destatis (2019b). It could also be other recycled aggregates, but these would also have to be reported at some point as output of corresponding plants under LoW 19 12 09 04.

For the year 2013, Großhans / Täube (without year) reported that of 14 million tons of reclaimed asphalt, 11.5 million tons went into hot reprocessing and 2.5 million tons went into unbound processing.

For the year 2016, the present estimate would result in 10.4 million tons in hot reprocessing[121] and approx. 4.8 million tons [122] in unbound processing. Compared to the figures according to Kreislaufwirtschaft Bau (2018) a congruent picture emerges if the majority of the unbound

[116] S. Destatis (2019a), table 17.2

[117] The separated metals are assigned to the recycling of the corresponding EWC-Stat code (see Chapter 8.1.2.2). Glass, wood and plastics are reported only in negligible quantities.

[118] Reported accumulation LoW 17 03 02 in 2016 16 million tons g and in 2017 16.3 million tons (Destatis 2019b).

[119] Of the 16.3 million tons reported for LoW 17 03 02 according to Destatis (2019b), 11 million tons goes to construction waste processing plants and 4.4 million tons to asphalt mixing plants.

[120] Assuming that only bitumen mixtures (LoW 17 03 02) are separated into this fraction.

[121] 6 million tons with LoW 19 12 09 04 from construction waste processing plus 4.4 million tons g with LoW-code 17 03 02 reported by the asphalt mixing plants.

[122] Of these, 4.5 million tons g are not reported as output for recycling in asphalt mixing plants from the input into the construction waste processing. The rest are smaller inputs in intermediate treatment plants (e.g. sorting plants) with unspecified end use.

processing is classified as recycling and only small quantities are classified as backfilling (cf. Table 74). The remaining inaccuracies are acceptable for the statement of the balance. For the climate relevance, it should be noted that no substitution of bitumen takes place through unbound recycling.

Table 74 Destination of asphalt (LoW 17 03 02, bitumen mixtures) in million tons

Source	Recycling	Backfilling	Landfill
Kreislaufwirtschaft Bau (2018)	15.26	0.4	0.34
Destatis (2019b), own evaluation	14.9	0.4	0.31
thereof	10.4 in asphalt mixing plants	0.1 Backfilling direct	0.31 direct
	4.5 assumed unbound (recycling)	0.3 assumed unbound (backfill)	

The approach described below was used to allocate the **remaining mineral construction and demolition waste (W121 excl. asphalt) to** the final destination.

Recycling was rated as:

1. Mineral outputs from construction waste processing, which continued to be reported with the corresponding codes of 17.[123]
2. Concrete specifically identified as products for use as concrete aggregate.[124]
3. Products from construction waste processing for use in road and path construction, as well as for other uses (e.g. landfill construction, sports field construction, noise barriers)[125] plus a comparatively small output of non-differentiable minerals (sand and stones)[126]
4. The net input of the code for soil and stone that is not included in the balance scope[127], as well as the share of the net input of bitumen mixtures that is not reported by the construction waste processing plants as products for use in asphalt mixing plants, have been deducted proportionally. The latter is assumed to go to unbound use, and is therefore included in the flows described under the point 3. However, it is reported separately under the asphalt entry for the present balance. The comparison with Kreislaufwirtschaft Bau (2018) shows that the unbound use is predominantly evaluated as recycling.

[123] In particular, concrete (LoW 17 01 01) and mixtures of concrete, bricks, tiles and ceramics (Low 17 01 07), but also separately identified bricks, tiles and ceramics as well as track ballast (LoW 17 01 02, 17 01 03 and 17 05 08).

[124] LoW 19 12 09 03

[125] LoW 19 12 09 01 and 19 12 09 05

[126] LoW 19 12 09 00

[127] LoW 17 05 04; for simplification, a 50-50 split between high-grade recovery (recycling) and simple disposal (backfilling) was assumed for the proportional allocation.

5. Proportionate input to other treatment facilities (soil treatment, shredders/scrap shears, sorting facilities, other treatment)[128] .

Backfilling was assessed as:[129]

1. The sum of all 17-codes directly reported as storage of non-mining waste in surface mining sites[130] included in the balance scope.
2. Products from construction waste processing plants for use in other earthworks (including backfilling).[131]
3. The net input of the code for soil and stones not included in the balance scope was deducted proportionally.[127]
4. Proportionate input to other treatment facilities (soil treatment, shredders/scrap shears, sorting facilities, other treatment).[128]

The differentiation between recycling and backfilling is not clearly delineated for products for use in other earthworks and other uses (e.g. landfill construction, sports ground construction, noise barriers). For example, the use of mineral construction and demolition waste in noise barriers can be mentioned here. With regard to GHG balancing, however, a precise differentiation of the applications is not relevant, as comparable processes are substituted, so that the allocation described above can be used.

With regard to the recycling of concrete, it should be emphasised that only a very small proportion is specifically recycled as concrete aggregate. According to the evaluation by Destatis (2019b), only 0.45 million tons are separated into this recycling route from construction waste processing plants, which receive 95% of concrete waste[132] . An output of 0.7 million tons is still reported with Low 17 01 01 (concrete)[133], with unspecified destination. By far the largest share of the concrete reported in the input (approx. 95%) thus goes to applications such as road and path construction or other earthworks. The analysis of Kreislaufwirtschaft Bau (2018) about produced recycled building materials does not provide any indication that larger quantities of concrete are recycled as concrete aggregate.

Combustion (energy recovery, R1) includes:

1. Mineral waste incinerated in waste incineration plants (0.48 million tons) and in substitute fuel power plants (0.024 million tons).[134]

Landfill includes:

1. The sum of all codes of 17 keys reported directly under landfills included in the balance scope.

[128] In these plants, waste is accepted from different areas of origin, so that, unlike in the case of construction waste processing plants, it is not possible to allocate the accepted C&D waste to the different output streams. Since these plants also receive only a small part of the other mineral C&D wastes, a generic allocation was carried out here for the sake of simplicity. The approach and the values used for the allocation are described in Chapter 8.1.2.2 and Table 75.

[129] LoW 19 12 09 02

[130] Destatis (2019a), table 16.1

[131] LoW 19 12 09 02

[132] LoW 17 01 01

[133] From soil treatment plants and other treatment plants, an output with LoW 17 01 01 of 0.03 and 0.04 million tons, respectively, is reported.

[134] Exclusively from mixed construction and demolition waste (LoW 17 09 04), probably proportions of wood and plastic.

2. Proportionate input to other treatment facilities (soil treatment, shredders/scrap shears, sorting facilities, other treatment). [135]

8.1.2.2 Separately reported recyclables

The separately reported recyclables include ferrous metals (W061), non-ferrous metals (W062) as well as mixed metals (W063), glass (W071), plastics (W074) and wood (W075). In order to estimate the final destination after intermediate treatment plants, the output from construction waste processing plants was evaluated here. The evaluation showed that especially ferrous metals and to a lesser extent non-ferrous metals are separated from construction waste processing plants[136] . It was assumed that 100% of these metals are recycled, as they are separated for this purpose. Glass, plastic and wood are reported as outputs from construction waste processing plants in negligible quantities.

For the other intermediate treatment facilities (shredders/scrap shears, sorting facilities, other treatment), a generic distribution between the different final residues was chosen. The distribution based on estimation is shown in Table 75. Since the plants work with the main objective of separating recyclable materials, a high proportion was assumed for recycling, especially for metals and glass.[137] The remaining quantity was allocated to landfilling for the sake of simplicity. For plastics, it is expected that energy recovery must also be considered. For wood, it is assumed that mainly energy recovery takes place. The assumed distribution (82% incineration, 18% recycling) was also reconciled with the results od the study from Flamme et al. (2020). This study shows a distribution of wood flows from waste wood treatment plants of 75% for energy recovery, 23% for recycling and 2% for disposal, which supports the selected order of magnitude. A direct comparison is not possible, as in the presentation according to Flamme et al. (2020) different LoW-codes, also of other origins and including hazardous waste, are shown aggregated. For separately collected wood, Destatis (2019b) also shows relevant quantities that are delivered directly to combustion plants (use in biomass power plants, Destatis 2019c).

The breakdown for the in Chapter 8.1.2.1 described aggregate of mineral waste (W121 excl. asphalt) is shown in Table 75. It was taken into account that the mixed construction and demolition waste (LoW 17 09 04) contains 20% of wood according to Flamme et al. (2020). Furthermore, a plastic share of 10% was assumed for this stream. The rest is mineral waste. For the sake of simplicity, the following breakdowns are assumed for the estimation of the allocation:

- Mineral waste: 50%-25%-25% recycling-landfill-backfill
- Plastics: 50%-50% recycling-energy recovery
- Wood: 100% energy recovery

Mathematically, this allocation results in the values shown in Table 75 for the aggregate of mineral waste (W121 excl. asphalt).

[135] In these plants, waste is accepted from different areas of origin, so that, unlike in the case of construction waste processing plants, it is not possible to allocate the accepted construction and demolition waste to the different output streams. Since these plants also receive only a small part of the other mineral construction and demolition wastes, a generic allocation was carried out here for the sake of simplicity. The approach and the values used for the allocation are presented in Chapter 8.1.2.2 and Table 70.

[136] More than the input of the corresponding LoW-codes, i.e. additional metals are separated from mineral waste (e.g. steel from concrete).

[137] For glass, the resulting quantity for recycling of a good 200,000 t/year agrees very well with the values determined in the context of the project of the German Environment Agency about resource- and greenhouse gas-neutral Germany.

Table 75: Estimation of final destination from intermediate treatment plants[138] - generic shares

	Recycling	Landfill	Energy recovery (R1)	Backfilling
Ferrous metals (W061)	95%	5%	0%	0%
Non-ferrous metals (W062)	95%	5%	0%	0%
Mixed metals (W063)	95%	5%	0%	0%
Glass (W071)	91%	9%	0%	0%
Plastic (W074)	67%	0%	33%	0%
Wood (W075)	18%	0%	82%	0%
Minera waste excl. asphalt (W121)	60%	9%	2%	29%
Asphalt	95%	2%	0%	3%

8.1.3 Quantity and destination for the balancing

The result of the previously described allocation of C&D waste to the final destination are listed in Table 76. This allocation of the material flows forms the quantity basis for the GHG balance and is also used as the interface for the German material flows at EU level (see partial report EU). The cut-off criterion for the destination of very small quantities does not apply here. The quantities for final treatment are above 1% in each case.

The amount of mineral waste (W121 excl. asphalt) for incineration is composed of the directly delivered quantities and the estimated shares of wood and plastics for energy recovery after intermediate treatment. The resulting breakdown of the latter into 80% wood and 20% plastics is used in a simplified way for the overall GHG balance.

The result of the basic data collection for C&D waste Germany is shown in Figure 24 as a material flow diagram and in Figure 25 the quantity for final treatment is presented as a bar chart by waste type. Both diagrams visualise that C&D waste by mass is dominated by "mineral waste" (W121). This waste fraction accounts for 70% of the total volume. It is followed by the quantity of asphalt, which is considered separately from the "mineral waste", with a mass share of 18%. Among the other waste fractions, ferrous metals and wood account for 7% and 3% of the total quantity, respectively. The percentage share of the remaining waste fractions is around or < 1%.

Table 76: Basic table: final treatment of construction and demolition waste, 2017 Germany (in 1000 tons)

Waste type	Recycling	Backfilling	Energy recovery (R1)	Landfill	Total
Mineral waste (W121 excl. asphalt)	38,224	18,428	1,236	5,640	**63,529**

[138] Soil treatment, shredders/scrap shears, sorting plants, other treatment according to Destatis (2019a)

Waste type	Recycling	Backfilling	Energy recovery (R1)	Landfill	Total
Asphalt	15,264	400	0	336	**16,000**
Ferrous metals (W061)	6,310	0	0	319	**6,629**
Non-ferrous metals (W062)	442	0	0	23	**465**
Mixed metals (W063)	177	0	0	9	**186**
Glass (W071)	221	0	0	23	**244**
Plastic (W074)	73	0	36	0	**109**
Wood (W075)	553	0	2,452	0	**3,005**
Total C&D waste	**61,263**	**18,828**	**3,724**	**6,350**	**90,166**

Figure 24 Sankey diagram C&D waste Germany 2017

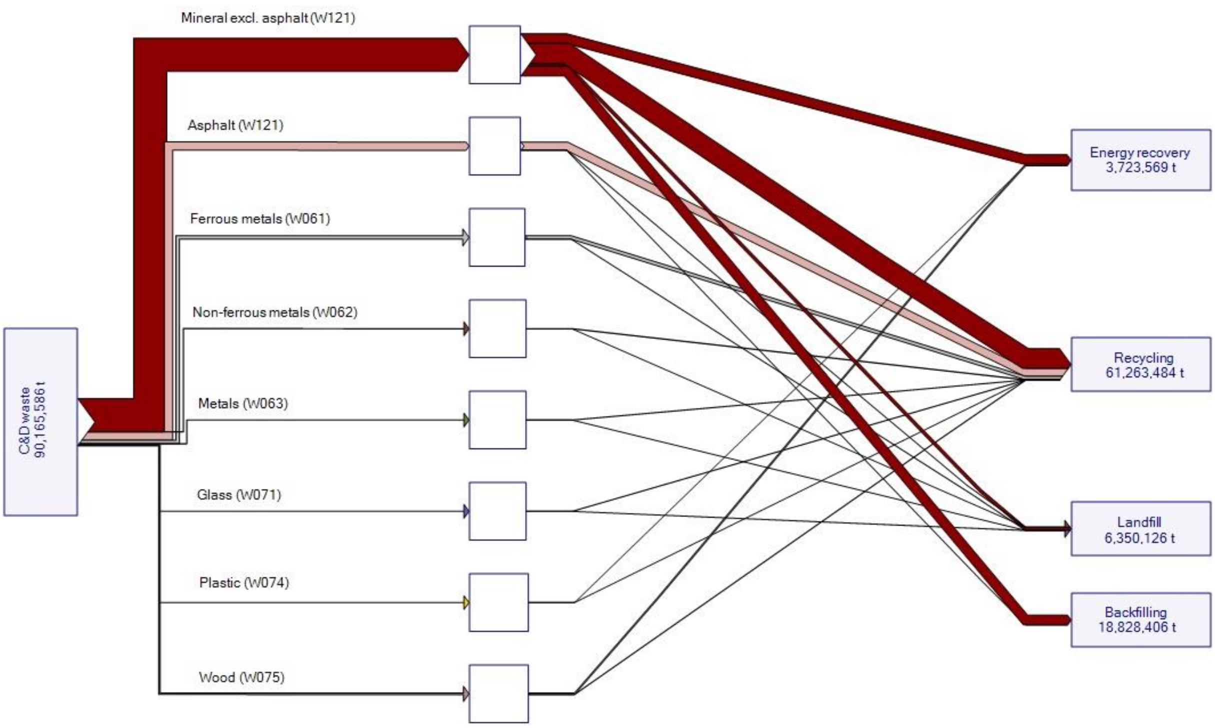
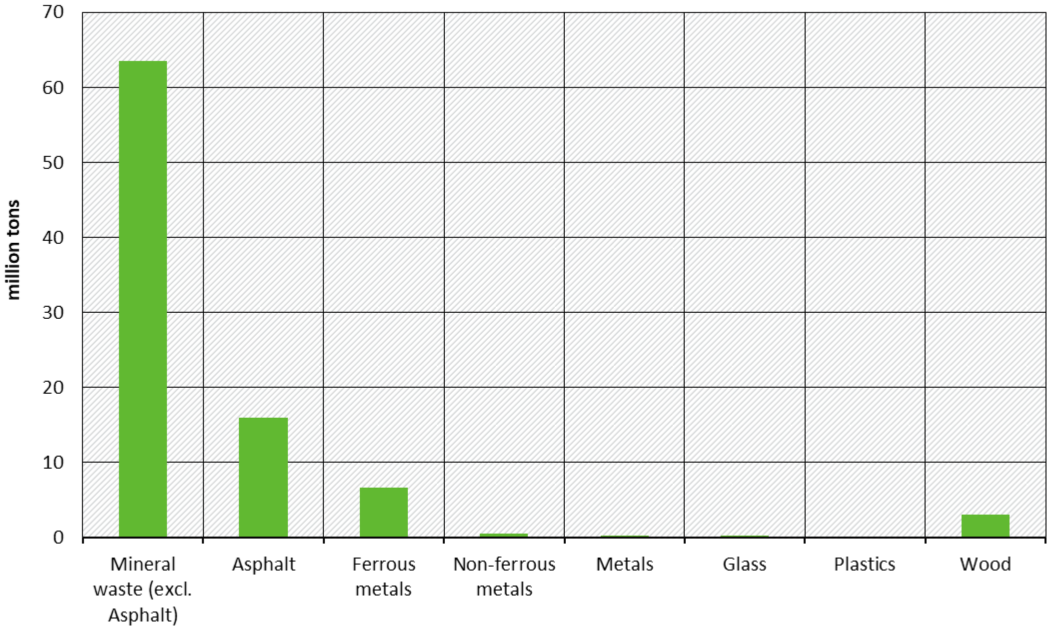


Figure 25: Volume of final treatment of C&D waste in Germany 2017



8.2 Procedure of balancing and characteristics of waste fractions

C&D waste is accounted for according to the previously reported waste fractions and the specified final treatment. Insofar as sorting costs from primary treatment are relevant and can be mapped, as in the case of dry recyclables, input quantities for these are recalculated in the balance on the basis of sorting losses. The procedure for balancing is described below according to the different waste fractions.

Dry recyclables (W061, W062, W063, W071, W074)

The dry recyclables from the C&D waste - the metals, glass and plastics - are mainly assigned to recycling after final treatment. About 5% of the metal fractions are also landfilled, and 9% of glass. 33% of plastics are also recovered for energy.

The balancing of the recycling of dry recyclables is carried out in the same way as the balancing of the dry recyclables in MSW as described in Chapter 4.2.7. In contrast to the C&I waste, for which higher yields were assumed in some cases (Table 15), since they are not wastes from post-consumer use, no justified deviations are assumed for the dry recyclables from C&D wastes compared to the dry recyclables from MSW. The division of the mixed metals into ferrous and non-ferrous metals is based on the division of the pure fractions and results in 93% ferrous metals and 7% non-ferrous metals for the metals from C&D waste for Germany (Table 14).

No GHG emissions are generated for the landfilling of metals and glass waste. For the proportional energy recovery of plastics, the characteristic data - calorific value and fossil C content - were calculated according to the market mix for plastics in Germany (Table 13) (calorific value 34.2 MJ/kg; fossil C content 69.9%).

The balancing of energy production in thermal waste treatment plant corresponds to the procedure described in Chapter 4.2.4. The average values resulting from the data according to Flamme et al. (2018) (11.3% electrical, 34.0% thermal).

Wood (W075)

Wood waste from C&D waste is 82% recovered for energy and 18% recycled. The balancing corresponds to the procedure described in Chapter 4.2.9.

Mineral waste (W121) without asphalt

Mineral waste, which makes up the bulk of C&D waste, is 60% recycled, 29% backfilled, 9% landfilled and 2% used for energy recovery. For recycling, use in road and path construction or other earthworks was assumed. Since this waste fraction is inert material, its disposal is not associated with any GHG emissions. Pollution is only caused by transport, the influence of which is of minor importance despite the comparatively high mass fraction. The same applies to the quantities landfilled and the quantities used for backfilling.

Energy recovery concerns wood and plastic fractions contained in mixed construction and demolition waste in the waste fraction mineral waste. The breakdown is assumed to be 20% plastics and 80% wood (see Chap. 8.1.2). The balancing of energy generation for these fractions in thermal waste treatment (energy recovery, R1) corresponds to the procedure described in Chapter 4.2.4. The average values resulting from the data according to Flamme et al. (2018) (11.3% electrical, 34.0% thermal). The characteristic data for plastics again correspond to the values calculated according to the market mix for plastics in Germany (calorific value 34.2 MJ/kg; fossil C content 69.9%), the characteristic data for wood correspond to the values according to Flamme et al. (2018).

Asphalt

For balancing purposes, asphalt is considered separately from the waste fraction mineral waste due to the different type of recycling in which RC asphalt is re-used in asphalt mixing plants. Overall, 95% of asphalt is recycled, 3% is backfilled and 2% is landfilled. Apart from transport costs, no other GHG emissions are attributed to landfilling and backfilling, as the inert material is not subject to biodegradation.

Bitumen is proportionally replaced during recycling in asphalt mixing plants. According to knowledge (Vogt et al. 2012) the proportion of fresh bitumen in asphalt products is about 4%. This proportion can be replaced on a mass-equivalent basis through the use of RC asphalt. According to operators, the production of virgin bitumen causes about 13 kg CO_2 per ton of virgin asphalt. This value was also used for this study.

8.3 Description of the scenarios

For C&D waste, analogous to C&I waste, two scenarios are envisaged that differ in their ambitions and consider both material flow diversions and optimisation potentials. The ambitious scenario 2 uses the potentials here within a technically feasible framework, while scenario 1 is based on the same assumptions, but assumes significantly lower improvements.

The following wastes have no optimisation potential in the scenario 1 and there are also no legal regulations that effect a material flow diversion:

- Mineral wastes (without asphalt) (W121)
- Asphalt (W121)
- Ferrous metals (W061)
- Non-ferrous metals (W062)
- Mixed metals (W063)

The following table provides an overview of the shifts in the waste streams assumed in both scenarios.

Table 77: Percentage shifts between the utilisation endpoints for scenarios 1 and 2

	Scenario 1				Scenario 2			
Waste stream	**Landfill**	**Energy recovery**	**Filling**	**Recy-cling**	**Landfill**	**Energy recovery**	**Filling**	**Recy-cling**
Mineral waste (without asphalt)	-	-	-	-	-	-	- 10%	+ 10%
Asphalt	-	-	-	-	- 1%	-	- 1%	+ 2%
Ferrous metals	-	-	-	-	- 2%	-	-	+ 2%
Non-ferrous metals	-	-	-	-	- 2%	-	-	+ 2%
Mixed metals	-	-	-	-	- 2%	-	-	+ 2%
Glass	- 2%	-	-	+ 2%	- 4%	-	-	+ 4%
Plastic	-	- 5%	-	+ 5%	-	- 10%	-	+ 10%
Wood	-	- 2%	-	+ 2%	-	- 7%	-	+ 7%

As a technical optimisation, an increase in the yields of dry recyclables - plastics and non-ferrous metals - is also assumed, as with municipal solid waste (Table 32).

8.3.1 Scenario 1 "C&D 2030 SC1"

The following assumptions are made for the individual waste streams in scenario 1:

Glass (W071)

The recycling rate is 91% and an optimisation potential of 2% is seen. This is justified by the possibility of better sorting at the construction site, which improves material recycling.

Plastic (W074)

The recycling rate is 67% and an optimisation potential of 5% is seen. This is justified by the possibility of better sorting at the construction site as well as targeted promotion of the use of recyclates, which enable a shift towards material recycling.

Wood (W075)

The recycling rate is 18% and an optimisation potential of 2% is seen. This is justified by the possibility of better mechanical recycling. It is already possible today to use a high proportion of waste wood in chipboard (e.g. 90% waste wood in Italy). For economic reasons, however, this is not done because energy recovery is more profitable.

These assumptions result in the following changes:

For glass (W071), 4,880 tons are shifted from landfill to recycling. For plastic (W074), 5,425 tons are shifted from energy recovery (R1) to recycling. For wood (W075), 60,094 tons are shifted from energy recovery (R1) to recycling.

8.3.2 Scenario 2 " C&D 2030 SC2

The following assumptions are made for the individual waste streams in scenario 2:

Mineral wastes (without asphalt) (W121)

The recycling rate is 60% and 29% is backfilled, which is considered recycling at the EU level. A recycling rate of 70% is required by law. Assuming that backfilling is no longer considered recycling, a material flow shift of 10% can be assumed here. This is justified by the current practice of backfilling: it is backfilled directly and not processed, so it is logically justifiable that pre-treatment can lead to a diversion of the material flow.

Asphalt (W121)

The recycling rate is 95% and an optimisation potential of 2% is seen. This is justified by the possibility of better processing and use, which improves material recycling.

Ferrous metals (W061)

The recycling rate is 95% and an optimisation potential of 2% is seen. This is justified by the possibility of better sorting at the construction site, which improves material recycling.

Non-ferrous metals (W062)

The recycling rate is 95% and an optimisation potential of 2% is seen. This is justified by the possibility of better sorting at the construction site, which improves material recycling.

Mixed metals (W063)

The recycling rate is 95% and an optimisation potential of 2% is seen. This is justified by the possibility of better sorting at the construction site, which improves material recycling.

Glass (W071)

The recycling rate is 91% and an optimisation potential of 4% is seen. This is justified by the possibility of better sorting at the construction site, which improves material recycling.

Plastic (W074)

The recycling rate is 67% and an optimisation potential of 10% is seen. This is justified by the possibility of better sorting on the construction site as well as targeted promotion of the use of recyclates, which enable a shift towards material recycling.

Wood (W075)

The recycling rate is 18% and an optimisation potential of 7% is seen. This is justified by the possibility of better mechanical recycling. It is already possible today to use a high proportion of waste wood in chipboard (e.g. 90% waste wood in Italy). For economic reasons, however, this is not done, as energy recovery is more profitable.

These assumptions result in the following changes:

For mineral waste (W121 excl. asphalt), around 6.35 million tons are shifted from backfilling to recycling. For asphalt, 160,000 tons each are shifted from landfill and backfill to recycling, which thus increases by 320,000 tons. For ferrous metals (W061) 132,582 tons are shifted from landfill to recycling. For non-ferrous metals (W062), 9,296 tons are shifted from landfill to recycling. For mixed metals (W063), 3,714 tons are shifted from landfill to recycling. For glass (W071), 9,760 tons are shifted from landfill to recycling. For plastic (W074), 10,850 tons are shifted from energy recovery (R1) to recycling. For wood (W075), 210,329 tons are shifted from energy recovery (R1) to recycling.

8.4 Results GHG balances

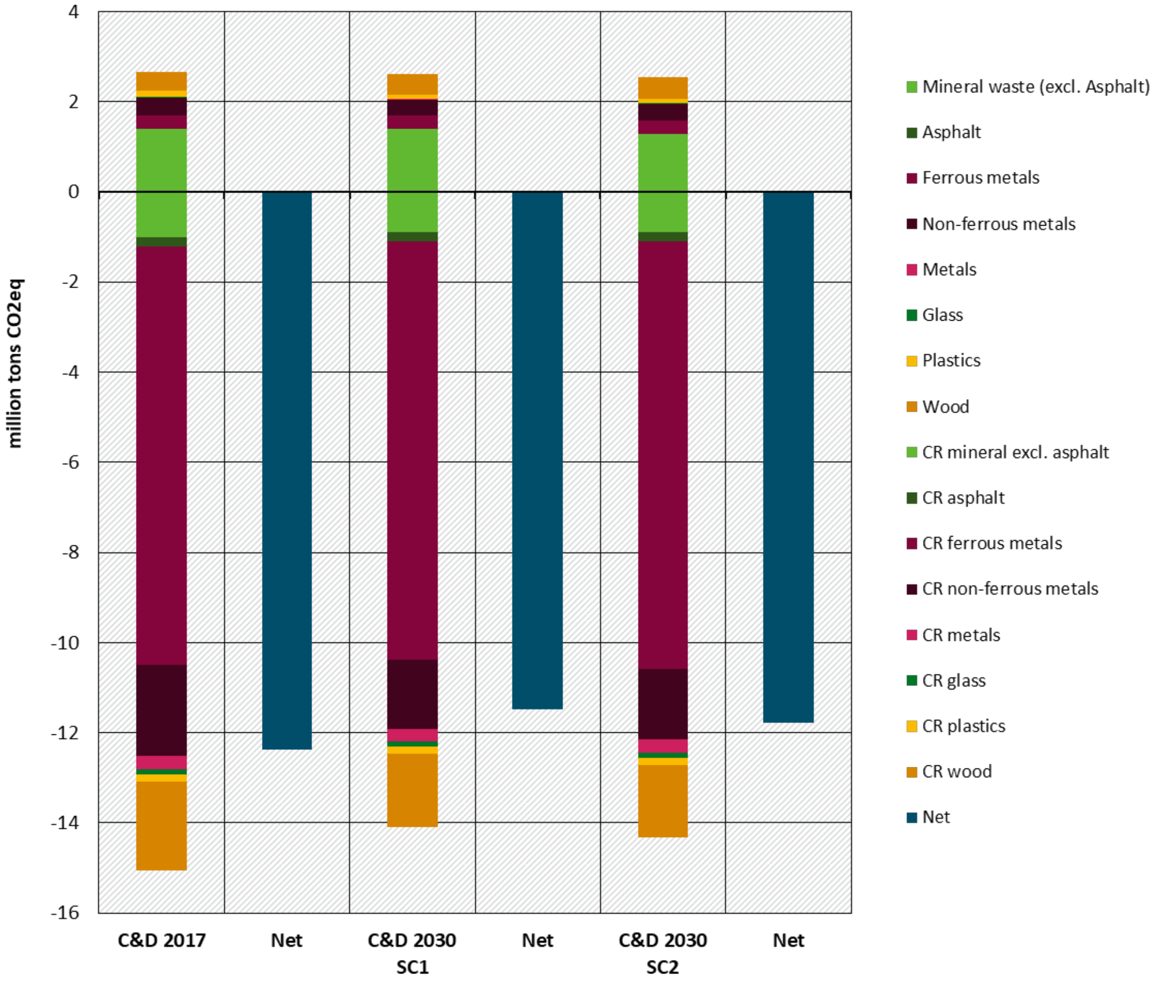
This chapter presents the results of the GHG balance of the actual situation (Table 76) in comparison with the two scenarios described above for the year 2030. In principle, the results are to be understood as orientational due to data uncertainties and data gaps (cf. Chap. **Fehler! Verweisquelle konnte nicht gefunden werden.**). The following designations are used for the figures:

- Actual situation 2017: "C&D 2017"
- Scenario 1 2030: "C&D 2030 SC1"
- Scenario 2 2030: "C&D 2030 SC2"

Figure 26 shows the absolute results according to the debits and credits of the waste fractions as well as the total net result in a year-on-year comparison. For the **actual situation in 2017, there is an absolute net emission savings potential of around -12.4 million tons CO_2eq.** The underlying debits amount to around 2.7 million tons CO_2eq and the emission savings potential to around -15.0 million tons CO_2eq. The figure clearly shows that metals and wood in particular make a significant contribution to the result, with a total share of 11%. Separately collected plastics and glass only have mass shares < 0.5% and therefore play no role in the absolute overall result. The mineral wastes, which make up the main mass, have a net impact. This is due to the transport costs (approx. 50%) and the proportionate plastic incineration, where the ratio of fossil C content to calorific value leads to a net debit that cannot be offset by the likewise proportionate wood incineration. The treatment of the inert main mass itself is not associated with any GHG emissions. The transports taken into account are of downstream importance in the overall result of the C&D waste, despite the high mass fractions.

The comparative scenarios for 2030 show slightly reduced debits and emission savings potentials. The differences between the scenarios are less pronounced compared to MSW and C&I waste. This is due to the dominant share of ferrous metals in the result. The recycling of ferrous metals is hardly influenced by defossilisation for the 2030 scenarios. For the **comparison scenario 1 ("C&D 2030 SC1"), there is an absolute net emission savings potential of around -11.5 million tons CO_2eq.** The underlying debits amount to around 2.6 million tons CO_2eq and the emission savings potential to around -14.1 million tons CO_2eq. For the **comparison scenario 2 ("C&D 2030 SC2"), the absolute net emission savings potential is around -11.8 million tons CO_2eq**. The underlying debits amount to around 2.5 million tons CO_2eq and the emission savings potential to around -14.3 million tons CO_2eq.

Figure 26 Scenario comparison C&D waste Germany



GS: Credit or emission savings potential

The overall GHG net results for C&D waste by waste fraction in absolute values as well as specific per capita and per ton for the actual situation in 2017 and for the comparative scenarios in 2030 (2030 SC1, 2030 SC2) are shown in Table 78.

For the EU balance, no separate balance is required for C&D waste for Germany with the emission factors for electricity and heat of the EU27. Since all quantity data - those for the EU27 and those for Germany - are derived from European statistics using the same procedure. For the EU27 balance, only the quantities for the EU27 without Germany are merged with those for Germany. For the 2030 scenario, scenario 2 is used for the EU balance, for which only one scenario is to be calculated.

Based on the **specific net results by waste fraction per ton of waste,** the differences in results can be explained:

As was already the case for C&I waste (and also for MSW for metals), non-ferrous metals in particular, and subsequently ferrous and mixed metals (93% ferrous metals), have high specific net emission emission savings potentials. The production of pig iron and aluminium is associated with comparatively high GHG emissions. The other waste fractions glass and wood have net emission savings potentials of a similar magnitude. In contrast, the net emission savings potential for plastics is about half as high in the base year 2017 and similar in the comparison scenarios. The net emission savings potential for asphalt is comparatively low. The disposal of mineral waste (without asphalt) has a low impact in the specific net result.

In the comparative scenarios 2030, the specific net results are changed that are affected by defossilisation and/or for which optimisations are assumed. The changes due to the defossilisation of the energy system for the dry recyclables have already been described in more detail for MSW (cf. Chap. 5.4.1). The impact on ferrous metals and glass is small. For non-ferrous metals, which are accounted for as aluminium, the specific net emission savings is lower due to the estimated reduced GHG impact of electricity-intensive primary production. This is somewhat counteracted by the assumed increased recycling yield. In Scenario 2, the slightly higher specific net emission savings potential compared to Scenario 1 results from the assumed proportional diversion from landfill to recycling. The latter applies analogously to ferrous metals and mixed metals.

In the case of plastic waste, there is an increase in the specific net emission savings potential mainly due to the lower GHG debit for the electricity required for processing (defossilisation) and also due to the redirection of energy recovery (R1) to recycling (reduction of fossil CO_2 emissions from incineration). The specific emission savings potential is only slightly changed by the assumed increase in yield.

In the case of wood, the reduced specific net emission savings potential is primarily due to the lower electricity and heat credits (defossilisation), which are only partially compensated for by the higher heat utilisation efficiency assumed for 2030. In addition, the proportionate diversion to recycling results in a reduced net emission savings, as chipboard recycling is associated with a lower specific net emission savings (see Chap. 4.2.9).

Table 78 Absolute and specific net results by waste fraction – C&D waste Germany actual situation 2017 and comparative scenarios 2030

Waste fraction	absolute	absolute	absolute	spec. per capita[1]	spec. per capita[1]	spec. per capita[1]	spec. per ton	spec. per ton	spec. per ton
B& A waste	**2017**	**2030 SC1**	**2030 SC2**	**2017**	**2030 SC1**	**2030 SC2**	**2017**	**2030 SC1**	**2030 SC2**
	t CO_2eq			kg CO_2eq/cap			kg CO_2eq/t		
Mineral waste (without asphalt)	0.37	0.49	0.38	4.5	5.9	4.6	6	8	6
Asphalt	-0.19	-0.19	-0.20	-2.3	-2.3	-2.4	-12	-12	-12
Ferrous metals	-8.98	-8.98	-9.17	-108.5	-108.5	-110.8	-1,355	-1,355	-1,384
Non-ferrous metals	-1.65	-1.20	-1.22	-19.9	-14.4	-14.7	-3,540	-2,571	-2,625
Metals	-0.28	-0.27	-0.27	-3.4	-3.2	-3.3	-1,497	-1,434	-1,464
Glass	-0.11	-0.11	-0.11	-1.3	-1.3	-1.3	-433	-438	-448
Plastics	-0.02	-0.05	-0.07	-0.3	-0.6	-0.8	-195	-481	-604
Wood	-1.54	-1.18	-1.11	-18.5	-14.3	-13.5	-511	-393	-371
Sum/average	**-12.38**	**-11.49**	**-11.77**	**-149.6**	**-138.7**	**-142.2**	**-137**	**-127**	**-131**

1) calculated with a population of 82,792,351 in 2017 (Federal Statistical Office (Destatis) 2017)

9 Results Germany at a glance

The results for Germany from the individual balance areas - MSW, C&I waste, C&D waste - are summarised here. The results for the special balance area food waste are also taken up again, but they are not additive, but a subset of the balance areas or source areas MSW and C&I waste. In principle, the results for C&I, C&D waste and food waste are to be understood as orientational due to data uncertainties and data gaps (cf. Chap. **Fehler! Verweisquelle konnte nicht gefunden werden.**).

For the overall view of the actual situation in Germany and the potential situation for 2030, the following scenarios are used:

- MSW waste: Baseline 2017 and lead scenario 2030
- C&I waste: Actual situation 2017 and scenario 2 2030
- C&D waste: Actual situation 2017 and scenario 2 2030

For 2030, these are the more ambitious scenarios in each case. Figure 27 shows the absolute net results of the three waste source sectors by waste fraction. Under "Metals", the GHG results for C&I and C&D waste are summarised for ferrous metals, non-ferrous metals and metals. Under "Other", the results for hospital waste, incineration residues and other mineral waste are summarised for C&I waste, and the results of mineral waste and asphalt are summarised for C&D waste.

The overall picture shows that all source areas have similar relevant net emission savings potentials. For C&D waste, this is dominated by metals, which account for 8% by mass (7.3 million tons). For C&I waste, the metals (2.8 million tons) contribute about half of the total net emission savings potential. The other contributions are made by the other dry recyclables, organic waste and wood. In the case of MSW, the contribution from metals is downstream due to the smaller quantity (0.4 million tons). Net emission savings potentials are primarily shaped by the other dry recyclables and, to a similar extent, by residual waste (still slightly higher in 2017), organic waste and wood.

In total, this results in a **total absolute net emission savings potential of around -38.6 million tons CO_2eq for** Germany for the balance year **2017**. The underlying debits amount to a total of around 24.4 million tons CO_2eq and the emission savings potential to around -63.0 million tons CO_2eq. For the selected comparison scenarios for the year **2030, the total absolute net emission savings potential is around -32.9 million tons CO_2eq**. The underlying debits amount to around 19.2 million tons CO_2eq and the emission savings potential to around -52.1 million tons CO_2eq. The results for the various source sectors are explained in detail in the respective chapters.

Table 79 once again shows an overview of the waste quantities as well as the absolute and specific net results according to balance areas or areas of origin and as a total sum or specific average values. In terms of total generation, MSW and C&I waste are similarly high (26% each). C&D waste accounts for 48%, but 88% consists of mineral waste (incl. asphalt), which contributes only minor GHG effects.

Figure 27: Waste Germany - absolute GHG net results by source sector and waste fractions

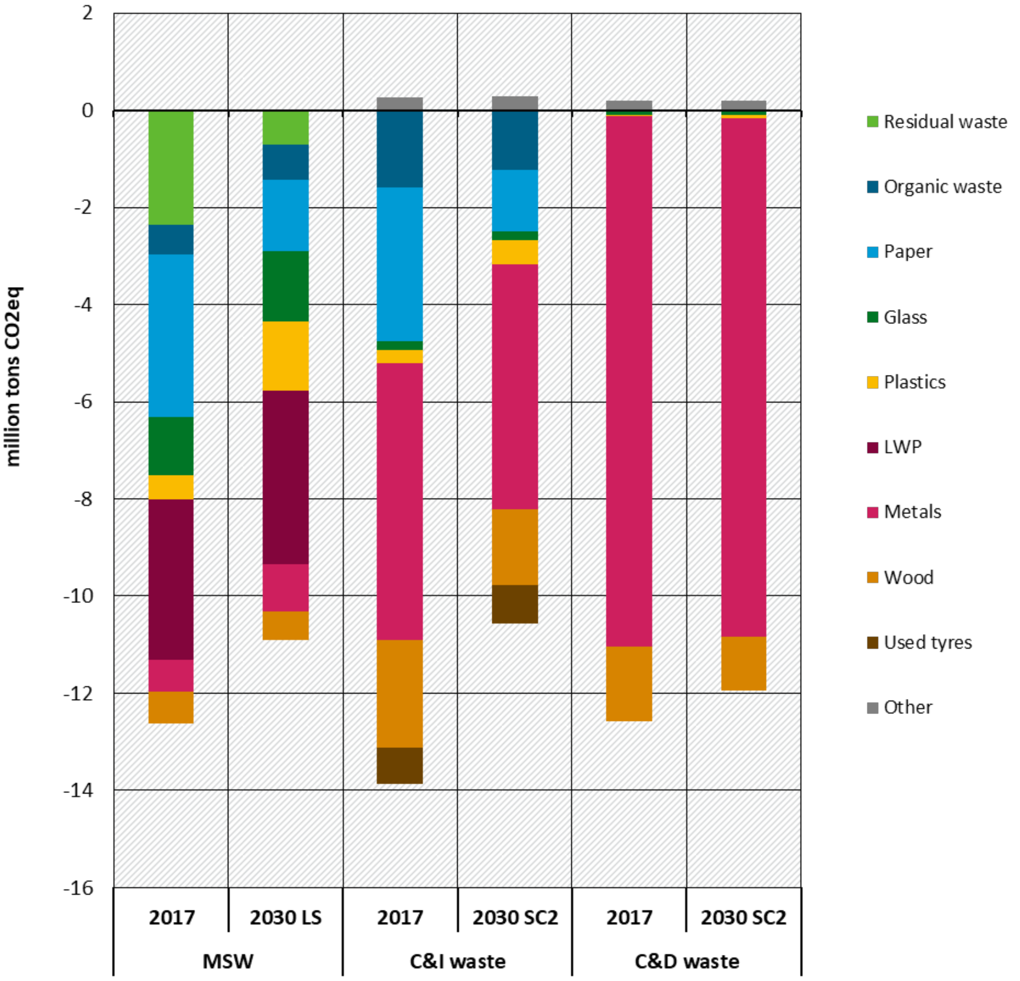


Table 79 Waste Germany - quantities and absolute and specific net results by source sector, 2030 more ambitious scenarios

Balance room	Amount	GHG absolute	GHG absolute	spec. per capita[1]	spec. per capita[1]	spec. per ton	spec. per ton
		2017	2030	2017	2030	2017	2030
	million t	t CO₂eq		kg CO₂eq/cap		kg CO₂eq/t	
MSW	49.2	-12.6	-10.9	-152	-131	-256	-221
C&I waste	49.8	-13.6	-10.3	-164	-124	-273	-207
C&D waste	90.2	-12.4	-11.8	-150	-142	-137	-131
Sum/average	**189.2**	**-38.6**	**32.9**	**-466**	**-398**	**-204**	**-174**

2) calculated with a population of 82,792,351 in 2017 (Federal Statistical Office (Destatis) 2017)

With a total of around 4 million tons of waste from the MSW and C&I waste balance areas, the food waste special balance area accounts for a small share of the total volume. The absolute net emission savings potential for food waste in the baseline comparison for 2017 is around -0.8 million t CO_2eq and for 2030 around -0.7 million t CO_2eq (cf. Chap. 6.4.1).

10 Conclusions and recommendations

In this study, in addition to the source area of MSW, the source areas of C&I and C&D waste were also examined and, as a special consideration, food waste, which represents a subset of MSW and C&I waste.

10.1 Data situation on waste generation and destination

MSW in Germany is generally well documented in the waste statistics according to its generation and destination at primary treatment plants. For the more extensive material flow analysis of the output, which is required for life cycle assessments, the waste statistics cannot be used or can only be used to a limited extent. By researching additional sources of information (studies, association data), the scientific expertise from the online workshops and the expertise of the contractors on life cycle assessments of waste management, it was nevertheless possible to depict the treatment of MSW and its GHG balance largely well[139] .

However, the waste statistics miss quantities that are important for monitoring a circular economy. For example, the **export of non-notifiable waste is not recorded in the waste statistics** and thus is not considered in this study. On the one hand, this means that the polluter-pays principle cannot be fully considered, and on the other hand, the possibility of monitoring these wastes within the framework of the waste and circular economy regime is lost. **This is especially important for plastic waste. Their origin, composition and whereabouts require a better information foundation.**

Furthermore, information from the waste statistics often does not compare well with association data or other data collections. In the case of MSW, this applies above all to packaging waste and in particular those under the LoW-code 15 01 06. Only for about half of these wastes, there is a further differentiation into LWP and non-packaging waste of the same material. Only for LWP the composition is known, at least through studies. **For the monitoring and implementation of an increased separate collection of recyclables, better transparency is needed for these wastes.**

In addition, the implementation of a circular economy also requires a data basis for the preparation for re-use and the re-use itself. These data have not yet been collected statistically.

The data situation is much more difficult for the C&I and C&D waste balance areas and the special food waste balance area. Although the volume can be determined from the waste statistics, there are sometimes considerable data uncertainties and data gaps for the destination and the associated environmental impacts. In many cases, the statistics - including the LoW-code in the German statistics - show types of waste whose designation provides only vague clues about the type of waste. It is particularly difficult to assess C&I waste derived from Eurostat according to EWC-Stat codes, as these sometimes include a large number of LoW-codes. This also applies to food waste from C&I waste, 66% of which is labelled "substances unfit for consumption or processing". Overall, many assumptions had to be made regarding the characteristics of the waste and its treatment.

In order to improve the data situation, it is proposed to bring all relevant parties - statistical offices, associations, experts for waste flows and for environmental assessment - to one table in order to develop innovative collection and documentation possibilities. For C&I, C&D and food waste, it is proposed to improve the data situation specifically for the waste types that show particular relevance (see GHG result below). Smaller

[139] An exception is "mixed waste sorting" for which no representative data is available.

improvements in the waste statistics with a view to easier environmental assessment lie, for example, in a different allocation for thermal waste treatment plants and combustion plants: RDF power plants and biomass power plants should be allocated to thermal waste treatment plants and/or the differentiation by type of plant should be included in the German waste statistics and published[140] .

10.2 GHG balance and scenarios

The GHG balancing for MSW and food waste is more detailed, and for C&I and C&D waste it is carried out roughly. Due to the greater data uncertainties and data gaps, the GHG results for C&I, C&D waste and for the special balance area food waste (source area C&I waste) are to be understood as orienting results.

It is certain that in the sectoral analysis according to the life cycle assessment method of waste management in Germany, net emission savings potentials are achieved in the GHG balance for all waste sources. With regard to organic waste, this is primarily due to the fact that since 2005 no more untreated MSW may be landfilled in Germany. Separately collected recyclable materials are also predominantly recycled and the incineration or co-incineration of residual waste and RDFs as well as sorting and processing residues is carried out with energy recovery or substitution of regular fuel. **With the implementation of the energy transition and other measures of the Paris Agreement, the climate protection potential of the circular economy necessarily decreases, since the substitution potential for electricity and heat generation from waste also decreases as a result of the defossilisation of the energy sector**. This is already evident for MSW in the lower net emission savings potential for 2017 compared to the previous study (cf. Appendix, Chap. B.4) and becomes even more apparent in the scenarios for 2030. **The influence of defossilisation also exists in the primary production of products and the associated substitution potential for recycling.** For the primarily relevant electricity-intensive production of aluminium as well as wood and pulp, the influence for recycling in 2030 was included in this study by means of an estimate.

The study shows that the circular economy can nevertheless continue to make important future contributions to climate protection through measures to increase the separate collection of recyclable materials, increase recycling and technical optimisation of facilities.

This becomes clear in the "business as usual" sensitivity analysis for 2030 for **MSW.** Without measures, the potential climate protection contribution would be almost halved compared to the base year 2017, and compared to the lead scenario 2030, the contribution is 40% lower. The lead scenario 2030 for MSW takes into account the target achievement of the legally required recycling rate of 60% through increased separate collection. Both the authors of this study and participants of the two online workshops with associations consider this increase to be very ambitious (see also Appendix B.2).

Here, politics is called upon to identify and implement supporting measures together with the waste management actors.

From a climate protection point of view, according to the model-theoretical consideration in the scenario "home composting in the RC rate", a half as high level of ambition in the increased separate collection would lead to a loss of about 1 million tons CO_2eq in the net emission savings potential. The loss would be lower if the ambitious increase in separate collection were accompanied by relevant quality losses and, for example, if separately collected organic waste

[140] The data are not publicly available and were purchased for this study.

were increasingly contaminated with fossil-based plastic waste that is incinerated. The fact that the loss due to a half as high level of ambition is not significantly higher is because about half of the increased separate collection is for native organic waste. The role of these in greenhouse gas balances is - since the landfill ban - comparatively neutral with scarce net emission savings potentials. On the one hand, however, it should be noted here that the observations in this study are scenario observations. They are necessarily based on average values and assumptions. On the other hand, the increased separate collection and treatment of organic waste is an important component of a circular economy with regard to resource protection.

In the case of C&I and C&D waste, the indicative GHG results show that, from a climate protection perspective, it is mainly metals and, further on, dry recyclables, organic waste and wood that offer net emission savings contributions. Mineral and other inert waste types, which are mainly used or disposed of in road and path construction, for backfilling and as landfill substitute construction material, have only minor GHG effects. These wastes are relevant with regard to resource conservation (RC building materials) and possible pollutant contents and should be considered separately under this focus. In order to determine the climate protection potentials from these waste sources, it is recommended for future studies to focus on the above-mentioned GHG-relevant waste types. Here, there are considerable uncertainties about the type and quality of the waste. Furthermore, in the case of C&I waste, waste streams that are also thermally treated (especially plastics) should remain in view. Due to the data uncertainties, the optimisation potentials examined in the 2030 scenarios should also be understood as orientational. Depending on the initial situation, type and quality, there may be higher potentials here, which can also be better assessed and investigated with better knowledge of the actual situation.

For the **food waste** investigated as a special balance area, there are also considerable data uncertainties and assumptions and estimates had to be made in many cases. While the amount and potential for waste prevention are comparatively well studied and measures to reduce food waste have been initiated, knowledge about the type and quality of food waste as well as about the anaerobic digestion processes (main type of treatment) are very limited. The GHG emissions and emission savings potentials determined for anaerobic digestion may be over- or underestimated. So far, studies on GHG emissions have only been carried out for anaerobic digestion plants treating biowaste. Future measurement campaigns should also include anaerobic digestion plants that process commercial food waste (kitchen/canteen waste, commercial food waste, overstocked food waste). For this purpose, ways and possibilities should be found to achieve cooperation with the predominantly privately operated plants.

In summary, the following measures are recommended in order to be able to continue to identify and achieve relevant climate protection contributions from the waste and circular economy on the basis of a valid data framework:

- The study shows that increasing the recycling of dry recyclables in particular achieves high net emission savings potentials. →The corresponding climate protection contributions can only be achieved if the data situation and knowledge of the quantity potential is improved , e.g. by commissioning analyses of the current situation at district level for dry recyclables, studies on the optimisation of collection systems[141] , development of a roadmap for the further increase of separate collection under the premise of good separation qualities, ecologically accompanied pilot projects,and financial incentives for actors.

[141] E.g. nationwide recycling bins, what infrastructure is needed, what quality requirements, what control mechanisms.

- The results of the study are necessarily based on assumptions or data of limited reliability for certain types of waste. → For a better assessment of recycling and its potential for further increase, the composition and quality of household-like commercial waste, bulky waste and mixed packaging waste (especially the fractions not sent for recycling) should be analysed. For LWP, the nationwide mass flow data should be published in detail on the website of the Central Agency Packaging Register (Stiftung Zentrale Stelle Verpackungsregister) for better data availability and transparency.[142]

- For waste from the bio bin and garden waste, the result shows that these also make a contribution to climate protection, albeit a smaller one. Fossil-based plastic-containing discards have a negative impact on the result. → In order to achieve further climate protection contributions, measures are needed to ensure that the increase in the separate collection of organic waste does not lead to a further increase in the rate of incorrectly discarded waste. As an example, a successful implementation requires the cooperation of citizens. In many cases there is still uncertainty about what can be put in the bio bin, and in many cases disposal is still subject to charges. Politicians should continue to offer their support for nationwide harmonisation and intensified public relations work.

- The climate protection contribution of waste from the bio bin is higher in the case of anaerobic digestion - the combined material and energy recovery. → In order to achieve further climate protection contributions, their share must be increased and corresponding plants must be built (total capacities about 5 million tons in the lead scenario 2030). Planning and construction of the infrastructure require organisational and financial support; questions of sector coupling and system efficiency for biogas should also be considered. The municipal guideline is an instrument for promoting low-emission and efficient anaerobic digestion plants, which could be further expanded or supplemented by additional subsidies. Other important measures include improving the data situation for the anaerobic digestion of waste from bio bins through further measurement programmes and optimisation options for GHG emissions.

- The climate protection contribution from the anaerobic digestion of commercial organic waste (kitchen/canteen waste, commercial food waste, overstocked food waste) can only be determined as an orientation. → For a reliable assessment, the data situation needs to be improved through projects to collect data and GHG emissions from anaerobic digestion plants specialising in the treatment of these waste types. Corresponding projects could also help to better assess possibilities for food waste prevention.

- The study shows that residual waste treatment can also continue to contribute to climate protection. → Optimisation measures are essential to achieve these further climate protection contributions. For thermal waste treatment, this concerns the increases in utilisation rates assumed for 2030. These are not a foregone conclusion. For waste incineration plants and RDF power plants as well as for biomass power plants, possibilities for optimisation must be further examined and implementation supported (especially heat utilisation). The co-incineration of refuse-derived fuels in cement plants offers a relevant - and, compared to energy recovery, higher - contribution to climate protection as long as coal can still be used as a regular fuel, which can be substituted by RDF. In this respect, it is also important to further support MBT plants in their optimisation efforts.

[142] Quantities for liquid beverage cartons, other paper composites, tinplate, aluminium, foils, mixed plastics, plastic types (ideally further subdivided) and information on RDF quantities and sorting residues.

For **preparation for re-use and waste prevention,** this study was able to show a methodical approach to including these areas in the life cycle assessment of waste management. According to the available data, only a relatively small amount of preparation for re-use could be determined for the GHG balance, which is removed from residual waste (especially bulky waste). In subsequent studies, on the one hand, the potential should be examined more closely through analyses of the bulky waste with regard to qualities. On the other hand, the waste statistics presumably miss out on relevant quantities here as well, and it is necessary to be able to statistically record flows of used goods according to suitable product categories. It was also not possible to take old textiles and old electrical appliances into account in this study. These offer further potential, but are also not sufficiently recorded in the waste statistics. Used textiles are an impressive example here. The volume (domestic availability) is given in (bvse 2020) is given as about 20 kg/cap*year. After deducting 4.5 kg/cap*year, which are disposed of via household waste (Dornbusch et al. 2020) and another 1.5 kg/cap*year (clothing reserve, wear and tear), 14 kg/cap remain that would have to be collected separately each year. The waste statistics only show about 3 kg/cap*year of this. Overall, there is a need for statistical recording possibilities of the accumulation here in order to better recognise and control the potential for preparation for re-use. In addition, further studies are needed to better assess the climate protection potential. The most important parameter here is the potential service life extension. Helpful would be, on the one hand, information from manufacturers on the technical service life (at least estimates) and, on the other hand, surveys of users on their purchasing and consumption behaviour. For the second-hand department stores considered in this study, it can be assumed that buying behaviour has no significant rebound effect. In the case of online trade, a rebound - I buy more because I can buy second-hand goods cheaper and because buying and selling is so easy - is more likely to be observed or to be feared.

This study uses food waste as an example to illustrate the inclusion of complete waste prevention (waste is not produced in the first place due to more effective purchasing behaviour or optimised production processes) in the life cycle assessment of waste management. The climate protection potentials that can be achieved in this way are considerable in relation to the special balance area of food waste. If Germany were to achieve the goal of halving food waste from households and out-of-home consumption by 2030, the climate protection potential could be increased by a factor of almost 4 compared to the lead scenario 2030. The calculated GHG emission savings potential through food waste prevention can be considered sufficiently valid, as data is available for both the waste composition and the GHG debit from its production. Inaccuracies that exist due to averaging from the comprehensive food waste range could be narrowed down in follow-up studies by evaluating the trade statistics. A transfer of the procedure to other types of waste is possible. For this, analogous data regarding the composition, the preventalble amount of waste and its GHG impact from production are required.

Finally, it should be mentioned that in future studies, the sole focus on climate protection potentials is no longer sufficient. It is still necessary to investigate the climate protection potentials of the circular economy in order to be able to identify optimisation potentials and possible measures. However, the goal of climate neutrality is not only accompanied by decreasing potential climate protection contributions, but conversely also by a hunger for raw materials, especially for renewable energy production plants, which must be kept in view. The aspect of resource conservation is essentially linked to the contribution of the circular economy. In future projects, it should first be determined which areas or resources are relevant for an investigation of resource conservation and how these should be evaluated.

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A Appendix

A.1 Data sources: Data from the German waste statistics - Destatis

The German waste statistics, Destatis, publishes yearly the "waste balance" (Destatis 2019c) and “Fachserie 19, Reihe 1” on "waste disposal" (Destatis 2019b). For this project, additionally, more differentiated information on the types of facilities was acquired (Destatis 2019c). For the food waste balance, additional calculations for the years 2014 and 2016 were provided by Destatis. (Destatis 2020).

A.1.1 Waste balance (source Destatis 2019a)

In the waste balance sheet, the generation and destination of waste by waste type are summarised in:

- Municipal solid waste (typical household and other)
- Wastes from extraction and treatment of mineral resources
- Construction and demolition waste and
- Other waste (especially from production and industry)

MSW is understood to be "all wastes of waste chapter 20 (household and similar commercial and industrial wastes as well as wastes from facilities, including separately collected fractions) and waste group 1501 (packaging - including separately collected, municipal packaging wastes)" (Destatis 2019c).

The waste balance is based primarily on the data in Table 1.1 of the German waste statistics (Fachserie 19, Reihe 1, FS19, R1). The input data include the waste delivered from within Germany together with the waste generated on the company's own premises. In addition, the waste quantities exported from Germany are included from Table 20.1, FS19, R1, which, however, are named there exclusively for waste chapters (2-digit LoW-codes). For packaging waste and similar (LoW 15), the quantity imported into Germany in 2017 was 184,000 tons, while the quantity exported from Germany was 49,000 tons. 297,000 tons of MSW (LoW 20) was imported and 213,000 tons exported (Destatis 2019b).

The exported quantities of MSW are comparatively small. They are included in this study because this also corresponds to the logic of the European waste statistics and there is thus consistency with the balancing of the EU balance areas.

In the waste balance sheet, the destination is only roughly subdivided into various disposal processes, energy recovery and material recycling. Since this breakdown is not sufficient for the GHG balance to be compiled here, it is necessary to use the data from FS19, R1. This can lead to minor deviations in relation to the waste balance, as the assignments of the LoW-codes to the designations in the waste balance are not always known. Since exports are taken into account as described above, this does not result in any difference to the waste balance sheet. The handling of exports in the other waste streams is documented in the respective chapters.

A.1.2 Waste disposal, German waste statistics „Fachserie 19, Reihe 1“ (Destatis 2019b)

The german waste statistics “Fachserie 19, Reihe 1” (FS19, R1) (Destatis 2019b) documents waste disposal. It is based on queries to the operators of waste treatment plants.

As additional information, in the context of FS19, R1 in Table 23.1.1-2 and following, the surveys of the German states are combined from reports of the districts or the public waste disposal companies on the nationwide generation of household waste. Since these are completely different survey procedures, they are not congruent in all cases.

In addition to inputs, most waste management facilities also report their outputs by waste type. However, this information cannot be used for the GHG balance because the statistics record "waste from waste treatment facilities" under waste chapter 19 (LoW 19). For MSW, for example, an allocation to LoW-codes 15 and 20 of the reported input is not possible. The waste types of waste chapters 1501 and 20, which are also listed in the output, are generally small quantities of waste that were either only handled in the treatment plant or were generated in the plant's own operations. An exception is the construction and demolition waste treatment plants considered in the balance area C&D waste. Here, C&D waste is accepted for the most part, so that an output analysis could be carried out for this type of treatment (see chapter 8.1.2.1).

A.1.3 Special tables by type of installation (Destatis 2019c)

In the FS19, R1, several types of installations are combined in some tables for different installations, so that a concrete allocation of the waste codes becomes more difficult.

For this reason, additional tables were acquired from Destatis as part of the research for this study, each of which provides a more detailed breakdown of the input and output of the following plants.

- Thermal waste treatment plants:
    - Waste incineration plants
    - Sewage sludge incineration plants
    - Hazardous waste incineration plants
    - Other plants for the thermal treatment of waste (e.g. pyrolysis plants)
- Combustion plants with energy recovery from waste:
    - RDF power plants
    - Biomass CHP plants
    - Other power plant (e.g. coal-fired power plant)
    - Combined heat and power plant (plants that generate heat but no electricity)
    - Plant for other production purposes (e.g. co-incineration in cement, lime, brick or steel plants)
- Biological treatment plants:
    - Biowaste composting plants
    - Green waste composting plants (for predominantly green waste)
    - Biogas and anaerobic digestion plants
    - Combined composting and anaerobic digestion plants
    - Sewage sludge composting plants
    - Other biological treatment plants

In the special evaluations, some of the data is not given in full, as company secrets have to be kept. In addition, the data is only available as total input, i.e. including deliveries from abroad. Therefore, the data in the individual plant types can be both higher and lower than the values in the corresponding tables of FS19, R1, in which the individual plant types are summarised. In detail, a case-by-case decision and explanation is made as to whether values of the special evaluations or values of the tables from FS19, R1 are used.

A.1.4 Additional calculations of the Federal Statistical Office of Germany (Destatis 2020)

For the accounting of food waste, additional calculations were provided by Destatis. These could be used, in particular, to assess the breakdown of the generation by NACE sectors in the relevant EWC-Stat categories at the level of the LoW-codes.

A.2 Data sources: Other sources

An important source for supplementing the statistical information were the results of **studies** by **the German Environment Agency (Umweltbundesamt, UBA)**. In particular, the following projects were taken into account (available in German):

- UBA-Text 18/2015: Material flow-oriented solution approaches for high-quality recycling of mixed commercial municipal solid waste (Dehne et al. 2015)
- UBA-Text 51/2018: Energy generation from waste (Flamme et al. 2018)
- UBA-Text 49/2019: Determination of criteria for high-quality recycling of biowaste and determination of requirements for the plant inventory (Knappe et al. 2019)
- UBA-Text 139/2019: Generation and recovery of packaging waste in Germany (GVM 2019)
- FKZ 3717 34 331 0: Further development of mechanical-biological waste treatment (MBT) with the goals of optimising resource efficiency and minimising greenhouse gas emissions - 2nd interim report (Ketelsen / Becker 2019)
- FKZ 3717 34 341 0: Determination of criteria for high-quality alternative recycling of biowaste (Bulach et al. 2021)
- FKZ 3717 35 344 0: Comparative analysis of residual municipal solid waste from representative regions in Germany to determine the proportion of problematic and recyclable materials (Dornbusch et al. 2020)
- FKZ 3717 35 340 0: Evaluation of the Waste Wood Ordinance with regard to a necessary amendment (Flamme et al. 2020)

For the food waste balance area, the Thünen Report 71 "Food waste in Germany - Baseline 2015" was also used in particular (Thünen 2019a). This currently most comprehensive study on food waste, which the Thünen Institute presented together with the University of Stuttgart in 2019, was used to check the plausibility of the data used for this study (in particular on the quantity, see Chapter 6.1.2). However, for the balancing within the scope of this study, the data provided by Destatis (2019b, 2019c, 2020) was used for the calculations, as these sources provide more detailed information on the destination of food waste in waste treatment plants. This is essential for the quantification of the GHG emissions associated with their treatment.[143]

[143] In the area of food processing, the underlying quantity thus deviates significantly from the data in Thünen (2019a) for some food types, but the deviations were assessed as justifiable overall in view of the generally uncertain data situation (see Chapter 4.2.2).

Further relevant studies that were used as sources of information are documented in the bibliography (see Chapter 11).

In addition, information provided by **professional associations was** used or requested.

For slags from thermal waste treatment, information from IGAM and ITAD was used (ITAD / IGAM 2019). Furthermore, information from ITAD on the performance of incineration plants was evaluated. For the balance of C&D waste, the 11th monitoring report of Circular Economy Construction[144] was used (Kreislaufwirtschaft Bau 2018). For information on the use of former foodstuffs in animal feed production, the Federal Association of Feed from By-Products (Bundesverband Futtermittel aus Nebenprodukten e.V., BFaN) was contacted.

The information from the associations was supplemented with **interviews with experts,** especially in the area of food waste and the production of animal feed.

A.3 MSW - Comparison of packaging waste quantities Destatis - GVM

Table 80: Comparison of "recovery" according to Destatis versus GVM - 2017, for GVM without shares in waste incineration without R1; co-incineration and other (GVM 2019)

Material fraction	Results Destatis (2019b)			GVM (4)	Difference (5)
	Sales packaging (1)	Transport packaging, sales packaging, wholesale trade (2)	Total (3)		
	1,000 t	1,000 t	1,000 t	1,000 t	1,000 t
Glass	1,870.80	225.2	2,096.00	2,440.30	344.3
Paper, cardboard, carton	1,232.10	3,107.60	4,339.70	7,262.70	2,923.00
Plastic	1,233.80	329.1	1,562.90	2,433.10	870.2
Aluminium	61.2	3.4	64.6	107.5	42.9
Tinplate (steel)	271.4	68.3	339.7	793.9	454.2
Wood	n.a.	495.8	495.8	2,090.00	1,594.20
Other (6)	722.6	651	1,373.60	136.7	-1,236.90
Total	**5,391.80**	**4,880.30**	**10,272.30**	**15,264.20**	**4,991.90**

(1) Quantities handed over by dual systems and industry solutions after sorting, including separately collected materials, according to Destatis (2019b) Tbl. 22.2

(2) Transport packaging and secondary packaging collected and sales packaging collected from commercial and industrial final consumers, according to Destatis (2019b) Tbl. 21.1

(3) Sum column (1) and column (2)

(4) Underlying quantities according to GVM results (material and energy recovery, here without energy recovery in waste incineration plants or of materials from mechanical-biological treatment plants) according to (GVM 2019)

(5) Column (4) minus column (3)

(6) in column (4) only liquid board considered, therefore not at all comparable with the delineations of columns (1) and (2)

[144] Association of the German building materials industry, the construction industry and the waste disposal industry; http://kreislaufwirtschaft-bau.de/, last accessed: 10.06.2020

As the main reasons for the differences, GVM states that:

- the collecting companies have very diverse organisational forms and are often only active as collectors on the side,
- Disposal structures as well as distribution and recycling channels are complex, the collection interface is not clear,
- Commercial enterprises sometimes conclude -disposal contracts directly with dealers, processors and -recyclers, which are presumably only insufficiently taken into account.
- GVM takes into account the quantities from the one-way deposit of 0.41 million tons, Destatis does not,
- Collection quantities from discarded reusable packaging could be disregarded.

A.4 MSW - home composting

Including home composting in the recycling rate is not straightforward, as compost volumes are subject to uncertainty and there is no consistent data on the release of gaseous emissions during organic waste decomposition. According to Bulach et al. (2021) studies show that the amount of waste treated by home composting consists mainly of garden waste, especially as garden area increases. The amount of garden waste produced depends strongly on the settlement structure, the size of the garden and the season. Eating habits, but also the possibility of using other disposal channels, such as green waste collection points, make it difficult to generate a reliable database on home composting. Also of interest is the legal situation described in Bulach et al. (2021) regarding the compulsory connection to the bio bin collection system. A possible exemption can be handled differently at the municipal level, in some cases only a reduction of the bio bin volume is possible. Criteria such as the minimum distance of the composter from the property boundary or an existing minimum area for spreading the compost can be required to verify home composting; in practice, however, they are rarely checked. (Bulach et al. 2021).

With regard to the environmental impacts, Bulach et al. (2021) lists both positive and negative impacts, which are briefly summarised as follows: positive contributions are achieved, among other things, by using the self-produced compost as a fertiliser and soil conditioner, thereby substituting purchased compost that may contain peat and industrially produced commercial fertiliser. According to Krause et al. (2014) around 0.6 m^3 of compost can be produced per ton of garden and kitchen waste; for the life cycle assessment in Bulach et al. (2021) 468 kg of compost per ton was calculated. The logistical effort is significantly lower than for large-scale composting, as transport, plant technology and marketing are not required. Home composting can also reduce the organic fraction in residual waste. Disadvantages of home composting are that it does not generate energy and heat as large-scale processes do. In the case of poor professional practice, specific emission values can exceed those of the large-scale plant. Further details as well as information on the legal framework and requirements can be found in Bulach et al. (2021).

The emissions of home composting depend, among other things, on the composition of the material to be composted, the process management and the weather conditions, which can vary greatly. Several studies (Adhikari et al. 2013; Amlinger et al. 2008; Andersen et al. 2010, 2011, 2012; Chan et al. 2010; Colón et al. 2010; Lleó et al. 2013; Lu et al. 2020; Martínez-Blanco et al. 2010; Quirós et al. 2014) investigated the quantity and effects of methane (CH_4) and nitrous oxide emissions (N_2O). Nevertheless, not all studies report greenhouse gas emissions, and some recent studies, such as (Lu et al. 2020) and(Quirós et al. 2014) refer to the results of earlier studies. In Table 81, the CH_4 and N_2O emissions as well as the CO_2 equivalents from studies in which emission measurements were carried out are listed.

Table 81: Summary of CH_4 and N_2O emissions from studies on home composting

CH_4	N_2O	CO_2eq	Type of waste	Mixing frequency	Reference
	in kg/t waste				
4.2	0.45	239	Kitchen waste	Weekly	(Andersen et al. 2010)
3.7	0.39	210	Kitchen waste	Weekly	(Andersen et al. 2010)
0.8	0.39	127	Kitchen waste	Every 6th week	(Andersen et al. 2010)
1	0.55	187	Kitchen waste	Every 6th week	(Andersen et al. 2010)
0.4	0.3	100	Kitchen waste	No mixing	(Andersen et al. 2010)
0.6	0.32	111	Kitchen waste	No mixing	(Andersen et al. 2010)
0.788	0.192	76	Biowaste[1]	Once	(Amlinger et al. 2008)
2.185	0.454	187	Biowaste	No mixing	(Amlinger et al. 2008)
0.158	0.676		Biowaste	Weekly	(Martínez-Blanco et al. 2010)
	0.333	99	Waste from the bio bin[2]	Weekly	(Adhikari et al. 2013)
	0.187	56	Waste from the bio bin	Weekly	(Adhikari et al. 2013)
	0.327	97	Waste from the bio bin	Weekly	(Adhikari et al. 2013)
0.05	0.253	75.05	Waste from the bio bin	No mixing	(Adhikari et al. 2013)
1.35	1.16		Waste from the bio bin	Weekly	(Lleó et al. 2013)
0.3		83	Waste from the bio bin	Weekly	(Colón et al. 2010)
0.85	0.72	50	Waste from the bio bin	No mixing	(bifa 2014)[3]

1) Biowaste: Food and kitchen waste as well as garden waste from private households collected separately in bio bins and/or organic waste sacks.
2) Waste from the bio bin: Sum of biowaste and green waste (green waste: separately collected garden waste from private households as well as park and landscape maintenance waste produced during municipal maintenance).
3) No independent studies; emissions are estimated analogously to green waste composting.

According to (Amlinger et al. 2008) the most important aspects of composting that affect emissions are aeration rate, mechanical agitation, moisture control and temperature control. In the study, they compared home composting and windrow composting and found that a home composting unit that was mechanically turned once during the 52-week period had emissions of 0.788 kg CH_4/t waste and 0.192 kgN_2O/t waste. The result shows that gaseous emissions can be higher in home composting than in windrow composting.

(Adhikari et al. 2013) investigated the gaseous emissions from different types of compost bins, namely wooden bins, plastic bins, mixed soil piles and unmixed soil piles. They could not detect any CH_4 release from composters that were regularly mixed, while unmixed soil piles emitted 0.05 kg CH_4/t waste. They argued that the high CH_4 emissions were due to a lack of mixing and a higher content of food waste on a dry matter basis. Both together could lead to lower aeration rates and at the same time higher oxygen demand due to greater biodegradability, which increases methanogenic conditions (Adhikari et al. 2013). Nitrous oxide emissions were lowest (0.187 kg N_2O/t waste) for the plastic container with aeration holes at the bottom and top. The wooden container and the mixed soil pile had the highest nitrous oxide emissions (0.333 and. 0.327 kg N_2O/t waste), but also produced the driest composts.

In addition, (Andersen et al. 2010) investigated emissions from home composting with different mixing frequencies. During the one-year control period, the weekly mixed units had 11 times higher CH_4 emission levels (3.7 - 4.2 kg CH_4/t waste) than the units without any mixing (0.4 - 0.6 kg CH_4/t waste). N_2 O emissions were independent of treatment method and ranged from 0.3 to 0.55 kg N_2O/t waste. In contrast to other studies, (Andersen et al. 2010) observed that methane emissions tended to increase significantly after mixing the organic waste, but returned to the original level within one hour. In contrast, the same trend was observed for nitrous oxide only to a very small extent. The unexpected differences in CH_4 emissions between the treatment methods could be related to the different degree of compaction of the material, air infiltration into the composting facilities and CH_4 oxidation(Andersen et al. 2010). It was concluded that frequently repeated mechanical aeration should be avoided to prevent increased methane emissions. However, the organic material could degrade and mature more slowly with less aeration, which could further influence the composition of the final product. In addition, seasonal temperature variations affect gaseous emissions. In spring and summer, at average temperatures of 15 °C, high CH_4 and N_2O emissions can occur, while they decrease significantly in winter at temperatures below 0 °C (Andersen et al. 2010).

In some studies on home composting, measurements were made in summer and autumn when conditions were warm and humid (e.g.(Chan et al. 2010)), but in some in the colder months of winter and early spring. (Colón et al. 2010; Martínez-Blanco et al. 2010). This fact may contribute to some extent to the different emission factors of home composting and should be taken into account when making a comparison.

CH_4 and N_2O emissions vary depending on factors such as the type of compost bin, the amount of organic waste added and the treatment method. The overall range of emissions from the different studies on home composting is from 0.05 to 4.2 kg CH_4/t waste and 0.187 to 1.16 kg N_2O/t waste. For comparison: (IPCC 2006) gives standard values for central composting that are either in a similar range as for CH_4 (4 kg CH_4/t waste) or much lower than for N_2O (0.24 kgN_2O/t waste). It should be noted that emissions of N_2O in particular, which has a higher global warming potential than CH_4, exceed the IPCC default value by a factor of 2.5 to 15.7.

Overall, clear uncertainties remain. Due to the many variables influencing methane and nitrous oxide emissions, it is very difficult to determine them representatively on a larger scale. Overall, further research is needed to more accurately quantify the gaseous emissions associated with home composting, to identify the factors that influence emissions and to find methods to minimise these emissions. In light of these uncertainties, as well as the further uncertainties related to the benefits of home composting, and because the scenario of home composting in the RC rate in this study is only used to show the impact on the recycling rate, home composting is assessed as "neutral" for climate change in this study.

A.5 Food waste – LoW-code and food waste shares considered

Table 82: Food waste – LoW-codes considered and food waste proportions

EWC-Stat code or LoW-code	Waste type	Food waste share	Source
W091 Animal and mixed food waste			
LoW 02 01 02	Animal tissue waste	67%	Technical assessment Argus
LoW 02 02 01	Sludges from washing and cleaning operations	31%	Technical assessment Argus
LoW 02 02 02	Animal tissue waste	100%	Technical assessment Argus
LoW 02 02 03	Substances unsuitable for consumption or processing	55%	Technical assessment Argus
LoW 02 03 02	Preservative waste	0%	Technical assessment Argus
LoW 02 05 01	Substances unsuitable for consumption or processing	100%	Technical assessment Argus
LoW 02 06 02	Preservative waste	0%	Technical assessment Argus
LoW 19 08 09	Grease and oil mixtures from oil separators containing edible oils and fats	100%	Technical assessment Argus
LoW 20 01 08	Biodegradable kitchen & canteen waste	100%	Technical assessment Argus
LoW 20 01 25	Edible oils and fats	100%	Technical assessment Argus
W092 Vegetable waste			Technical assessment Argus
LoW 02 01 01	Sludges from washing and cleaning operations	0%	Technical assessment Argus
LoW 02 01 03	Vegetable tissue waste	13%	Technical assessment Argus
LoW 02 01 07	Waste from forestry	0%	Technical assessment Argus

EWC-Stat code or LoW-code	Waste type	Food waste share	Source
LoW 02 03 01	Sludges from washing, cleaning, peeling, centrifuging and separation processes	61%	Technical assessment Argus
LoW 02 03 03	Waste from extraction with solvents	49%	Technical assessment Argus
LoW 02 03 04	Substances unsuitable for consumption or processing	67%	Technical assessment Argus
LoW 02 06 01	Substances unsuitable for consumption or processing	100%	Technical assessment Argus
LoW 02 07 01	Waste from washing, cleaning & mechanical comminution of raw material	25%	Technical assessment Argus
LoW 02 07 02	Waste from alcohol distillation	38%	Technical assessment Argus
LoW 02 07 04	Substances unsuitable for consumption or processing	83%	Technical assessment Argus
LoW 20 02 01	Biodegradable waste	0%	No food waste expected (garden, park and cemetery waste)
LoW 20 03 01 04	Waste from the bio bin	34%	Thünen (2019a)
W101 Household and similar waste			
LoW 20030101 plus pro rata 20030100 (according to Destatis 2019a)	Household waste, household-like commercial waste, collected together via the public waste collection service	34%	Dornbusch et al. (2020)
LoW 20030102 plus pro rata 20030100 (according to Destatis 2019a)	household-like commercial waste, delivered or collected separately from household waste	6%	Dehne et al. (2015), Veras (2020)

EWC-Stat code or LoW-code	Waste type	Food waste share	Source
LoW 200302	Market waste	50%	Expert opinion Öko-Institut
LoW 20 03 03, 20 03 07, 20 03 99	Street sweepings, bulky waste, MSW n.e.c.	0%	No food waste expected

A.6 Food waste - generation according to Destatis ((2019a) & (2019b)) and share of food waste for the individual LoW-codes (excl. NACE A quantities)

Table 83: Food waste - generation according to Destatis ((2019a) & (2019b)) and share of food waste for the individual LoW-codes (excl. NACE A quantities)

Waste type	LoW-code	Input volume , total	Food waste
Quantities in 1,000 t	Table	Tbl. 1.1	Tbl. 1.1
		incl. food waste share (see Appendix A.3) and excl. NACE A according to Destatis (2019c)	
Sludges from washing and cleaning operations	02 01 01	12	0
Animal tissue waste	02 01 02	59	36
Vegetable tissue waste	02 01 03	514	33
Waste from forestry	02 01 07	475	0
Sludges from washing and cleaning operations	02 02 01	23	7
Animal tissue waste	02 02 02	174	164
Substances unsuitable for consumption or processing	02 02 03	521	282
Sludges from washing, cleaning, peeling, centrifuging & separation processes	02 03 01	214	130
Preservative waste	02 03 02	0	0
Waste from solvent extraction	02 03 03	0	0
Substances unsuitable for consumption or processing	02 03 04	542	362
Substances unsuitable for consumption or processing	02 05 01	72	72

Waste type	LoW-code	Input volume , total	Food waste
Substances unsuitable for consumption or processing	02 06 01	275	275
Preservative waste	02 06 02	0	0
Waste from washing, cleaning and mechanical comminution of raw material	02 07 01	2	0,4
Waste from alcohol distillation	02 07 02	307	117
Substances unsuitable for consumption or processing	02 07 04	54	44
Grease and oil mixtures from oil separators	19 08 09	64	63
Biodegradable kitchen and canteen waste	20 01 08	1,003	971
Edible oils and fats	20 01 25	61	60
Biodegradable waste	20 02 01	5,908	0
Waste from the bio bin	20 03 01 04	4,466	1,533
Household waste, household-like commercial waste (public waste collection)	20 03 01 01, pro rata 20 03 01 00	14,108	4,717
Household-like commercial waste, collected separately from public waste collection	20 03 01 02, pro rata 20 03 01 00	3,493	205
Market waste	20 03 02	87	44
W091		1,976	1,655
W092 (incl. 20030104)		12,768	2,494
W101 (without 20 03 03, 20 03 07, 20 03 99)		17,688	4,966
Sum, total		**32,432**	**9,115**
Total, without household waste & household-like commercial waste			**4,193**
of which MSW (organic waste bin, 20 01 08, market waste)			2,547
of which commercial waste (LoW 02 & 19, 20 01 25)			1,645

A.7 Quantity of primary treatment for food waste streams

Table 84: Quantity of primary treatment for food waste streams

EWC-Stat code	Waste type	LoW	Waste INC	Biomass CHP	Cement plant	AD	Com-posting	Other treatment plants	Calculated quantity
W091	Animal tissue waste	02 01 02	13,061		7,226	2,498		12,897	35,682
W091	Animal tissue waste	02 02 02	60,153		33,282	11,503		59,398	164,335
W091	Substances unsuitable for consumption or processing	02 02 03	3,628		69,422	189,367		19,657	282,074
W091	Substances unsuitable for consumption or processing	02 05 01	900			37,700		32,900	71,500
W091	Grease and oil mixtures from oil separators containing edible oils and fats	19 08 09				19,152		43,563	62,715
W091	Biodegradable kitchen and canteen waste	20 01 08	7,124			544,631	53,974	361,173	966,903
W091	Edible oils and fats	20 01 25				7,019		53,186	60,205
W092	Vegetable tissue waste	02 01 03	45	5,434		9,812	14,761	338	30,390
W092	Sludges from washing, cleaning, peeling, centrifuging and separation processes	02 03 01				61,793		3,294	65,087
W092	Substances unsuitable for consumption or processing	02 03 04	9,493	24,801		223,566	14,887	83,695	356,441
W092	Substances unsuitable for consumption or processing	02 06 01	2,300			72,300		200,200	274,800

EWC-Stat code	Waste type	LoW	Waste INC	Biomass CHP	Cement plant	AD	Com-posting	Other treatment plants	Calculated quantity
W092	Waste from washing, cleaning and mechanical comminution of raw material	02 07 01				361			361
W092	Wastes from alcohol distillation	02 07 02				112,098		4,638	116,736
W092	Substances unsuitable for consumption or processing	02 07 04				15,661		17,770	33,431
W092	Waste from the bio bin	20 03 01 04				662,473	846,541		1,509,014
W101	Market waste	20 03 02	4,735			24,373	6,132	6,181	41,421
Total			**101,439**	**30,235**	**109,930**	**1,994,307**	**936,295**	**898,890**	**4,071,095**

A.8 Comparison of waste generation according to Destatis and Thünen (2019a)

The presentation and discussion of food waste generation for the reference year 2015 is differentiated in Thünen (2019a) according to origin, whereby a distinction is made for food processing according to NACE sectors. For comparison with Destatis, the additional calculations of the Federal Statistical Office of Germany were therefore used. (Destatis 2020) which allow a differentiation according to NACE origin. For comparison with Thünen (2019a), the reference year 2016 was used[145]. The comparison of the quantities reported by Destatis for the reference year 2016 in the FS19, R1[146] with Destatis (2020) shows that the additional calculations are also based on the quantities from Table 1.1 "Total input (domestic)". Small deviations from the volumes presented in Chapter 6.1.2.1 according to Destatis (2019b) can therefore be attributed to the different reference year.

In addition to the NACE Destatis (2020), the categories "other services" and "other NACE codes" were introduced and calculated from the differences to the respective parent aggregate.

In order to convert the total Destatis (2020) reported quantity to the food waste share, the values shown in the Appendix A.3 were used for each LoW-code. For simplification, it was also assumed that the distribution among the NACE sectors remains proportionally the same.

Table 85O shows one result of the comparison for food waste from the commercial sector or from bio bins and residual waste. The quantities reported from the bio bin correspond very well. A comparison that is not shown also shows good compliance for food waste from trade and industry.

The food waste quantities from food processing show significant deviations in some sectors. In Thünen (2019a) they were estimated using sector-specific waste quotas, which relate to the respective production volumes in the different economic sectors and were determined via company surveys. Especially in the case of meat waste, as well as waste from dairy, bakery and beverage production, the values differ greatly. In all cases, it is not easy to achieve a good match through an imaginable variation of the food waste shares.

In the case of meat waste, the estimated value of 350,000 t based on Destatis (2020) is significantly higher than the quantities extrapolated via the waste quotas according to Thünen (2019a) with 3,000 to 61,000 t. A possible explanation would be that meat waste is subject to special legal regulations, according to which it must usually first be declared as animal by-products and then be sent to appropriate treatment facilities (e.g. rendering plants). Thus, they may not have been considered as waste by the companies surveyed in Thünen (2019a).

In the case of food waste from the bakery, dairy and beverage production sectors, the quantity of 347,000 t derived based on Destatis (2020) are significantly below the figures of Thünen (2019a) with 552,000 to 821,000 t. A possible explanation here is the further processing into animal feed: the latter is not recorded by Destatis (2020) if former foodstuffs intended for use as animal feed are reported as by-products and not as waste (see also Chapter A.9). The quantities reported by Thünen (2019a) could, however, include these due to the different collection method. However, also Thünen (2019a) points out that according to the current determinations of the UN and the European Commission, quantities that go into feed production should not be

[145] Biennial reporting cycle in even years, so no values are available for 2015.

[146] According to Table 1.1 (as Destatis 2019b, but for reference year 2016)

reported as food losses or waste. However, these determinations are relatively recent[147], so they may not yet have been taken into account in the data collection (see also. Thünen 2019b).

Table 85 Comparison of food waste in the bio bin and residual waste

Quantities in 1,000 t		Destatis (2020) plus FW share	Thünen (2019a)			
			average	min	max	Comment
Residual waste	Households	4,913	3,317	3,015	3,619	
	Household-like commercial waste (municipal)		830	750	900	shown under "Out-of-home consumption
	Household-like commercial waste (separated)	196	n. a.	n. a.	n. a.	
Bio bin		1,529	1,732	1,577	1,887	
Other Disposal	Home composting, feeding to pets	n. a.	1,095	825	1,356	

In view of the generally uncertain data situation (cf. also Thünen (2019a), results when using waste coefficients from the literature), the deviations described above are assessed as acceptable overall. On the other hand, the data situation and allocation are too uncertain for quantitative conclusions to be drawn, e.g. with regard to quantities for feeding.

A.9 Further processing of former food for use as animal feed

A.9.1 Differentiating the treatment of food waste from its use as animal feed

Whether former foodstuffs intended for further processing as animal feed are statistically recorded as waste depends on whether they are declared as by-products (or also directly animal feed) or as waste for recovery. Only in the latter case do the streams reach waste status and are accordingly recorded with LoW-code via the waste statistics. During the discussions with experts, the tendency emerged that the share of foodstuff that is processed from food production in the feed industry is not declared as waste. This, however, also depends on the company that is handing it over and the assessment by the authorities. The classification also varies for former foodstuffs that were already end products, and the official decision in the specific case plays a role. A quantitative estimate of how the proportions are distributed could not be determined. The European umbrella organisation European Former Foodstuff Processors Association (EFFPA) demands that former foodstuffs intended for further use as animal feed should not be classified as waste at any point.[148]

A handout from the European Commission differentiates the classification options as follows. (EC 2018):

[147] UN level (Champions 12.3) from 2017, EU level from 2018/2019 (see Thünen 2019a).

[148] https://www.effpa.eu/what-are-former-foodstuffs/, last access: 18.05.2020

3. Products which do not consist of, do not contain and are not contaminated by products of animal origin; these products of non-animal origin may:
   f) become feed directly within the definition and scope of Regulation (EC) No 178/2002 if they are by-products resulting from the food manufacturing process, or
   g) become waste within the definition and scope of the Waste Framework Directive (before becoming feed) if they are final products;
4. Products consisting of, containing or contaminated by products of animal origin; these products of animal origin become animal by-products within the definition and scope of the Animal By-products Regulation (before they become feed).

This handout was published in April 2018, before the current Waste Framework Directive was issued. The presentation in EC (2018) suggests that with the current version of the Waste Framework Directive[64] food end-products destined for processing into animal feed are no longer considered waste. Packaged biscuits or packaged bread are also mentioned as examples of final food products.

The Waste Framework Directive[64] formulates in this respect for substances of plant origin in Article 2 (2 e) that "substances intended for use as straight feeding stuffs as referred to in Article 3 (paragraph 2 g) of Regulation (EC) No 767/2009 of the European Parliament and of the Council (2), which do not consist of or contain animal by-products."excluded from the scope of this Directive" to the extent that they are "already covered by other Community legislation". No details are mentioned with regard to the condition of these substances, e.g. with regard to packaging.

This is also interpreted by EFFPA as a general exemption from the waste regime for former foodstuffs intended for use as animal feed.[149]

According to the assessment of the Ministry of the Environment (Germany), however, packaged food that is no longer suitable for human consumption is to be considered waste. They should not regularly be considered animal feed, as they first have to be unpacked, whereby residues of the packaging always remain in the organic matrix, which preclude processing into animal feed (BMU 2020). Feed producers reported that packaged food is usually unpackaged and cleaned of packaging material by machine and, if necessary, also subjected to manual post-control in order to comply with the requirement that the feed cannot not contain any more packaging components.[150]

A clear demarcation between the treatment of food waste from further processing for use as animal feed could not be identified within the scope of this study. Based on different sources and since the reference year of the study is before the adoption of the current version of the Waste Framework Directive, it seems possible that food waste also appears in the waste statistics that later goes into animal feed. However, it seems equally likely that in many cases they are declared as by-products and thus not recorded.

In the context of this study, the feeding of former foodstuffs is considered separately. The association data for feed production from the bakery and confectionery sector are used as a quantity framework (see Chap. A.9.2), which may include a proportion of statistically recorded food waste. The basic balance for the statistically recorded food waste (see Chap. 6.1.2.1), on the other hand, completely excludes further processing into animal feed as a treatment option. For

[149] https://www.effpa.eu/revised-waste-framework-directive-confirms-former-foodstuffs-are-not-waste/, last access: 03.06.2020

[150] Regulation (EC) No 767/2009 on the placing on the market and use of feed (Appendix III) includes packaging and packaging parts as prohibited materials.

the quantities treated in "other treatment facilities", it is assumed that they are pre-treated (in particular unpacked) and then anaerobically digested (or fats/oils converted to biodiesel).[151]

A.9.2 Quantity flows for feed from former food

Regardless of the specific classification, bakery products, pasta and confectionery, both from food production and from final food products, are most frequently named as feed materials. Furthermore, by-products from potato plants, wheat starch plants and dairies are processed. According to EFFPA, only former milk-based foods, eggs, honey and pig gelatine are permitted as animal by-products.[148] This is also found in the representation of EC (2018) in the event that the feed is to be used for animals, which in turn are part of the food chain.[152]

Quantity estimates feeding

The feed from **by-products** reported by the Federal Office for Agriculture and Food (Bundesanstalt für Landwirtschaft und Ernährung, BLE) in **accordance with the Market Reporting Ordinance** contains exclusively substances from food production. Their order of magnitude for the 2017/2018 marketing year is approx. **5.6 million tons of vegetable**[153] **and approx. 1.0 million tons animal**[154] feed of domestic origin (BLE 2019).

For feed production from the **bakery products**[155] **and confectionery**[156] sectors, estimates by BFaN assume **approx. 0.8 million tons per year for** the total market in Germany, with bakery products being the significantly larger quantity. EFFPA also mentions bakery and confectionery products as typical feedstocks.[148] At the European level, EFFPA states that approximately 3.5 million tons per year of former foodstuffs are recycled from its member area. For the EU as a whole, it estimates 5 million tons per year.[157] Also in Thünen (2019b) the use of bakery products as animal feed is described.

No production of feed from the fruit and vegetable sector was mentioned during the interviews. According to Thünen (2019b) this rather takes place in the primary production/agriculture sector, which is excluded from this study. Furthermore Thünen (2019b) reports the possibility that unsold goods from food retailing and processing can be used as animal feed (e.g. for wildlife parks or hobby farming) to reduce food losses, in addition to being given to food banks. However, based on the presentation, it is assumed that this is not a relevant practice in terms of scale. Food from catering is not allowed to be recycled in feed production according to EFFPA[158]. According to expert assessment, these quantities are statistically recorded in the waste regime and usually go to anaerobic digestion plants.[159]

[151] Particularly in the area of bakery products, further use/processing into animal feed seems to be possible on a pro rata basis; however, based on the research described above, no reliable quantification of a share for animal feed production could be determined.

[152] There are different regulations for fur and pet animals.

[153] e.g. bran, spent grains, yeast, slops, starch, molasses, oil cake and meal

[154] Mainly whole milk, as well as skimmed milk and whey powder

[155] Bread, rolls, toast

[156] e.g. sweet biscuits, cakes, sweets, chocolate

[157] https://www.effpa.eu/figures-network/, last access: 04.06.2020

[158] Chapter 9 of the feed catalogue also lists catering feed; however, the feed materials in this chapter must meet the requirements of various regulations or may be subject to restrictions. For example, the use of meat-containing food residues is only permitted for the production of feed for pets and fur animals, and partly for aquaculture animals (EC 2018). However, according to expert opinion, slaughter by-products are used for this purpose.

[159] In addition to food waste from large kitchens, canteens and restaurants (LoW-code 20 01 08), "materials unsuitable for consumption or processing", e.g. from trade, are usually disposed of in this way under LoW-code 20 03 04.

Thünen (2019a) also states that approximately 4.3 kg per capita are fed to **domestic animals from households in Germany** each year, which corresponds to **approximately 0.36 million tons/year.**

The balance of feeding can be made roughly for the association data on feed from bakery and confectionery products with the assumption that about 50% of the quantity is packaged food. For the packaging, according to BFaN (2020) a mass share of 2% can be assumed for the packaging. For the substitution of cereal varieties (substituted feed), suitable substitution factors would have to be derived (e.g. from feed value tables).

Substituted feed

According to BFaN estimates, about 25% liquid feed and 75% individual or compound feed (after drying, compound feed industry) are produced from the bakery and confectionery products into feed. These are mainly used in pig feeding, where they replace the use of cereals. (BFaN 2020).

A.10 EWC-Stat code and the LoW-codes contained therein by definition in each case

Table 86: EWC-Stat keys and the LoW-codes contained therein by definition

EWC-Stat code	Name	Included LoW codes
W012	Acids, alkalis or salts	03 03 09, 05 01 16, 05 07 02, 06 03 14, 06 03 16, 06 06 03, 11 01 14, 11 02 06
W02A	Chemical waste	02 01 09, 02 07 03, 03 02 99, 03 03 02, 04 01 04, 04 01 05, 04 01 09, 04 02 15, 04 02 17, 05 01 17, 06 13 03, 07 02 15, 07 02 17, 07 05 14, 08 01 12, 08 01 14, 08 01 16, 08 01 18, 08 01 20, 08 02 01, 08 03 07, 08 03 08, 08 03 13, 08 03 15, 08 03 18, 08 04 10, 08 04 12, 08 04 14, 08 04 16, 10 01 25, 10 03 02, 10 03 18, 10 08 13, 10 08 14, 10 0916, 10 10 14, 10 10 16, 11 01 12, 11 02 03, 15 02 03, 16 01 15, 16 05 05, 16 05 09, 16 08 01, 16 08 03, 16 08 04, 18 01 07, 18 01 09, 18 02 06, 18 02 08, 19 09 03, 19 09 04, 19 09 05, 19 09 06, 20 01 28, 20 01 30, 20 01 32, 20 01 41
W032	Sludges from industrial waste water	03 03 05, 03 03 10, 04 01 06, 04 01 07, 04 02 20, 05 01 10, 05 01 14, 05 06 04, 06 05 03, 07 01 12, 07 02 12, 07 03 12, 07 04 12, 07 05 12, 07 06 12, 07 07 12, 100121, 100123, 10 01 26, 10 02 12, 10 02 15, 10 03 28, 10 04 10, 10 05 09, 10 06 10, 10 07 08, 10 08 20, 10 11 20, 10 12 13, 11 01 10, 12 01 15, 16 10 02, 16 10 04, 19 08 12, 19 08 14, 19 13 04, 19 13 06, 19 13 08
W05	Medical and biological waste	18 01 01, 18 01 02, 18 01 04, 18 02 01, 18 02 03
W061	Metallic waste, ferrous	10 02 10, 10 12 06, 12 01 01, 12 01 02, 16 01 17, 17 04 05, 19 01 02, 19 10 01, 19 12 02
W062	Metallic waste, non-ferrous	11 05 01, 12 01 03, 12 01 04, 16 01 18, 17 04 01, 17 04 02, 17 04 03, 17 04 04, 17 04 06, 17 04 11, 19 10 02, 19 12 03

EWC-Stat code	Name	Included LoW codes
W063	Metal waste, ferrous and non-ferrous mixed	02 01 10, 15 01 04, 17 04 07, 20 01 40
W071	Glass waste	10 11 12, 15 01 07, 16 01 20, 17 02 02, 19 12 05, 20 01 02
W072	Paper and cardboard waste	15 01 01, 19 12 01, 20 01 01
W074	Plastic waste	02 01 04, 07 02 13, 12 01 05, 15 01 02, 16 01 19, 17 02 03, 19 12 04, 20 01 39
W075	Wood waste	03 01 01, 03 01 05, 03 03 01, 15 01 03, 17 02 01, 19 12 07, 20 01 38
W091	Animal and mixed food waste	02 01 02, 02 02 01, 02 02 02, 02 02 03, 02 03 02, 02 05 01, 02 06 02, 19 08 09, 20 01 08, 20 01 25
W092	Vegetable waste	02 01 01, 02 01 03, 02 01 07, 02 03 01, 02 03 03, 02 03 04, 02 06 01, 02 07 01, 02 07 02, 02 07 04, 20 02 01
W101	Household and similar waste	20 03 01, 20 03 02, 20 03 03, 20 03 07, 20 03 99
W102	Mixed and undifferentiated substances	01 03 99, 01 04 99, 01 05 99, 02 01 99, 02 02 99, 02 03 99, 02 04 99, 02 05 99, 02 06 99, 02 07 99, 03 01 99, 03 03 07, 03 03 08, 03 03 99, 04 01 99, 04 02 99, 05 01 99, 05 06 99, 05 07 99, 06 01 99, 06 02 99, 06 03 99, 06 04 99, 06 06 99, 06 07 99, 06 08 99, 06 09 99, 06 10 99, 06 11 99, 06 13 99, 07 01 99, 07 02 99, 07 03 99, 07 04 99, 07 05 99, 07 06 99, 07 07 99, 08 01 99, 08 02 99, 08 03 99, 08 04 99, 09 01 07, 09 01 08, 09 01 99, 10 01 99, 10 02 99, 10 03 99, 10 04 99, 10 05 99, 10 06 99, 10 07 99, 10 08 99, 10 09 99, 10 10 99, 10 11 99, 10 12 99, 10 13 99, 11 01 99, 11 02 99, 11 05 99, 12 01 13, 12 01 99, 15 01 05, 15 01 06, 16 01 99, 16 03 04, 16 03 06, 16 07 99, 19 01 99, 19 02 99, 19 05 99, 19 06 99, 19 08 01, 19 08 99, 19 09 99, 19 11 99, 20 01 99
W11	Common sludge	02 02 04, 02 03 05, 02 04 03, 02 05 02, 02 06 03, 02 07 05, 03 03 11, 05 01 13, 19 08 05, 19 09 02, 20 03 04, 20 03 06
W124	Combustion residues	06 09 02, 10 01 01, 10 01 02, 10 01 03, 10 01 05, 10 01 07, 10 01 15, 10 01 17, 10 01 19, 10 01 24, 10 02 01, 10 02 02, 10 02 08, 10 02 14, 10 03 16, 10 03 20, 10 03 22, 10 03 24, 10 03 26, 10 03 30, 10 05 01, 10 05 04, 10 05 11, 10 06 01, 10 06 02, 10 06 04, 10 07 01, 10 07 02, 10 07 03, 10 07 04, 10 07 05, 10 08 04, 10 08 09, 10 08 11, 10 08 16, 10 08 18, 10 09 03, 10 09 10, 10 09 12, 10 10 03, 10 10 10, 10 10 12, 10 11 16, 10 11 18, 10 12 03, 10 12 05, 10 12 10, 10 13 07, 10 13 13, 11 05 02
W12B	Other mineral waste	01 01 01, 01 01 02, 01 03 06, 01 03 08, 01 03 09, 01 04 08, 01 04 09, 01 04 10, 01 04 11, 01 04 12, 01 04 13, 01 05 04,

EWC-Stat code	Name	Included LoW codes
		01 05 07, 01 05 08, 02 04 01, 02 04 02, 06 09 04, 06 11 01, 08 02 02, 08 02 03, 10 03 05, 10 09 06, 10 09 08, 10 09 14, 10 10 06, 10 10 08, 10 11 03, 10 11 05, 10 11 10, 10 11 14, 101201, 101208, 101212, 101301, 101304, 101306, 101310, 101311, 101314, 120117, 120121, 16 11 02, 16 11 04, 16 11 06, 19 08 02, 19 09 01, 19 13 02, 20 02 03

B Appendix

B.1 Legal requirements

Table 87 Recycling quotas for packaging waste

	Packaging Act Germany[1]	**Future EU Packaging Directive**[2]	
	as of 01.01.2022	until 31.12.2025	until 31.12.2030
Plastics	63%	50%	55%
Wood	-	25%	30%
Ferrous metals	90%	70%	80%
Aluminium	90%	50%	60%
Glass	90%	70%	75%
Paper, cardboard, carton	90%	75%	85%
Beverage carton packaging	80%	-	-
Other composite packaging	70%	-	-

Source: UBA (2018b)

1) Only concerns packaging waste from private end consumers
2) Refers to all packaging waste

B.2 Online workshops with associations

As part of the project, online workshops were conducted to inform relevant stakeholders - association and scientific representatives - about the project status on municipal solid waste in Germany and to involve them in the scenario development. The first online workshop took place on 30.09.2020. The results of the volume data collection, the GHG balance for the current situation and the envisaged boundary conditions for the 2030 scenarios were presented. The event, which was held in three blocks, included comprehension questions and a dialogue round after each block. On the part of the contractors, the event was also used to question necessary assumptions with the stakeholders. Thanks to the feedback and advice, individual calculations could be placed on a better data basis. A central element in the dialogue rounds and the discussion was the 2030 scenarios, which were considered too ambitious in terms of increased separate collection. The feasibility of this and the qualities that can be achieved in the process were problematised. Further points of discussion concerned the uniform use of emission factors for electricity in the EU27 as well as the assumptions on the change in treatment quantities in the 2030 scenario (above all remaining residual waste). The problem of the high level of ambition was shared by the commissioning parties. However, according to the contract, legal requirements must be taken into account for the scenarios. The recycling rate of 60% for MSW required by the Circular Economy Act (KrWG) calls for a significant increase in separate collection. As a result of the event, it was agreed to continue the exchange. This was done with a second online workshop on 03.03.2021. In preparation for this, background documents were prepared and sent out: An information paper for the exchange on municipal solid waste in

Germany with a request to comment on this in the run-up to the event, and a document with information for the other balance areas. The information paper for MSW contained the further project-internal discussion status: information on adjustments already agreed, adjustments under discussion and new proposals for the 2030 scenarios, such as in particular a new scenario with home composting in the RC rate.

One of the agreed adjustments was that the balances for Germany are calculated with the emission factors for electricity and heat for Germany. However, for the consolidation into the EU27 balance, the uniform emission factors for the EU27 must be retained for consistency reasons. In addition, it was agreed to investigate a sensitivity for the accounting of electricity from waste (see Chap. 5.3.3). The information paper formed the basis for the second online workshop. Conceptually, this was divided into two blocks (Part 1 Adjustments, Part 2 Scenarios), each of which comprised a presentation of the contents, the feedback received in advance from the associations and a dialogue round. The participants had been informed in advance that a final decision would be made after the workshop with the German Environment Agency (UBA)/Federal Ministry for Environment, Nature Conservation and Nuclear Safety (Germany) (BMU) as to which suggestions of the associations would be taken up and how, and which would not and why. Accordingly, the participants were first sent a protocol and then documentation with information on the final agreed procedure. The most important discussion points, suggestions and final procedures were:

- Composition of residual waste: here it was pointed out that neither the household waste composition according to (Dornbusch et al. 2020) nor the composition for commercial waste according to (Dehne et al. 2015) is representative for household-like commercial waste. As a solution, a new approach was developed and mean values were used (see Chap. 5.2).
- Based on the newly resulting residual waste composition, the lead scenario 2030 was developed again and the assumptions for increased separate collection were adjusted.
- Initial treatment of residual waste volume in 2030: in the first approach, the reduced residual waste volume due to increased separate collection was unequally deducted on the basis of available studies, which was questioned. Subsequently, and after further internal discussion, it became clear that the studies used as a basis contain significantly smaller changes in volume than the lead scenario in this study, so that the original assumption could no longer be justified. A new, percentage-weighted equal distribution of the residual waste volume to be reduced was made to all residual waste treatment paths.
- As a consequence of this equal distribution, the increase in metal yields from residual waste assumed for the 2030 scenario was also applied uniformly to all treatment routes (previously different due to input with different metal reductions).
- The problem of increasing proportions of contaminants in the organic waste bin due to a significant increase in separate collection as in the lead scenario was addressed in a sensitivity analysis.
- The newly proposed scenario with home composting in the RC rate could be understood according to its purpose of being able to discuss a scenario with a lower level of ambition in a comparative way. There was agreement that the defined home composting rate is not representative and probably too high. It was nevertheless retained, as it offers good relevance for discussing the high ambition level in the lead scenario (see Chap. 5.3). The GHG assessment of home composting with zero could be reproduced.

B.3 Characteristics and specific emission values GHG balance

B.3.1 Characteristics Waste types

Table 88 Overview of calculated values for calorific value and fossil C-content

Waste type	Calorific value in MJ/kg	Fossil C content in % wet weight	Source
Residual waste 2017	9.2	9.4%	calculated (Chap. 5.2)
Residual waste 2030 Lead scenario	9.1	8.9%	calculated (Chap. 5.3.1)
Residual waste 2030 scenario with home composting in the RC rate	9.2	9.2%	calculated (Chap. 5.3.2)
Refuse-derived fuell (RDF)	13	15%	(Flamme et al. 2018)
Wood waste	16	2.3%	(Flamme et al. 2018)
Contaminants bio bin	12	21%	calculated (Chap. 4.2.8)
Sorting residues from LWP	16.942	25.6%	(Dehoust et al. 2016a)
Processing residues from LWP	16	26.0%	(Dehoust et al. 2016a)
RDF from LWP	38	76.6%	(Dehoust et al. 2016a)
Mixed plastic as RDF	33.97	68.9%	(Dehoust et al. 2016a)
Residues paper industry	9.94	1.2%	(UBA 2006)
PE (Reject) Beverage carton reprocessing	37.82	71.6%	ifeu internal
Plastic waste, C&I waste DE	34.2	69.9%	calculated (Chap. 4.2.7)
Plastic waste, C&I waste EU	34.7	71.2%	calculated (Chap. 4.2.7)
Hospital waste	14.9	19%	(Vogt / Ludmann 2019)
Used tyres	28	52.8%	H_i (VDZ 2018); C_{foss} (Flamme et al. 2018)

B.3.2 Specific emission values recycling

For the avoided emissions through recycling and substitution of primary production, harmonised values are generally used - as in the previous study Vogt et al. (2015) - harmonised values are used. Table 89 shows the specific net emission values for recycling determined in this study. In contrast to Vogt et al. (2015) the values shown include sorting costs and GHG emissions from transport from the sorting plant. Transport costs from the sorting plant are assumed to be uniform distances in this study (see Chap. 4.2.2). The values in Table 89 are for recycling in Germany in 2017. In the results chapters for the individual balance areas, on the other hand, the overall results are shown, i.e. the specific values include all disposal paths for a waste type (e.g.

also incineration, landfilling) insofar as these play a role. The values for recycling differ according to the balance areas MSW, C&I waste, C&D waste insofar as different assumptions or boundary conditions are given.

For glass, the differences by area of origin are minimal. For metals, on the other hand, there are greater differences. On the one hand, these are caused by the different division into ferrous and non-ferrous metals (cf. Table 14). In addition, the net emission savings potentials for metals from C&I waste are higher due to the assumed higher-grade purity and thus higher yields (Table 15). For paper from C&I waste, the slightly higher net emission savings exists compared to paper from MSW, because the quantity attributed to C&I waste in the balance area is delivered directly to paper mills and it can be assumed that these are pure fractions that can be used without prior sorting. In the case of plastics, the specific net emission savings is significantly lower if proportionally less virgin material can be replaced by recyclates, as was the case in this study for plastic waste from MSW (cf. Chap. 4.2.7.3). The difference between plastics from C&I waste and from C&D waste is again due to the higher grade purity and correspondingly higher assumed yield for the production waste source area.

Table 89 Specific net emission values recycling dry recyclables this study for 2017

Waste or sorting fractions	Net
	[kg CO_2eq/t waste fraction]
Metals, MSW	-1,769
Metals, C&I waste	-2,035
Metals, C&D waste	-1,575
Paper, cardboard, cardboard packaging	-430
Paper, C&I waste (direct delivery)	-438
Glass	-464
LWP	-820
Plastics, MSW	-431
Plastics, C&I waste	-937
Plastics, C&D waste	-851

LWP only exists for MSW. The modelling largely corresponds to the procedure in (Dehoust et al. 2016a) (cf. Chap. 4.2.7.6). The specific result for LWP in this study deviates somewhat from that reported in (Dehoust et al. 2016a). In this study, the specific net value is given as -782 kg CO_2eq/t. This is due to minor differences in the specific debits and credits caused by the recalculation in this study with current emission factors for electricity and heat as well as the own calculation for beverage compounds and paper composites for which no specifications are given in (Dehoust et al. 2016a).

B.4 Comparison of MSW results 2017 with previous study

Climate protection potentials of waste management for MSW in Germany were last examined in Dehoust et al. (2010) for the balance year 2006. In the following, the underlying waste quantities and parameters are first presented comparatively and then the results of the GHG balance are compared.

B.4.1 Comparison of occurrence of initial treatment and parameters

The quantity for primary treatment in this study is presented in Figure 28 compared to the primary treatment volume in Dehoust et al. (2010) for the balance year 2006. The total volume for the balance year 2017 is initially about 1.8 million tons higher than in 2006. It should be noted here that the waste wood volume for 2006 is not directly comparable, since in 2006 all source areas were taken into account for wood (total approx. 7 million tons), whereas in this study the various source areas are considered separately. In total, for the three balance areas of MSW, C&I waste and C&D waste, a volume of separately recorded wood of around 8 million tons was determined for this study[160] . Excluding waste wood, the amount of MSW in 2017 is about 18% higher than in 2006. This is due to the additional waste fractions of plastics, metals and kitchen/canteen waste evaluated in this study[161], but would otherwise have to be attributed to increased waste quantities.

Higher quantities can be seen in Figure 28 especially for residual waste, organic waste and glass, while the volume for primary treatment for paper and LWP is somewhat lower for the balance year 2017, whereby plastics were also subsumed under LWP for the balance year 2006.

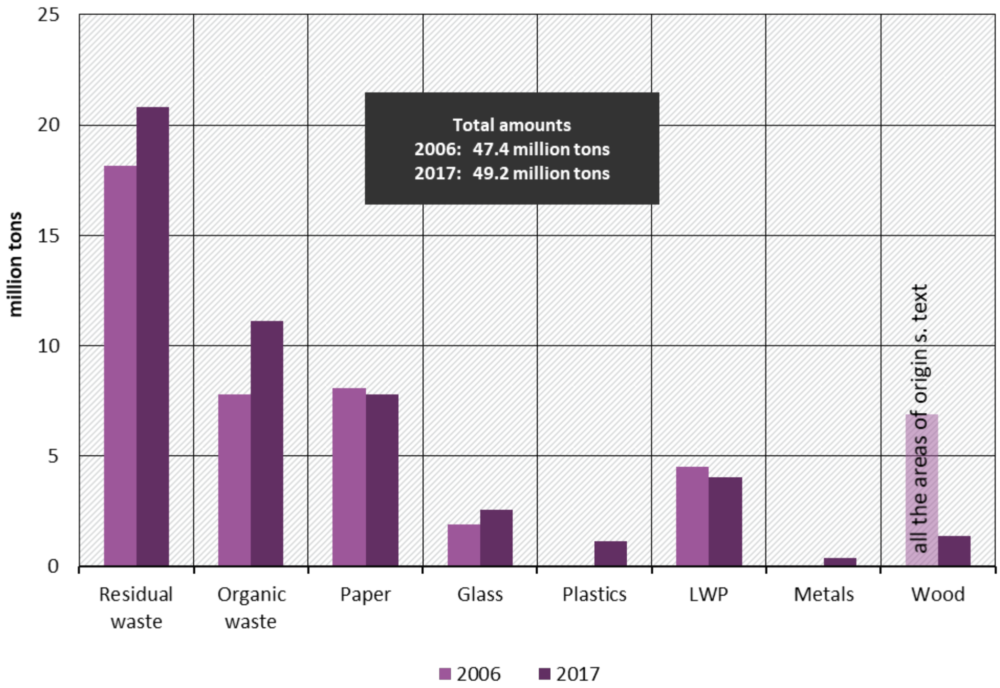
Parameters and characteristics for the balancing in Dehoust et al. (2010) compared to this study are shown in Table 90. Among them, the emission factors for electricity and heat are particularly relevant, especially for the electricity credit. Thus, the debits from the energy demand in 2006 were higher, but conversely also the emission savings potentials, which have a significantly higher influence on the result. This means that energy recovery via thermal waste treatment or biomass CHP still led to significantly higher climate protection contributions in 2006 than is currently the case.

The characteristic data for residual waste - calorific value and fossil C content - are in a similar ratio for 2017, so that only minor differences result from this. The utilisation rates for thermal waste treatment are slightly higher for waste incineration plants, lower for electricity and higher for heat for RDF power plants. Even if the overall utilisation rate is higher, no relevant changes in results are to be expected for this, as the emission factors for heat substitution are lower than for electricity substitution. For biomass CHP plants, the electricity utilisation rate is slightly higher, but the heat utilisation rate is lower.

[160] MSW approx. 1.4 million tons (Table 23), C&I waste approx. 3.6 million tons (Table 69), C&D waste approx. 3 million tons (Table 76).

[161] Kitchen/canteen waste in 2017 approx. 1 million tons or approx. 9% of organic waste.

Figure 28: Volume of primary treatment of MSW in Germany 2017 and 2006



Values 2006 (Dehoust et al. 2010); Values 2017 this study

Table 90 Parameters and characteristics 2006 and 2017

	Unit	2006	2017
EF electricity calculated value	g CO_2eq/kWh	598	562
EF Eelectricity Credit	g CO_2eq/kWh	887	562
EF heat (also credit)	g CO_2eq/kWh	334	256
EF natural gas	g CO_2eq/kWh	454	227[1]
Calorific value residual waste	kJ/kg	9,195	9,220
Fossil C content Residual waste	% wet weight	9.0%	9.4%
Utilisation rates for thermal waste treament			
Waste incineration			
Electric	%	10.0%	11.1%
Thermal	%	30.0%	33.5%
RDF power plant			
Electric	%	18.8%	14.7%
Thermal	%	16.0%	45.4%
Biomass CHP			

	Unit	2006	2017
electric	%	20.0%	21.3%
thermal	%	20.0%	15.0%
Biological treatment			
Contaminants for waste incineration	%	5%	5%
Characteristics of impurities		Hu 9.1 MJ/kg; Cfoss 9%.	Hu 12 MJ/kg; Cfoss 21%
Share of waste from bio bin to AD	%	15%	44%
Share of garden waste to AD	%	0%	12%
Biomethane share	%	-	20%
LWP			
Yield of aluminium	%	20%	32%
Yield of tinplate	%	84%	93%
Share of output from sorting plant for material recycling	%	48%	40%

1) GHG emissions of natural gas upstream chain is currently rather underestimated

For the organic recyclables, the proportionate anaerobic digestion is significantly higher, which is reflected in higher GHG emission savings. In contrast to this, but of secondary importance, are the characteristics for the contaminants to the waste incineration plant from biological treatment. While this was assumed to be the same as residual waste in 2006, a composition with a comparatively higher proportion of plastics was determined for 2017. The calculated ratio of calorific value and fossil C content leads to specific net debits. For LWP, the yields are higher, resulting in fundamentally higher GHG emission savings for material recycling.

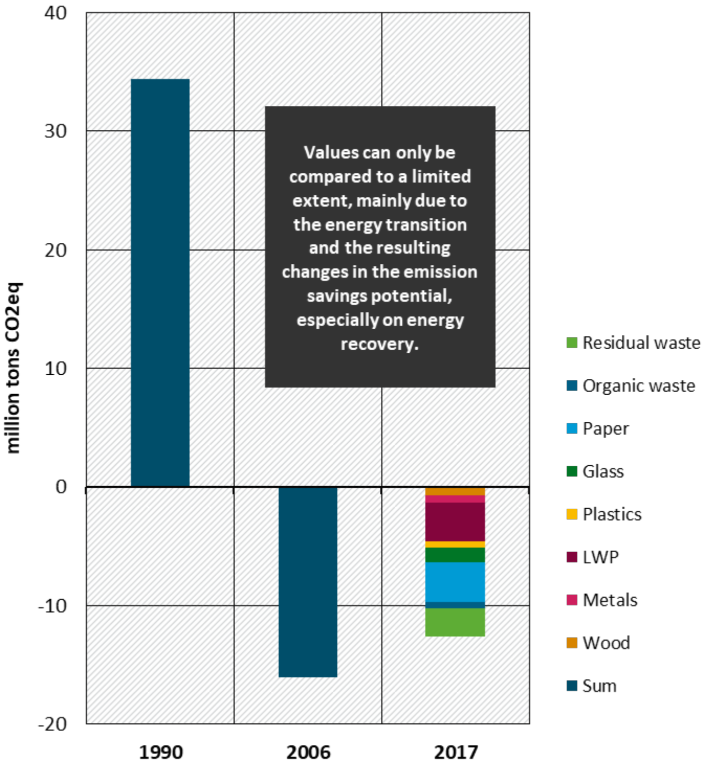
Further relevant differences result from the updated emission values for the substituted primary production by dry recyclables (cf. Chap. 4.2.7), which predominantly have lower GHG debits and thus lead to lower emission savings potentials.

B.4.2 Comparison of GHG balance results

For a time comparison on an absolute level with the balance year 2006 and also 1990 as the base year for climate protection targets, it is necessary to standardise the GHG results. The life cycle assessment method only allows comparisons for the same total waste quantities. For this purpose, the specific results for the balance year 2006 and 1990 were used and related to the total waste volume of the balance year 2017. A subdivision of the absolute results according to the individual results of the waste types is not possible in a meaningful way.

Figure 29 shows the absolute GHG results normalised to the waste volume in 2017 in a time comparison. For the accounting year 2017, the breakdown by absolute net results of the waste fractions is shown, which correspond to the differences in absolute debits and creditss per fraction. The figure again clearly illustrates the result from the previous studies: Compared to the balance year 1990, the waste management sector in Germany has already made a significant contribution to climate protection. The landfill ban has succeeded in avoiding the formation of methane emissions, which were mainly responsible for the pollution in 1990.

Figure 29 Absolute net results GHG balance MSW Germany in time comparison



The absolute net result for 2017 is slightly lower than in 2006. This is mainly due to the energy transition and the resulting change in the emission savings potential for energy from waste. If the share of renewable energy in 2017 were unchanged from 2006 and marginal electricity continued to be credited, the net emission savings potential would be 1 million tons CO_2eq higher than in 2006. This illustrates that a lower net result does not mean that the waste management services have decreased, but rather that it means that it is increasingly successful in advancing the energy transition and achieving climate protection goals.