Classification of the climate impacts of the circular economy

Recommendations and background

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The Academy of the Circular Economy

The Academy of the Circular Economy brings together scientists with over 40 years of expertise in the waste and circular economy to discuss current topics independently and on a scientific basis. It analyses underlying facts and data and develops recommendations for a resilient and efficient waste and circular economy on this basis. The Academy makes recommendations on relevant research topics and programmes and draws attention to areas that currently (still) receive little attention. People, climate, environment and resources are placed in the context of waste management/legal framework conditions and current technological solutions.

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Part 1 – Recommendations

Circular waste management offers considerable potential for reducing greenhouse gas (GHG) emissions and for sustainable and targeted carbon management, both through direct measures (e. g. reducing methane emissions from landfills and waste treatment processes) and through indirect effects, namely by closing material cycles, i.e. by recycling waste and generating high-quality recyclates / secondary raw materials[1] , which can be used to replace (substitute) primary raw materials and avoid the GHG emissions and other environmental impacts associated with their provision. Although material cycles have been established for many years for products such as paper and steel, the potential of recycling for many products such as batteries or materials such as plastics is still insufficiently exploited. In order to promote them in the best possible way, technological innovations for high-quality logistics and recycling processes are necessary; at the same time, products must be designed and developed to be recyclable before waste is generated. In addition, new transformative business models and attractive incentive systems are of great importance for the realisation of material recycling.

Close cooperation between all actors involved in material cycles must be promoted in order to create positive framework conditions for closing high-quality material cycles. The following groups of actors in particular must be taken into account / addressed:

- Waste producers: for recycling-oriented collection
- Waste management industry: efficient logistics and processing into high-quality recyclates
- Manufacturing industry: design for reuse and recycling, and targeted use of recycled materials

Various policy instruments are currently being used in the recycling and waste management sectors, some of which have been established for a long time (e. g. recycling quotas), while others have been introduced in recent years as part of current climate policy or are only now being introduced (e. g. inclusion of parts of the recycling industry in emissions trading and/or sustainability reporting). However, these instruments are the subject of controversial debate, both in terms of their accuracy in reducing GHG emissions and raw material consumption and in terms of their practicality and the effort involved.

The Academy for Circular Economy believes that none of these policy instruments is "the best" for the circular economy, as each of them addresses different actors and has different levels of effectiveness. Rather, the aim must be to find effective solutions for shaping the circular economy and, in particular, for realising material cycles through a coordinated combination of different policy instruments.

In its first recommendation paper, the Academy for Circular Economy examined the instrument of quotas. This second recommendation paper deals with the newly added steering instruments from the context of climate policy, which are based on the allocation of climate impacts to actors in various greenhouse gas accounting systems. The background section of this recommendation paper analyses in particular EU certificate trading and the reporting requirements of the Green Deal based on the life cycle approach. From the perspective of the circular economy, various challenges/shortcomings can be identified here:

- Existing instruments and accounting systems are not sufficiently tailored to different waste streams with different characteristics (e. g. mass flows versus critical resources) and different actors.
- Existing accounting systems consistently lack specific incentives for waste management (preliminary) services for the provision of secondary raw materials. Current GHG accounting systems primarily provide incentives for the manufacturing sector by attributing the potential savings from the use of secondary raw materials to this sector. In some cases, this leads to a motivational imbalance along the treatment/disposal and supply chain. In principle, incentives should be carefully considered and created for all actors involved in the value chain (waste producers, waste management companies, manufacturing industry) in order, for example, to create more scope for investment in upstream processes, longer-term planning in the waste management sector and, as a result, better quality and higher quantities of secondary raw materials.
- The reactions of markets for secondary raw materials to the use of the aforementioned steering instruments are not well known in the context of their respective functions, with the assessment of the risks of possible market failure representing a particular challenge.

[1] This text uses the established terms primary and secondary raw materials. However, a circular economy requires the priority use of secondary raw materials, so that in future the language used should also reflect the fact that secondary raw materials are not a "second choice".

The Academy for Circular Economy makes the following recommendations for the further development of accounting systems as an instrument for promoting material cycles:

Design of certificate trading

The certificate trading scheme (emissions trading in accordance with EU ETS I) is aimed at operators of installations that are considered energy-intensive and therefore emit large quantities of GHG from their production processes. In the area of material cycles, this concerns the basic materials industry, i.e. bulk materials such as metals, cement or certain basic processes in the chemical industry. Certificate trading is a very effective instrument for climate protection, but has not yet been specifically examined/designed with regard to its steering effect on recycling and the actors involved in the material cycle. The following points should be taken into account with a view to optimising it:

- There are significant **differences in the scope of certificate trading** for facilities producing different materials/waste streams:
  a. Those that are already included in certificate trading and where certificate trading has a major impact: e. g. bulk metals such as steel, aluminium and basic chemicals
  b. Those that are not included in certificate trading: non-energy-intensive industries such as the manufacture of plastic products

  Recommendations on how recycling could be better taken into account in certificate trading therefore only refer to installations in category a).
- **The use of certificate trading as a market-based mechanism** is already well established, liberalisation is in place and it creates fundamental incentives for investments in the manufacturing industry subject to certificate trading to use secondary raw materials. Where recycling processes are already established on a large scale, as in the case of steel scrap, this is already acting as an incentive in certificate trading. However, there are still some shortcomings in this regard with regard to the accounting of GHG emissions, which may stand in the way of intensifying the use of scrap in the circular economy. For example, Pothen et al. (2021) point to various gaps in the EU ETS – such as the consideration of mining-related emissions and emissions from raw materials and intermediate products in steel production – which should be closed[2]. In addition / alternatively, it would also be possible to link the use of scrap to the free allocation of certificates.
- **Clear and targeted allocation of savings in certificate trading**: It is essential to carefully consider and examine in advance (e. g. by means of comprehensive technology assessment and risk analysis) whether disruptive market shifts or ultimately market failure could occur if a "redistribution" of allocation options is considered as a steering instrument. Market failure can occur if credits are distributed among too many players, as this could dilute the incentives for individual players or cause CO_2 prices to rise significantly above material prices. This could impair the effectiveness of the instrument and jeopardise the desired recycling targets. It is therefore extremely important to focus on key players in order to allocate credits in a targeted manner to those players who have the greatest influence on the recycling chain and who have to absorb the greatest (market) uncertainties. Further risks arise from uncertain or lacking options for using secondary raw materials if credits are reduced in the manufacturing industry, or there could also be a shift in the use of recycled materials outside the EU if there is an excessive supply of waste/secondary raw materials due to increasing allocation of credits in the waste management sector.

Structure of reporting based on the life cycle approach

The reporting is aimed at companies in their role as organisations and manufacturers of products, as currently introduced in the Green Deal policy, primarily in the form of the Corporate Social Responsibility Directive (CSRD) and the Ecodesign Regulation.

- The organisation/product-related steering instruments should primarily target producers of complex consumer and investment products. Unlike producers of basic materials such as steel or cement, these companies are generally not covered by certificate trading, as the product-related GHG emissions occur primarily in the upstream chain and not at the end manufacturer itself. In order to exploit the considerable scope for action available to this group of companies, "soft" reporting instruments are therefore appropriate.

[2] The CBAM (Carbon Border Adjustment Mechanism) must be taken into account here, which is intended to limit CO_2 emissions from goods imported into the EU from 2026 (implementation phase) as a supplement to the EU ETS.

- Producers of complex consumer and investment products have the potential to exert considerable influence in the following areas: (i) use of secondary raw materials; (ii) recycling-friendly product design.
- The use of secondary raw materials is already taken into account in existing accounting systems based on the cut-off approach for end-of-life allocation and therefore acts as an incentive system. For this reason, and because of the standardisation of reporting, it seems sensible to retain this approach. The extent to which an approach based on the circular footprint formula should be used in the future depends primarily on whether the factors included in the formula for characterising markets for secondary raw materials can be justified on the basis of sound arguments and whether a corresponding steering effect can be demonstrated.
- Practical limitations to the recycling of materials from complex consumer and capital goods currently exist, particularly in that products are not designed with recycling in mind. In addition to the existing accounting systems, it would be desirable to report on the extent to which designs are geared towards future recycling and the effects this has on reducing GHG emissions. For such accounting, companies need both methodological guidance and data sets on recycling processes, especially for those that are still under development. In general, the aim should be to reduce the administrative burden along the entire value chain as much as possible.
- The basic materials industry is also affected by the aforementioned reporting instruments in its role as an organisation and manufacturer of products. As it is also covered by certificate trading, care must be taken to ensure that procedures and data bases for both areas are harmonised or can be used synergistically to reduce the burden on companies.
- Companies in the waste management sector are also included in relevant reporting instruments such as CSRD in their role as organisations. This reporting could be used directly to make information on the costs of recycling processes available, for example via the digital product passport or databases for the manufacturing industry. In addition, within the framework of such reporting, it would also be conceivable in principle to allocate the savings achieved through the substitution effect of secondary raw materials by using an accounting approach based on the circular footprint model, provided that the waste management industry were to be introduced as a third group for calculation purposes. However, it would need to be thoroughly investigated whether there are any well-founded factors for this and whether and what steering effect this would have.

Conclusion

For the areas of climate impact accounting examined, there are a number of approaches that could be used to strengthen recycling. It is essential to take into account the specific suitability for different groups of actors, in the case of certificate trading primarily the raw materials industry and upstream companies in the waste management sector, and in the case of reporting requirements based on the life cycle approach, primarily the producers of complex end products. For the latter in particular, it should be noted that the design, e. g. via the digital product passport, and the associated question of effectiveness are still open, as are the modalities for the possible involvement of the waste management industry.

As an alternative or supplement to the above approaches, greater use could be made of waste management instruments in the form of quotas and legal requirements for extended product responsibility. Combinations of legal framework requirements, e. g. mandatory quotas, sustainability- and life cycle-oriented accounting and documentation obligations (e. g. carbon footprint or digital product passport based on LCA) and market-based mechanisms (certificate trading) are conceivable, but require careful and comprehensive consideration and targeted design. In this context, fundamental research is desirable, particularly with regard to the function and legal design of secondary raw material markets, as well as intensified scientific research to accompany the implementation of new instruments, which could provide reliable information on their effectiveness and further optimisation.

Part 2 – Background

Introduction: Contribution of the circular economy to climate protection

The contribution of the circular economy to climate protection can basically be identified in several areas that are linked to the development from "linear" waste management in the period after the Second World War to a "circular economy". On the one hand, the direct greenhouse gas (GHG) emissions listed in the national projection report (UBA 2024) arise in waste management during certain waste treatment processes: Particularly noteworthy here is methane formation during the landfilling of biodegradable waste, but also residual gas emissions and methane slip during the biological treatment of biowaste (composting, fermentation). In this area, reducing GHG emissions is a direct contribution to climate protection, which has shown considerable success in Germany in recent years with a reduction of almost 77% compared to 1990 (waste and wastewater sector; UBA, 2022), but for which operational improvements and technical developments are still necessary. On the other hand, in the circular economy, recycling waste can lead to indirect GHG savings: this is the case when the secondary raw materials produced by recycling replace primary raw materials in the economy and the GHG emissions from recycling are lower than those from the provision of primary raw materials. This effect is particularly significant for metals. For example, in Germany, optimised aluminium recycling could save an additional 5.0 to 7.2 million tonnes of CO_2 emissions compared to the status quo (Raatz et al., 2022). Additional GHG-reducing effects can also be achieved from energy production from waste if this replaces fossil fuels. For non-fossil emissions, these processes can even generate negative emissions through CCS (carbon capture and storage) measures, e. g. from emissions from biogas plants.

From a circular economy perspective, the question arises as to how GHG savings are allocated and to whom. This process of allocation in GHG accounting reveals characteristic differences between the two areas of waste management and the circular economy (Schebek et al. 2022). Emissions reductions in disposal processes take effect directly at the relevant points in the waste management system (e. g. at the landfill site) and are therefore also allocated there, i.e. assigned to the waste management actor (e. g. the landfill operator). In contrast, GHG savings from recycling are only realised when many actors work together: the waste producers who separate their waste for collection and thus for recycling, the companies in the waste management sector that take care of transport, logistics and processing, and finally the manufacturing industry and agriculture, which use secondary raw materials (recyclates, nutrients, etc.) and, in the case of the manufacturing industry, also design their products with a view to their subsequent recyclability. The allocation of savings through substitution is therefore unclear and currently a controversial topic in climate policy, which increasingly uses GHG accounting as an incentive for control (Baehr et al. 2024).

This paper focuses on the contribution of the "circular economy" and its actors to GHG savings. It highlights the framework conditions and significance of recycling for different material flows and economic sectors on the one hand, and the approach to greenhouse gas accounting with regard to the allocation of potential climate gas savings from the circular economy on the other. Based on this overview, recommendations are derived on how the potential of the circular economy for reducing greenhouse gases can be exploited in the best possible way.

Climate impact of production from primary raw materials

As explained above, the contribution of the circular economy to climate protection lies in particular in the substitution of primary raw materials and the emissions associated with their provision by secondary raw materials. In order to measure this contribution, the reference scenario for the circular economy is the current provision of raw materials, which mainly comes from primary sources – in the case of non-renewable raw materials, these are natural deposits, and in the case of renewable raw materials, agriculture and forestry. It should be noted that, due to rising demand for raw materials, the degradation of materials during their use phase and unavoidable losses along the recycling chain, even maximising recycling is unlikely to completely eliminate the extraction of primary raw materials.

Mining and processing account for 4 to 7 % of global GHG emissions (Wani et al. 2022). More than 65% of GHG emissions from mining and processing come from the combustion of fossil fuels. In the mining sector, these include diesel engines used to power mining machinery. In addition, the extraction of fossil fuels can also result in direct emissions of methane (CH_4) and, in the case of deforestation to prepare land for raw material extraction in open-cast mining, significant CO_2 effects can arise through the use of machinery and the reduction of carbon storage capacity in biomass (Liu et al. 2021).

In pyrometallurgical processes, carbon or carbon monoxide (CO) is generally used as a reducing agent, which reduces the metals to their elemental state and is itself oxidised to carbon dioxide (CO_2). The use of hydrogen as a reducing agent, which is still in its infancy, is only climate-neutral if it is not produced from fossil raw materials, which is the case for 96% of the hydrogen currently produced (Le et al., 2023). However, carbon carriers such as coke not only serve as reducing agents, but also as alloying elements, for which biogenic raw materials could be used in the future, and as energy carriers, although they can be substituted by electrical energy in this field of application, as is the case in electric steelworks, for example. Pyrometallurgical processes not only release CO_2 from the reducing agent and the energy carrier, but also, in the case of smelting carbonate ores such as siderite ($FeCO_3$), during their calcination, which can take place either directly in the metallurgical process or in an upstream sintering process. Due to the sum of these processes, the iron and steel industry as a whole is responsible for 7 % of global GHG emissions (Hasanbeigi 2022). Hydrometallurgical processes use electrochemical processes in aqueous solution instead of thermochemical reduction, so that the source of electricity generation is a decisive factor in the ecological assessment. However, for zinc extraction, for example, the pyrometallurgical process currently generates around 28 % less GHG emissions than the hydrometallurgical process (Bobrowski & Nejranowski 2023).

In mineral processing, i.e. the production of glass, ceramics and binders from inorganic non-metallic raw materials, no chemical reduction work is required, so that GHG emissions result only from the use of fossil fuels and the calcination of carbonate raw materials. Nevertheless, the cement industry alone is responsible for 8 % of global GHG emissions (Andrew 2019). While the former can be increasingly reduced through the use of electrically heated furnaces, the latter emissions are difficult to avoid ("hard to abate") and can only be reduced through the use of CCUS technologies (carbon capture, utilisation and storage).

While the combustion of fossil fuels as a source of GHG accounts for around 64% of global emissions (IPCC 2022), GHG emissions from production-related processes in the petrochemical industry account for only around 3 % of global GHG emissions (Isella & Manca 2022). Products from the petrochemical industry are the raw materials for the chemical industry, which manufactures a wide range of products, among which plastics are particularly relevant in terms of the quantities produced. The carbon content of these products is ultimately released when the polymers are converted to CO_2 in waste incineration or when used as a substitute fuel in combustion processes, or in the case of biodegradable plastics, during their biological degradation. Accordingly, the use of CCUS technologies to reduce GHG emissions is also necessary here to supplement recycling activities. Due to the central role of waste incineration in the disposal of polymer materials that cannot be recycled (either as materials or raw materials), this is currently being discussed as part of future carbon management in the economy. According to a study by DECHEMA (Krämer 2024), the chemical industry assumes an annual C demand in the range of 7.9 to 12.4 million tonnes per year in the long term (here: 2035), depending on the scenario. This demand must be met from non-fossil sources in the long term (by 2050), with recycling processes, biomass and carbon from CO_2 (CCU/BECCU) being addressed as C sources (Krämer 2024).

With regard to CO_2 capture, the German government's Carbon Management Strategy (CMS) considers thermal waste treatment to be a priority area of application. According to the CMS key issues paper, CO_2 emissions from thermal waste treatment plants are considered "unavoidable" even if high standards of waste separation are met. Nevertheless, there is still no clear legal basis (certificates, cost allocation, etc.) for the eligibility of captured C in the context of its respective use (CCS/CCU). CCS effects are easier to assess than heterogeneous CCU measures (duration of C binding in products). With regard to the economic viability of CO_2 capture, with capture costs of €50 - 100/t CO_2 (World Energy Council for Germany 2021)[3], it cannot be assumed in the short to medium term that the CO_2 price will be sufficient to cover the increased costs, especially as additional effects on the energy balance of an MSW incineration plant are to be expected depending on the technology used. Additional costs would then have to be covered by fees.

The agricultural and forestry production of renewable raw materials provides carbon carriers from biomass, i.e. biogenic carbon, thereby avoiding the extraction of fossil raw materials such as oil, natural gas and coal from the lithosphere. Nevertheless, agricultural production in particular is associated with considerable problems: competition for land between the production of raw materials for the economy (e. g. biofuels) and food, the consumption of fossil fuels in agriculture and transport, and the emission of nitrous oxide (N_2O) from nitrogen fertilisers. In this respect, recycling is also an important strategy for the circular economy for products made from renewable raw materials, for example in the case of waste wood or textiles.

For both biogenic and fossil carbon carriers, there is also a specific measure that can contribute to climate protection: the removal of carbon from economic cycles. In carbon capture and storage (CCS), the

[3] (Karpf 2021) assumes separation costs of €54/t CO2 for amine scrubbing in a case study.

captured carbon is stored outside the biosphere, e. g. in old gas deposits. In carbon capture and utilisation (CCU), the carbon is used in the biosphere (agriculture) or the economy (e. g. in construction). Whether this can be regarded as capture depends on the extent to which the carbon carriers remain in use permanently, i.e. whether a storage facility can be established and how long this storage facility will remain in place.

Framework conditions for the circular economy and case studies on reducing greenhouse gas emissions

The waste management sector is now part of the broader concept of a circular economy (CE), which can be understood as a new economic system for the production and consumption of products (European Parliament, 2023). According to a new study, CE measures could reduce 26% of Germany's global CO_2 emissions by 2045 (WWF 2023). However, a significant proportion of these savings are attributable to measures taken before waste is generated, such as changes in product demand, design or use. Nevertheless, recycling through circular and waste management remains an essential part of the circular economy, as all products must eventually reach the end of their useful life for technical, economic or social reasons, and the need to recover the materials they contain then inevitably arises.

The term "products" encompasses all goods in society, from short-lived items such as packaging to very durable items such as vehicles, capital goods, infrastructure and buildings. Considering this diversity, it becomes clear that the path to recovering material as a secondary raw material is a long one: goods enter the waste management system when they are collected, and similar goods from different collection areas (e. g. households and businesses) are brought together. If they consist of different components and materials, these must first be separated, which involves processes of dismantling, sorting or chemical-physical material separation. Only then are largely homogeneous material streams available that can be fed into the actual material cycle – e. g. paper, glass, metals – once they have been cleaned or processed to a certain quality through further treatment steps. Various actors are involved in this chain: product manufacturers, who influence the subsequent recyclability of their products through their design; users, who ensure (separate) disposal ensure that waste streams are as uniform as possible during collection, recycling companies, which separate and process materials, and the materials/raw materials industry, into whose material flows the homogeneous materials flow until their waste properties end as secondary raw materials.

The point at which a material loses its waste status is when it has achieved a quality required by the manufacturing industry for use as a raw material. This is precisely where substitution takes place, as the secondary material becomes equivalent to a primary material. The positive climate impact of recycling compared to primary production occurs when the emissions of the secondary route are lower than those of the primary route. Whether this is the case depends on two factors: firstly, how much effort is required to process waste from collection to the point of substitution, and secondly, how emission-intensive the substituted primary production processes are. The latter is directly related to the question of at which stage of the primary production process chain substitution takes place. As shown in Chapter 2, it is the emission-intensive sectors of the economy, in particular raw material extraction and the basic materials industry, which, on the one hand, have a high demand for (fossil) energy sources and, on the other hand, directly lead to the emission of CO_2 or other greenhouse gases through chemical processes in production.

Accordingly, major savings are achieved above all when secondary raw materials are used at a stage where processes in the basic materials industry can be avoided, such as thermochemical reduction in pyrometallurgical processes. This is the case when the waste, in this case scrap, is already in metallic form. If, on the other hand, metal-containing waste, such as slag, dross and dust, which contain metals in oxidised form, has to be returned to pyrometallurgical processes, this effect does not occur to the same extent. Even greater savings can be achieved if waste does not have to go through the thermochemical process stage again in order to be reused in products that would otherwise be manufactured in this way. This is the case, for example, when furnace breakage is directly reincorporated into refractory masses in crushed form after sensor-based sorting (Horckmans et al. 2019).

This clearly illustrates the importance of the point of use of secondary raw materials for calculating the climate impact of the recycling process. The later in the production process the secondary raw material is recycled, the greater the savings. This can be illustrated by the example of substitute raw materials and additives in the cement industry. Using waste as a substitute raw material, i.e. adding it to the raw meal in the rotary kiln, avoids the emissions generated during the extraction and processing of primary raw materials (adjusted for emissions from the collection and processing of secondary raw materials), but not the emissions resulting from the energy input into the rotary kiln. However, there is an advantage over the use of primary raw materials in the clinker burning process if the secondary raw materials are already "deacidified", i.e. if the Ca carrier phases are not carbonates but oxides or silicates and therefore do not release CO_2 during clinker burning. Subsequent use as an additional raw material, i.e. as a clinker substitute in the cement mill, offers the additional advantage that the emissions resulting from energy consumption during clinker firing are also reduced in proportion to the substitution rate. However, one disadvantage is that the chemical reactions in the clinker process do not offer the possibility of increasing hydraulic activity. Taking these factors into account in a life cycle assessment is a major challenge.

A second example of the importance of the point of use in the production chain is the recycling of fused alumina, which is used as an abrasive. Direct reuse in grinding tools is more advantageous in terms of avoided emissions than remelting with primary raw materials in fused alumina production. On the other hand, qualitative defects such as cracks or decreasing particle size can no longer be corrected.

These examples also highlight the importance of recycling quality. The use of construction and demolition waste, which consists mainly of old concrete, as recycled aggregate is an example of "cascading use", as the binder must be produced again from primary material. From a climate protection perspective, relevant CO_2 savings can only be achieved by substituting the binder, i.e. cement, as the emissions from cement production far outweigh the energy-related emissions from aggregate extraction. Another example of cascading use is the use of refractory ceramics in slag conditioning as opposed to closed-loop recycling. Closed-loop recycling is a form of recycling in which waste is returned to the product from which it originated, e. g. glass bottle → waste glass → glass bottle. In contrast, open-loop recycling describes processes in which a different product is produced, e. g. glass bottle → waste glass → glass wool. However, it should be noted that closed-loop recycling at the product level can only take place where the product consists of a homogeneous material, as in the example of the glass bottle. Otherwise, this term refers to the level of material cycles, which, as shown, mainly occur in the basic materials industry.

The dependence of GHG reduction effects on the duration of carbon sequestration in cycles can be demonstrated particularly clearly in the agricultural and timber sectors. These cycles are of particular interest because they do not only involve a material cycle – e. g. that of the timber industry – but also form part of the carbon cycle through the environment and the economy. Agriculture, which accounts for 8.2–9.6% of national GHG emissions (UBA 2024; mainly CH_4 and N_2O), can benefit in particular from the use of compost, biochar and nutrient recyclates from circular economy activities. However, there is considerable uncertainty regarding the climate protection effects that can actually be achieved, particularly due to the difficulty of estimating the time it takes for the carbon bound in compost/biochar to be released and the high complexity of soil-specific dependencies. In the waste wood sector, multiple cascade processes of material use can, depending on the approach and reference product(s), enable both lower and significantly higher GHG reduction potentials compared to direct energy recovery[4] .

The sometimes very complex relationships between the individual economic sectors of the raw materials and basic materials industry with regard to the intersectoral recycling of waste are simplified in Fig. 1.

[4] IZES et al., Regional concepts for expanding bioenergy production from wood – sustainable and energy-efficient strategy development with special consideration of wood cascade utilisation, DOI: 10.13140/RG.2.2.28750.61764, 2014

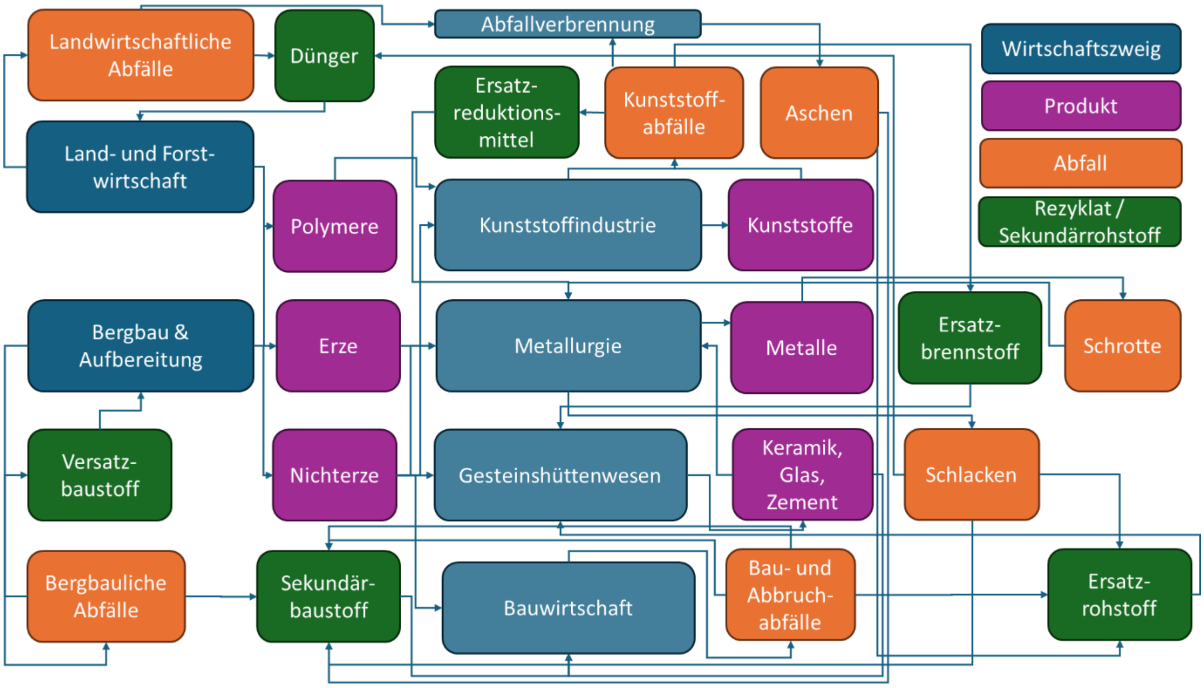

Figure 1: Selected material flows from the intersectoral recycling of waste with a focus on the raw materials and basic materials industry

Accounting methods for GHG and allocation of the climate impact of the "circular economy" / recycling economy

Various accounting methods exist for calculating total GHG emissions in a given system framework (or for calculating GHG savings through specific measures). Regardless of different names and variants, these can be traced back to three basic methodological approaches (Schebek et al. 2022):

- Accounting based on the system framework Nation as a political/economic entity according to the territorial principle[5] : This methodology is based on national statistics and international agreements, in particular: Environmental Economic Accounting (UGR)[6], International System of Environmental and Economic Accounting (SEEA)[7]; National inventory reports for international climate reporting; EU certificate trading.
- Accounting based on the system framework Organisation as a legal entity: This methodology was developed by the Greenhouse Gas Protocol (GHG Protocol), which provides a further structure with three scopes for direct, indirect and upstream/downstream emissions.
- Accounting based on the system framework of the life cycle of products as a conceptual unit: This methodology is standardised in the Life Cycle Assessment (ISO 14040/14044) standards, which consider environmental impacts beyond GHG, and in the LCA-based Carbon Footprint (ISO 14067) standard, which is limited to GHG.

The allocation of GHG or GHG savings to actors is carried out within the framework of these three approaches using their respective calculation methods. As a fundamental difference, accounting according to the territorial principle is limited to national emissions, while GHG and LCA cover international supply chains of products and also disposal processes. Accordingly, different actors are addressed: in the territorial principle, these are the direct emitters of greenhouse gases from installations (e. g. power plants, large industrial facilities) or from defined sectors (transport, agriculture). GHG addresses organisations, in

[5] A variant of accounting within national borders is accounting according to the so-called residence principle. This is not considered separately here, as it is mainly used in the EU for air emission accounts.
[6] https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/UGR/ueberblick/Publikationen/Downloads/einfuehrung-ugr-pdf-5850021.pdf
[7] https://seea.un.org

particular companies, but also non-commercial entities. LCA addresses in particular manufacturers of products or providers of services.

The calculation methodology used in the national inventory reports is based on the internationally agreed system for compiling greenhouse gas inventories[8] and for GHG reporting to the UNFCCC[9] . In general terms, emissions are allocated to the sectors in which the actors are located. For the circular economy, this means that emissions from disposal processes are allocated to the waste management sector, while savings through substitution are credited where secondary materials are used for energy or material purposes, i.e. in the energy sector or in manufacturing or agriculture. However, in accordance with the territorial principle, no international upstream chains are recorded, which is why the savings are mainly limited to the lower energy consumption associated with the domestic use of secondary materials.

In the case of the GHG Protocol, from the perspective of the manufacturing industry, both expenses and savings fall under so-called Scope 3 emissions, for which no methodological guidelines exist for calculation. In the LCA/carbon footprint calculation methodology, various approaches to so-called end-of-life (EoL) allocation have been developed in scientific literature (overviews can be found in VDI ESTEM; Allacker et al. 2014; Ekvall et al. 2020). However, no approach has yet been specified in standards or other regulations. Furthermore, for all EoL allocation approaches in LCA, it should be noted that the distribution of recycling costs and savings is only made between two groups: on the one hand, the waste owners who send their waste for recycling and, on the other hand, the producers who use recycled materials as secondary raw materials. The waste management industry appears only as a "process" and not as an actor.

For all approaches, the fundamental problem of the circular economy can be described objectively as follows (Schebek et al. 2024): The costs and benefits of waste recycling are unevenly distributed among the actors. The recycling processes in the waste management industry necessarily require the use of energy (whose production leads to GHG emissions) and, where applicable, resources (e. g. auxiliary and operating materials). Numerous actors may be involved in these process chains of transport, pre-treatment/sorting and recycling. In contrast, the desired benefit of GHG savings only occurs once, namely when a manufacturing company actually substitutes primary raw materials with secondary raw materials. On the other hand, these secondary raw materials would not be on the market without the recycling processes carried out by the waste management industry, and the waste producer may also incur costs, e. g. to keep waste separate and thus enable recycling in the first place.

The question of how to allocate costs and savings can be examined and discussed from a scientific and analytical perspective. This question becomes relevant in practice when a calculation method based on a specific allocation approach becomes part of a policy instrument and the allocation within this instrument has a political steering effect or influences actors. Two areas are currently relevant for the circular economy, which will be discussed in the following chapters: firstly, the inclusion of waste management facilities and processes in the EU emissions trading system, and secondly, the integration of the waste management sector into mandatory reporting on the life cycle of products.

Allocation within the framework of emissions trading in Germany/the EU based on the territorial principle (substitution factors)

As a steering instrument for reducing GHG emissions, the European Emissions Trading Scheme (EU ETS 1) was introduced at European level in 2005 in the context of the allocation problem outlined above, with the initial aim of triggering GHG reduction effects in the energy sector and energy-intensive industries. At national level, the corresponding European directive was implemented by the Greenhouse Gas Emissions Trading Act (TEHG). In the initial phases, the ETS only covered installations as direct emitters. In 2019, the ETS was supplemented in Germany by the Fuel Emissions Trading Act (BEHG), which is intended to have an impact particularly in the transport and building sectors, but will also apply in full to waste facilities (waste incineration plants, waste wood power plants) for the first time from 2024.

After the German government originally wanted to transfer waste incineration plants to the EU ETS[10] as part of an amendment to the TEHG in the context of an opt-in regulation, this regulation is no longer part of the amendment to the TEHG passed by the Bundestag on 31 January 2025. Waste incineration plants will therefore (initially) continue to be subject to CO_2 pricing under the BEHG from 2027 onwards.

[8] 2019 IPCC Guidelines: '2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories'

[9] UNFCCC (2013) FCCC/CP2013/10/Add.3 Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013

[10] To date, thermal waste treatment plants in the EU ETS are only subject to reporting requirements.

While the BEHG sells emission allowances at a fixed price of €55 per tonne of CO_2 eq. (reference: 2025; auctioning from 2026), the price under the EU ETS is determined by the interplay between the specified emission caps and the respective trading volume. Due to unambitious targets, the price remained at a very low level until 2017/2018 – at a low of £3 per tonne of CO_2 eq. – and only rose to around £73 per tonne of CO_2 eq. in 2023 – thanks to reforms (the "Fit for 55" package) – with a maximum price of £100 per tonne of CO_2 eq. in 2023 – to around €73 per tonne of CO_2 eq. (Statista 2025; as of 02/2025). In order to avoid the risk of carbon leakage[11], criteria-based free allowances will be allocated to defined energy- and competition-intensive sectors (e. g. the steel industry) or, in future (fully from 2026), measures will be taken via the supplementary Carbon Border Adjustment Mechanism (CBAM) to prevent EU products from being replaced by CO_2 -intensive imports.

The factual link between the ETS and the circular economy is provided by emissions control facilities in the basic materials industry which, as described in Chapter 2, carry out the emission-intensive processes of primary production in material cycles. Particular mention should be made here of the metal industry and cement production. One effect attributable to the circular economy can be seen, for example, in the steel industry, one of the main emitters among energy-intensive industries. According to Pothen et al. (2019), depending on the steel product and production process, 1.7 to 4.3 tonnes of CO_2 can be saved per tonne of steel scrap used, which, at an EU ETS certificate price of approximately €73 per tonne, equates to savings of approximately €124 to €314 per tonne of steel scrap used.[12] Rising demand has led to shortages on the scrap market and rising prices until mid-2024, whereas the weak order situation among steel manufacturers in the last quarter of 2024 is likely to lead to a decline in demand and prices (EUWID, 4 and 39/2024). This volatility leads to planning uncertainties and economic risks for steel scrap suppliers, while users are able to respond adequately to market fluctuations.

The risks associated with setting up and operating an infrastructure therefore lie mainly with the players in the circular economy. In addition, the costs of waste management have been increased by the BEHG. According to ITAD (2020), the additional costs are estimated at up to €2 billion by 2026. The cost relevance arises in particular from the chargeable fossil waste components, whose producers are not prosecuted in the context of waste disposal and whose derivation via the EBeV 2030[13] is comparatively complex[14].

Allocation within the framework of Green Deal reporting requirements based on the life cycle approach

During the last EU Commission, Green Deal policy has increasingly focused on the introduction of mandatory GHG reporting by companies. These new EU policy instruments, in particular the Ecodesign Regulation with the implementation of the Digital Product Passport (DPP) and the CSRD Directive, are based centrally on the life cycle approach (Baehr et al. 2024). Unlike certificate trading, this is not about direct monetary control, but rather about indirectly using the influence of various company stakeholders (consumers, investors) for control purposes. In the future, however, it is also conceivable that certain legislative regulations could be directly linked to the results of such accounting. The relevance of these control mechanisms will only become apparent in the coming years, as the implementation of the instruments introduced at the end of the last EU Commission is still in its infancy.

The factual links between reporting obligations based on the life cycle approach and the circular economy relate primarily to the following aspects:

- The Ecodesign Regulation applies to all manufacturers of products, regardless of whether the manufacturer itself generates direct GHG emissions. Since the end-of-life stage is part of every product's life cycle, manufacturers are also required to report on the intended recycling or design for recycling measures. This addresses both the role of producers as actors in material cycles and the principle of product responsibility anchored in the circular economy. In line with the allocation approaches used in the LCA, the waste management industry is not explicitly addressed here.
- The CSRD covers all companies in the economy, including those in the waste management sector. This opens up the possibility for waste management companies to report on their recycling

[11] Relocation of GHG-intensive industries to non-EU countries

[12] Pothen et al. (2019) assume a "scrap bonus" range of €79 - 502 per tonne of scrap, taking into account additional environmental costs and different production processes (carbon steel scrap/stainless steel scrap) and GHG trading prices. Furthermore, it is stated that the use of scrap would be favoured, among other things, by including mining-related emissions and those from raw materials and intermediate products in the accounting systems (currently not the case).

[13] Ordinance on emissions reporting under the Fuel Emissions Trading Act for the years 2023 to 2030 (Emissions Reporting Ordinance 2030 – EBeV 2030)

[14] According to EBeV 2030, there are five different assessment methods to choose from: standard values for different fuel types, individual fixed values per waste disposal company and waste type, individual representative sampling and analysis, agreed literature values and direct continuous measurement minus the biomass share (according to VKU, 2023).

processes and thus, on the one hand, document their own potential contributions to reducing emissions and, on the other hand, provide information to actors in material cycles (e. g. via a future digital product passport).

Currently, there are no methodological guidelines for calculating the complete or partial life cycle within the scope of the respective reporting beyond the general standards of LCA and carbon footprint, and therefore no specification of one of the allocation approaches developed in LCA. For example, it remains unclear to what extent the Product Environmental Footprint (PEF) methodology will be used, particularly for the digital product passport. The PEF was published in 2013 on the initiative of the EU Commission as part of the flagship initiative "Resource-efficient Europe" within the "Europe 2020" strategy to ensure greater consistency in the environmental assessment of products (Finkbeiner et al. 2018). The EoL allocation included in this methodology reflects criticism of the so-called cut-off approach: this is the most commonly used EoL allocation and assigns the burdens and benefits of recycling entirely to the use of secondary raw materials; the net benefits of recycling therefore accrue exclusively to the manufacturing industry. In contrast, the first (PEF) method[15] proposed the so-called 50:50 approach for EoL. Here, both environmental impacts from upstream or downstream recycling and credits are divided 50:50 between the providers and users of the secondary material. This approach has been modified with the Circular Footprint Formula (CFF), which is part of the proposals for the revised PEF methodology[16] . Instead of the fixed 50:50 split, factors have been introduced to reflect the relationship between supply and demand in a market[17] . The CFF approach means that both the provision and use of secondary material are promoted depending on the market situation and the quality of the material. However, these proposals have also been criticised, particularly as there is currently no valid and transparent methodology for objectively justifying the factors. Furthermore, no data sets based on the CFF methodology are currently available (VDI ESTEM).

The lack of methodological specifications for the digital product passport and other reporting instruments is currently causing uncertainty among the stakeholders concerned. On the other hand, there is currently considerable scope for design. It is clear that, in order to ensure comparability and acceptance, further standardisation of the calculation method is needed in future, taking into account the framework conditions for the application of different reporting instruments and their intended control function (Schebek et al. 2024). From the perspective of the circular economy, the following issues in particular need to be clarified:

- The discussion on the allocation of recycling burdens and credits has so far only considered waste producers and the manufacturing industry that uses secondary raw materials. Should the waste management industry be included in such an allocation, or should its role as part of public services, which inevitably involves expenditure, be strengthened?
- Which reporting or control instruments are actually suitable for the possible inclusion of the waste management industry – digital product passports, CSRD, etc.? Which stakeholder groups in the waste management industry should be involved, if any, and according to which principles could a distribution of burdens and credits be carried out in principle?

These questions encompass fundamental views on the role of the waste management industry, but also many detailed questions about the possible design of practical regulations. The ongoing implementation of the new reporting requirements will inevitably mean that answers will have to be found in the coming years, particularly with regard to the fundamental treatment of the contribution made by the waste management industry.

[15] European Commission (2013).
[16] See Wolf et al. (2019), p. 2.
[17] A low value indicates that demand is higher than the supply of secondary material. A high value indicates that supply is higher than demand. For the categories metal, paper, plastic, batteries, building materials, glass and chemicals, the default values of 0.2, 0.5 and 0.8 have been used to date.

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