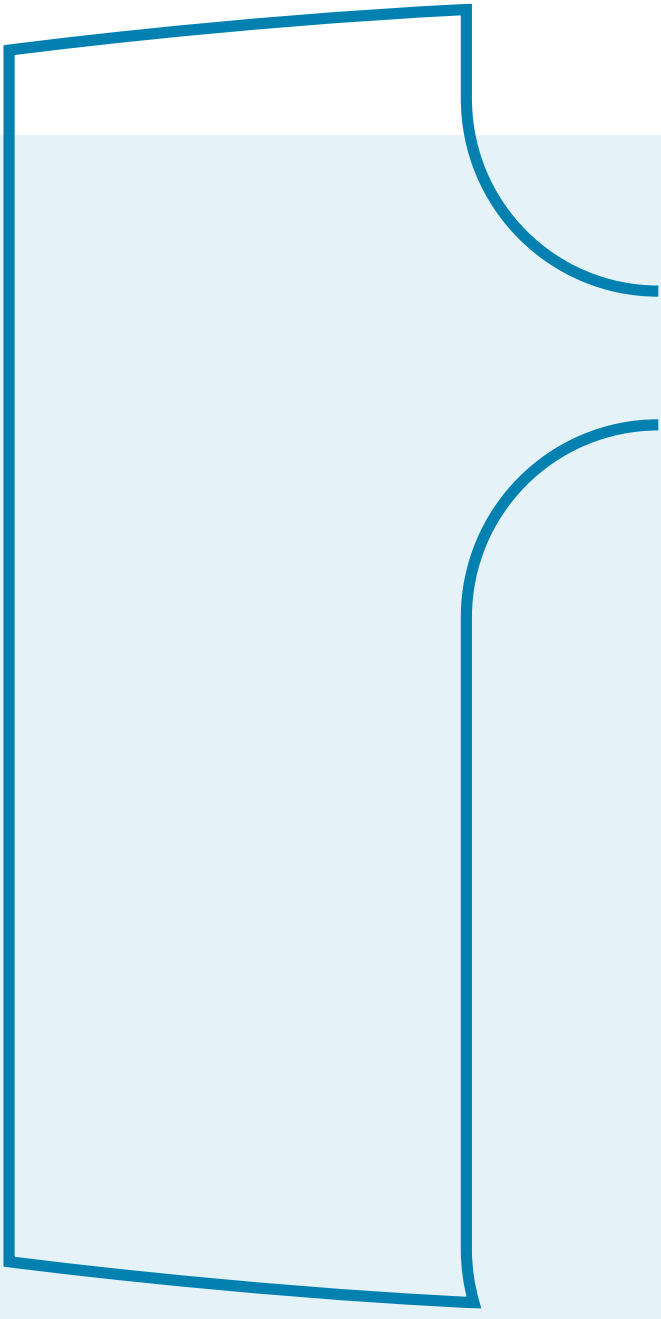
HAMBURG INSTITUT

consulting. research. engineering.

THE CHALLENGES OF PCF CREATION IN THE AUTOMOTIVE VALUE CHAIN

Harmonisation proposals for the
GHG accounting of products



Discussion Paper

Authors: Juliane Mundt, Marina Kemper

Hamburg, 12.12.2024

Discussion paper as part of the accompanying research in support of the **ad hoc group "Decarbonisation of automotive value chains"** of the **expert group "Transformation of the automotive industry" (ETA)** of the Federal Ministry for Economic Affairs and Climate Protection

On behalf of the Federal Environment Agency

CONTENTS

KEY TAKEAWAYS

On behalf of the Federal Ministry for Economic Affairs and Climate Protection (BMWK), the ad hoc working group (AhG) "Decarbonisation of the Automotive Value Chains" of the expert group "Transformation of the Automotive Industry" (ETA) developed recommendations for action to help make PCFs more standardised and comparable. This discussion paper summarises the methodological harmonisation requirements and the resulting recommendations for action that were developed on behalf of the Federal Environment Agency (UBA) as part of the accompanying research for the AhG. A detailed presentation of the project and the research results can be found in topic-specific short papers and in the final report of the accompanying research at the UBA "Methods for greenhouse gas balancing of products in the automotive industry".

INITIAL SITUATION AND CHALLENGE

- Against the backdrop of global decarbonisation, the product carbon footprint (PCF) is playing an increasingly important role in the automotive industry: It is becoming a currency in international competition. One reason for this is **the increasing regulation of reporting obligations as part of the CSRD**. The requirements for mandatory reporting on non-financial company data continue along the value chain. As a result, more and more companies that are not yet subject to the CSRD obligation must also collect emissions data.

- In addition, customer awareness of the need for transformation in the economy is also increasing, and with it the **demand for climate-friendly products**.

- Standards and norms for the preparation of PCFs have so far been aimed primarily at a scientific comparison of alternatives. Therefore, and due to the broad international field of application, they often offer methodological choices and room for interpretation. The effects of methodological decisions on the PCF result are usually not presented transparently in company reports, which is why the reasons for deviations and differences in the results are difficult to understand. **The desire for standardised accounting methods for greenhouse gases** (GHG) is becoming ever stronger in the automotive industry. The aim of accounting is increasingly shifting towards enabling cross-industry comparisons of products under fair competitive conditions.

APPROACHES

Energy balancing, allocation in multifunctional processes and recycling were identified as key topics that have a major impact on the results of GHG balancing of products in the automotive industry. Due to their importance for the PCF, there is a particular need to harmonise the methods in these areas. In addition, the attribution of green properties for physically homogeneous material or energy inputs is taken into account.

The industry is endeavouring to establish a carbon accounting principle along the entire automotive supply chain. The carbon accounting principle is understood here as a primary data-based recording of GHG emissions in a cradle-to-gate system boundary along the value chain. This corresponds to an inventory-based partial LCA approach in which the emissions of the individual production steps are ultimately added up to product-specific emissions.

Against this background, targeted method decisions can be made and the following recommendations for harmonising the methods can be derived:

➔ Allocation in multifunctional processes

In order to promote transparency and traceability of the PCF result, clearer guidelines on the selection, application and transparent presentation of allocation methods are required. Economic allocation in particular should be strengthened, as it can be a useful method for specific applications. Sector-specific allocation rules and regulations on allocation at sector transitions are also required. Further discussion and research is needed to consider allocation methods that can have a transformative effect on the overall system.

➔ Attribution of green properties to products

The attribution of green properties of homogeneous material and energy inputs can be assigned to different product groups within the balanced product system in accordance with mass balancing. However, rules on the geographical limits of the system, technical feasibility and appropriate verification must be observed.

➔ Accounting for recycled material

Recycling processes as a special allocation problem should be modelled according to the cut-off approach. Under these circumstances, incentives to strengthen the circularity of products must take place outside of the accounting methodology. Stimuli could be provided, for example, through appropriate adjustments to the regulatory framework as part of the EU Circular Economy Action Plan. A definition and differentiation of secondary materials and by-products should also be developed for the most important basic materials in the automotive supply chains. In order to reward - where necessary - the continuous decarbonisation of primary material production, the adaptation of a sliding scale approach for the automotive industry and the relevant value chains could be discussed. This can provide a further reference value for evaluating a PCF.

➔ Accounting for purchased energy

Where possible, energy should be accounted for along the entire automotive supply chain on a market-based basis in order to consistently avoid double counting of green characteristics. The use of contractual instruments requires criteria for the applicability of verification systems in the respective energy market as part of a market-based approach. If these criteria are established, such

as in the EU, this means that only market-based accounting can be used in this market. For other markets, a corresponding review of the verification systems would have to be carried out. The evaluation of the purchased green electricity should be located outside of the balancing methodology, i.e. the green electricity quality should be reported on a subsidiary basis. Incentives for the procurement of green electricity with additionality criteria should be set outside the balancing methodology via appropriate policy instruments. In addition, more specific guidelines should be developed for other energy sources such as heating/cooling, gases or hydrogen.

Such a harmonisation of methods for GHG accounting of products in the automotive industry poses challenges and requires a cross-sectoral discussion between experts from science and practice. As the industry's supply chain is both complex and international and encompasses various basic industries, it can act as a catalyst for standardisation. It should be noted here:

- A clear accounting objective is a prerequisite for the harmonisation of accounting methods.
- Harmonisation requires looking beyond sector boundaries and feedback with corresponding processes at regulatory level.
- GHG accounting should function purely as a recording methodology. Transformative incentives should be set outside the accounting methodology.

1 PCF ACCOUNTING IN THE AUTOMOTIVE INDUSTRY

Global decarbonisation requires the automotive industry to continuously reduce emissions in production and switch to electric drive technologies. The electrification of mobility has recently gained momentum, but more speed is still needed to achieve climate protection targets. This necessity is reflected in increasingly stringent regulatory requirements for the automotive industry.

Electrification shifts the main sources of greenhouse gas (GHG) emissions from the utilisation phase to the production phase. While around 90 % of emissions from combustion engines are generated during operation, emissions from electric drives can be virtually avoided by using renewable electricity . This means that the intensity of emissions during production and the publication of a product carbon footprint (PCF) is also becoming increasingly important for the automotive industry. Up to now, however, the GHG accounting of products has been based on the principle of voluntariness and the methods used to create it are not very binding. In addition, existing standards and norms for the preparation of PCFs are mainly aimed at using the results in a scientific context to evaluate different alternatives and are less intended for the comparison of products in a commercial environment. They offer methodological options and room for interpretation, the effects of which on the results of a PCF are often not made sufficiently clear and transparent.

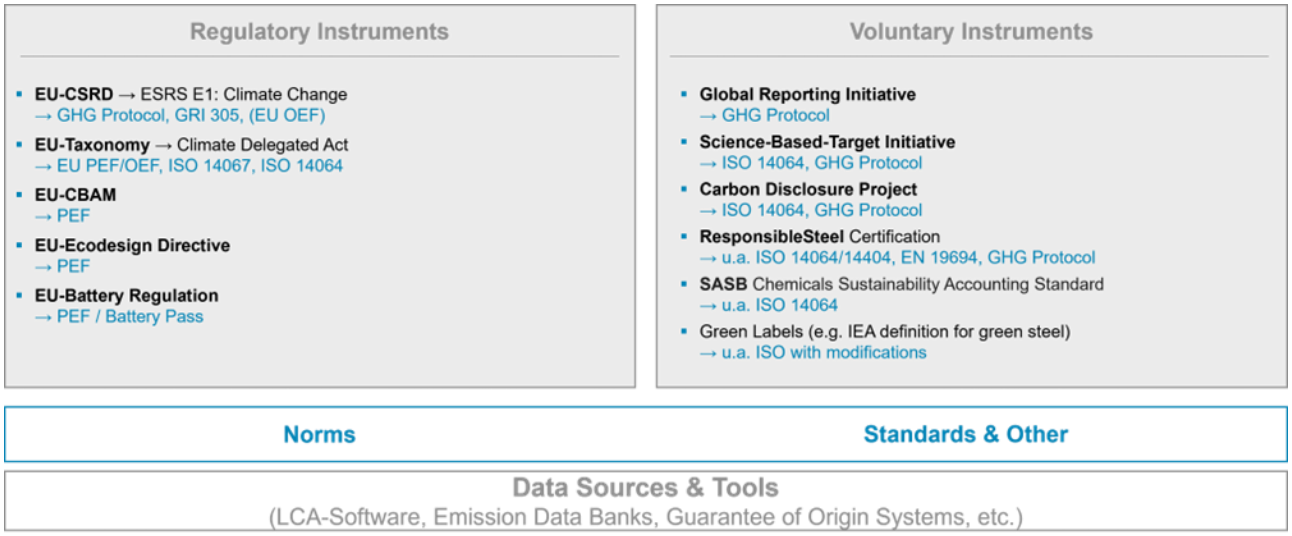
In light of the fact that the PCF is becoming increasingly important as a tool for verifying decarbonisation and that value chains and material procurement are internationally networked, there is also a need in the industry to standardise GHG accounting methods, preferably at a global level. The aim is to promote cross-industry comparability and a level playing field.

Due to the complex and internationally networked structures of automotive supply chains, which include important emission-intensive basic industries, the sector is suitable as a catalyst for the implementation of a revised methodology for the GHG accounting of products, in which GHG data can be passed on along the entire automotive value chain on the basis of primary data. The automotive industry could thus take on a pioneering role.

2 RELEVANT METHODS FOR PCF CREATION IN THE AUTOMOTIVE INDUSTRY

The quantification of GHG emissions is required in various contexts both by regulatory requirements and as part of voluntary reporting initiatives (Figure 1) and affects the entire value chain of the automotive industry. Different methodological requirements are placed on GHG accounting in the various contexts. Data sources for emission factors and tools for recording and tracking emissions have a further influence on the result of the balance.

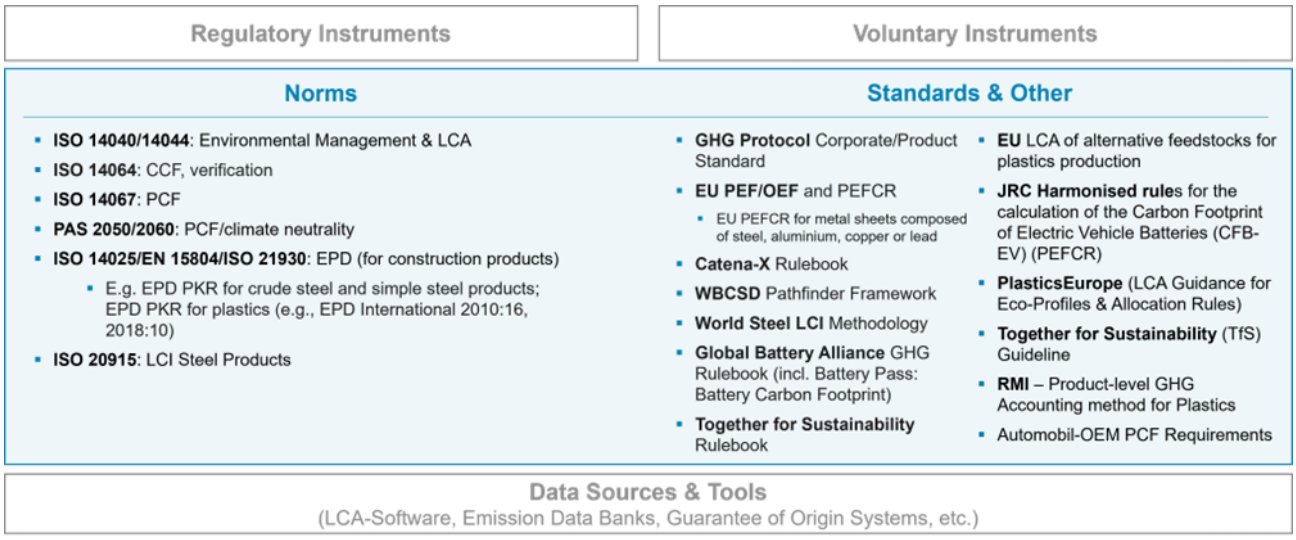
Figure 1: Requirements for the quantification of GHG emissions in the automotive industry and relevant value chains



Source: Hamburg Institut's own presentation, 2024

For the creation of PCFs in the complex automotive supply chain, both generally applicable and industry-specific standards and norms are relevant (Figure 1).

Figure 2: Methods for GHG accounting in the automotive industry



Source: Hamburg Institut's own presentation, 2024

The Life Cycle Assessment (LCA) standards, ISO 14040 "Environmental management - Life cycle assessment - Principles and framework" (ISO 14040:2006) and ISO 14044 "Environmental management - Life cycle assessment - Requirements and guidance" (ISO 14044:2006), provide basic rules for GHG assessment methods at product level and can be applied universally to products, services and services of all types and sectors. According to the ISO standards ISO 14040:2006 and ISO 14044:2006, in addition to greenhouse gas emissions, other environmental impacts of a product are also recorded as part of a life cycle assessment study - depending on the respective target definition. Most standards for balancing greenhouse gases at product level are based on these two standards.

Two overarching tools are considered to be particularly relevant in the context of harmonisation efforts: the ISO standard for PCF creation ISO 14067:2018 and the PCF guidelines of the Catena-X network (2023). Both can be applied in the automotive industry and linked value chains. Industry-specific standards are also particularly relevant. These include the guidelines of the Together for Sustainability Initiative (TfS) (2022), the Harmonised rules for the calculation of the Carbon Footprint of Electric Vehicle Batteries (CFB-EV) (JRC, 2023) and ISO 20915:2018 for conducting a life cycle inventory study (LCI study) for steel products.[1]

The **ISO standard ISO 14067** "Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification" (ISO 14067:2018), which is based on life cycle assessment, deals with the calculation of PCFs. It contains principles and guidelines for creating PCFs as well as specific methodological requirements for calculating a PCF. ISO 14067 can be applied across all sectors and is universally valid for products and services of all kinds, and thus for the entire automotive value chain and the associated sub-value chains. This is also reflected in its practical application: ISO 14067 is one of the most frequently used methods for calculating PCFs. It is therefore considered to be highly relevant in practice.

Together for Sustainability Initiative (TfS) is a global industry initiative founded in 2011 by several chemical companies. Its aim is to promote sustainability in the chemical industry. By developing a global standard for GHG accounting for chemical supply chains, the aim is to standardise accounting. The PCF guideline (TfS 2022), published in 2022, defines standardised methods for preparing a GHG product balance sheet and is intended to be applicable to companies in the chemical industry and beyond. The guideline is based on the accounting methods of the GHG Protocol and takes into account the regulations of the ISO standards ISO 14040, 14044 and the quantifying standards ISO 14067 and 14064 for the GHG accounting of products and organisations. The methods in the TfS guidelines are to be continuously developed and updated. Harmonisation with other methods is already being driven forward. In addition, the comparability of balance sheets is to be promoted. The TfS guidelines are considered to be more relevant in practice than other methods used in the plastics industry.

[1] Together with the AhG Decarbonisation, selected norms and standards from the range of methods to which particular relevance is attributed. These form the basis for detailed analysis with regard to methodological controversies and for the development of recommendations for action for method harmonisation. Methods from upstream value chains are also considered relevant here.

The European Commission's **Harmonised rules for the calculation of the Carbon Footprint of Electric Vehicle Batteries (CFB-EV)** (JRC 2023) is a proposal for rules to determine a PCF for batteries under the Battery Regulation (Regulation (EU) 2023/1542). This comprehensive document considers the entire battery life cycle from raw material extraction to end of life. The regulations will also be used to define the performance classes and maximum CO_2 values. In April 2024, the European Commission presented a draft delegated regulation to replace the previous Regulation (EU) 2023/1542 (European Commission 2024). The aim of this draft regulation is to improve the circular economy, resource utilisation and efficiency as well as the life cycle of batteries in terms of climate neutrality and environmental protection. It deviates from the proposals in the CFB-EV in some points, e.g. in the accounting of electricity. It can be assumed that the draft will replace the CFB-EV.

ISO 20915:2018 deals with methods for a life cycle inventory study (LCI study) for steel products. With regard to the calculation methodology, the focus is on the evaluation of secondary material and the handling of co-products. In terms of practical relevance, the ISO is considered to be equivalent to the World Steel industry standard. ISO 20915 is designed for the creation of LCI for commercial purposes of individual companies.

The **German Catena-X network** is working on a centralised system for PCF data management for the automotive industry. The transfer of data along the entire automotive value chain requires a common method for PCF calculation, which is regulated in the "Catena-X Product Carbon Footprint Rulebook Version 2.0" . The rulebook can be applied along the entire automotive value chain as well as in the neighbouring sub-value chains.

When comparing the methods for GHG accounting, it becomes clear that relevant accounting methods are currently being developed by standardisation organisations (e.g. ISO), government institutions (e.g. EU JRC) and business initiatives (e.g. TfS, Catena-X). On the one hand, this demonstrates the high relevance of the topic, but it also means that methodological decisions vary due to the different objectives. In addition, harmonisation of the methods requires the integration of numerous stakeholders.

In addition, clear methodological differences between the accounting approaches become apparent. In particular, options within the methods can have a major impact on the PCF result. The decision with regard to the respective option is left up to the person preparing the balance sheet. This can result in a very subjective application and a tendency to choose the method that leads to a lower carbon footprint. Different approaches in different sectors can lead to the same product being accounted for differently along the supply chain.

3 NEED FOR HARMONISATION AND POSSIBLE SOLUTIONS

The methodological aspects that have a major influence on the PCF result and are not uniformly defined in the standards relevant to the automotive industry for the GHG accounting of products include

- the balancing of purchased energy,
- the allocation of energy and material flows to co-products,
- the attribution of environmental impacts of energy and material flows that do not differ physically, and
- the allocation of GHG savings from recycling as a special allocation problem.

The following section outlines the discussions that have taken place in this regard, identifies potential solutions with regard to the harmonisation of methods and derives corresponding recommendations for action. [2]

The recommendations for action are derived with a focus on the transfer of PCF data along the value chain against the background of the following premises:

- *Cradle-to-gate approach*: A cradle-to-gate system boundary for accounting within the supply chain is specified as part of the considerations for harmonising the methods for PCF compilation along the automotive value chains. Emissions are recorded from the cradle to the factory gate.

- *Carbon accounting principle*: The long-term goal of integrated, primary data-based determination of emissions data across the entire supply chain is being pursued.

- *Attributional LCA approach*: PCF creation follows an inventory-based (attributional) LCA approach.[3]

3.1 Allocation of energy and material flows to co-products

In the balancing of a product system with multifunctional processes, allocation is understood as the allocation of the incoming material and energy flows and their environmental properties to the main products and co-products (ISO 14044:2006, S. 12). In multifunctional processes, co-products, each with their own value, are manufactured in the same product system alongside the main product. Particularly due to the advancing circular economy, by-products that were previously labelled as waste can be used in other production processes and thus acquire value (chapter 3.3.2).

The allocation of energy and material flows can be based on physical properties such as mass, weight and volume or according to economic value. The allocation hierarchy at ISO 14044:2006 describes a step-by-

[2] More detailed explanations can be found in the *short papers* written in support of the AhG "Decarbonisation of the automotive value chains" of the expert group "Transformation of the automotive industry" at the BMWK and in the final report on the UBA's accompanying research project entitled "Methods for greenhouse gas balancing in the automotive industry".

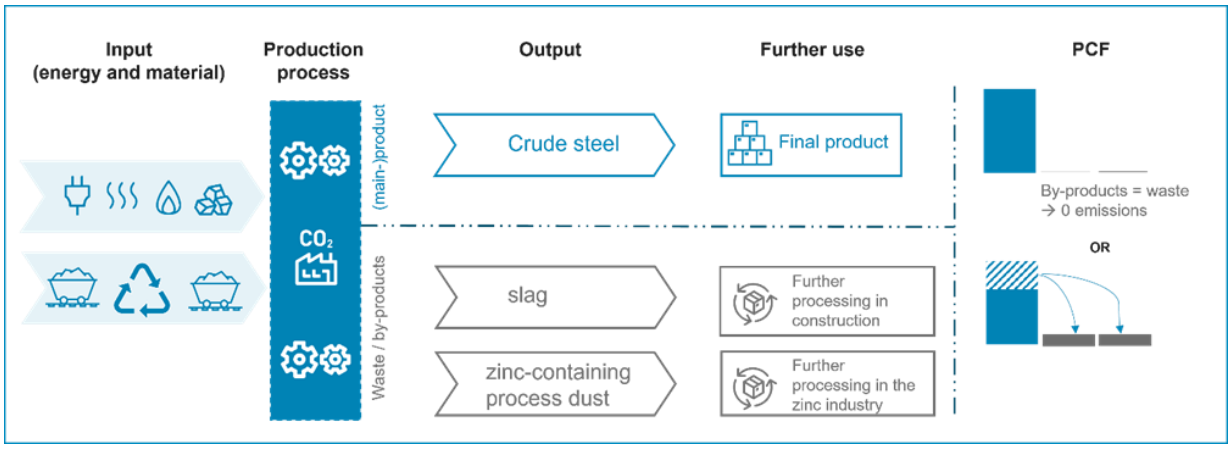
[3] The attributional LCA approach assigns the current global environmental impacts to the respective product. It is an inventory-based approach that describes the current situation. Changes become visible by comparing the results over time. The Consequential LCA approach, on the other hand, includes effects on the overall system in the balance, i.e. it is based on an impact-orientated approach. For example, the future change in environmental impacts through the use of the manufactured product is assessed in contrast to a conventional product (Ekvall 2020).

step procedure that is intended to help identify and apply the appropriate allocation method. This hierarchy stipulates that allocation should be avoided wherever possible. To this end, the system boundaries can be adjusted either by subdivision or by extending the production system under consideration ("system space extension"). If neither is possible, an allocation can be made according to physical relationships based on mass, volume or energy ISO, 2018a, p. 25). If this is also not possible, the allocation can be made according to economic relationships between the by-products, e.g. the relative market value.

However, this procedure only provides guidance; there are no clear criteria as to when which method should be used. It is therefore possible to choose a method of the allocation hierarchy that is most practicable for the company or that leads to a favoured allocation of emissions to the main product and co-product when creating the PCF. If the information on the allocation method used is not passed on transparently, this makes it more difficult to compare the PCFs and can even lead to emissions within the supply chain not being considered.

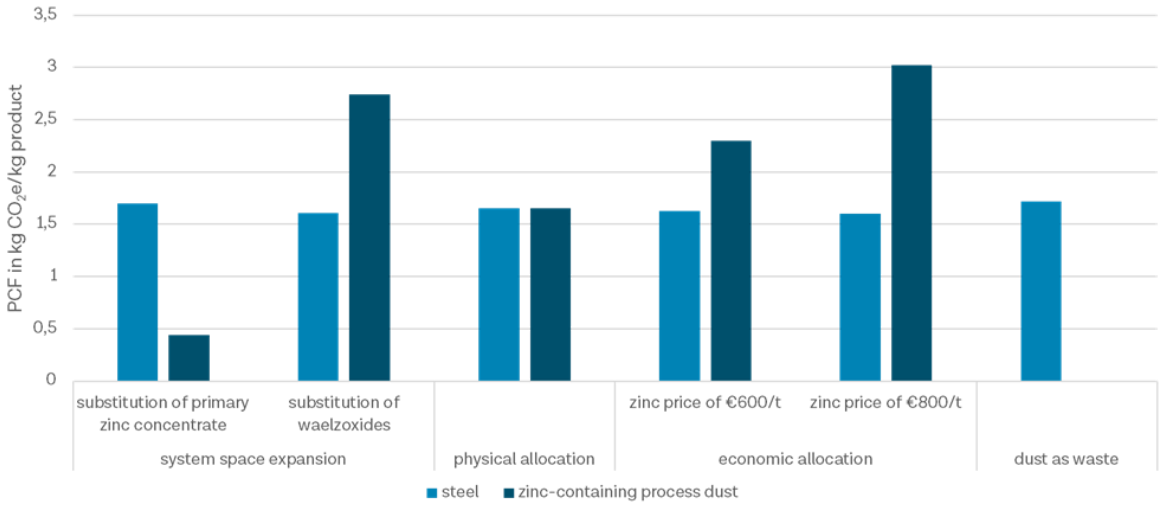
Figure 3 andFigure 4 illustrate these challenges using the example of steel production, in which crude steel is the main product and slag and zinc-containing process dust are by-products. Both of these by-products can be utilised in other branches of industry. Figure 3 shows the difference in the PCF of steel when co-products are seen as waste or are assigned a value. InFigure 4 it becomes clear how the allocated emissions per kg of output change according to the respective allocation method. While the emissions of the main product change only slightly, a strong influence on the emissions of the zinc-containing process dust can be recognised, depending on whether the physical, economic allocation or system space expansion with substitution is selected.

Figure 3: Breakdown of emissions from a multifunctional process - example of steel



Source: Hamburg Institut's own presentation, based on Fernandez et al.

Figure 4: Change in emissions with different allocation methods



Source: own illustration according to Fernadez et. al., 2024

Without standardised regulations on the application of the allocation method, it is possible that emissions are accounted for differently in different sectors, possibly even in one and the same sector.

If allocation methods lead to large differences, a sensitivity analysis, as Fernandez et. al. (2024) carried out for steel, can promote clarity and transparency. This analysis makes the causes of the differences clear. However, it is time-consuming to carry out and increases the cost of PCF accounting for companies. In addition, GHG values tend to be passed on within the supply chains and no underlying results on sensitivities. The detailed PCF reports are of lesser importance, meaning that the comparative values only serve to inform interested stakeholders, but do not contribute to the harmonisation of PCF preparation.

.

Recommendations for action

Specification of allocation rules focussing on the upgrading of economic allocation and the definition of rules for sector transitions

- The allocation hierarchy should be meaningfully expanded by providing clear guidelines for the selection, application and transparent presentation of allocation methods. This applies to both material and energy flows. Incorporated into the PCF report, this promotes transparency and traceability of the PCF result.
- Economic allocation should at least be equated with physical allocation.
- In addition to sector-specific allocation rules, rules should be defined at sector transitions.
- There is a need for further discussion and research to consider allocation methods that can have a transformative effect on the overall system. This is particularly the case for system space expansion with substitution, for the application of which verifiable methodological criteria would have to be developed. When focussing on a more primary data-based recording of GHG emissions along the entire automotive value chain, attributive allocation methods

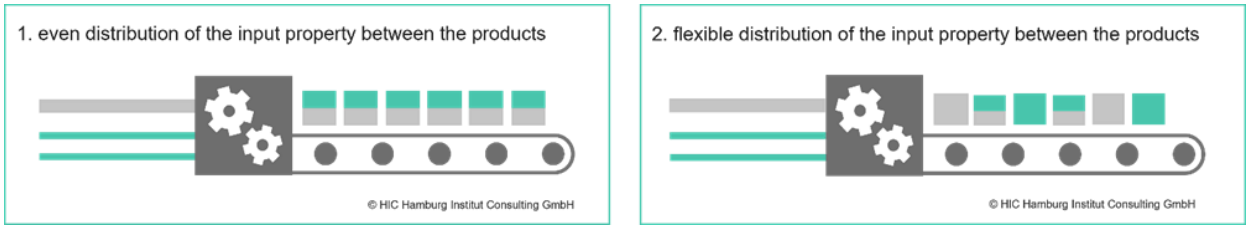
should be used consistently. Impact-orientated elements should be stimulated by other incentives and reported separately from PCF compilation.

3.2 Attribution of environmental impacts

If product differentiations are made within a physically standardised product system using ecological properties, this is referred to as attribution. This merely involves a quantitative allocation of environmental impacts, which does not require a special methodological approach as long as input and output quantities match. This differentiated allocation of the environmental impacts of a product system to individual product groups can be carried out using the mass balance approach.

This approach enables non-integrated companies in particular to fully allocate the proportion of low-emission input materials (material or energy) to individual product groups (Figure 5). In this way special customer requests for low-emission products can be met or a corresponding demand created. This offer can be an important building block for the transformation of companies. The mass balance enables the integration of proportionate low-emission material and energy flows into production and thus enables a cost-effective and gradual implementation of decarbonisation. Without such an offsetting approach, it would be necessary to set up separate production lines, which would be very cost- and resource-intensive and possibly inefficient.

Figure 5: Possible applications of the mass balance system in the PCF balance sheet



Source: Hamburg Institut's own presentation, 2024

Acceptance of the mass balance approach varies from sector to sector. While it is widely recognised and already in use in the chemicals and plastics industries (Together for Sustainability (TfS) 2022), it is seen rather critically in the aluminium and steel industries (EA_2021_European_Aluminium_Environmental_Profile_Rreport_Refining-Industry). In the construction sector, where EPDs are widely used, the mass balance approach is now being discussed but has not yet been accepted (ECO Platform 15.12.2023).

The definition and documentation of the system boundaries within which the mass balance is applied is relevant both for the credible and transparent implementation of the mass balance approach and for its acceptance. These system boundaries currently vary between individual production lines, locations or companies with internationally distributed sites. In order to formulate explicit rules on the recognisable limits, coordination between scientific experts and company representatives is necessary, as different premises prevail here: While from the scientific perspective, the tracking of the low-emission property should be linked as closely as possible to the physical material and energy flows, company representatives would like to see greater flexibility. For example, the mass balance approach could encompass the entire company with different branches, between which low-emission properties could then be balanced. In order to maintain credibility and prevent the double counting of low emissions, the chosen approach can be reviewed and confirmed by external third parties.

Transparent tracking within the defined system boundaries and the clear allocation of emissions are important for credibility. This also includes calculating a residual mix for the remaining products so that they are assigned correspondingly higher emission values.

The allocation of low emissions to individual products is repeatedly criticised as pure reallocation and therefore greenwashing. The mass balance does not lead to additional, low-emission material coming onto the market.

This additionality in particular, i.e. the requirement that the application of the mass balance approach should necessarily bring about an ecological improvement, still requires a detailed discussion between users and scientific experts. For example, the mass balance method does not directly lead to better availability of low-emission raw materials and energy in sectors where these are limited. The overall systemic effect therefore fails to materialise. For standardised and accepted implementation, a common understanding of both the overall balancing approach and the benefits and limitations of mass balancing should be found.

Mass balancing can incentivise transformation within companies. If the attributive approach to accounting within the supply chain is pursued, as proposed by the AhG Decarbonisation, additionality criteria should be tracked, implemented and reported on a side-by-side basis.

Requirements and guidelines for the implementation of mass balance and book & claim systems are currently being developed within the ISO standardisation process. The resulting findings and guidelines can be groundbreaking for the process.

Recommendations for action

The mass balance approach for attributing climate-friendly properties should be implemented subject to specific rules on system limits, technical feasibility and verification.

- emissions should be precisely allocated to the geographical boundaries of the system within which the mass balance approach is applied. A dialogue between science and business is necessary to define the system boundaries, as different perspectives prevail here.
- Within the selected mass balance approach, the allocated quantities should be limited to the technically maximum value of the production possibilities.
- Verification and transparent documentation in the PCF report can prevent greenwashing and promote traceability and credibility.
- A detailed discussion between users and scientific experts is necessary to define explicit rules. Key points here are the definition of system boundaries, but also the achievement of additional environmental benefits via additionality criteria. Here, too, it is necessary to differentiate from the impact-oriented accounting approach. If necessary, additionality criteria can be set separately and documented in the report.
- In future, the requirements and guidelines for the implementation of mass balance and book & claim systems developed within the ISO standardisation process should also be taken into account.

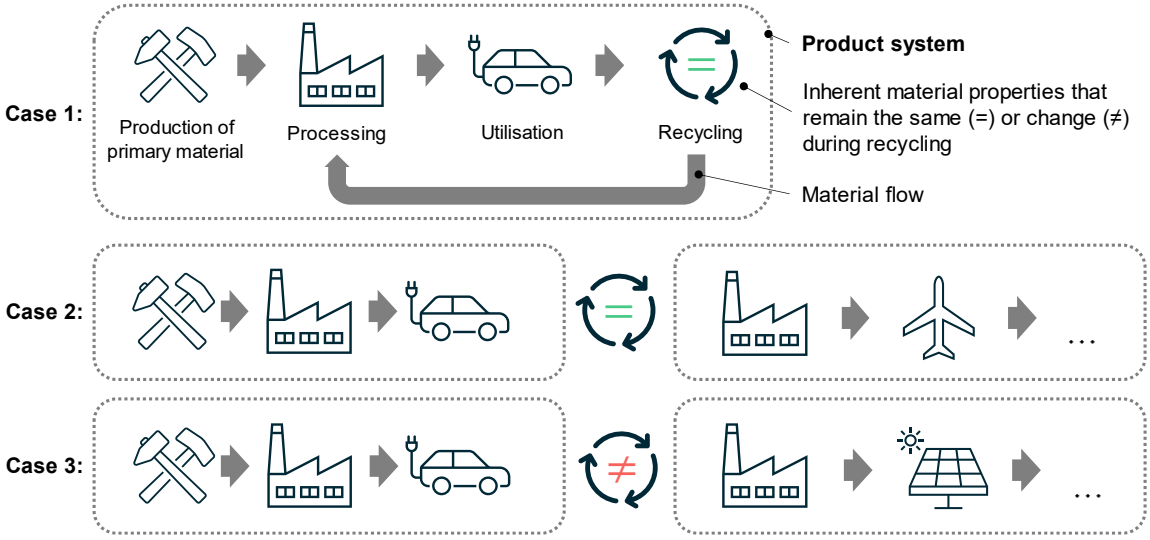
3.3 Allocation of GHG savings from recycling

The key methodological question when discussing recycling processes is which product or product system can be credited with the GHG emission savings resulting from recycling: the product system that is recyclable at the end of its life cycle, the product system in which the recycled material is used, or both. In addition, there is a challenge in relation to the definition and tracking of secondary material

3.3.1 Allocation of GHG savings due to recycling to a product system

The LCA standard distinguishes between three cases for modelling recycling processes. In the case of a closed-loop process, the recycled material is reused in the same product system in which it was created (Figure 6, case 1). In this case, no allocation of GHG savings from recycling between different product systems is necessary.

Figure 6: Cases for modelling recycling processes



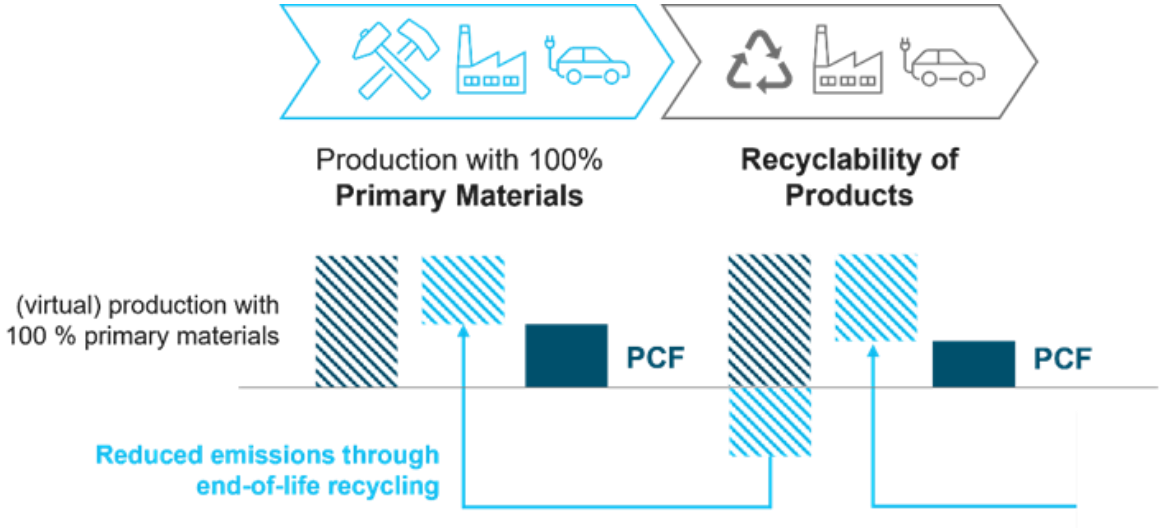
Source: Own illustration, Hamburg Institut

An allocation must be made when the material leaves the product system and is reused in another product system. If the material retains its inherent properties (Figure 6, case 2), this can still be modelled as a closed-loop process. For this purpose - as shown inFigure 7 - the input material of the product is initially fully valued with the emission factor for primary material. However, a credit is then deducted for the reusability of the product. This is determined via an assumed recycling rate, which can be used to determine how many emissions can be avoided in the next product by replacing primary material with reused material. This type of modelling of recycling processes is known as the avoided-burden approach [4] . The following applies: the

[4] The following terms are used as synonymous method designations: Closed-Loop-Approximation-Approach, 0/100-Approach, End-of-Life-Approach and (Recyclability-)Substitution-Approach.

better the recyclability of a product is assessed, the lower the PCF of the product will be. The avoided-burden approach therefore incentivises the recyclability of products

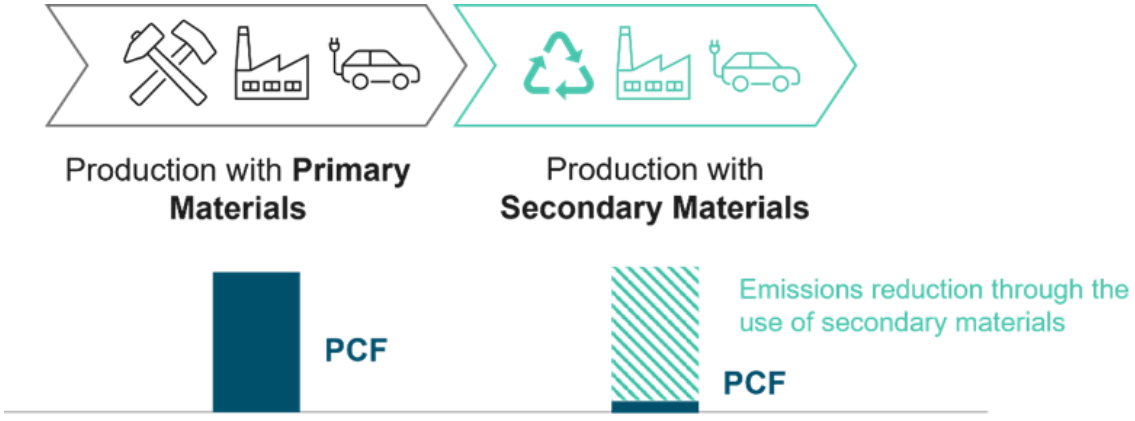
Figure 7: Modelling of recycling processes according to the avoided burden approach



Source: Own illustration, Hamburg Institut

If the inherent properties of a material change during the transition to another product system (Figure 6, case 3), an allocation must take place according to (ISO 14044:2006) based on physical properties, the economic value or the number of subsequent uses (in this prioritisation). One allocation variant is the cut-off approach, which - as shown inFigure 8 - allocates the emissions from primary material production entirely to the preceding product. The reused material enters the product system without emissions - but usually plus the emissions generated during reprocessing. The following applies here: the higher the proportion of recycled material in the product system, the lower the PCF of the product. The cut-off approach therefore incentivises the use of secondary materials.

Figure 8: Modelling of recycling processes according to the cut-off approach



Source: Own illustration, Hamburg Institut

There are numerous variations of the two options shown for modelling recycling processes. The Circular Footprint Formula (CFF) from the methodology for calculating a Product Environmental Footprint (PEF) according to EU specifications represents a combination of the two approaches (see (EU) 2021/2279)[5] . Here, both the recyclability of a product via an allocation factor and the use of secondary material via a quotient for the material quality of secondary to primary material are taken into account. In this way, the emissions are divided between the product systems that supply or use the material. However, cradle-to-gate considerations should initially be modelled according to the EU PEF methodology using the cut-off approach and the results using the CFF should only be presented for information purposes.

The scientific discussion regarding the advantages and disadvantages has been going on since the early 1990s. Depending on the criteria applied, different recommendations are made regarding the use of one or the other modelling approach for recycling processes. Table 1: Characteristics of the two approaches to modelling recycling processes shows an overview of the characteristics of the two approaches discussed here. Depending on the objective of an LCA or PCF calculation, the characteristics of these can be seen as favourable or unfavourable.

Table 1: Characteristics of the two approaches to modelling recycling processes

Criterion	Cut-off approach	Avoided Burden Approach
LCA approach	Inventorising; (more) Attributional LCA approach	Impact-orientated; (more) Consequential LCA approach
Sustainability principle	Strong sustainability principle; by accounting for the full emissions of primary material production plus the lower emissions of the recycled input material	Weak sustainability principle; credit is taken from future generations for environmental pollution; emissions from the use of primary materials are reduced.
Risk affinity	Low; secondary material content clearly determinable	High; based on assumptions about the hypothetical recycling process and recycling rates
Incentive effect	Incentive to use secondary material	Incentive to influence recyclability; supports circular economy

[5] Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the application of the environmental footprint calculation methods for measuring and disclosing the environmental performance of products and organisations along their life cycle.

Criterion	Cut-off approach	Avoided Burden Approach
Market impulse	Increases demand for secondary material; Recommended if market for secondary material: Supply > Demand	Strengthens the supply side of the secondary materials market; Recommended if market for secondary material: Supply < demand
Product useful life	Good for long product service life	Good for short and known service life

Source: Based on.Frischknecht 2010; World Business Council for Sustainable Development (WBCSD) und World Resources Institute (WRI) 2011; Schrijvers 2017; Ekvall 2020.

The requirements for a method vary depending on the objective of the application . With the increasing positioning of the PCF as a regulatory instrument and competitive criterion, the pressure to make decisions is increasing. The discussion is shifting from science to politics and business. The method preferences differ in the sectors relevant to the automotive industry (see Kemper et al. 2024)

Recommendations for action

Use of the cut-off approach to harmonise methods for modelling recycling processes in the automotive industry and the entire supply chain

- AhG decarbonisation aims to increase the primary data-based recording of GHG emissions along the entire automotive value chain, whereby cradle-to-gate PCFs are to be passed on along this chain. This corresponds to an attributional LCA approach. This approach implies the use of a cut-off approach. The fact that the useful life of an automobile is usually more than ten years and that assumptions about recyclability and downcycling would therefore be subject to considerable uncertainty reinforces this recommendation. The WBCSD Pathfinder Framework, which deals with the issue of transparency in data collection and the transfer of PCF data along value chains across industries, comes to the same conclusion under similar premises (World Business Council for Sustainable Development (WBCSD) 2023).

- The use of the cut-off approach incentivises the use of secondary materials. The recyclability of products is not taken into account in the PCF. It should therefore be discussed how this missing impetus can be provided in other ways for the automotive value chain. As part of the EU Circular Economy Action Plan, for example, the regulation to strengthen the automotive circular economy is currently in draft form, which is intended to set target values for recyclability. The EU Taxonomy Regulation and the Corporate Sustainability Reporting Directive also address aspects of the circular economy.

3.3.2 Definition of secondary material

The previous discussion on the allocation of emission savings through the use of recycled material within a product cascade is followed by the question of how the system boundaries are defined within this cascade and at which points in the life cycle primary material is transformed into secondary material. This has significant influence on the PCF, particularly when the cut-off approach and carbon footprint form are taken into account.

The distinguishes between three output categories. Products and co-products are defined as valuable goods or services, while waste is intended for disposal. Secondary material is recovered from waste and finally evaluated according to the methods described above. The standard for environmental labelling and declarations is often used as a definition. This distinguishes between secondary material or recycled content in pre-consumer and post-consumer material, depending on whether it is produced before or after the utilisation phase. However, this standard does not define whether pre-consumer material is categorised as secondary material or a co-product, leaving a key point open.

In standards for PCF creation, such as or the GHG Protocol Product Standard (WRI & WBCSD 2011), this distinction is no longer included. In practice, the respective categorisation is therefore not consistent. Pre-consumer material - just like post-consumer material - is often defined as secondary material. However, it is also argued that pre-consumer material, such as offcuts from metal processing, is not worthless and is therefore not intended for disposal. It is therefore not categorised as waste. According to the Together for Sustainability (TfS) Guideline (2022), which deals with PCF generation in the chemical industry, pre-consumer materials are also to be classified as by-products, for example.

In addition, ISO 14021:2016 leaves room for manoeuvre with regard to the definition of pre-consumer material itself. For example, materials that can be reused "in the same process" in which they were generated are not defined as pre-consumer material. The term "process" is not defined in more detail here. Some industry-specific methods therefore contain more specific definitions of the term "process" in relation to the respective value chain (WSA 2017). This is a particular challenge with regard to the different production depths of companies. Some companies cover large parts of the value chain in their production. This would mean that, in the sense of ISO 14021:2016, reused materials take place "in the same process" and could therefore not be counted as recycled content. To resolve this challenge, Wright, Liu, Wu and Chalasani (2023) propose a standardised assessment in the industry based on reference system boundaries using the example of steel.

Recommendations for action

Definition and differentiation of secondary materials and by-products for each primary industry

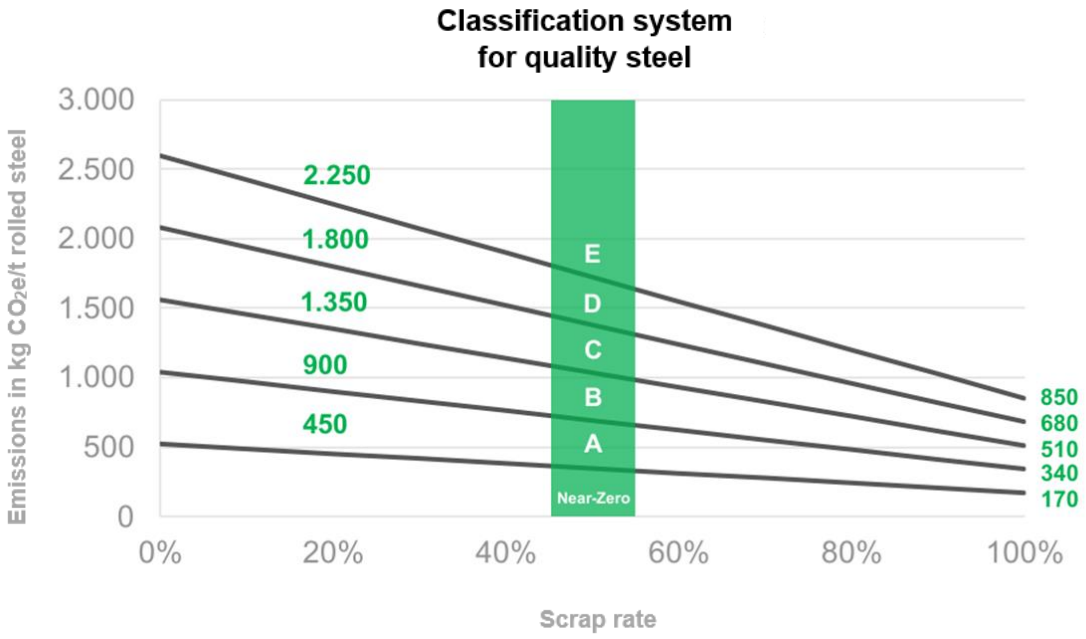
- Due to the strong incentive of the cut-off approach for the proportion of recycled material (recycled content), a standardised regulation is required with regard to the differentiation of secondary material.
- Credible recording and tracking of material flows is required for implementation. Small and medium-sized companies in particular should be supported in setting up suitable structures and processes.

3.3.3 Decarbonisation of primary material production

The use of the cut-off approach incentivises the use of secondary materials to reduce the PCF. However, for many basic materials, such as steel and aluminium, it is predicted that the global future demand for these basic materials cannot be met through the use of secondary materials (see e.g. MPP 2022, 2023). Primary material production remains necessary, as does the continuous decarbonisation of these materials, regardless of the circular economy factor. However, the necessary investments in technological change are significantly more expensive than the use of secondary materials. In addition, many of the required technological measures are not yet available on a commercial scale.

In the context of the definition of green steel, ResponsibleSteel (2022) and the International Energy Agency (IEA) (2022) pursue a sliding scale approach (Figure 9). The German Steel Federation has also developed a classification system for steel based on the sliding scale approach (Theuringer et al. 2024). In this way, the disproportionate methodological favouring of secondary material in GHG accounting can be avoided. In the sliding scale approach, the PCF is set in relation to a sector-specific decarbonisation target pathway depending on the proportion of secondary and primary material. The PCF is assigned a corresponding classification according to this categorisation. The PCF is thus no longer interpreted solely on the basis of the emission level, but also on the basis of an (abstracted) reference to technological framework conditions.

Figure 9 : Classification system for green steel according to the Low Emission Steel Standard



Source: (Theuringer et al. 2024)

Recommendations for action

Discussion of the possibility of implementing a sliding scale approach in the automotive industry

- Adaptation of the existing concept for the sliding scale approach to the automotive industry and expansion to other basic materials, in particular metals.
- In this way, a further reference value can be used to evaluate a PCF and thus reward investments in technology change or the decarbonisation of primary material production

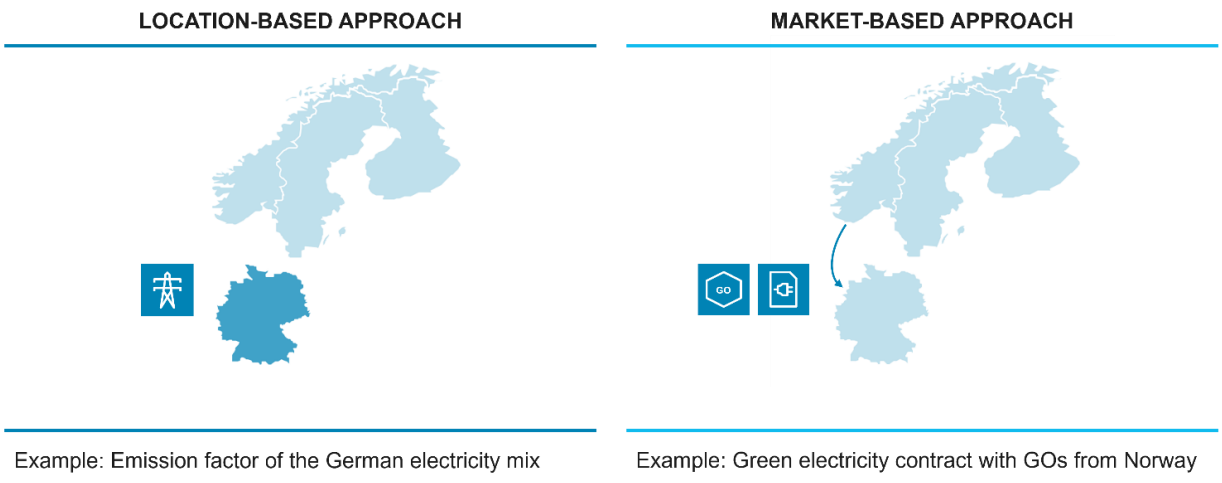
3.4 Accounting for purchased energy

The accounting of purchased energy is also handled differently in PCF accounting practice. Standards and methods distinguish between two approaches, focussing primarily on electricity purchases. To differentiate between the two approaches to accounting for purchased energy, the terms used in corporate carbon footprint accounting (CCF) are used: market-based and location-based (see WRI & WBCSD 2015).
In the context of the discussion on the use of the two approaches, the impact that GHG accounting of renewable energy (RE) in particular has or should have on the energy transition is also discussed.

3.4.1 Parallel application of two balancing approaches leads to double counting of renewable energies

In the context of ISO 14044:2006, no information is provided on the use of emission factors for the accounting of purchased electricity. In more specific regulations, such as or the GHG Protocol Product Standard (WRI & WBCSD 2011), emission hierarchies are specified for the use of emission factors to account for purchased energy.

Figure10: Approaches to balancing purchased energy



Source: Own illustration, Hamburg Institut

As shown inFigure10, a distinction is made between two approaches. If a location-based approach is followed, the emission factor to be used is derived on the basis of the energy composition in the respective grid from which the reporting unit obtains the electricity. An example of this would be the German electricity mix. The grid boundaries according to GHGP are to be selected, for example, in such a way that the generation capacities within the balance boundary guarantee grid stability (WRI & WBCSD 2015). A clear predefinition of grid boundaries in PCF standards is not common.

If a market-based approach is pursued, a contractual instrument between the reporting entity and the electricity supplier - e.g. a green electricity contract backed by corresponding guarantees of origin (HKN) - serves as the basis for determining an emission factor that can be used to determine the emissions from electricity purchases. Standards usually specify a hierarchy of application for the contractual instruments. In addition, they often have to fulfil quality criteria before they can be used as a contractual instrument within the framework of a market-based approach as a basis for determining emission factors for balancing purchased energy. These criteria are intended to ensure the reliability of contractual instruments and serve to avoid the double marketing of renewable energy volumes in particular. According to (ISO 14067:2018), contractual instruments should fulfil the following criteria, for example:

- Information on the characteristics of the electricity unit, such as the generation plant, energy sources used, location and period of electricity production must be provided.
- The contractual instrument must ensure that the properties are utilised once.
- The contractual instrument must ensure that the characteristics of the energy supplied can be tracked and ultimately clearly assigned to the supplied company - e.g. by cancelling Energy Attribute Certificates (e.g. HKN).
- There should be a temporal proximity to the electricity supply.
  Electricity transmitted using the contractual instrument should have been generated within the market boundaries in which it is also consumed.

The European HCN system fulfils existing criteria for market-based instruments (e.g. according to the GHG Protocol, ISO 14067, EU PEF). In combination with mandatory electricity labelling within the EU, under which HCNs must be used to verify the renewable energy content of electricity products, this serves as a secure basis for market-based energy accounting. Other international verification systems would have to be examined accordingly with regard to their fulfilment of the criteria for market-based instruments.

If there is no contractual instrument, the residual energy mix is used as the basis for determining the emissions from electricity procurement in accordance with the market-based approach. This represents the characteristics of a country's total energy mix, minus the energy volumes tracked by contractual means (usually RE volumes). This prevents energy volumes from being counted twice under the market-based approach. In Europe, this is published, for example, by the Association of Issuing Bodies (AIB), which brings together the Member States' HCN issuing bodies and has established a common European standard for HCN systems.(AIB 2023).

The use of the two approaches is specified differently in accounting standards. While more recent industry standards for PCF preparation favour the market-based accounting approach (see e.g. Catena-X 2023; TfS 2022; JRC 2023 , the location-based approach is also preferred in some contexts. This applies, for example, to industry LCIs that refer to average data and do not reflect a specific product of a particular company .(see e.g. EA 2018; VDI 2023; WSA 2017)

The advantages and disadvantages of the two approaches are discussed in detail in the scientific debate. As shown inTable2 , both approaches to accounting for purchased energy have different characteristics, which

can be advantageous or disadvantageous depending on the objective of the accounting. This results in different recommendations for the use of one or the other approach.

Table2 : Characteristics of the location-based and market-based accounting approach

Criterion	Location-based approach	Market-based approach
Assessment basis	Energy mix of the grid from which the energy is drawn	Energy characteristics transmitted by the contractual instrument (e.g. electricity contract)
Emission factor & verification	Grid emission factors published by appropriate bodies (e.g. German electricity mix published by the Federal Environment Agency); often including upstream emissions No special proof required	Emission factor is transmitted with energy product Included emissions depend on the determination of emission values by the energy supplier Verification system must be in place (e.g. use of HKN)
International applicability	Applicable for every energy market	Approach corresponds to liberalised electricity markets with established verification systems
Mapping of physical conditions	An approximation to physical reality is possible depending on the set network limits	Commercial separation of physical energy flow and energy property
Corporate influence on the decarbonisation of electricity procurement	No direct or only marginal influence on the decarbonisation of electricity procurement possible through investments in generation plants	Direct influence possible through corresponding procurement decisions
Entrepreneurial influence on the energy transition	No influence	Influence possible if the energy purchase fulfils additionality criteria (see section 3.4.2.)
Influence on the PCF	Influence possible through energy efficiency measures, in-house generation or choice of location	Direct influence possible through choice of energy product

Based on WRI & WBCSD 2015; Mundt et al. 2019

Double counting of energy properties

The fact that there is no consensus on the application of only one accounting approach means that both approaches are used in parallel in practice. Depending on the company location and energy procurement practice, it may be more favourable for reporting companies to use one or the other accounting approach.

Not only can this make it difficult to compare PCFs, it also leads to energy volumes - especially RES volumes - being counted twice. For example, if company A has concluded a green electricity contract deposited with HKN from Norway and balances this on a market-based basis, and company B - based in Norway - uses the Norwegian grid mix to balance on a location-based basis. In this example, the same amount of RE is counted in two GHG balances. This results in double counting of RE quantities, which leads to an overestimation of the environmental impacts of renewable energies (Schneider et al. 2015; Holzapfel et al. 2023)

In order to avoid double counting of energy properties, only one accounting approach for energy would have to be used consistently. It would therefore be necessary to agree on the use of either the location-based or the market-based approach.

Avoiding double counting within the location-based approach poses a challenge. It must be ensured that all balancing units refer to the same temporal and geographical delimitations of grids, e.g. annual analyses of nationally delimited grids. This ensures that RE quantities that are attributed to company A via a locally defined grid emission factor are not also attributed to company B via the national emission factor. A temporally and geographically granular and therefore physically more realistic view without double counting can only be guaranteed by appropriate offsetting mechanisms between different electricity mix resolutions . In order to establish such an offsetting system, appropriate data must first be available in a suitable form. Projects such as the CO_2 monitor from TenneT and Gasunie (NetAnders 2023) as well as TenneT and FfE (Reck et al. 2024) can create such a data basis. However, this is currently only being developed in the Netherlands and Germany.

A verification system, which can be used as part of the market-based approach, ensures that every quantity of energy produced has been utilised and accounted for once. The residual energy mix to be used can be used to avoid double counting when balancing energy purchases. The prerequisite for this is, of course, that a corresponding residual energy mix is published.(Holzapfel et al. 2023).

Recommendations for action

Consistent use of the market-based approach

- Reduction of the risk of double counting possible through clear application rules and use of the residual energy mix.
- The market-based approach can reflect the procurement decisions of companies and thus allows companies to decide for themselves whether green electricity is procured and how this affects the GHG balance. It also enables ambitious green electricity projects (e.g. PPAs) to be taken into account, even if the additional financing effect for the energy

transition is controversial (see section 3.4.2).

- Corresponding criteria for market-based instruments must be adhered to. It should be discussed whether existing criteria should be supplemented, for example, by the existence of an obligation for energy labelling by means of corresponding proof (such as the electricity labelling obligation in Europe).

- In Europe, market-based accounting is possible due to the existing HCN system, which fulfils the criteria for a market-based approach. With regard to non-EU markets, the existence of corresponding verification systems would have to be reviewed regularly. If no adequate verification system is available, the location-based approach should be used. The exclusive use of one approach per energy market can prevent double counting in the markets.

- In the context of balancing according to the market-based approach, it should be ensured that upstream emissions from energy generation are included.

3.4.2 Discussion on the energy transition benefits of the market-based approach

Especially in the context of recommendations for the use of a market-based approach, its benefits for the energy transition are repeatedly criticised.

The direct benefit of the market-based approach in the form of a financing effect of the additional revenue that can be realised via energy attribute certificates for renewable energy volumes is doubted in scientific discourse. Such a financing effect has not yet been proven by quantitative studies. A higher demand for green electricity may be required to achieve actual financing effects (Brander et al. 2018). Nevertheless, energy attribute certificates or HKNs can be attributed an indirect benefit for the energy transition. Without corresponding verification systems, the transfer of green attributes in the context of innovative green electricity projects such as a PPA, for example, would not be possible (see Styles et al. 2021).

There are also concerns regarding the market-based approach's ability to promote the energy transition with regard to the significance of emission reductions in a PCF through the purchase of green electricity. It is criticised that, due to the design of the market-based approach, it cannot be assumed that reduced emissions from the purchase of energy in a PCF are due to the addition of new renewable energy installations, but that existing renewable energy volumes may have been redistributed (Bjørn et al. 2022; Brander et al. 2018).

In order to ensure an actual reduction in emissions, so-called additionality criteria would have to be taken into account when purchasing green electricity. The demand for green electricity of a certain quality (e.g. in relation to the age of the plant or the technology of the plant) is ascribed an energy transition benefit. Such additionality criteria have been developed, for example, by the Federal Environment Agency (2017), the WWF (2021) or the international initiative for the procurement of green electricity RE100 (2022).

In the current design of the market-based approach, the quality of the purchased energy is not taken into account in PCF accounting and additionality criteria are not included in the accounting methodology. As part of the update of the GHG Protocol Scope 2 Guidance, two central options for dealing with this are currently being discussed (WRI 2023) : Either reporting organisations could be required to report on the quality of the electricity they procure in the form of a secondary balance sheet or in the form of an additional consideration of the actual environmental impact. This solution follows a consistent inventory-based (attributional) LCA

approach. The second option takes a more impact-oriented (consequential) LCA approach. To this end, the criteria for contractual instruments could be expanded to include additionality criteria. Possible criteria include stricter requirements for plant age, accepted technologies or the geographical and temporal relationship between green electricity production and demand. A change to the calculation of Scope 2 emissions is also proposed (WRI 2023). It is still unclear whether and to what extent these changes will be applied to the GHG Protocol Product Standard in future.

Recommendations for action

Subsidiary balance sheet reporting on green electricity quality

- The quality of the green electricity purchased should not be a prerequisite for the applicability of the market-based approach.
- In line with the attributional LCA approach, overall systemic incentives should not be integrated into the accounting methodology. Incentives for the quality of green electricity procurement should be set elsewhere.
- Incentives for the quality of green electricity procurement could be created via policy instruments, e.g. by integrating them into the assessment criteria of funding programmes such as EEW funding, the decarbonisation of industry or climate protection contracts.[6]

3.4.3 Further regulatory requirements in the context of energy balancing

The regulations described on the balancing of energy mostly relate to the purchase of electricity and set clear guidelines for dealing with the balancing of different forms of electricity purchase. However, they should also be used for other purchased forms of energy (see ISO 14067:2018).

Due to the different procurement modes compared to electricity procurement, existing methods for energy balancing should be extended to other energy sources (heating/cooling, gases and hydrogen). To this end, the different framework conditions of the markets as well as existing and newly established verification systems must be taken into account. Compared to the balancing of electricity purchases, the balancing of district heating/cooling purchases, for example, presents a challenge. The district heating and cooling markets are not liberalised, European-organised markets, but rather small monopolistic structures that need to be mapped using suitable accounting methods across the board.

In addition, the balancing of self-generation plants should also be regulated in more detail, particularly with regard to plants that additionally supply electricity to a grid. This is a frequent use case for the steel industry, for example (see Wright et al. 2023) . Here it is particularly important to be able to reliably verify the quantities produced for own consumption and the quantities fed into the grid. Corresponding verification requirements should be specified as part of the harmonisation of methods for PCF determination in the automotive industry in order to avoid double counting.

[6] Bundesförderung für Energie- und Ressourceneffizienz in der Wirtschaft (EEW) | Bundesministerium für Wirtschaft und Klimaschutz (BMWK) 2023; Dekarbonisierung in der Industrie | Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU) 2023; Förderrichtlinie Klimaschutzverträge | Bundesministerium für Wirtschaft und Klimaschutz (BMWK) 2020.

4 CONCLUSION: REQUIREMENTS FOR THE HARMONISATION OF ACCOUNTING METHODS

Need for harmonisation in relation to energy, recycling & allocation/attribution

- Methods for GHG accounting of products in the automotive industry needs to be harmonised, particularly with regard to the methodological aspects of energy accounting and allocation in multifunctional processes.
- In addition, the allocation of GHG savings from recycling processes and the attribution of properties of physically homogeneous material and energy inputs should be considered as special allocation cases.

Clear targets needed for the GHG accounting of products

- One challenge in the harmonisation of methods for GHG accounting in the automotive industry is the different boundary conditions and objectives of the sectors and other stakeholders involved.
- Depending on the objective of a PCF and how, for example, the technological framework conditions in sectors are organised, a different methodological decision may appear advisable.
- The first step towards harmonisation was to find a jointly agreed target for the GHG accounting of products in the automotive industry.

Harmonisation across sector boundaries

- Harmonisation of methods for GHG accounting in the automotive industry requires a look beyond sector boundaries. Existing work from sector initiatives, standardisation and regulation should be incorporated into harmonisation projects.
- Negotiation processes regarding the methods for GHG accounting are particularly necessary at sector transitions, e.g. with regard to the allocation of GHG emissions between two sectors. This requires an intensive exchange between different stakeholders and experts.
- Feedback with corresponding processes for defining GHG accounting methods for products at regulatory level is also necessary to ensure regulatory compatibility of the methods. Developments at EU level with regard to accounting methods, which are primarily characterised by the EU PEF methodology, should be taken into account.

- The harmonisation of methods should be carried out integratively and in close cooperation with all relevant sectors in order to ensure uniform application. The aim is to create a broad consensus through joint coordination, which leads to voluntary but widely binding use, even though the methods are not anchored in regulation.

GHG accounting as a pure recording tool

- The objective within the automotive industry is to pursue a carbon accounting principle along the entire automotive supply chain. The carbon accounting principle is understood here as a primary data-based recording of GHG emissions in a cradle-to-gate system boundary along the entire supply chain, which comes close to an inventory-based LCA approach.

- This is intended to promote the comparability and transparency of the GHG balances of products. The PCF logic is increasingly deviating from the original LCA logic. Instead, it is moving closer to the primarily primary data-based and inventory-based recording processes of GHG accounting at company level (CCF).

- Against this background, GHG accounting should be understood as a pure recording tool.

- Transformative incentives should be created outside of the accounting methodology. This concerns, for example, incentives to promote the recyclability of products, reward the decarbonisation of primary material production or the procurement of green electricity with additionality criteria.

5 LIST OF ILLUSTRATIONS

6 LIST OF TABLES

7 LITERATURE

Association of Issuing Bodies (AIB) (2023): European Residual Mixes 2022, Brussels. Available online at https://www.aib-net.org/sites/default/files/assets/facts/residual-mix/2022/AIB_2022_Residual_Mix_Results_inclAnnex.pdf, last checked on 22.12.2023.

Bjørn, Anders; Lloyd, Shannon M.; Brander, Matthew; Matthews, H. Damon (2022): Renewable energy certificates allow companies to overstate their emission reductions. In: *Nat. Clim. Chang.* 12 (6), pp. 508-509. DOI: 10.1038/s41558-022-01385-7.

Brander, Matthew; Gillenwater, Michael; Ascui, Francisco (2018): Creative accounting: A critical perspective on the market-based method for reporting purchased electricity (scope 2) emissions. In: *Energy Policy* 112, pp. 29-33. DOI: 10.1016/j.enpol.2017.09.051.

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) (2023): Decarbonisation in industry. Available online at https://www.klimaschutz-industrie.de/foerderung/dekarbonisierung-in-der-industrie/, last updated on 14.12.2023, last checked on 14.12.2023.

Federal Ministry of Economics and Climate Protection (BMWK) (2020): Guideline for the promotion of climate-neutral production processes in industry through climate protection contracts. (Funding guideline for climate protection contracts - FRL KSV). DRAFT of 6.6.2023. Available online at https://www.bmwk.de/Redaktion/DE/Downloads/F/klimaschutzvertraege-foerderrichtlinie.pdf?__blob=publicationFile&v=2, last checked on 14.12.2023.

Federal Ministry of Economics and Climate Protection (BMWK) (2023): Announcement* of the guidelines for federal funding for energy and resource efficiency in the economy - funding competition (BAnz AT 25.05.2023 B1). Available online at https://www.bundesanzeiger.de/pub/publication/EcD1UbbCMpayBkED8Ui/content/EcD1UbbCMpayBkED8Ui/BAnz%20AT%2025.05.2023%20B1.pdf?inline, last checked on 14.12.2023.

Catena-X Automotive Network e.V. (Catena-X) (2023): Catena-X Product Carbon Footprint Rulebook CX-PCF Rules. Version 2.0. Berlin.

EA_2021_European_Aluminium_Environmental_Profile_Report_Refining-Industry.

Ekvall, Tomas (2020): Attributional and Consequential Life Cycle Assessment. In: María José Bastante-Ceca, Jose Luis Fuentes-Bargues, Levente Hufnagel, Florin-Constantin Mihai and Corneliu Iatu (eds.): Sustainability Assessment at the 21st century: IntechOpen.

Ekvall, Tomas; Björklund, Anna; Sandin, Gustav; Jelse, Kristian; Lagergren, Jenny; Rydberg, Maria (2020): Modelling recycling in life cycle assessment. Ed. by Swedish Life Cycle Centre. Gothenburg, Sweden (2020:05). Available online at https://www.lifecyclecenter.se/wp-content/uploads/2020_05_Modeling-recyling-in-life-cycle-assessment-1.pdf, last checked on 15.11.2023.

European Aluminium (EA) (2018): Environmental Profile Report. Life-Cycle inventory data for aluminium production and transformation processes in Europe.

European Commission (2024): Commission Delegated Regulation (EU) supplementing Regulation (EU) 2023/1542 of the European Parliament and of the Council by establishing the methodology for the

calculation and verification of the carbon footprint of electric vehicle batteries. Draft. https://eur-lex.europa.eu/legal-content/EN/PIN/?uri=PI_COM%3AAres%282024%293131389

Expert Group on the Transformation of the Automotive Industry (2024): A currency for climate protection: A plea for a globally harmonised carbon accounting methodology in the supply chains of the automotive industry.

Fernandez, Marta Cruz; Grund, Sabina; Phillips, Chris; Fradet, Jeanne; Hage, Johannes; Silk, Nick et al. (2024): Attribution of Global Warming Potential impacts in a multifunctional metals industry system using different system expansion and allocation methodologies. In: *Int J Life Cycle Assess* 29 (5), pp. 873-889. DOI: 10.1007/s11367-023-02274-7.

Frischknecht, Rolf (2010): LCI modelling approaches applied on recycling of materials in view of environmental sustainability, risk perception and eco-efficiency. In: *Int J Life Cycle Assess* 15 (7), pp. 666-671. DOI: 10.1007/s11367-010-0201-6.

Holzapfel, Peter; Bach, Vanessa; Finkbeiner, Matthias (2023): Electricity accounting in life cycle assessment: the challenge of double counting. In: *Int J Life Cycle Assess* 28 (7), pp. 771-787. DOI: 10.1007/s11367-023-02158-w.

Institute for Energy and Environmental Research gGmbH, ecoinvent Association (2024): Analysing the environmental balance of motor vehicles with alternative drive systems or fuels on the way to greenhouse gas-neutral transport. In collaboration with Kirsten Biemann, Hinrich Helms, Daniel Münter, Axel Liebich, Julia Pelzeter, Claudia Kämper and Johannes Müller. Edited by the Federal Environment Agency (UBA) (TEXTE, 13/2024). Available online at https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/13_2024_texte_analyse_der_umweltbilanz_von_kraftfahrzeugen_0.pdf.

International Energy Agency (IEA) (2022): Achieving Net Zero Heavy Industry Sectors in G7 Members. Paris. Available online at https://www.iea.org/reports/achieving-net-zero-heavy-industry-sectors-in-g7-members.

Joint Research Centre (JRC) (2023): Harmonised rules for the calculation of the Carbon Footprint of Electric Vehicle Batteries (CFB-EV). Draft Version. European Commission (JRC Science for Policy Report).

Kemper, M.; Mundt, J.; Sünkel, J. (2024): Product Carbon Footprint: Energy. Short paper commissioned by the Federal Environment Agency for the Ad-hoc Group (AhG) "Decarbonisation of the Automotive Value Chain" of the Expert Group "Transformation of the Automotive Industry" (ETA) of the Federal Ministry of Economics and Climate Protection. In: Eine Währung für den Klimaschutz: Plädoyer für eine weltweit harmonisierte Carbon Accounting Methodik in den Lieferketten der Automobilindustrie, Anhang. Available online at https://expertenkreis-automobilwirtschaft.de/media/pages/home/7b60121c03-1713348676/expertenkreis-transformation-automobilwirtschaft_uba-hir_kurzpapiere_pcf_allokation_energie_recycling_januar_2024.pdf.

ISO 20915:2018, November 2018: Life cycle inventory calculation methodology for steel products.

Mission Possible Partnership (MPP) (2022): Making net zero steel possible. Available online at https://missionpossiblepartnership.org/wp-content/uploads/2022/09/Making-Net-Zero-Steel-possible.pdf, last checked on 19.12.2023.

Mission Possible Partnership (MPP) (2023): Making net-zero aluminium possible. An industry-backed, 1.5°C-aligned transition strategy. Available online at https://missionpossiblepartnership.org/wp-content/uploads/2023/04/Making-1.5-Aligned-Aluminium-possible.pdf, last checked on 19.12.2023.

Mundt, J.; Werner, R.; Maaß, C. (2019): WP 4: Identification of the environmental impact of electricity purchased by companies and the public sector. In: Federal Environment Agency (UBA) (ed.): Marktanalyse Ökostrom II. market analysis of green electricity and HKN, further development of the guarantee of origin system and electricity labelling final report. In collaboration with IZES gGmbH, Hamburg Institute, imug (Climate Change, 30/2019), pp. 317-383.

NetAnders (2023): CO2 Monitor - Principles. Ed. by TenneT and Gasunie Energy. Available online at https://co2monitor.nl/en/principles, last updated on 16.08.2023, last checked on 13.12.2023.

RE100 (2022): RE100 Technical Criteria. Version 4.1. ed. by Carbon Disclosure Project (CDP). London, New York, New Delhi. Available online at https://www.there100.org/sites/re100/files/2022-12/Dec%2012%20-%20RE100%20technical%20criteria%20%2B%20appendices.pdf, last checked on 12/12/2023.

Reck, Regina; Neitz-Regett, Anika Dr; Ferstl, Joachim; Bogensperger, Alexander Dr; Bruckmeier, Andreas; Nolting, Lars Dr; Kiessling, Axel (2024): CO_2 -monitor. Methodological report. In collaboration with TenneT. Ed. by FfE. Munich.

ResponsibleSteel (2022): ResponsibleSteel International Standard version 2.0.

Schneider, Lambert; Kollmuss, Anja; Lazarus, Michael (2015): Addressing the risk of double counting emission reductions under the UNFCCC. In: *Climatic Change* 131 (4), pp. 473-486. DOI: 10.1007/s10584-015-1398-y.

Schrijvers, Dieuwertje (2017): Environmental evaluation of recycling options according to the Life Cycle Assessment methodology. Establishment of a consistent approach applied to case studies from the chemical industry. Dissertation. Université de Bordeaux, Bordeaux.

Styles, A.; Werner, R.; Maaß, C. (2021): Purpose and instrumental performance of guarantees of origin Status quo and perspectives for further development. GO4Industry basics - report G2. Funded by BMU (FKZ: UM20DC003). Hamburg Institute. Hamburg. Available online at https://go4industry.com/wp-content/uploads/2021/11/HIC_2021_Einsatzzwecke-von-Herkunftsnachweisen_final.pdf, last checked on 14.12.2023.

Theuringer, M. Dr.; Endemann, Gerhard; Geres, Roland; Holzner, Dominik; Weigert, Stefan; Beckmann, Martin et al. (2024): Rulebook for the classification system in the Low Emission Steel Standard. Ed. by the German Steel Federation. German Steel Federation; FutureCamp Climate GmbH; verico SCE.

Together for Sustainability (TfS) (2022): The Product Carbon Footprint Guideline for the Chemical Industry. Specification for product Carbon Footprint and Corporate Scope 3.1 Emission Accounting and Reporting. Version 2.0.

ISO 14067:2018: Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification.

Federal Environment Agency (UBA) (2017): Procurement of green electricity - Working aid for a Europe-wide tender for the supply of green electricity in an open procedure. Dessau-Roßlau. Available online at https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-03-17_broschuere_leitfaden-oekostrom-ausschreibung_korr.pdf, last checked on 12.12.2023.

ISO 14021:2016 , March 2016: Environmental labels and declarations - Environmental supplier declarations (Type II environmental labelling).

ISO 14044:2006, 2018: Environmental management - Life cycle assessment - Requirements and guidance.

ISO 14040:2006: Environmental management - Life cycle assessment - Principles and framework.

Association of German Engineers (VDI) (2023): VDI analysis of CO2eq emissions from passenger cars with different drive systems. When will driving go green?

World Business Council for Sustainable Development (WBCSD) (2023): Pathfinder Framework. Guidance for the Accounting and Exchange of Product Life Cycle Emissions. Available online at https://www.wbcsd.org/contentwbc/download/15625/226889/1, last checked on 25/09/2023.

World Business Council for Sustainable Development (WBCSD); World Resources Institute (WRI) (2011): Greenhouse Gas Protocol - Product Life Cycle Accounting and Reporting Standard.

World Resources Institute (WRI) (2023): Greenhouse Gas Protocol Detailed Summary of Responses from Scope 2 Guidance Stakeholder Survey. In collaboration with Michael Macrae and Kyla Aiuto. Available online at https://ghgprotocol.org/sites/default/files/2023-11/Scope%202%20Survey%20Summary_Final_0.pdf, last checked on 08.12.2023.

World Resources Institute (WRI); World Business Council for Sustainable Development (WBCSD) (2015): GHG Protocol Scope 2 Guidance. An amendment to the GHG Protocol Corporate Standard. In collaboration with P. Bhatia, C. Cummis, M. Didden, A. Kovac, J. Ryor and A. Stevens. Available online at https://ghgprotocol.org/sites/default/files/2023-03/Scope%202%20Guidance.pdf, last checked on 07.12.2023.

World Steel Association (WSA) (2017): Life cycle inventory methodology report for steel products. Ed. by World Steel Association.

World Wide Fund for Nature (WWF) (2021): WWF criteria for green electricity. What criteria should be used to procure green electricity in order to promote the energy transition? Berlin. Available online at https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Klima/WWF-oekostrom-kriterien.pdf, last checked on 12.12.2023.

Wright, Lachlan; Liu, Xiyuan; Wu, Iris; Chalasani, Sravan (2023): Steel Emissions Reporting Guidance. Edited by Rocky Mountain Institute. Available online at https://rmi.org/wp-content/uploads/2022/09/steel_emissions_reporting_guidance.pdf, last checked on 05.10.2023 .

The Challenges of PCF Creation in the Automotive Value Chain

ISSN: 2747-478X

CONTACT

Juliane Mundt

HIR Hamburg Institute Research gGmbH

Paul-Nevermann-Platz 5

22765 Hamburg

Phone: +49 (0)40-39106989-32

mundt@hamburg-institut.com

www.hamburg-institut.com