WHITEPAPER

Improvements for calculating and labeling the product carbon footprint on the basis of the Nutri-Score

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Summary

The effects of climate change show the importance of mitigating the effects of rising temperatures like extreme weather events (e.g. droughts). Hereby, the industry sector and especially energy production are the biggest greenhouse gas emitter worldwide. Consequently, companies have to reduce their carbon footprint. Nevertheless, it is often argued that customers should make sustainable shopping choices and in doing so influence retailers to become more sustainable. However, to enable consumers to purchase climate-friendly products, they need a reliable source of information. Therefore, companies should calculate the carbon footprint for each of their products. The product carbon footprint (PCF) is most commonly evaluated with the Greenhouse Gas Protocol Product Standard, the PAS 2050, or the ISO 14067. In this whitepaper, these three standards are compared based on their different rules of calculation, result, and usability. The main calculation differences were found in the categories cut-off-criteria, capital goods, allocation & recycling, reporting, stored carbon, land-use change, green electricity, and uncertainty assessment. The GHG product standard has the most detailed explanations and guidelines. Furthermore, improvements to the standards are proposed to enhance their application and comparability. This is important to offer customers reliable information to enable climate-friendly choices.

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1. Introduction

Global warming is becoming more visible and already starting to unleash its catastrophic effects like storms, heat waves, and unavailability of water. The amount of greenhouse gases (GHG) released plays a central role in global warming. Scientific research has proven that an increasing amount of GHG emissions in the atmosphere causes infrared radiation to be emitted back into the atmosphere instead of leaving it. The rising infrared radiation causes the temperature to rise [1], [2], [3]. The leading researching institution for the effects of global warming and climate change is the intergovernmental panel on climate change (IPCC). In 2018 the IPCC released a detailed report on the cause and effects of global warming of 1.5°C. The research shows that the global temperature already increased by 0.8°C to 1.2°C compared to the pre-industrial level (1850-1900). A further increase to 1.5°C is likely to be reached between 2030 and 2052 by the current global warming rate. However, the effects and destruction caused by a temperature rise of 1.5°C compared to 2.0°C are crucial. The long-term goal of the IPCC is to advise and educate world leaders to make necessary policies to reduce emissions. To keep the climate goals in reach, like from the Paris agreement, GHG emissions have to decline well before 2030 [3].

The biggest economic sectors which emit the most GHG emissions are electricity and heat production, agriculture forestry and other land use, Industry, and transportation. In Germany, the sectors producing the most emissions are energy followed by transportation [4]. Calculating a carbon footprint (CF) is the first step to evaluate GHG emissions. Once the data is recorded and analyzed, measures can be taken to mitigate the effects of global warming. This can be achieved by reducing the assessed CF [5]. In contrast to standards for environmental management and reporting, which focus, among other things, on process architectures. the CO_2 footprint addresses the entire production chain of a product or a company's production [6], [7]. Over the years different international contracts have been formed to reduce GHG emissions. In 1997 the Kyoto protocol was formed and in 2005 it was ratified by 192 parties. It was followed by the Paris climate agreement which has been ratified by 196 parties in 2015 [2]. The goal of the Paris climate agreement is to restrict global warming to 1.5°C and reach neutral emissions by 2050 [8]. In Germany, regulatory policies are implemented to push companies towards sustainable productions. Since 2005 the carbon certificates have been established to limit the GHG emissions a company is allowed to emit. In 2021 a CO_2-tax was introduced, which raises the prices for gas, petrol, and heating oil [9]. Driven by climate change and increasing political pressure, there is a growing need for companies to achieve more sustainability [10].

This paper proposes improvements for calculating a product carbon footprint. This approach is based on existing standards and aims at creating a model to

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make carbon reduction more attractive for companies. At first, the carbon footprint is introduced followed by an explanation and comparison of internationally accepted product carbon footprint assessment standards. The three standards compared are PAS 2050 (2011), GHG Protocol product standard (2011), and ISO 14067 (2018). The comparison is based on assessment steps that have methodological differences between the standards. Mitigation strategies proposed by the IPCC are then introduced to identify effective measures to reduce global warming. These measures are transferred to the affected footprint calculation steps. Additionally, the widely accepted Nutri-score system for processed foods is applied as a best-practice method to create an easily understandable carbon label for consumers.

The history of ecological footprints dates back to the 1970s when the first designs emerged. In the meantime, they have become a widespread marketing and political tool. There is a variety of different footprints in literature, which provide information about specific environmental aspects of products [11]. In the scientific context, eight common footprints are used for achieving sustainable development: the environmental, carbon, energy, water, biodiversity, land, phosphorus, and nitrogen footprint. Each footprint focuses on a different environmental impact factor. Depending on the product or company, that is assessed, the main impact factor for the sustainability of a product changes [12], [13], [14]. Recent attempts by the European Union focused on creating a comprehensive footprint, that includes many different factors and is internationally accepted. In 2012 the product environmental footprint (PEF) guide was published and in the following years until 2016, the first product assessments were carried out. To date, there are 25 different product categories for which product specific guidelines have been released. The calculation is life cycle oriented and based on several ISO standards, International Reference Life Cycle Data System (ILCD), the GHG Protocol and the PAS 2050. Nevertheless, the PEF has not been established yet and is considerably more complex than the CF since it considers 13 impact categories. These categories include GHG emissions, effects on the ozone layer, toxins, water consumption, land change and eutrophication of waters [15]. Due to the lack of a wide application range and the higher complexity this paper focuses on the more common carbon footprints.

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2. Carbon Footprints

The carbon footprint is defined by ISO 14067 as the result of greenhouse gas emissions along the entire life cycle of a product in a defined application and unit of use [16] [17]. The six different kinds of greenhouse gases from the Kyoto protocol from 1997 are carbon dioxide, methane, nitrous oxide, partially halogenated hydrofluorocarbons, perfluorinated hydrocarbons, and sulfur hexafluoride [18], [19]. These have been further researched and completed by the IPCC. The 2007 report from IPCC includes already 63 different GHGs in their greenhouse gases report [20]. This may be misleading since GHG are more than just carbon emissions. To still present a result in carbon dioxide emissions an equivalent of carbon dioxide (CO_2-eq) is calculated for the other GHG emission, the global warming potential (GWP) [21], [18], [19]. Carbon dioxide has a GWP of 1 kg CO_2-eq, this is used as a normalization factor for GWP. Other GHG receive, depending on their greenhouse effect compared to carbon dioxide, a multiple of this. For example, methane has a GWP of 25 kg CO_2-eq. The GWP can be calculated for different time horizons, for the CF it is 100 years. This is based on the consideration that after a certain time the GWP is becoming irrelevant [21].

The carbon footprint mainly distinguishes between the footprint of a product and the footprint of a company. The corporate-related CO_2 footprint includes the GHG emissions in the production phase of the respective company, which can include multiple products. The product-related carbon footprint (PCF) comprises the total amount of GHG emissions caused over the entire life cycle of a product or service. These emissions can occur during the procurement of resources, production, transport, distribution, final consumption, and disposal [11], [19].

2.1. Corporate carbon footprint

A corporate-related footprint can be calculated using, for example, the Greenhouse Gas Protocol Corporate Standard (2004) or ISO DIN EN 14064-1:2019-06 [22]. The GHG Protocol is the most commonly used method to calculate direct and indirect carbon emissions on an organizational level. The standard from 2004 defines three different scopes for a CCF. Scope 1 is defined by the GHG protocol as direct emissions, meaning everything that happens within the organization like facilities or company vehicles, which are owned or controlled by the company. Scope 2 includes indirect emissions (upstream emission) from electricity consumption. However, steam, heating, and cooling, which are consumed by the organization have to be considered as well [18]. The Scope 3 standard from the

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GHG protocol also known as the Corporate value chain Standard includes all other indirect emissions up- or downstream [23]. These can be for example purchased goods and services, capital goods, transportation, and business travel for upstream emissions. For downstream emissions Scope 3 includes the processing of sold products, use of sold products, end-of-life treatment of products, and investments. The Scope 3 standard is often underestimated by organizations and it is optional even though Scope 3 emissions account for a significant amount of the overall footprint [18].

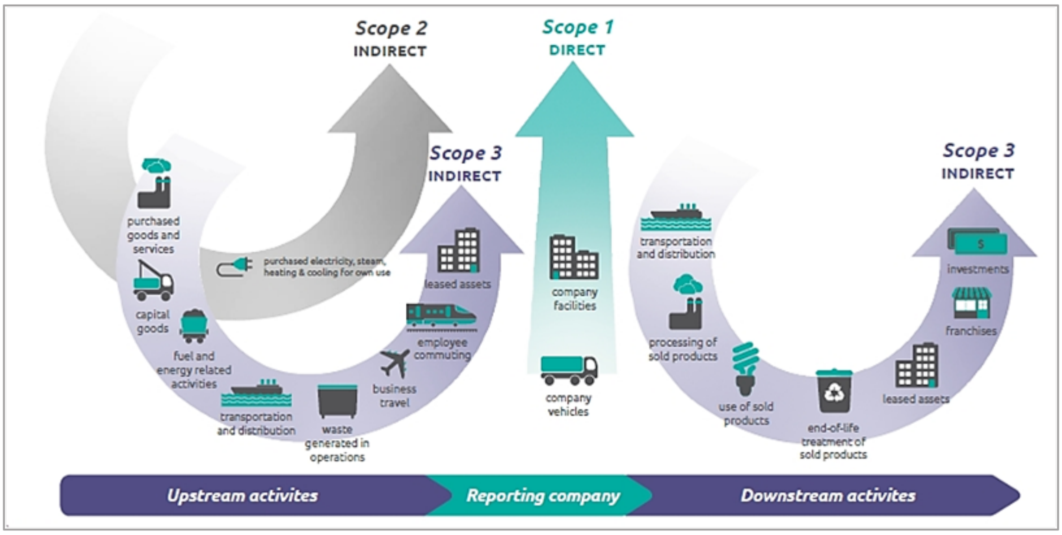

Figure 1: The three scopes of the GHG protocol [24]

The ISO 14064 Standard is based on the GHG protocol [25]. A difference between the two standards for example is that ISO can be certified and is fitted for industrial usage whereas the GHG protocol is also performed by NGOs and governments [14].

Benefits for companies calculating a CCF can be synergies with other functional areas. The data can help the R&D department to develop “greener” products [25], [26]. Furthermore, the data can be used for internal and external carbon reporting. Lastly, it can be used for corporate branding [26] and employee marketing [25]. The goal is to integrate the CCF within the different departments of an organization (production, logistics, innovations, marketing, finance, and accounting) to use the CCF as a support to make sustainable decisions [25] and gain transparency [26].

The corporate carbon footprint can be a foundation to start the calculation of the product's carbon footprint. However, there are methodological issues that Navarro et al. identified, which have to be addressed when corporate data is used to calculate products. In a detailed study in the wine industry, the authors collabora-

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ted with 18 wineries to perform carbon footprint calculations and conducted a literature review as well. First, the corporate and product standards include different scopes. A PCF includes all related emissions along the life-cycle of the product, whereas the CCF is calculated in different scopes (1-3). Fugitive emissions (like hydrofluorocarbon from the use of a refrigerator) are part of the CCF Scope 1. These emissions are mostly not specified for PCF calculations, particularly if they are not directly linked to the product. Secondly, the approach for the calculation of waste recycling is different for CCF and PCF, however, calculations show that the calculated difference is negligible. Differences in referencing can become a problem. For example, in the wine industry, the PCF is calculated per bottle of wine. The vineyards, that produce the grapes, can calculate their emissions based on ha cultivated or kg per grape. This causes a noticeable difference when used for further calculation. Accumulation can cause further differences due to stored glass bottles in the wine industry, which are sold from previous years but are not considered within the yearly numbers of produced bottles of wine as well as bottles that are longer stored. The last identified issue is to use organizational data for minor products. The smaller the representativeness a product has compared to the total amount of produced products by the company, the bigger the calculation error [27].

2.2. Life Cycle assessment

Even though there are methodological differences in the calculation of carbon footprints they are widely based on the life-cycle assessment (LCA) approach [11]. There are primarily three different methodological approaches to LCA: input-output, process-based, and hybrid. The main idea of the input-output method is to model processes or industries based on their input and output flows. These flows can be accumulated in tables. Meaning the outputs of an economy are known and by using these total numbers, like the amount of material from one industry bought by another, can be broken down into individual companies or products. It can be described as: "(…) a mathematically defined procedure using economic and environmental data to determine the effect of change in the output of a single sector. This method can be applied to any economy defined by the transactions between sectors (agriculture, heavy machinery, etc.)." [28]. The relationships between the sectors are calculated with the produce from industry A necessary to produce one dollar in industry B. For example how many screws do I need to produce one dollar of revenue in the car industry? The calculation of energy consumption can be done reliably with the process-based method. The hybrid LAC methodology is a mix of both methods [28].

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An LCA can be performed with the ISO 14040 and ISO 14044 standards, which are input-output based [29]. Most common is the cradle-to-grave method, which includes every step of a product's life-cycle [11]. These are common raw materials, manufacturing/processing, usage, disposal [29]. The basic steps of an LCA are (1) definition of goal and scope, (2) analysis of the inventory, (3) life cycle impact assessment, (4) Interpretation and explanation of the results [29], [28]. Figure 2 visualizes the LCA steps:

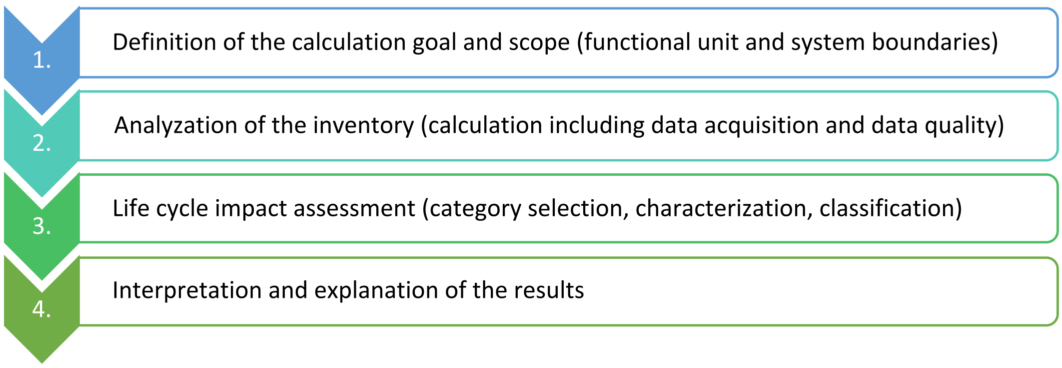

Figure 2: Steps for an LCA assessment

The calculation scope for manufacturers has to be defined and enables the omitting of certain processes. This is useful for some products due to their large number of production steps. In the next step, the available or collected data is analyzed and with the help of set formulas, it is used to calculate the GHG emissions [11]. LCA software that supports the necessary calculations are for example GaBi and OpenLCA. They can identify the percentages of emissions within different scopes (1-3 GHG protocol), processes, and visualize the results [14].

2.3. Product carbon footprint

The three common standards for calculating a PCF are Publicly Available Specifications (PAS) 2050, the Greenhouse Gas Protocol Product Standard (2011), and ISO 14067 [11], [21], [30], [31] [14]. In addition to these three standards, many guidelines exist for calculating a carbon footprint. Many countries have started initiatives to calculate carbon footprints. In most countries, the calculation of a PCF is not required by law. Nevertheless, own guidelines and standards have been developed for example in Germany (pcf-project), the US (carbon fund), and Thailand. Some countries have regulatory requirements like France, Australia, and Japan (TSQ001). In France, certain products must be certified and follow the legal requirements established in 2010. Another policy to encourage participation is practiced in Thailand where companies receive subsidies for consultants

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helping to assess the CF [11]. However, the overall lack of a uniform internationally recognized standard is also one of the biggest criticisms concerning the PCF and hinders its acceptance [11], [13], [31], [14], [32].

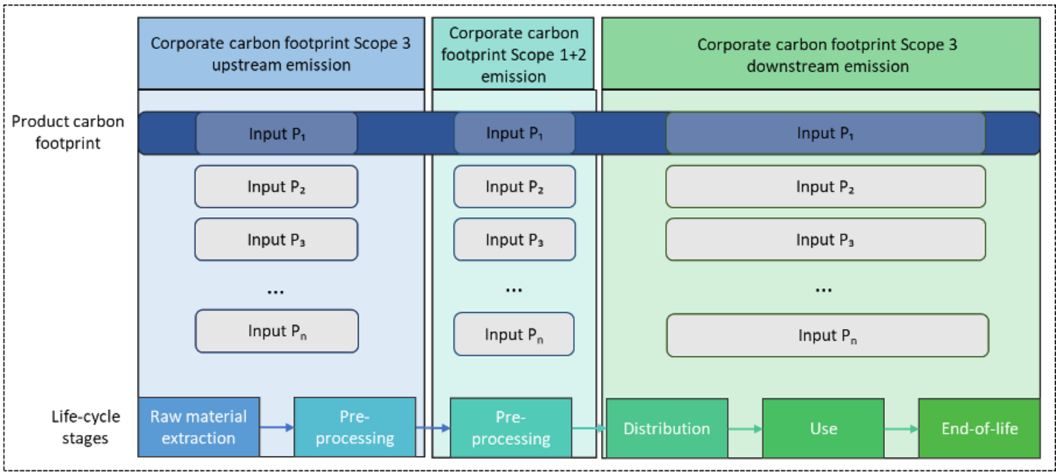

Figure 3: Visualization of des PCF and CCF scope in accordance with [14]

The Graphic shows the “conceptual relationship” between the PCF and the CCF [14]. Caused by the variance within the different carbon footprint methodologies there is a rising initiative for “integrated approaches to increase comparability and reduce complexity” [14]. This method starts by calculating a comprehensive CCF, which can be gradually broken down to the processes, products, and services in the company with the support of weighting. This approach is similar to the method mentioned earlier, however with the use of weighting factors, some of the methodological issues (e.g. system boundaries) should be resolved [13]. Other issues concerning the calculation of PCFs make comparisons difficult since these issues lead to differences in results are the scope of GHG emissions, cut-off criteria specifications, and the [13]. Especially the problem of the system boundary is well discussed in the literature [19], [32], [33]. In chapter 4 a detailed comparison of the differences between the standards is made.

An opportunity for companies is the rising interest in sustainable investments. The carbon report is used as evidence for the company’s efforts to be more climate-friendly and reduce its CF. There are a lot of free databases and tools which help calculating a PCF [13]. Furthermore, there is a strong marketing trend for sustainable production, a PCF calculation offers a distinction between the labels and gives the customer more proof than the label “eco-friendly”. By now there are more than 546 eco-labels and a rising number of fake ones [13].

There are different approaches to design a carbon footprint label. However, design studies have shown, that not all labels are meaningful and understandable for consumers. It has been proven that the simple number of calculated CO_2-eq is

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not helpful for consumers. To generate an added value with the CF labels, costumers have to a) be able to compare products or b) need a color code as an evaluation on how the product performs [34] [35] [36].

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3. PCF International Standards

In the following the three standards PAS 2050, GHG Protocol Product Standard, and ISO 14067 are introduced.

3.1. PAS 2050 (2011)

PAS 2050 was published in 2008 by the British Standards Institution (BSI) and jointly promoted by the Carbon Trust and the UK Department of Environment [11]. The standard was revised in 2011 to correspond with the GHG product protocol in key points [37]. Carbon Trust aims to support other companies in establishing a low carbon economy. The standard responded to the market need for more sustainable products and is one of the first examples of using a single indicator to compare products for assessing GHG emissions over the life-cycle of products. PAS 2050 developed a framework for quantifying GHG emissions along the life-cycle of products. The life-cycle analysis is based on ISO 14044 and ISO 14040 which document in detail how to perform the assessment [5]. The PAS 2050 standard, as well as a guide, are freely available online [21]. The PAS 2050 does not provide communication requirements [37] however, carbon trust offers certifications and labels for communication purposes. The certifications are not limited to the PAS 2050 standard and can be applied for the GHG Product Protocol and ISO 14067 as well [38]. The standard does not provide specific product category rules like ISO 14025 but recommends the use or development of such supplementary rules with industry-specific guidelines [37]. The PAS 2050 can be performed in 4 steps (1) scoping (product description and system boundaries), (2) data collection (data collection plan and data quality check), (3) footprint calculation (multiply activity data with GWP, (4) interpretation (of results and identification of carbon reduction potentials) [37]. Figure 4 shows the PAS 2050 steps.

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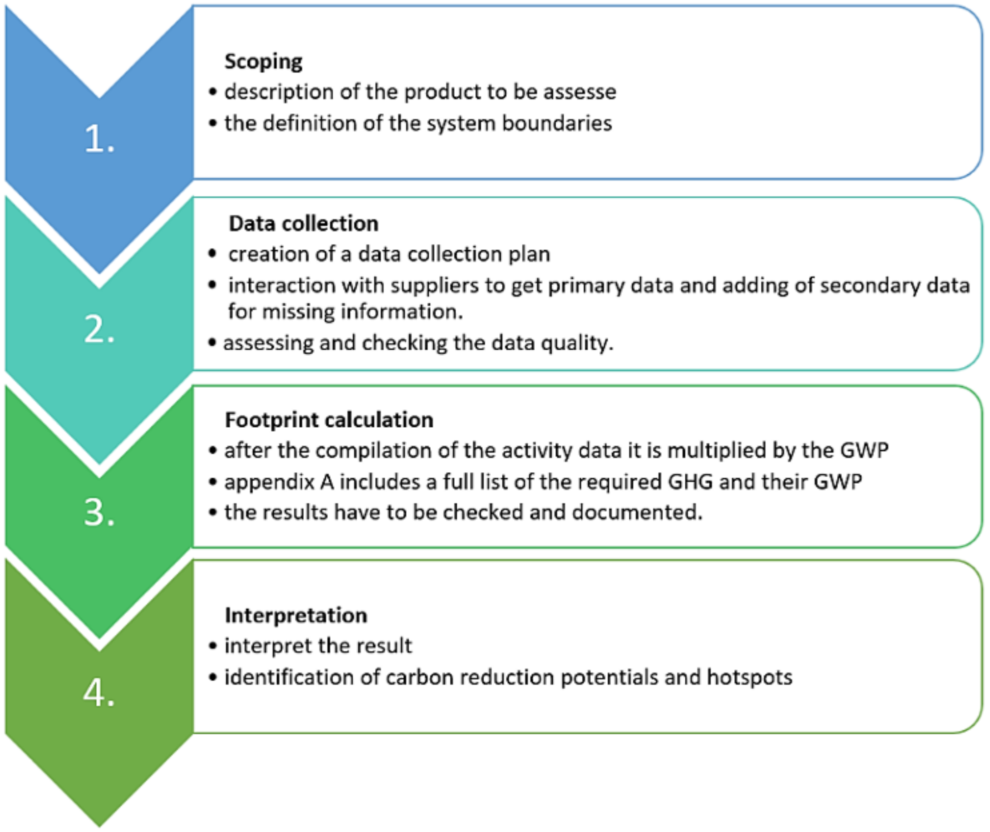

Figure 4: PAS 2050 steps

To start the footprint assessment, the company should have updated material lists and bills or a clear picture of the processes regarding the product/service. Additionally, statistics about energy consumption, waste, and overall production are needed as well as logistics insights. This can be supplemented by a list of suppliers and their locations [37].

3.2. GHG Protocol Product Standard (2011)

In 2011, the "Greenhouse gas protocol: Product life cycle accounting and reporting standard" was published by the World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) [39]. All greenhouse gas protocol standards are freely available online [21]. The standard is largely based on the PAS 2050 standard and life-cycle analysis. Consequently, there is a strong overlap in quantifying the principles in terms of key methodological rules [39]. The objective of the standard is to provide detailed guidance on the calculation of product-related GHG emissions and to establish an international standard. Besides, the outcome of the calculation is a basis for the identification of emission reduction potentials and the tracking of product performances. Fur-

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thermore, the GHG product protocol sets requirements for accounting and reporting related to public information of product-related CO_2 emissions [11]. The standard aims to apply to all industries and their different companies and organizations [5]. The different GHG Protocols can be applied on the cooperate level (GHG Protocol 2004) as well as on the product level. As a result, companies, that are already using the GHG protocol to report corporate emissions, can profit from the synergies and structures within the standards [21].

The Protocol follows the GHGs mentioned in the Kyoto protocol and only requires other GHG emissions to be listed separately [39]. The standard resembles the PAS 2050 concerning specific product rules, as none are provided, but the use is recommended [30]. Nevertheless, the standard offers guidance on the Product comparison (Appendix A), the ISO 14044 rules are explicitly not applicable. To compare two products assessed with the GHG product standard the functional unit of these products has to be identical. Products can be compared based on their performance, labels, or consumer and business purchasing behavior. However, only the tracking of the performance can be solemnly compared based on the product standard. For other claims additional GHG program specifications are necessary or product rules. The product rules are established by a group of stakeholders and have to be peer-reviewed by experts [39].

The GHG protocol can be performed in twelve steps (1) define business goals, (2) review principles, (3) review fundamentals, (4) define the scope, (5) set the boundary, (6) collect and assess data quality, (7) perform allocation, (8) assess uncertainty, (9) calculate inventory results, (10) perform assurance, (11) report inventory results, (12) set reduction targets [39]. Figure 5 visualizes the GHG protocol product standard process.

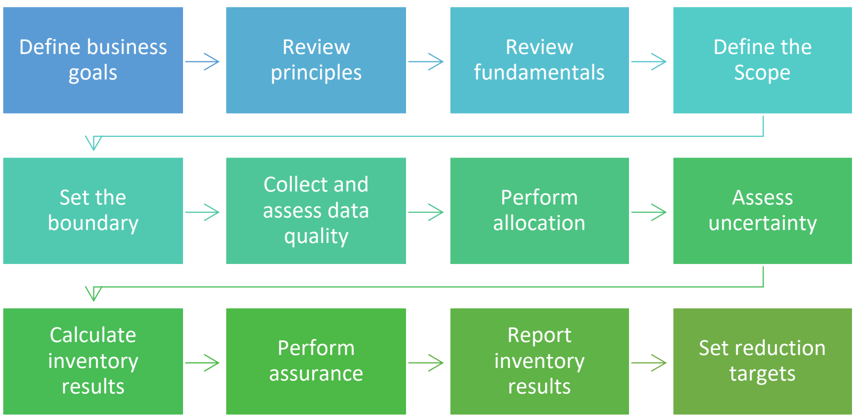

Figure 5: Steps of the GHG product standard (in accordance with [39]).

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3.3. ISO 14067:2018

The latest standard for calculating a PCF is ISO 14067. ISO was first published in 2013 as a technical norm ISO/TS 14067:2013 and could be tested by companies till ISO 14067 was released in 2018 [16], [21], [5]. It is based on many other existing ISO standards such as LCA (ISO 14040, ISO 14044), guidelines for ecological labels (ISO 14020 series), and product category rules (ISO 14025). Similar to the GHG product standard ISO aligns the PAS2050 and GHG product standard further and aims at a broad range of applications [21]. The standard was developed to set clear quantification and communication rules for GHG results [16]. Clear quantification rules were established to prevent so-called "greenwashing". "Greenwashing" denotes, that companies advertise sustainability without a sufficient basis [5]. The Standard established nine assessment principles and therefore added four more to the existing principles in the PAS 2050 and GHG protocol. The principles are explained in chapter 4. here only the principle of coherence, should be mentioned since it enables the comparison of different products from the same category [11]. The steps of the assessment are similar to the four steps developed in the PAS 2050 and mentioned in chapter 0. The assessment is then followed by a report and a critical review. The specific rules for the communication of the results have been outsourced to other standards such as ISO 14026 in the revised version from 2018 [16]. Requirements for publication include a communication plan, product category rules, and third-party verification. In the last assessment, step ISO includes mandatory rules concerning the reduction of emissions [11]. Figure 6 represents the relationship of ISO 14067 to other relevant ISO GHG standards.

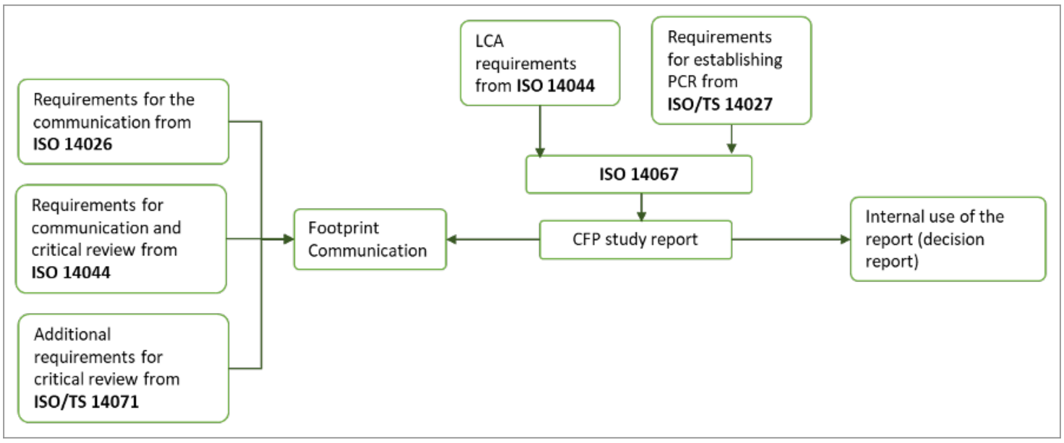

Figure 6: Relationship between ISO 14067 and the other relevant GHG management standards (in accordance with [16]).

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4. Comparison of the three standards along the PCF process

The overall process of a footprint assessment includes the following five steps [21]: (1) scope and goal, (2) footprint and calculation, (3) uncertainty and quality assessment, (4) results, (5) communication.

The five steps have different sub-steps, which have to be performed for the assessment. These sub-steps differ between the three standards and make up the criteria on which the comparison is based. The differences have been identified through supporting literature [30], [5], [40], [41], and the in-depth description of the PCF assessments as described by the standards [16], [37], [42], [39]. In this chapter (4) the similarities and differences between the guidelines are explained. In the first step scope and goal the guidelines are compared based on (1) the assessment principles, (2) life-cycle phases, (3) cut-off-criteria, (4) excluded emissions, (5) capital goods, and the underlying (6) GHG emissions which have to be assessed. The footprint calculation has the underlying criteria (1) data quality requirements, (2) allocation and recycling, (3) carbon removals, (4) delayed emissions and stored carbon, (5) land-use-change, (6) green electricity and airplane GHG emissions. In the third step of the PCF assessment uncertainty factors and the overall quality have to be reported. The standards are compared based on the (1) uncertainty assessment, (2) allowed assurers and (3) the allowed conformity claims. The Report requirements differ in the (1) scope, (2) included and separately listed GHG emissions and (3) other claims which have to be included. Lastly the communication of the PCF has (1) different requirements and (2) varies in the allowed marketing statements between the standards. Figure 7 summarizes the criteria.

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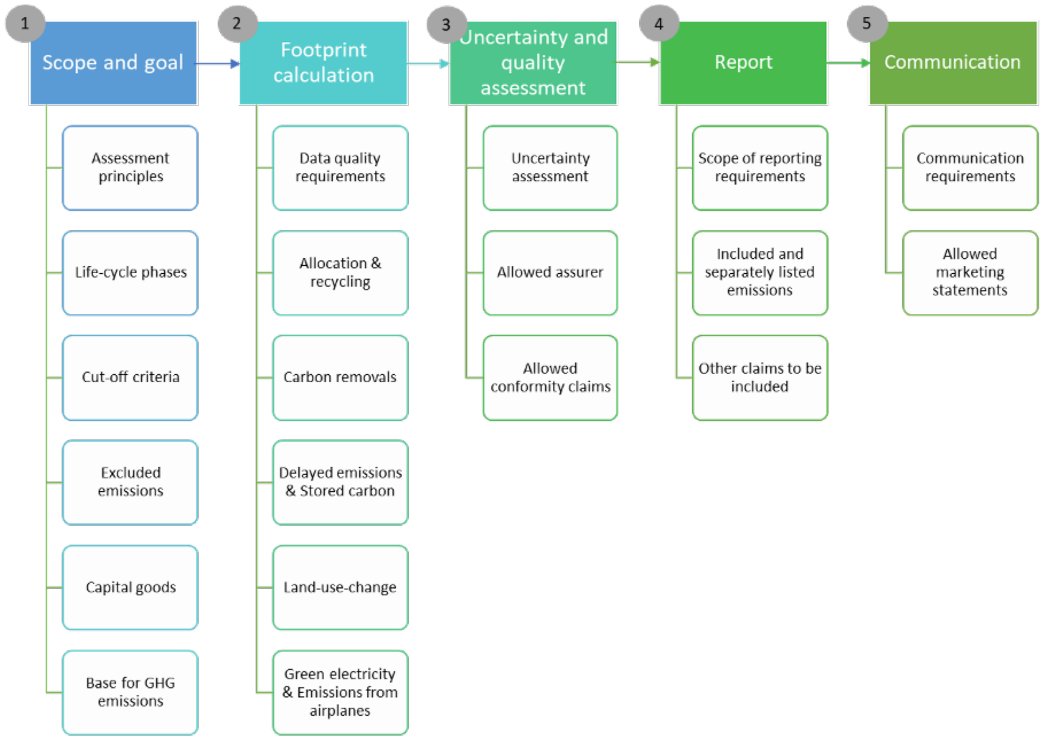

Figure 7: Visualization of the PCF assessment steps and comparison criteria

4.1. Goal and scope

In the first step, the goal and scope of the footprint analysis must be specified. As shown in Figure 5, additionally the functional unit and the system boundary have to be defined for a PCF assessment. The two steps are similar in the three standards and therefore are no criteria for the comparison. Nevertheless, the steps are very important for the calculation and consequently have been included in the overall explanation of the assessment. Figure 8 shows the complete sub-steps for the scope and goal of a PCF.

The general principles for conducting a PCF are relevance, completeness, consistency, accuracy and, transparency for PAS 2050 and the GHG product standard [21], [37]. The ISO 14067 standard adds six principles to the existing ones from the other two standards. The principles are life cycle perspective, coherence, relative approach and functional or declared unit, iterative approach, priority of scientific approach and, avoidance of double counting.

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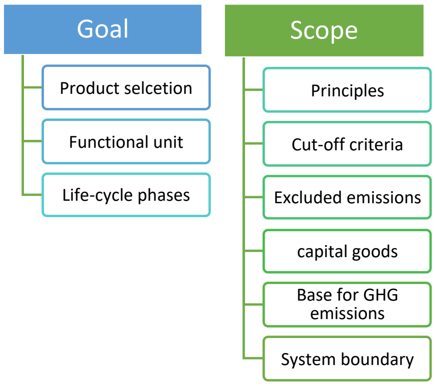

Figure 8: Visualization of the sub-steps for the goal and scope setting of the PCF

Different goals can be performance tracking (GHG reduction), responsibilities towards suppliers and customers, product differentiation, management of climate change risks. Once the goal is defined the product, which shall be assessed, has to be selected. Additionally, it is required to define the functional unit for all three guidelines. However, the unit is especially important when it comes to the product comparison. The definition of the functional unit given by ISO is: "[a] quantified performance of a product system (...) for use as a reference unit" [16]. This means the use of the product is known and therefore quantified in the input and output flows of the product. For example, if wall paint is the assessed product, it can be quantified by its function (coloring), duration (5 years), quantity (20 sqm) and, quality (98% of cover capability). This can be more suitable than measuring the product in kg or sqm since the product use is not always fully reflected by those quantities [21]. Afterward, the different life-cycle assessment phases are defined. The PAS 2050 and GHG Protocol allow cradle-to-grave and cradle-to-gate assessments. Cradle-to-gate includes all life-cycle stages till the product is sold or used [21] If the ISO Standard is chosen gate-to-gate and partial life-cycle assessments can be performed as well [40]. The partial PCF considers the GHG emissions of "one or more selected process(es) (...) in a product system" [16].

The system boundaries include the cut-off criteria, the timeframe, technical and geographic boundary. The cut-off-criteria differ between the standards which can result in varying PCF results. Overall, cut-off criteria define which parts of a production process are included in the assessment [21]. The PAS 2050 requires at least 95% of GHG emissions to be included in the study [42]. As a result, inputs which contribute to less than 1% of the total GHG emissions can be excluded. For example, for medium density fireboard these excluded inputs can be chemicals (paraffin wax) or specific energy flows (energy for seedling cultivation) [40].

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In detail the standard excludes the following emissions:

- Human energy inputs to processes
- Transportation of consumers for retail purposes
- Transportation of employees concerning their daily workplace
- Transportation services provided by animals [42].

The ISO standard states, that generally all emissions should be included however, if “individual material or energy flows are found to be insignificant (…) these may be excluded for practical reasons” [16]. If data is excluded it needs to be reported separately as excluded data. Therefore, no specific percentage or rule is given, leading to similar exclusions as explained with PAS 2050. Contrary the GHG product standard requires all emissions to be included (100%). Since the protocol is based on an attributional life-cycle approach, meaning that only GHG emissions and removals, which are “attributed to the unit of analysis of the studied product” [39] have to be considered. Consequently, the following emissions are excluded since they are “non-attributable processes” [39]:

- Transportation of consumers for retail purposes
- Transportation of employees concerning their daily workplace
- Capital goods (like machinery)
- Overhead operations (like air conditioning)
- Corporate activities and services (like R&D, marketing) [39].

Capital goods, like machines or buildings, are excluded in PAS 2050 as well. Contrary ISO 14067 states, that capital goods may only be excluded if they are insignificant and do not alter the calculations significantly [40], [16]. Capital goods can make up a significant amount of GHG emissions, like in the production of fiberboards they can make up to 11,3%, and consequently play an important role for the comparison of the standards [40]. The GHG product standard considers offsets and avoided emissions to be outside the life-cycle boundaries and therefore are not considered [39]. The PAS 2050 and ISO standards exclude offsetting as well, but they do not mention avoided emissions [16], [42].

The time boundary is picked for the data collection phase. The inventory results will be accounted for within that time boundary [21]. Therefore, a report using the ISO standard considers the length of the product life-cycle. The same rules apply to the GHG product standard and PAS 2050. If supplementary product category rules exist these shall be applied [16], [42], [39]. However, if the time period is unknown one hundred years have to be considered as a default value [37], [39]. The technological system boundary documents which manufacturing processes are included in the report. Resources, manufacturing and, consumption have geographic peculiarities, which need to be considered to have a representative report fitting the functional unit. As a supportive measure for this step, a

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process map can be created. The map shows all input and output flows based on the life cycle stage of the product [21].

Lastly, all relevant GHG emissions must be included. For the GHG product standard these are the six GHG emissions named in the Kyoto protocol (see chapter 2). It is recommended to further include all emissions recorded from the IPCC (2007 report, table 2.14). The IPCC emissions are the base for a calculation with the PAS 2050, all 63 have to be included [21]. However, the latest release of GWP calculations shall be used [42]. The ISO also requires the list of GHG emissions from the latest IPCC assessment report (till now it is 2013) [16].

4.2. Footprint calculation

The second step of the PCF process is the calculation of the PCF. This process consists of the following sub-steps: data collection, allocation, biogenetic carbon dioxide, carbon removals, stored carbon dioxide, land-use change, energy, transportation and, calculation [21]. The focus here will be on the steps which differ between the standards. Figure 9 visualizes the eight sub-steps.

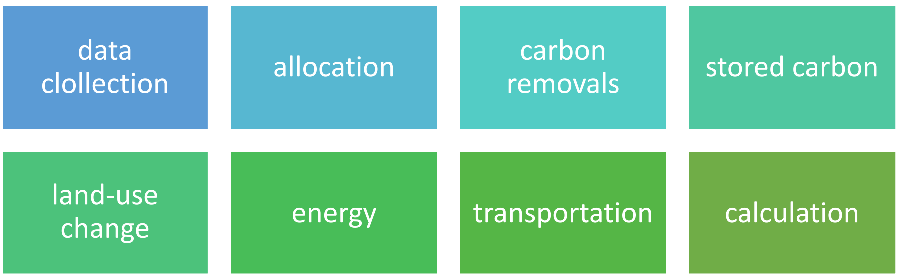

Figure 9: Visualization of the sub-steps concerning the PCF calculation

The data collection process must align with the general principles of the standards. Additionally, the data quality is characterized by ISO as time-related, geographical coverage, technological coverage, precision, representativeness, reproducibility, sources of the data and, the uncertainty of the information [16]. The data quality characteristics are an updated list of the ones defined in the GHG product standard and the PAS 2050 [42], [39]. Primary data is not necessary for downstream emission, but shall be collected for all processes which are controlled by the company [42]. Upstream emission can be calculated with secondary data as well. Databases that can be used for acquiring secondary data are for example ProBas, GEMIS, ELCD, and ecoinvent [21].

Some processes include a co-production of two products, nevertheless only one product is the subject of the PCF study. Consequently, the input and output flow of both products must be assigned to each product. This method is called allocation. Generally, allocation should be avoided [21] by creating sub-processes, re-

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defining the functional unit, or expand the system and therefore the direct emissions of the co-product are known [39]. If it is not possible to avoid the co-production the standards offer different guidance. The PAS 2050 states to further include supplementary requirements for guidelines on allocation. If no supplementary requirements exist economic allocation shall be used [42]. The GHG protocol standard explains three methods to perform allocation: economic allocation (like PAS 2050), physical allocation, and other relationships [39].

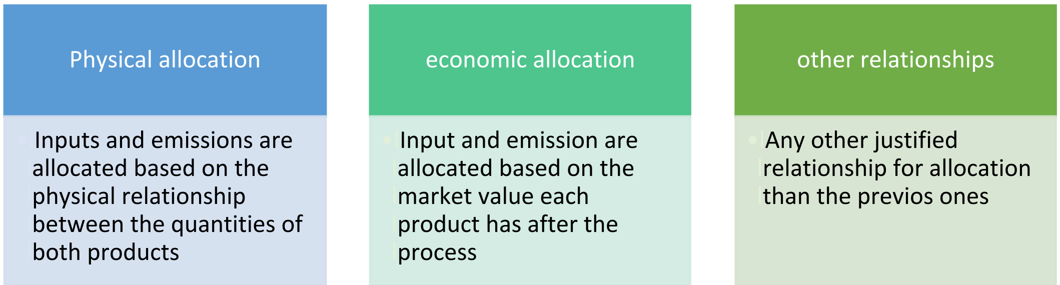

Figure 10: The three different allocation methods

The ISO standard follows the methods proposed by the GHG product standard. For recycling, the same rules are applied like allocation. There is a differentiation between closed-loop and open-loop recycling methods. In an open-loop production, the recycled material undergoes an inherent change and is reused in a different production system. In a closed-loop production, which can also apply to open-loop productions, the material does not undergo inherent changes, and as a result, allocation can be avoided [16]. Meaning in a closed-loop recycling system the emissions occurring in the process is included in the calculation [39].

Biogenetic carbon describes emissions that are derived from biomass. Contrary emissions derived from fossil fuels are referred to as non-biogenic. In the GHG product standard biogenetic and non-biogenetic emissions should be reported separately [39]. The same applies to the ISO standard [16]. PAS 2050 offers no guidance on this topic and the given examples in the guide make no separations [42], [37]. If the PCF study is cradle-to-gate based information on biogenic carbon has to be provided [16], [42], [39]. If Biogenetic carbon removals occur, these are subtracted from the calculation in PAS 2050 and GHG product standard [42], [39]. In contrast, ISO 14067 requires carbon removals to be reported separately as negative values [16]. The difference in the calculation approach can cause noticeable fluctuation in the results. Consequently, industries, which have a high share of biogenetic carbon, profit from the subtraction method since it reduces their PCF [30], [40]. It is important to note that PAS 2050 excludes food and feed products from the calculation of carbon removals. Instead, a “zero-weighting” factor is used at the end of the life-cycle setting both carbon removals and subsequent emissions to zero [37]. The ISO standard requires all emissions to be treated as released and therefore does not take delayed emissions or removals into account

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[16]. The PAS 2050 offers a weighting factor to calculate delayed emissions but it is not required [42]. The GHG product standard on the contrary does not allow a weighting factor and it is optional to show the impact of delayed emissions in a separate report [39]. Another subtopic is the treatment of stored carbon dioxide. Part of the first step is to set the time boundary for the footprint calculation. Stored carbon occurs according to the PAS 2050 guide, in long-lasting products which store carbon dioxide and do not release it within one hundred years [37]. The GHG product standard clarifies stored carbon as chemical components, which can occur in non-biogenic or biogenic products and are “recycled or reused in another product cycle, released as CO_2 or CH_4 during waste treatment (…), or stored as a result of waste treatment” [39]. If products can not be decomposition they can be disposed in landfills [39]. The ISO standard follows the assumptions made in the GHG protocol (2011) [16]. However, the ISO requires the stored carbon to be reported separately, whereas PAS and the GHG standards allow the amount of stored carbon to be deducted from the PCF results. This can cause further differences in the obtained results [40]. For example in medium density fiberboard the PCF is -658.42 kg CO_2eq when using the GHG product standard, but when using the ISO the PCF is 816.92 kg CO_2eq. Due to the inclusion of capital goods in ISO the net results of the PCF are still higher with -567.32 kg CO_2eq [40].

The treatment of land-use change is one of the key points when calculating a PCF since it can have a significant impact on the footprint. When land is used to produce a product the changes in carbon stocks must be assessed. Changes in carbon stocks consider the change in biomass within the set time boundary above- and below ground. This includes emissions as well as carbon removals or stored carbon, that occurs due to indirect or direct land-use must be reported. Examples of emissions from direct land-use change are the conversion of grassland to energy crops, conversion of land to infrastructure, or production plans. The example of indirect land-use change given by the standard is, that the direct land-use change of a field from producing food to biofuel can lead to another land-use change somewhere else to producing food since the demand for food needs to be met. The ISO standard refers to the calculation from the IPCC guideline and requires the net direct land-use change to be documented separately. The land-use change can be calculated by assessing the difference in GHG emissions and removals compared to a reference land use. Furthermore, GHG emissions or removals which originate from land use must be included in the PCF report [16]. The PAS 2050 offers additional default values for selected countries for the calculation in Annex C. Contrary to ISO indirect land-use changes are excluded [42]. All GHG emissions which occur due to direct land-use change like clearing a forest to plant cultivated crops are assessed. Although these emissions occur within a year, mostly a 20 year period is used for the calculation. Alternatively, to the 20 year period the harvest cycle is also used, the rule for the time period is, that the lon-

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ger timeframe has to be applied. This also works backward, if it is unknown when the last land-use change was and it cannot be proven, that no land-use changes were made within the last 20 years or harvest cycle, the GHG emissions and removals are relevant. The PAS guide follows six steps for the assessment [37]:

1. Checking if the emissions from land-use change are relevant
2. The place of origin/ location needs to be known
3. Previous land use has to be discovered
4. Use of Annex C to identify the emissions factor
5. The percentage of the land area which is used is multiplied by the factor
6. The results from five are divided by yield (ha/year) [37].

The GHG product standard considers direct land-use change impacts in two categories. One is a change in carbon stock due to the conversion of land within or between different categories for land use. Categories for land use are but not limited to the forest, cropland, settlements, rock, and bare soil. And Secondly "from the preparation of converted land, such as biomass burning" [39]. Additionally, to the definition given by ISO 14067 for carbon stock, the protocol also includes dead and soil organic matter like litter. The protocol further offers a detailed example of the calculation for direct land-use change, which is a mix of the methods explained above. Indirect land-use changes are excluded by the GHG product standard since it is based on a consequential life-cycle approach and indirect land-use is not attributional. The standard gives the example for indirect land-use change as an increase for animal food crops in the US, which leads to rising demand for cropland in Brazil. The higher demand triggers deforestation in Brazil to produce more crops and satisfy the US market [39].

Overall the energy assessment includes upstream and downstream emissions which occur within the life cycle of the energy provider. Further, energy generation is included and distribution and transmission losses must be taken into account as well [16]. The PAS 2050 allows "renewable energy-specific emission factors" [42]. The factor can only be used if there is "a direct and isolated causal link between the generation of renewable electricity and its use in a product system in order for it to count as renewable" [37]. If any of these two criteria are not met, the national average energy emission factor is applied. These rules are set to prevent double-counting [21]. The ISO standard does not consider renewable energy sources, since the differentiation between renewable energy and not green energy is not represented in the public energy grid [16]. GHG product standard does not mention a special treatment for renewable energy [21].

The emissions concerning transportation have been mentioned earlier with the cut-off criteria of the standards (chapter 4.1). Generally, all transports which occur and are directly linked to the production like the transportation of resources

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or distributional purposes must be assessed. The online calculator ECO TransIT Wold can be useful when assessing global supply chains [21]. The PAS 2050 has no specific factor for aircraft emissions. The GHG product standard and ISO state that, since these emissions can have a higher impact on the atmosphere, an aviation multiplier can be used [16], [39]. The GHG product standard further requires the source to be disclosed in the report [39]. The ISO requires the results of the multiplier to be reported separately and they can not be included in the PCF [16].

For the calculation of the footprint only the GHG protocol and the PAS 2050 give an approach [42], [39]. The ISO 14067 includes no calculation formulas except for allocation purposes. No other steps or explicit support is given [16]. The GHG protocol recommends six calculation steps for the PCF:

1. Setting the GWP value
   The most recent IPCC values are recommended but other values like the ones following the UNFCCC are accepted as well.
2. Calculation of the carbon dioxide equivalents (CO_2e) using collected data
   The formula for processes or financial data is:
   kg CO_2eq = activity Data (unit) * emission factor (kg GHG/unit) * GWP (kg CO_2eq/kg GHG)
   The emission factors represent the GHG emissions (one gas or a specific mix of CO_2eq) per unit of activity data.
   For direct emissions, the formula is:
   kg CO_2eq = direct emissions data (kg GHG) * GWP (kg CO_2eq/kg GHG)
   Carbon removals can be calculated by multiplying the amount of carbon by “the ratio of molecular weights of CO_2 (44) and carbon (12)” [39].
   kg CO_2eq = kg biogenic carbon * (44/12) * GWP (kg CO_2eq/kg GHG)
3. Calculation of total inventory results (CO_2e/unit)
   The formula is:

$$\frac{Total\ \mathrm{CO_2eq}}{unit} = \frac{CO_2\mathrm{eq\ biogenic\ emissions}}{reference\ flow} - \frac{CO_2\mathrm{eq\ biogenic\ removals}}{reference\ flow} + \frac{CO_2\mathrm{eq\ emissions\ (non\ biogenic)}}{reference\ flow} - \frac{CO_2\mathrm{eq\ removals\ (non\ biogenic)}}{reference\ flow} + \frac{CO_2\mathrm{eq\ land-use\ change\ impact}}{reference\ flow}$$

   Emissions are positive values and removals are negative since the inventory results represent the amount of GHGs which enter the atmosphere.
4. Inventory results per life cycle stage
   The formula is:

$$Percentage\ per\ life\ cycle\ stage = \frac{CO_2eq\ per\ life\ cycle\ stage}{Total\ CO_2eq\ inventory\ resutls} \times 100$$

5. Separation of reportings
   If appropriate biogenetic and non-biogenetic removals and emissions, and land-use impacts should be reported separately.
6. Life-cycle stages specifications
   Cradle-to-gate and gate-to-gate inventory results have to be calculated separately [39].

The approach proposed in PAS 2050 has five steps which are similar to the ones explained from the GHG product standard. However, step five is not a requirement for PAS 2050. The guideline to PAS 2050 also displays a full example for the calculation of the PCF for the production of one liter of orange juice for guidance [42].

4.3. Uncertainty and quality assessment

Step three is the evaluation of uncertainty factors. A bias in the results can occur due to the quality of the data, specific life cycle assumptions (included processes and system boundaries) [21]. Whereas the PAS 2050 only demands to reduce uncertainty as much as possible [42] the ISO and GHG standards differentiate between three different types. The types of uncertainty are parameter, scenario and model uncertainty. Parameter uncertainty includes GHG emission factors, activity data, and direct emission data. Scenario uncertainty deals with methodological choices like the end-of-life scenario or the allocation method. Lastly model uncertainty considers limitations of the model which can occur from assumptions made during the calculation, like a linear development of fertilizer per ha [16], [39].

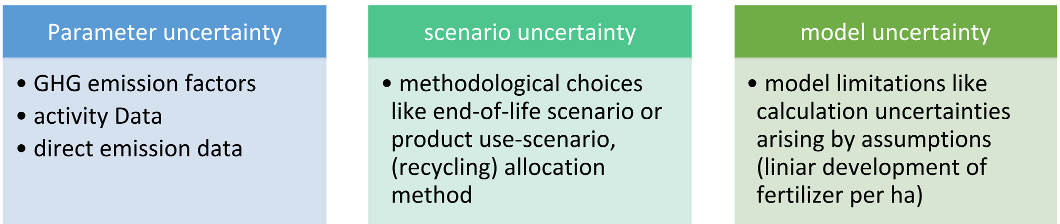

Figure 11: The three different types of uncertainty in the PCF assessment

When uncertainty is considered the results are usually given within a confidence interval, meaning the calculated PCF should be expressed e.g. as 10 kg CO_2eq ± 21% or PCF = (10 ± 2,1) kg CO_2eq. Nevertheless, depending on the depth of the uncertainty assessment it can be quite complex. Therefore the effort must be in proportion to the benefits since all calculated PCF from all companies have uncertainty [21]. The GHG product standard requires all sources (mentioned above) of uncertainty to be listed and described. This is necessary to compare products

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or improve one's performance since the assumptions made in the calculation have to be the same [39]. ISO 14067 requires a critical assessment of the results which equals the one described by the GHG product standard [16].

To substantiate the findings they should be assured by the reporting company, stakeholder, and the "assurer". Therefore, a first-party assurer is an employee of the party, but independent from the complete PCF assessment process. A third-party assurer is consequently independent of the organization which assessed the PCF. It is considered to be useful for a company to first have the results revised within the company and then confirmed by a third party. Additionally, the level of assurance, which can either be limited or reasonable, must be reported. The level is determined by the underlying tone of the statement, which can be negative (limited) or positive (reasonable). ISO 14040 and ISO 14044 give more detailed insights on critical reviews [39]. The PAS 2050 proposes very similar types of assurance to support the PCF claims. The standard further defines the eligible claims a company can make based on the type of conformity. If conformity is given by an independent third-party, which is accredited to provide certification to PAS 2050, it shall be stated as certified. Is the assurance made by any other third-party the report is labeled as "declared". Lastly, the report can be "self-declared" if an independent person within the organization reviewed the report [42]. ISO 14067 requires the critical review of the PCF assessment to be aligned with ISO/TS 14071 [16].

4.4. Report

For the assessment or accounting the five principles in the PAS 2050 and the GHG product standard are applied [42], [39], and further for the ISO the additional principles [16]. The GHG protocol product standard sets clear requirements for the information to be included in the report. The general information includes company and product information, functional unit and reference flow, included life-cycle stages, additional GHGs, PCRs, inventory date and version. The boundary setting has to include life-cycle stages, process map, excluded and included (non) attributional processes, time period and land-use change method. If allocation was performed a disclosure and justification of the methods needs to be given. For the data collection and quality, a statement on the data sources and the quality must be given. Additional there needs to be a qualitative statement on uncertainty and methodological choices. And lastly the inventory results include sources and data for GWP, total PCF results, results by life-cycle stages in percent, (non) biogenic emissions and removals separately, and carbon storage. Figure 12 visualizes the reporting requirements of the GHG protocol product standard.

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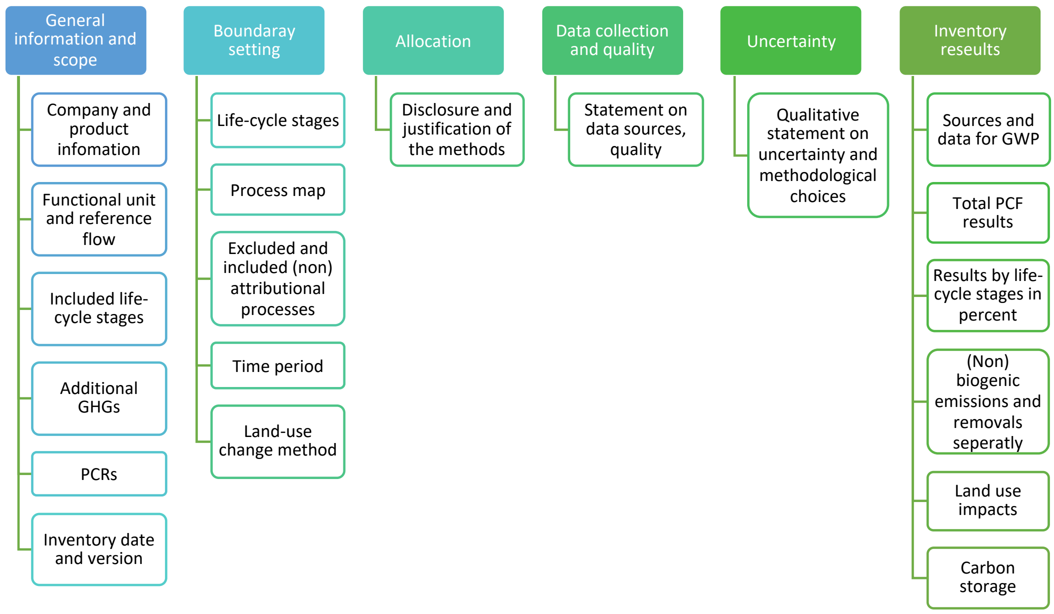

Figure 12: GHG protocol product standard reporting requirements

The ISO 14067 has a similarly detailed request concerning the report and gives clear guidance on the required information and which numbers should be reported separately [16]. The PAS 2050 gives requirements for the report of the PCF in Annex B. They are not as elaborate as the ones from the GHG protocol. Contrary, the focus is more on Information, which sets the standards apart. The PAS requires a description of the system boundary, carbon storage, land-use change, exclusions based on materiality, production materials, energy sources, use phase analysis, allocation of emissions, recycling, and secondary data sources [42], [37].

The overall goal when assessing the PCF of a product should be the reduction of emissions [21]. The PAS 2050 and the GHG product standard further give guidelines on how to reduce one's carbon footprint [37], [39]. Especially the GHG product protocol has clear requirements if a company decides to include information on carbon reduction targets in their report. This requires a company to report changes concerning the assessed PCF and to update the results based on the same functional unit. Further, after the initial PCF assessment reduction targets should be set based on the total results and may add a detailed goal for specific life-cycle stages. When the reduction targets are met, the report has to be repeated to include and account for the reductions [39]. The PAS 2050 guide explains how to identify “hotspots” in the process stages, which shall be addressed [37]. ISO 14067 points out, that the assessment enables the reduction of emissions, but does not give any further guidance [16].

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4.5. Communication

The communication of the PCF can involve different target groups. Depending on the targeted audience, being internal or external stakeholders of a company, suppliers, or customers a report or a label can be more effective. It is important to note that statements involving the overall sustainability of products are not permitted [21]. Since only the GHG emissions are assessed but other impact factors like water or energy use are not considered. The PAS 2050 gives no specific requirements for communication. Instead, further information should be sought from other international standards [42]. The ISO standard had originally in the ISO/TS 14067 from 2013 communication rules integrated. But with the revised version other ISO standards like ISO 14026 are now referenced as a requirement for communicating the results (see Figure 6, chapter 3.3).

The GHG product protocol gives examples for PR messages. The Report can be used to differentiate the product in advertisements and for internal purposes. If the main processes for the GHG emissions are identified, they can be effectively reduced. For example, Coca-Cola conducted a PCF assessment and by reducing mainly their refrigerator emissions they could reduce their PCF by around 35 percent. The overall marketing statement was that if all retailers did the same 5-16% percent of total GHG emissions from drinks could be saved. Nevertheless, the standard gives no clear requirements towards labeling, even though communication is part of the reporting chapter the requirements are only high level [39].

The Labels used to communicate the PCF differ and are not specified by the standards. It can state: carbon footprint measured, carbon footprint reduced, or a specific number [21]. However, studies have shown that these lack information for the customers. A coloring and comparison method is required for a label to be informative for the customers [11], [36].

4.6. Summary of the main differences

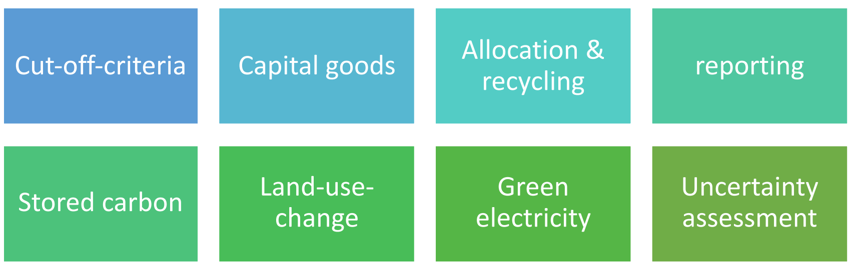

Figure 13: The main criteria which are treated differently in the standards.

As a summary, the biggest differences between the standards are in the categories: cut-off-criteria, capital goods, allocation & recycling, reporting, stored carbon, land-use change, green electricity, and uncertainty assessment.

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A complete summary of the comparison has been made in table 1, where all categories and steps are listed. The different dealings with the criteria can lead to significant variations between the PCF assessments. The most detailed guidance and requirements are given by the GHG product standard, followed by PAS 2050 and ISO 14067.

Standard / Criteria	PAS 2050 (2011)	GHG Protocol (2011)	ISO 14067 (2018)
Goal	To provide a standard to calculate GHG emissions of goods and services	Detailed guidelines for accounting and reporting of GHG emissions	Unified standard of the quantification process and communication of GHG emissions
Label example			
General principles	· Relevance · Completeness · Consistency · Accuracy · Transparency	· Relevance · Completeness · Consistency · Accuracy · Transparency	· Life cycle perspective · Relative approach and functional or declared unit · Iterative approach · Priority of scientific approach · Relevance · Completeness · Consistency · Coherence · Accuracy · Transparency · Avoidance of double counting
Base for GHG emissions	IPCC 2007a	Kyoto Protocol	IPCC 2013
Life-Cycle Assessment Phases	· Cradle-to-gate · Cradle-to-grave	· Cradle-to-gate · Cradle-to-grave	· Cradle-to-gate · Cradle-to-grave · Gate-to-gate · Partial life cycle
Cut off criteria	At least 95% of total GHG emissions must be included, if materiality is below 1% it can be excluded	No criteria, 100% completeness is required	No specific criteria, insignificant emissions can be excluded (compulsory disclosure for these)

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Excluded emissions	Human energy inputs, transportation: consumers for retail purposes; employees concerning their daily workplace; services provided by animals	All non-attributional processes (capital goods, overhead operations, corporate activities, consumers for retail purposes; commute distances of employees	Nothing mentioned
Capital goods	excluded	excluded	Can be excluded if they are insignificant
Data quality requirements	· time-related coverage · geographical specificity · technology coverage · accuracy · precision · completeness · consistency · reproducibility · data sources	· technological representativeness · geographical representativeness · temporal representativeness · completeness · reliability	· time-related coverage · geographical specificity · technology coverage · precision · completeness · representativeness · consistency · reproducibility · data sources · uncertainty of information
Standard / Criteria	1. PAS 2050 (2011)	1. GHG Protocol (2011)	1. ISO 14067 (2018)
Allocation	2. avoidance 3. economic allocation	2. avoidance 3. economic, physical allocation or other relationship	2. avoidance 3. economic, physical allocation or other relationship
recycling	Formulars given for closed and open loop recycling	Open or closed loop recycling procedure following the rules of allocation	Open or closed loop recycling procedure following the rules of allocation
Carbon removals	Are included and subtracted from the total emissions	Are included and subtracted from the total emissions and must be reported separately	Must be calculated and reported separately
Delayed emissions	Can be calculated with a weighting factor	Can be reported separately	Excluded
Stored carbon	Stored emissions shall be included within the 100 year assessment period	Stored carbon should be reported	Stored carbon shall be calculated and reported separately
Land-use-change	Clear calculation procedure for direct land use change and default emission factor per country	Clear guidance for direct land use change, indirect land use changes are excluded	Direct and indirect GHG emissions and removals are required following the IPCC Guideline, net emissions must be documented separately
Green electricity	Special green-energy factor if criteria are fulfilled	Not mentioned	Not considered

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Emissions from air-planes	No special treatment	A multiplier shall be used to represent the higher impact	A multiplier can be used, but has to be reported se-parately
Further exclusions	Offsets	Offsets and avoided emissions	Offsets
Uncer-tainty	Should be avoided	Has to be assesses and reported	Should be considered and reported
Assurance	Level of assurance and conformity claims given	Level of assurance based the assurer's relation to the as-sessment	Has to follow ISO/TS 14071
Reporting require-ments	Clear requirements	Detailed and clear requirements	Detailed and clear require-ments
Reduction targets	Not required, but give guidance to identify "carbon hot-spots"	Voluntary to set re-duction targets, but gives requirements if an organization choo-ses to set reduction targets	Not required
Commu-nication	Not included	Not included	Guideline in ISO

Table 1: Comparison of the PAS 205, GHG protocol product standard, and ISO 14067

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5. PCF improvements

The overall goal of a PCF assessment is to analyze the results to gain transparency over the company's emissions and to be able to reduce the emissions of the product. To further enhance the introduction and tracking of carbon emissions, actions recommended by the IPCC are incorporated in the assessment. These are further aligned with existing requirements by the guidelines, which are beneficial to carbon reductions. In the last step, the communication concept from the Nutri-score system is applied as a best practice method, to solve existing insecurities concerning carbon labels. The Nutri-score was chosen since it is a well-accepted and known product evaluation system for customers in the food sector [43].

5.1. Improvement criteria and methods

The IPCC includes mitigation strategies in its reports on climate change. Since the PCF focuses on GHG emissions, which are the main drivers of climate change. The PCF should give further instructions on how to reduce the PCF and make it attractive for companies to achieve a lower PCF. One approach is to include and evaluate mitigation strategies within the PCF assessment.

The IPCC proposes different mitigation and adaptation strategies, which are efficient but never sufficient by themselves, only in combination. The mitigation strategies propose active interventions to reduce emissions. Whereas adaption strategies are adjustments to reduce harmful climate change effects or use advantageous opportunities. For every measure, there are benefits and trade-offs. For example, an adaption option could be to use biotechnology to create genetically modified crops, that will be more drought and pesticide resistant and consequently result in higher yields. However, there is a perceived risk to human health and skepticism towards its safety. Furthermore, there are ecological risks to introducing genetically modified crops to natural environments [3]. Consequently, there is no perfect way to handle climate change only a set of strategies to reduce the effects. Each strategy is designed to reduce different side effects of climate change, this is why the proposed strategies are only efficient in combination.

There is very high confidence that "innovations and investments in environmentally sound infrastructure" can lower GHG emissions [3]. Innovations can create further mitigation options and enhance their effectiveness. At the same time, inventions and infrastructure can reduce the negative impacts of climate change. This includes investments in sustainable (low-carbon) energy production, which can reduce the overall carbon footprint of the energy sector. The IPCC proposes environmental policies, available financial support, and technologies to create a wider economic development. This is underlined by robust evidence that the en-

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ergy demand needs to be reduced in the near future to prevent lock-in effects in carbon-intensive energy productions e.g lignite power plants. Low-carbon productions are renewable energies like wind, bioenergy, solar alternatively nuclear energy. If this form of energy production is increased to 80% by 2050 on a worldwide scale (and increased further in the future) the temperature rise could be reduced to 2 degrees. [3]. The carbon footprint category which is impacted by this strategy is energy. Investments are not considered in the PCF and are more applicable on a cooperate level than on a product level. The IPCC further states that "emissions can be substantially lowered through changes in consumption patterns" [3]. The PCF will educate the consumer on the carbon footprint of the products they buy and therefore build a knowledge base for consumption emissions. Based on this information consumers can make a purchasing decision based on climate friendliness.

Another mitigation measure is to reduce transport emissions. This can be archived by reducing or avoiding travel distances. Additionally, the carbon and energy intensity in the transportation sector needs to be reduced [3]. This implies the promotion of more local productions and fewer employee/ resources/ product journeys. A reduction can also be achieved through increased efficiency in the production process or energy usage [3].

The Nutri-score is a scoring system used for processed food, to give consumers a quick and easy overview of the healthiness of a product. The Nutri-score is based on a scoring system that gives positive values for "unhealthy" ingredients like sugar, salt, and saturated fat. On the other side, favorable ingredients like proteins, vegetables, and fruits have negative values. The ingredients have therefore negative or positive weighting factors which are summed in the Nutri-score. The calculated number is not displayed but transferred into categories. These categories range from "A" to "E" where "A" stands for a healthier product than "E". Additionally, a color code is used from green (A) to red (E). The Nutri-score can be used to compare products within one category or even beyond like the display of calories on food. It is a simple comparison based on the ingredients and if a customer wants to know if a ready-to-eat pasta has more favorable ingredients than a ready-to-eat pizza the comparison can be made [43]. The system of the Nutri-score will be applied to the PCF concept in the next chapters.

5.2. Calculation alterations

The proposed PCF-Score method transfers the idea from the Nutri-Score System to the product carbon footprint calculation. This elaborates the GHG protocol product standard approach to carbon removals. Here the GHG removals are subtracted from the final results and all results have to be separately reported.

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However, this idea can be taken further to distinguish between emission reduction measures and the omission of those. The impact of avoided emissions is described later in this chapter.

The energy assessment needs a favorable calculation for low-carbon energy productions like renewable energy sources to enforce the mitigation strategy from the IPCC. Therefore, the factor as proposed by the PAS 2050 is the minimum to support green energy sources. The criteria have to be adjusted to be more applicable and supportive of renewable energy. If a company has a pure green energy contract and they support the production of wind, solar, and water energy, they should be treated differently than other energy sources. Pure means in this context that the energy payments are 100% invested in renewable energy production by the energy supplier. Therefore the organization needs to have a certificate stating that their energy contract supplies renwable energy. Even though the actual energy provided by the grid may not be green, sine energy always takes the smallest route. When comparing the number of a traditional fossil power plant with a solar, or wind power plant the differences in terms of GHG emissions are huge. To produce one kWh of energy a: lignite power plant produces about 875 to 1125 g CO_2eq/kWh [44], biopower plant about 16 to 74 g of CO_2eq/kWh, photovoltaic power system about 14 to 32 g CO_2eq/kWh, and a wind power plant about 8 to 20 g CO_2eq/kWh [45]. Figure 14 shows the GHG emissions from the mentioned power systems to produce one kWh.

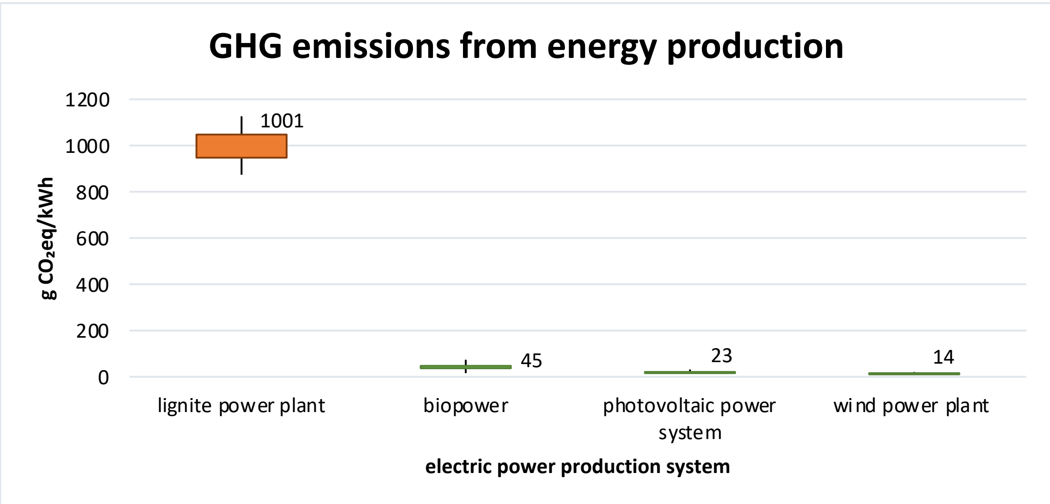

Figure 14: GHG emissions from energy production

The exact numbers vary based on the specifics of the power plant. The numbers displayed in figure 12 are the median of the given ranges. The ranges displayed are from the IPCC reports on renewable energy from 2012 [45] and 2014 [44].

For the PCF assessment alterations are proposed. This means, that an organization which has a renewable energy contract can use it. A company producing wall

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paint in Berlin would rely on lignite power since most power plants around the city are still lignite power plants. The company had to account e.g. 120 kWh (fictional number) needed to produce one liter of paint. This means with the existing guideline they had to account for:

- 120kWh * 1,001 kg CO_2eq/kWh = 120,2 kg CO_2eq (average number for lignite power plant used, as given above).

Now the company can calculate its emissions based on a solar energy contract. There has to be no point-to-point connection. Only a certificate which states this type of energy production (here solar) is 100% supported by this contract. In terms of calculation, this leads to:

- 120 kWh * 0,023 kg CO_2eq/kWh = 2,76 kg CO_2eq (average number for photovoltaic power system used, as given above).

A further factor here is avoided GHG emissions. In the assessed standards they are outside the boundaries. However, it would be useful to allow companies to report avoided GHG emissions separately as “avoided fossil emissions through renewable energies” to show and promote the impact of green energy. The company producing the paint, as an example, could report that they saved 117,44 kg CO_2eq due to using renewable energy. This number can serve as a best-practice method for other companies, to identify hot-spots and reduction potentials.

The PCF assessment should include the employee's GHG emissions from business travels and commuting to draw the firm’s attention towards these emissions. Both the PAS 2050 and GHG product standard explicitly exclude these. However, since they are key factors for mitigation as proposed by the IPCC, these emissions should be included on a product level and not only on a corporate level. The overall production transportations are already included in all three guidelines. However, companies should be informed to pay attention to these areas and look for reduction potentials in energy supply and transportation. The calculation alteration is to include chapter 6 “Business travel” and chapter 7 “Employee commuting” from the GHG protocol scope 3 standard in the PCF assessment. These include but are not limited to air, rail, bus, and automobile travel [23]. These emissions may make up only a small amount of the total emissions, but they are still an important factor. It raises awareness for private and business transportation methods and the number varies between companies. The fictional example of the company producing wall paint would have to account for their business travels and employee commuting. For simplification, reasons are all employers from Berlin and therefore their distance to work is on average 10km. All employees use the bus. To produce the paint four managers fly 4000km each for procurement reasons. However, since the deal includes the production of 10.000 liters of paint only, not all GHG emissions are attributed to one liter of paint. Additionally,

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as proposed by the ISO and GHG product standard a multiplier it used to account for radiative forcing. The multiplier used for the example is five as proposed by the Umweltbundesamt [46]. The database ProBas is used for reference GHG emission data.

The company's employer transportation emissions are calculated:

- 0,0362 kg CO_2eq/ km (average diesel fueled bus [47]) * 40 km = 1,448 kg CO_2eq
- (0,145 kg CO_2eq/km (average international flight [47])*16000km* 5 (multiplier)/10000 = 1,16 kg CO_2eq

This results in additional 2,608 kg CO_2eq for one liter of wall paint.

The Nutri-score has a system of subtracting favorable ingredients and subtracting less favorable ones. PAS 2050 and GHG product standards already allow the subtraction of carbon removals. However, to take this a step further and for example to favor biogenetic emissions over fossil GHG emissions, to follow the Nutri-score system would be canceling out the goal of the whole PCF assessment. The goal is to reduce GHG emissions as much as possible and not create a shift in their origin. Therefore, this part of the Nutri-score cannot be adapted further. Even though the standards offer different life-cycle options for the calculation of a PCF (cradle-to-gate or cradle-to-grave), the PCF displayed on product should be cradle-to grave based. On the back of the product the numbers of the total PCF, avoided emissions, and the percentage of cradle-to-gate, and gate-to-grave emissions should be displayed to give the customer a more detailed overview. The number should be displayed in the same style as calories intakes are described on food products. This way customers are already used to the concept and have more detailed information than just the category, if they are interested.

The GHG product standard offers voluntary requirements for setting reduction targets. However, it should be obligatory for organizations to set reduction targets after the PCF assessment. When relevant changes to the calculation occur with in the whole PCF assessment an updated report should be made. Relevant changes can be differences e.g., in the production, the use resources, transportation.

To summarize the example of the company producing wall paint PCF: they now have 2,76 kg CO_2eq emissions for energy use and additional 2,608 kg CO_2eq due to transportation. However, the company also reports 117,44 kg CO_2eq avoided emissions with renewable energy. In terms of emissions reductions, both categories offer potential. Changing to renewable energy, however has a much greater effect.

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5.3. Communication approach

The Nutri-score has a scale from A to E with A being the best and E less healthy. Additionally, there is a color code used for emphasizing the meaning of the letters. The Nutri-score is used for labeling processed foods after an easy and open set of rules. Its limitations are the optional usage and the hindrance by organic foods since it only takes the ingredients but no pesticides or other harmful additives for humans into account.

Figure 15: Nutri-score label

For companies that seek a competitive advantage with the PCF assessment and for consumers assessing the climate friendliness of a product the missing comparability is a big border. Since the functional unit is the bottle-neck for product comparisons. Only products with the same functional units can be compared according to the three standards. Considering the common consumer knowledge of PCFs and how other labels work it is argued that the fact will be ignored, and consumers will naturally start to compare products. Especially since the functional unit is not included in PCF labels e.g. from carbon trust [38]. There are two options to mitigate the issue. One, clear product category rules with a set definition of the functional unit have to be developed. These PCRs would then be included in the guidelines and be a clear requirement. A more radical approach would be to simply calculate the GHG emissions based on the product's weight or the product as a whole.

The Nutri-score for example simply takes all ingredients into account and then displays the result. It does not matter if one meal is heavier than the other or produced differently, only the ingredients matter and their amount of e.g. sugar, salt, or fat in 100 grams or liters. The same can be applied to products. Of course, the calculated amount of kg CO_2eq is only valid for this specific product, with the specified functional unit. However, in terms of product use and comparisons, it is irrelevant. The consumer is simply interested in the amount of GHG emissions associated with this product and then be able to pick a product with a low footprint. Coming back to the assessed product being wall paint the definition of the functional unit includes the cover capability and kg CO_2eq for one liter of color. Assuming in a store there are two white paints available A and B. Paint A has a higher cover capability than B, but also a higher carbon footprint for one liter of Paint. In scenario one if the customer only wants to renew the white wall paint color B would be sufficient and have a lower footprint. It could be assumed that consumers are manipulated into buying seemingly lower carbon footprint pro-

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ducts, but increasing consumption through these, since more paint is needed to have the same color coverage with B than with A. Consequently, paint A has the lower carbon footprint in this special use case where a customer, for example, wants to cover up a dark wall with white paint. The example visualizes the general buying criteria customer have for a specific product use which are based on the quality of the product. Nevertheless, these criteria are always there. In conclusion, if the definition of the functional unit is similar to the use criteria consumers have, and uses the same calculation basis (grams, liters, etc.), it can be defined as the buyer's knowledge. If the buyer then has that knowledge (as assumed) they would also be able to compare two products based on different functional units and take these differences into account, when looking at the carbon footprints of color A and B. The same process is also happening with calories accounting, ingredients, and energy use information.

To follow the KISS method also applied by the Nutri-score. KISS stands for Keep it short and simple. This implies that the label needs to convey its message in an easily understandable statement and quick way [48]. The PCF label needs to convey the overall performance in a category. Nothing more. No product category comparison, the goal is not to have “greener” charcoal than others but simply to state if the amount of kg CO_2eq is high or low. Since all results are calculated based on kg CO_2eq they are comparable and can be assigned to a specific category. This enables a quick product differentiation between products. To help the customer decide whether the stated performance is a high carbon footprint or low. The category can be further used to compare two different products. For example, a snack can be e.g. a yogurt, ice, or fruit. To decide which of these is the more climate-friendly snack the categories can be compared.

Due to uncertainty issues, the footprint should be given within a range. This approach follows the Nutri-score, where the results are displayed in letters (A-E) similar to the energy certificate (letters A-G) of the product. In both assessments, the final number is not displayed only the category score. Since the exact number of the PCF is only under certain conditions true and hardly replicable, it is proposed to only display a categorial result of the PCF and not the exact number. PCF label design studies have shown that the exact number has little value to the customer. Only a rating makes the assessment valuable to the customer and can support purchase decisions and comparisons. The color code behind the letters helps the customer assess which letter is “the best” and which one is “the worst” [34] [35] [36]. An example of a PCF label similar to the Nutri-score is shown in figure 16. Nevertheless, the reporting guidelines mentioned earlier imply more detailed information on the back of the product, where the calculated number should be displayed with additional information as given below.

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Figure 16: Label design example PCF

Information on the back for the fictional paint company:

Total PCF: 25 kg CO_2eq
Avoided emissions: 117,44 kg CO_2eq
Emissions until purchase: 90%
Emissions during use-phase and disposal: 10%.
The Nutri-score uses different scales for food products. One scale is based on grams and the other is based on milliliters [43]. The same concepts should be applied to the PCF label categories. Depending on the unit the scale should be adapted. The fictional paint company as a locally owned medium-business reaches a score of B. The categories would still have to be properly assessed and defined. But as a fictional example, this company is already aware of low-carbon production concepts and conscious of its carbon footprint.

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6. Discussion

To validate the alterations proposed to the existing standards and create a PCF scoring system different studies have to be carried out. Firstly, the reasonable categories for the number of kg CO_2eq need to be determined. This can be achieved by comparing different studies based on different products to identify the overall kg CO_2e range. A database like ProBas or ecoinvent can be used to perform a cluster analysis to identify reasonable clusters and category ranges. The categories can differ between industries or the calculated unit (kWh, liters, kg). These categories ranges as well as the calculation changes should be evaluated with experts from the industry and scientists. Pilot studies will be necessary to rule out any unwanted results and to validate the sought impact of supporting a low carbon behavior in companies. Once the footprints are calculated and the categories are developed, a design study concerning the labels has to be conducted. If the consumer understands the label and feels secure in its use a unified understandable product carbon footprint label can be used. The necessity of more detailed information on the back of a product has to be tested as well in a case study.

Even with these alterations, the focus is still only on GHG emissions. Consequently, the label will suggest climate friendliness of products but can not make general claims of sustainability or other environmental aspects. Here the PEF can help to also display water use or other environmental impacts. A further outlook is to animate companies to develop products based on a low carbon product design [49].

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7. Conclusion

This study compared the three main standards for a PCF assessment. To make the comparison the concept of the carbon footprint was introduced. To reduce GHG emissions companies need to know their carbon footprint and identify reduction potentials. The three internationally accepted standards for a PCF assessment are PAS 2050, the GHG protocol product standard, and ISO 14067. These standards were explained and compared in detail based on their assessment categories. The main calculation differences were found in the categories cut-off-criteria, capital goods, allocation & recycling, reporting, stored carbon, land-use change, green electricity, and uncertainty assessment. The GHG product standard has the most detailed explanations and guidelines.

It was further argued that the different standards have to be unified and push for a climate-friendly behavior. To make companies focus more on the reduction of carbon emissions after the assessment mitigation strategies from the IPCC were introduced. For the categories green-energy and transportation, new calculation criteria are proposed. These changes make green-energy accounting more accessible and show off the big impact of renewable energy sources. Transportation emissions are an important factor and should also include journey GHG emissions from employees. Carbon reductions should reduce the calculation like it is already done in some standards. However, avoided emissions should also be reported to create an incentive for companies to reduce their carbon footprint.

Product comparison needs to be possible with the PCF assessments. It will be done naturally by consumers since it is possible with all other known product labels. Products have special criteria which give them value, this may influence the PCF assessment, but it also influences the buyer's decision in the same way. Therefore, the criteria which are used to define the functional unit, are also used to make a buying decision. The Label should not display the calculated PCF result, but rather use categories like the Nutri-score to adjust to uncertainties and give the customers a ranking for the product's performance. Like the Nutri-score the label should convey the information easily and quickly. Using categories that are ranked this can be achieved. Nevertheless, for more interested consumer a more detailed reporting should be included on the back of the product. Implications for further research are to analyze existing PCF data to form suitable PCF categories and validate the label and calculation adjustments.

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