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Development of a Calculation Tool for the Determination of the Product Carbon Footprint of In-House Manufactured Products at TAKKT AG

1st examiner: Prof. Dr. Thomas Wunder

Company contact: Philipp Petry

Author: Cosima Deutschländer (Enrolment number: 318626)

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1 Excel File

Abstract

The objective of this thesis is to determine the methodology for developing an Excel-based tool for calculating the Product Carbon Footprint (PCF). The tool automates the calculation of the PCF when product-specific data is input, thus enabling the calculation of the PCF for an entire product portfolio. Consequently, national and international regulations regarding Greenhouse Gas (GHG) emissions can be complied with, and the emissions caused by products can be reduced.

The methodological approach comprises comparative analyses, the objective of which is to identify a suitable, recognized calculation standard, determine the requirements for the calculation tool and identify an appropriate emission factor database to be used. The results of the methodological approaches provide the foundation for the development of the calculation tool, which is aligned with the requirements by the GHG Protocol.

The findings indicate the feasibility of developing a PCF calculation tool that aligns with the defined requirements. The tool is founded upon a database logic structure, which enables continuous expansion and adaptation to changing circumstances and requirements. The results demonstrate that the tool is not universally applicable, but offers a robust, scientifically proven foundation for determining the PCFs of several products.

The comprehensive and complex data structure, particularly when multiple products are incorporated into the calculation tool, results in a partial limitation of the approach due to technological constraints.

The outcomes of this study can be utilized as a basis for calculating PCFs. It is advised that the optimization options and recommended actions be considered to enhance the accuracy, completeness, and credibility of the PCF results.

Keywords: Product Carbon Footprint, Emission Factor, Product Life Cycle, Greenhouse Gas Emission, Calculation Model, Carbon Reduction

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IV. List of Abbreviations

B2B .... *Business-to-Business*

B2C .... *Business-to-Consumer*

BOM .... *Bill of materials*

CCF .... *Corporate Carbon Footprint*

CF .... *Carbon Footprint*

CO_2 .... *Carbon dioxide*

CO_2e .... *carbon dioxide equivalents, Carbon dioxide equivalents*

CSRD .... *Corporate Sustainability Reporting Directive*

GHG .... *Greenhouse gas*

GHG Protocol ..... *Greenhouse Gas Protocol: Product Life Cycle Accounting and Reporting Standard*

GLEC .... *Global Logistics Emissions Council Framework*

GWP .... *Global Warming Potential*

IPCC .... *Intergovernmental Panel on Climate Change*

LCA .... *Life Cycle Assessment*

PAS .... *Publicly Available Specification*

PCF .... *Product Carbon Footprint*

PEF .... *Product Environmental Footprint*

SBT .... *Science Based Targets*

WBCSD .... *World Business Council for Sustainable Development*

WRI .... *World Resource Institute*

1 Introduction

1.1 Problem Statement

Rising global temperatures and the resulting severe effects on the global climate require decisive action to reduce greenhouse gas (GHG) emissions. (IPCC, 2023, p. 12) By 2020, the global average temperature has already been 1.1 degrees Celsius above pre-industrial levels, making it challenging to meet the Paris Agreement's goal of limiting the temperature increase to no more than 1.5 degrees Celsius. (LpB BW, 2023; United Nations Framework Convention on Climate Change, n.d.) The primary reason for this phenomenon is the heightened concentration of GHG in the atmosphere due to anthropogenic activities, which disrupts the natural radiation balance. (IPCC, 2023, p. 22; Nda et al., 2018, p. 170) To address these challenges, the European Union has established specific objectives in the EU Climate Law, such as achieving greenhouse gas neutrality by 2050 and reducing GHG emissions by 55 % by 2030 compared to 1990 levels. (BMWK, 2022, p. 6) Consequently, the assessment of a company's carbon footprint is becoming increasingly essential. Determining current GHG emissions enables companies to identify potential reduction opportunities and set specific targets for reducing their emissions. (Olivier & Peters, 2020, p. 20) In particular, the separate calculation of emissions caused by a product offers companies an effective lever for reducing their overall emissions in the long term. (CDP, 2018, p. 32; Hu et al., 2017, p. 292) The classification of emissions into three distinct categories (Scope 1, 2, and 3[1]) is derived from the Greenhouse Gas Protocol. (Ranganathan et al., 2002, p. 25) Product emissions are included in customers' scope 3 upstream emissions. As a consequence of the extensive nature of supply chains and the high volume of emissions within this scope, customer inquiries regarding product carbon footprint (PCF) results have been on the rise at TAKKT AG. (Matthews et al., 2008, p. 5840; WBCSD, 2021, p. 6) This is due to the fact that the most precise accounting of scope 3.1 "purchased goods and services" emissions is achieved through the PCF of suppliers. (WBCSD, 2021, p. 24) The forthcoming Corporate Sustainability Reporting Directive (CSRD) will require organizations to calculate and disclose emissions along the entire value chain. Therefore, reporting companies will be required to gather data from their suppliers in order to calculate

[1] Scope 1 includes all direct greenhouse gas emissions that are within the control of the company. Scope 2 encompasses all indirect emissions resulting from purchased energy. Scope 3 covers all emissions that are caused upstream and downstream along the value chain by the company's business activities, but which the company cannot directly control. (Ranganathan et al., 2002, p. 25)

emissions. (European Union, 2023, p. 80) In certain instances, they may only collaborate with suppliers who are able to provide this information. According to a study by the TCFD, the main challenge for most companies is to obtain the necessary data in an adequate quality, which makes this calculation difficult. (TCFD, 2021, p. 19)

Determining the PCF is a time-consuming and expensive process due to the extensive data collection. The pressure to analyze and disclose the emissions caused is growing due to external stakeholder requirements. The number and scope of international laws, standards, and reporting frameworks such as the CSRD or EU Taxonomy is constantly increasing. Another key factor is the growing demand from customers for the disclosure of sustainability data and more environmentally friendly solutions. One of the most significant challenges is the lack of accessibility to the data, as many commonly utilized databases and ERP systems[2] have yet to be optimized for the retrieval and storage of this information. (Perau et al., 2023, p. 70)

The calculation of the PCF is not only relevant for TAKKT's own production, but also for products from the company's portfolio that are not manufactured by TAKKT but are purchased as finished products and resold to customers. By calculating the PCF, the company strives to serve as a role model for its suppliers, providing not only justification for requesting their PCF but also assistance with their calculations and implementation of reduction measures through product design. This enables the company to take responsibility for the emissions generated in its supply chain, thereby contributing to its strategic goals of combating climate change by reducing GHG emissions.

The PCF can be calculated internally or by an external service provider. Nevertheless, there are numerous challenges associated with outsourcing the calculation to an external service provider. Firstly, it is not possible to guarantee the transparency of the calculation. Furthermore, the possibility of recalculation in the event of changes is not feasible, as the calculation is conducted only once. In Addition, the transfer of internal company data raises concerns regarding data protection. Moreover, the limited number of solutions on the market that calculate an entire portfolio at a reasonable cost is another factor that weighs against an external valuation of the entire portfolio. These findings were verified through discussions with external service providers. It became evident that the predominant practice is to calculate the PCF of individual products, frequently at the customer's request.

[2] “Enterprise Resource Planning (ERP) comprises management, planning, documentation, and control of all business processes and resources of an enterprise.” (Munkelt & Völker, 2013, p. 26)

1.2 Goal and Research Questions

This thesis aims to develop an Excel-based tool that makes it possible to calculate the PCF of individual products manufactured by TAKKT.

The resulting research question is:

How can an internal calculation tool for TAKKT be developed in Microsoft Excel that will automatically determine the emissions caused by a product after the product-related data has been entered?

Overcoming the aforementioned challenges requires the definition of subgoals. To ensure acceptance by external auditors and sustainability standards and initiatives, the calculation model must be based on an established methodology. Beyond methodology, external and internal requirements must be met to deliver a satisfactory result. Calculating the PCF is an iterative process. Therefore, the data model must be flexible to allow for improvements in data quality and adaptation to changing requirements and standards. Additionally, the ability to make decisions based on the possible calculation of PCFs, such as reduction targets, product design, and cost savings, is another key objective. An internally standardized calculation should be developed to enable comparison of the climate impact of individual products.

These sub-objectives provide a basis for the following sub-questions:

- *Which calculation methodology fits the goals and requirements and therefore forms the basis of the model?*
- *Which internal and external stakeholder requirements must be met?*
- *What parameters, such as system boundaries, and assumptions are defined to establish comparability between products using a standardized calculation?*
- *How will the tool adapt to changing requirements and standards?*
- *What processes and standards are needed to improve data quality and iteration for greater accuracy?*
- *How can the calculation tool be verified to ensure that the results can be used for decision making?*

The aim of this research is the development of a tool which is tailored to the needs of TAKKT for calculating PCFs where appropriate data is available. The aim is not to calculate the PCFs of all products manufactured by TAKKT. Furthermore, the calculation only considers emissions measured in carbon dioxide equivalents (CO_2e) and excludes other environmental impacts such as water consumption and land use, which are included in a more

comprehensive Life Cycle Assessment (LCA). The objective is to create a tool that facilitates internal use, satisfies external auditors and sustainability standards, and provides a basis for informed decisions regarding the climate impact of products.
This master's thesis is therefore dedicated to an in-depth analysis and the development of a proposed solution in the form of an Excel-based calculation tool for the time- and cost-saving assessment of the PCF of TAKKT's products manufactured in-house.

1.3 Methodological Approach and Structure

This study is based on a solid comprehension of the theoretical foundation of the PCF and its computation. The methodology and fundamentals focus on identifying a suitable calculation methodology as the basis for the data model. A comparative analysis of recognized calculation methods is used to ensure that the tool developed meets internal requirements and external auditing and sustainability standards.
This is followed by a discussion of why this case study is chosen. Subsequently, the rationale behind the selection of this case study is presented. The requirements analysis encompasses both the internal requirements for optimizing the calculation tool for internal use and the external stakeholder requirements for ensuring customer satisfaction, auditor acceptance, and compliance with standards.
The analysis findings serve as the foundation for the subsequent sections of the thesis. To address the key research question, the theoretical foundations are used to design the development process of the calculation tool. The process and resulting outcome are then presented in detail. Specific consideration is given to the selection of the emission factor database, as this is a pivotal element that significantly impacts the precision and dependability of the calculated PCFs. Once more, the comparative analysis is employed for this objective.
The subsequent sections concentrate on the practical application in the corporate setting. This is where limitations and challenges are emphasized, and suggestions for implementation are provided. Additionally, possibilities for further optimization and development of the developed tool are considered.
The paper concludes by summarizing and reflecting on the findings. This allows for an overall assessment of the developed PCF calculation methodology, as well as a critical reflection on its applicability and potential for further development.

2 Theoretical Foundation

2.1 Product Carbon Footprint

2.1.1 Definition and Terminology

The primary question to be addressed is the definition of a carbon footprint (CF) and the differentiation between the corporate carbon footprint (CCF) and the product carbon footprint (PCF). A brief literature search has been conducted to facilitate a clear and uniform understanding of the terms. The results pertaining to CF, the fundamental term, are presented in Table 1.

Table 1 Literature review on the definitions of CF. Source: Own presentation

Definition	Source
"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."	Wiedmann & Minx, 2007, p. 4
"A direct measure of greenhouse gas emissions (expressed in tonnes of carbon dioxide [CO_2] equivalents) caused by a defined activity. At a minimum this measurement includes emissions resulting from activities within the control or ownership of the emitter and indirect emissions resulting from the use of purchased electricity."	East, 2008, p. 3
"Carbon footprint is widely defined as the amount of carbon (usually in tons) that is emitted during a process or by an organization or entity."	Harkiolakis, 2013, p. 310
"The term carbon footprint (CF) refers to the measurement of direct and indirect net climate change impacts of a product, process, company, or system. The sole impact category of the CF is climate change, typically expressed as global warming potential (GWP) impacts caused by greenhouse gas emissions."	Uusitalo et al., 2023, p. 467
"A carbon footprint is the total set of greenhouse gas (GHG) emissions caused by an organisation or individual, or by a single event, service, or product. The emissions are calculated over a set period, generally a year (or the lifetime of an event or product), that can then be used as a baseline against which reduction efforts can be measured."	Climate Partner (n.d.)

The review of the scientific literature revealed that no uniform definition of CF exists. However, a comparable conceptualization of the term has been identified, which will be addressed in a new definition of the term. Accordingly, this paper defines “carbon footprint” as *the total amount of GHG emissions caused by an organization, individual, event, service, or product over a defined period of time.* As stated in the definition, emissions can be caused by various sources, which distinguishes the CCF from the PCF. (Nguyen et al., 2021a, p. 3)
In contrast to the PCF, which is limited to emissions caused by a product during its entire life cycle, the CCF measures emissions resulting from all company activities and products over a one-year period. The PCF is defined as a *measure of all GHG emissions caused by a product throughout its entire life cycle*. The systematic aggregation of emission sources and the quantification of these GHG emissions according to standardized methods, as well as the assessment of their GHG impact is referred to as GHG inventory. (Bhatia et al., 2011, p. 136; United States Environmental Protection Agency, 2024)
The term “product” refers to both goods and services. If a product is used in different ways, the PCF refers to a defined application. (Boukherroub et al., 2017, p. 44)

Functional Unit

The PCF can be calculated for both final and intermediate products. This paper focuses on calculating PCF for final products produced and sold by the company. To calculate the PCF for final products, a functional unit should be defined for each product, as specified by the standards. The Greenhouse Gas Protocol: Product Life Cycle Accounting and Reporting Standard (GHG Protocol) defines the functional unit as “[…] the performance characteristics and services delivered by the product being studied”, which should include the function, duration, and expected quality. (Bhatia et al., 2011, p. 28) This definition makes the functional unit measurable and enables comparison with other products. This enables the functional unit to be measured and compared with other products. Including the definition of the functional unit in stakeholder communications is therefore important. (Together for Sustainability, 2022, p. 40)

Carbon Dioxide Equivalents, Greenhouse Gases and Global Warming Potential

The unit of measurement for the PCF is CO_2e, which includes not only carbon dioxide (CO_2), the largest contributor with around 80 %, but also other gases that affect the radiative forcing and are considered greenhouse gases. (IPCC, 2014, p. 142, 2018, p. 550; LUBW, n.d.) The Kyoto Protocol from the year 1997 identifies six greenhouse gases, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) Hydrofluorocarbons (HFCs) Perfluorocarbons (PFCs)

Sulfur hexafluoride (SF6), that are significant contributors to global warming, persistent in the atmosphere, and primarily caused by human activity. (United Nations, 1998, p. 19) To ensure an accurate comparison, it is necessary to include all relevant GHG as defined by the Intergovernmental Panel on Climate Change (IPCC), at least the six listed in the Kyoto Protocol, in the calculation using accepted methods for calculating the PCF. (Gao et al., 2014, p. 242; Lewandowski & Ullrich, 2022, p. 20) To facilitate comparison, all GHGs are converted into CO_2e. (IPCC Guidelines, 2006, p. G.3) CO_2e uses the Global Warming Potential (GWP) metric to express the climate impact of various greenhouse gases relative to CO_2. The GWP is defined by the EPA as "[…] a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). […] The time period usually used for GWPs is 100 years". (United States Environmental Protection Agency, 2023)

The IPCC has defined a coefficient for each of these gases to determine their equivalent value in relation to CO_2 over a certain time horizon. For example, one kilogram of methane is over a 100-year period equivalent to 27.9 kg of CO_2e. (Smith et al., 2021, p. 16)

2.1.2 Scope

Product Life Cycle

A company's business activities generate emissions that are categorized into three areas: scope 1, scope 2, and scope 3. Scope 1 refers to all direct greenhouse gas emissions that are within the control of the company. Scope 2 includes all indirect emissions resulting from purchased energy. Scope 3 encompasses all emissions that are caused upstream and downstream along the value chain by the company's business activities, but which the company cannot directly control. (Boukherroub et al., 2017, p. 50; Nguyen et al., 2021b, p. 3) The life cycle stages of a company's products are associated with the company's emissions scopes. In the literature, the term "product life cycle" often refers to a market cycle and describes the phases of introduction, growth, maturity, and decline. (Thommen et al., 2020, p. 93) These phases are subdivided based on time intervals and market characteristics. In the context of sustainability, the product life cycle generally refers to the physical life cycle of a product, which is the definition used in this paper. The product life cycle includes the stages of raw material extraction, production, distribution, use, and end-of-life. (Baumgartner, 2018, p. 348) The cycle typically consists of five phases, although the names of these phases may vary slightly across different sources. Figure 1 presents a general overview of the stages within the product life cycle and the respective emission scopes allocated to each stage.

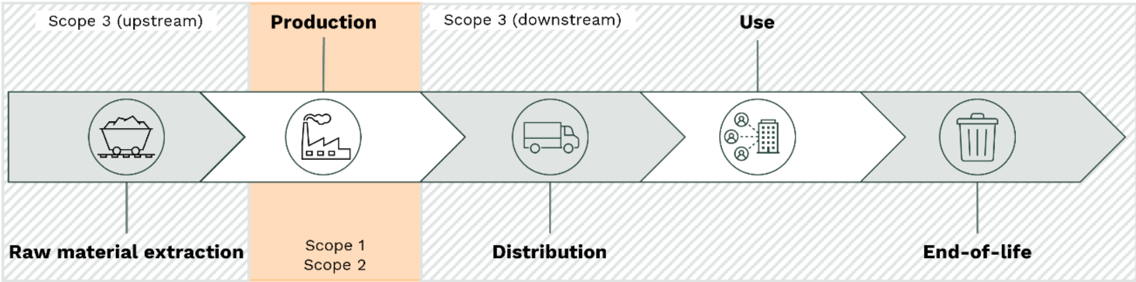

Figure 1 Product life cycle. Source: Own presentation

Scope 1 and 2 can only assign the production phase, as the company controls the emissions from this phase (scope 1), except for those resulting from purchased energy (scope 2). The upstream scope 3 emissions are attributed to the raw material extraction phase, whereas all life cycle phases subsequent to production are assigned to downstream scope 3 emissions. (Bhatia et al., 2011, p. 7) Consequently, the calculation of the PCF encompasses emissions from all three scopes.

System Boundaries

The scope analyzed for calculating the PCF is considered a system with incoming and outgoing flows, which can be divided into elementary and product flows. Elementary flows can be either material or energy and are characterized by entering and leaving the system without human modification or influence from outside the system. Product flows are (preliminary) products received from or delivered to another product system. (DIN Deutsches Institut für Normung, 2006, p. 9)

The scope of the assessment is defined not only by the product life cycle but also by the system boundaries. These boundaries determine which areas of the value chain are included in the assessment and which are excluded. (Meisel et al., 2023, p. 7) The selection of the calculation standard, the goal of the calculation, and the requirements of customers or other stakeholders can influence where the boundaries are set. There are several ways to determine which stages of the life cycle are included in the calculation. The two most commonly used approaches are cradle-to-gate and cradle-to-grave. Cradle-to-gate includes only the first stages of the product life cycle, from raw material extraction to the leaving of the production facility. The last two stages, use and end-of-life, are excluded. Figure 2 illustrates the system boundaries throughout the product life cycle. This approach can be used for intermediate products where information on their function, use, and disposal is unavailable, and double accounting of subsequent stages must be avoided. The cradle-to-grave assessment considers the entire life cycle of a product, from raw material extraction to end-of-life. (Wang et al., 2018, p. 4)

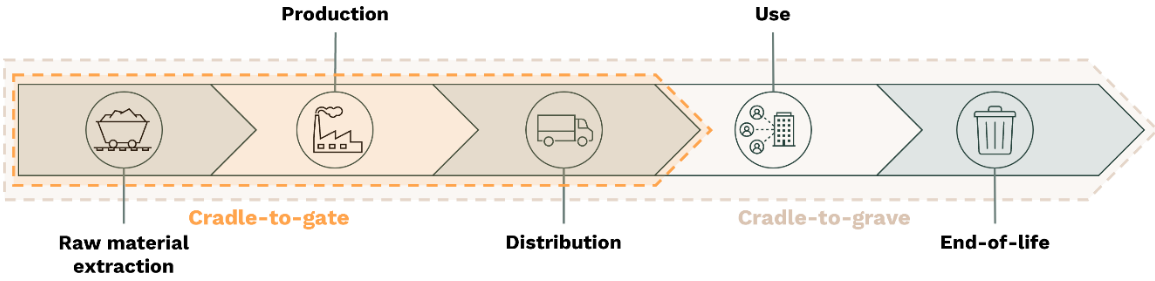

Figure 2 System boundaries. Source: Own presentation

End-of-Life

In the end-of-life stage of a product's life cycle, it is important to note that the disposal options available, including incineration, recycling, and landfill, vary depending on both the geographical location and the specific material to be disposed of. (BMUV (Bundesministerium für Umwelt Naturschutz nukleare Sicherheit und Verbraucherschutz), 2024, p. 16; Statista, 2020)

The disposal of products and packaging through incineration and recycling results in the creation of new materials. Incineration of waste materials can be used to generate electricity and heat, thereby replacing the use of fossil fuels. The newly created product is integrated into a new product system, unless the incineration occurs within the original system boundaries with on-site energy recovery and operational control. The practice of recycling can also be seen as a positive contribution towards environmental impact, insofar as it allows for the avoidance of waste disposal and the preservation of primary materials. As shown in Figure 3, two different recycling systems can be distinguished.

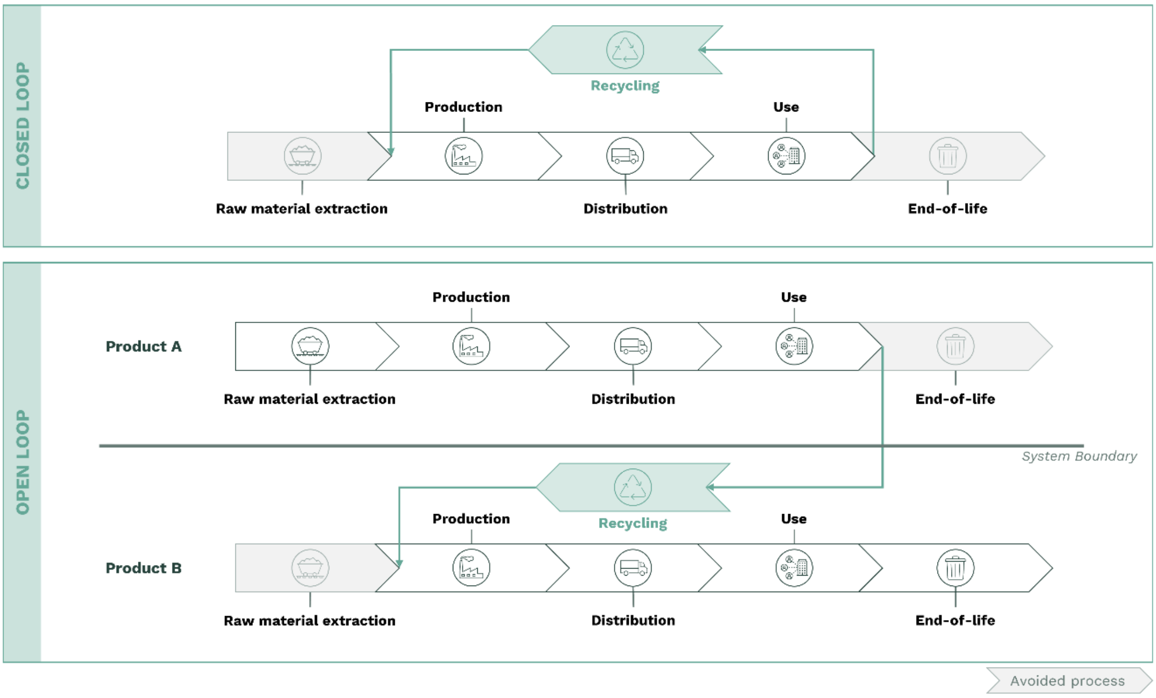

Figure 3 Illustration of the closed-loop and open-loop method. Source: Own presentation following Hottenroth et al. (2013), p.67

The first is the closed loop, in which the disposed material is returned to the same product system as secondary material. This process has the potential to reduce emissions associated with the disposal and production of primary material within the system boundaries (see Figure 3). However, emissions are generated during processing. The method for reporting avoided emissions varies depending on the specific calculation standard employed. The method of reporting avoided emissions is contingent upon the calculation standard in question. In accordance with the specific calculation standard, the avoided emissions may be offset within the emissions balance of the end-of-life stage, or they may be presented separately. (Hottenroth et al., 2013, p. 65)

Conversely, the open loop represents a scenario in which the material is utilized in an alternative product system. Given the involvement of multiple product systems, it is essential to allocate emissions generated and avoided in a manner that avoids double counting. This can be achieved through the use of the recycled content method, for instance. In order to achieve this, the system boundary is defined in such a way that the emissions can be allocated to the respective product systems in a clear and unambiguous manner, thereby eliminating the need for offsetting between the systems. Figure 3 illustrates that product system B is benefited by the avoided disposal, while product system C is benefited by the avoided primary production. (Hottenroth et al., 2013, p. 66)

Cut-off Criteria

In general, when calculating the PCF, it is important to follow the principle of completeness and not exclude any data. However, there are certain cut-off criteria that allow for the exclusion of data that is not quantitatively available, has an insignificant impact on the overall PCF, and requires unreasonable effort to collect. These excluded data are recorded in the report. To prevent the exclusion of inputs with a significant impact on GHG emissions due to their low mass, the percentage share of GHG emissions in the total GHG emissions of the process, life cycle phase, or the entire functional unit is used as a criterion, in addition to the cut-off criteria of mass and energy. (Hottenroth et al., 2013, p. 32; Together for Sustainability, 2022, p. 42)

To ensure transparency and comparability, it is crucial to clearly define the system boundaries and excluded processes and materials in the result report. (Gao et al., 2014, p. 240)

Temporal Scope

The calculation standards do not provide a clear specification for the general validity period of a PCF. It is recommended to perform regular calculations (e.g., annually) to track changes and identify possible reduction targets. However, manual calculation of the PCF can be time-consuming without automation, and therefore, longer validity periods of more than one year can be found in the literature. The Guideline from the initiative “Together for Sustainability” and the Environmental Product Declaration standard 15804-2:2019 limit the validity period to five years, provided that no significant changes[1] have been made to the production process. (ift Rosenheim GmbH, 2017, p. 2; Together for Sustainability, 2022, p. 41) As an external verifier, the TÜV SÜD Group specifies a validity period of three years for its certificates. (TÜV SÜD Group, n.d.)

2.1.3 Delimitation from the Life Cycle Assessment

The concept of LCA, which considers the environmental impact of a product over its entire life cycle, complements the PCF. While the PCF focuses on the climate impact, the LCA evaluates other environmental impacts as well. To achieve this, various emissions that have the same environmental impact are grouped into impact categories. These categories include among others acidification, toxicity, water, resources, and land use. (Finnveden et al., 2009,

[1] Changes with an impact of more than 20 % on the original PCF

p. 2) The assessment procedure is comparable to that of GHG emissions for the PCF, but more extensive due to the evaluation of multiple categories. (ISO, 2006)

The LCA aims to prevent the transfer of high environmental impacts between life stages and impact categories. Reduction measures based solely on the PCF assessment can result in the shifting of climate impacts another impact area. Therefore, the LCA takes a holistic approach to avoid such shifts. (Oblakovic et al., 2023, p. 2227)

2.1.4 Data Types and Emission Factors

It is essential to differentiate between two categories of data upon which a PCF calculation is based: primary data and secondary data. Primary data represent processes occurring within the system boundaries and can be collected in two ways: by measuring the precise GHG emissions of a particular activity or by measuring activity data, such as the weight of input material or the electricity consumption of a manufacturing process on a machine. In the latter case, the data are then multiplied by the corresponding emission factors to obtain the emissions caused by the activity. In order to ensure the greatest possible accuracy of the results, it is essential that primary data be collected wherever feasible. This may be derived from the activities of the company undertaking the analysis or from suppliers with regard to processes within the upstream value chain. It is preferable to utilize activity data derived from company-specific processes rather than data that is facility- or site-specific. Nevertheless, the latter data can also be employed and disaggregated to the corresponding product. (Together for Sustainability (TfS), 2024, p. 43)

Secondary data is primarily collected in instances where no primary data is available. Such data may originate from external sources, including industry standards, average data from databases or statistics, or data that are available within the company for processes of other products and are comparable with the processes of the product to be evaluated. It is important to distinguish between financial activity data and process activity data. While both are company-specific and process-related, financial activity data is not considered primary data. This is because other factors, in addition to the product-specific characteristics, can influence changes in financial activity data. (Bhatia et al., 2011, p. 53; WBCSD, 2021, p. 41)

Given the greater accuracy of primary data, many calculation standards require that primary data be used at least for internal processes and that secondary data only be used to fill data gaps, which in turn should usually be disclosed. (WBCSD, 2021, p. 19)

When direct measurement of GHG emissions is not feasible, emission factors are employed for both primary and secondary data. They are defined as coefficient that quantifies “GHG emissions per unit of activity data” (Bhatia et al., 2011, p. 134). It is of great importance to select the appropriate emission factors and then multiply them by the activity data, when calculating the GHG emissions of a given product. Emission factors vary in terms of the scope of emissions included, such as whether all GHG emissions are mapped as CO_2e or only one GHG, and in the scope of processes included, such as the mapping of a single process or all upstream processes in the supply chain. It is also important to note that the emission factors must align with the specified activity data. For instance, an emission factor expressing the unit kg CO_2e/kg is required for a given material for which the weight is available. (Bhatia et al., 2011, p. 52)

Emission factor databases provide a compilation of GHG emission factors, encompassing a range of materials, activities, and electricity types. It should be noted that the emission factors may vary depending on a number of factors, including the region in question, the time period under consideration, and other relevant variables. Two categories of databases can be distinguished: those that are publicly accessible, such as Ökobaudat, Exiobase or government databases such as DEFRA in the UK; and those that are commercial, such as Ecoinvent and Agri-footprint. (Global Changer, 2024)

2.1.5 Methodological Approaches

Activity-based vs. spend-based approach

The PCF can be calculated using one of two methods, depending on the availability of the data types described in the previous chapter. In the event that solely financial activity data is available, the spend-based method is the selected approach. This entails multiplying the financial value of the activity data, such as the price of a material or the electricity costs of a production step, by a general emission factor in order to obtain the value of the emissions caused. The principal advantage of this method is that it requires only a modest investment of time, as the necessary data are often readily available in a company. However, this approach is relatively generic and is better suited to an initial estimation of the emissions generated over the life cycle of the product than to a precise calculation. It should be noted that expenditure may fluctuate for reasons that are not directly related to the generation or avoidance of emissions. Such factors may include the impact of inflation, the application of discounts, or the incurrence of higher costs associated with trademark rights. (Kumar et al., 2023, p. 110)

If data on the activity of the process is accessible for incorporation into the calculation, then the activity-based approach may be selected. This is a considerably more intricate process, as it incorporates a number of input variables. In contrast to the previous approach, the emissions are not calculated based on the financial value, but on the actual consumption in the relevant units multiplied by the corresponding emission factors. While the source of data is inconsequential, as discussed in section 2.1.4, the utilization of primary data enhances the precision of the calculation. However, the collection of primary data can be a time-consuming and challenging process, potentially leading organizations to adopt a hybrid approach, wherein primary data is predominantly collected and supplemented with average or proxy data to facilitate the filling of data gaps. (Kumar et al., 2023, p. 111)

The activity-based approach offers a precise and product-specific method for quantifying emissions, which is a significant advantage. Conversely, it is a resource-intensive and complex process. In light of the specific calculation standard and requirements at hand, a decision can be made as to whether the calculation of the PCF should be based on the activity-based method or whether a hybrid approach should be selected. Given the potential for significant discrepancies in results based on different calculation methods, it is crucial to conduct a thorough examination of the data availability and to provide a transparent disclosure of the approaches and data types utilized in the calculations. (Steubing et al., 2022, p. 1418)

Consequential vs. Attributional Approach

An additional differentiation between the two methodologies, namely the consequential and the attributional approach, is relevant when modeling the PCF. The objective of the consequential approach is to determine the causal effects of decisions on overall emissions. Consequently, no fixed system boundaries are established; instead, indirect emissions resulting from external factors, such as market effects or consumer behavior, can be incorporated into the calculation. In addition to activity data and emission factors, this approach employs forecast values and modeling to analyze future effects. This approach is particularly well-suited to decision-making based on scenario analyses or reduction projects. (Weidema, 2022, p. 7)

The attributional approach is focused on quantifying direct emissions in relation to a specific product by combining attributable processes over the life cycle. In order to achieve this, fixed system boundaries are defined, which, depending on the calculation standard and business objective, may encompass parts of the value chain or the entire value chain. (Bhatia et al., 2011, p. 22; Weidema, 2022, p. 8)

The choice between the two approaches is dependent on the specifications of the calculation standard used and the intended use of the PCF calculation.

2.1.6 Goals of the PCF Calculation

Various reasons exist for calculating the PCF, depending on the industry, corporate strategy, and business model. This study analyzed the literature to compile a list of reasons and examined corporate practice, as well as the reasons given by companies that calculate their PCF or have it calculated, service providers, and consultancies. The data indicates a substantial overlap, which can be summarized by the following primary reasons.

The primary objective of PCF calculation is to contribute to the carbon reduction strategy. This involves identifying GHG emission reduction measures by uncovering the largest emission hotspots. Identifying the largest emission hotspots enables the company to determine specific measures for reducing GHG emissions. (Grießhammer et al., 2009, p. 4; Hottenroth et al., 2013, p. 9; iPoint-systems GmbH, n.d.) The quantified values can also be used to set reduction targets. (ClimatePartner, n.d.) In addition to achieving corporate targets, reducing GHG emissions can also contribute to national or global climate targets. (iPoint-systems GmbH, n.d.) The calculation of the PCF not only facilitates the reduction of GHG emissions but also allows for the identification of optimization potential, climate risks, and cost savings. (GreenCo, n.d.; myclimate, n.d.; PwC, n.d.) The findings can also be used to design products with minimal emissions and energy consumption, setting them apart from the competition. (Bird, 2013; GreenCo, n.d.; myclimate, n.d.; Siemens, 2022) Standardized calculation methods enable a comparison of climate impact between products or product groups within an industry. (Grießhammer et al., 2009, p. 4; iPoint-systems GmbH, n.d.; myclimate, n.d.) This enables the company to identify opportunities for action by partners, such as suppliers or customers, and to evaluate suppliers based on their GHG emissions performance. (GreenCo, n.d.; Grießhammer et al., 2009, p. 4) Transparency is frequently cited as a reason for using the PCF, both in literature and by companies. Additionally, external stakeholders, such as customers or suppliers, require carbon footprint data for their own calculations, selection procedures, or reduction measures. (Lewandowski et al., 2021, p. 18; PwC, n.d.) Unlike an "eco-friendly" label, the PCF is a quantified value that communicates the climate impact of a product. To ensure external acceptance of the PCF and prevent inefficient measures, calculations must be based on recognized standards. (GreenCo, n.d.; Lewandowski & Ullrich, 2022, p. 10) The following section presents and evaluates these standards.

2.2 PCF Calculation Methodology Standards

2.2.1 PAS 2050

The Publicly Available Specification (PAS) 2050 is the first standard to provide an internationally applicable, consistent method for assessing the GHG emissions of products. It was first published in 2008 and is freely available for use. PAS 2050 was developed by the British Standards Institute and promoted in partnership with the Carbon Trust and the British Department for Environment, Food and Rural Affairs. It is the first standard to provide comparability of multiple products in terms of their lifecycle global warming impact using a single indicator. It serves as a framework for calculating and reporting the PCF. In 2011, PAS 2050 was revised with external advice from stakeholders and companies already using the standard. (British Standards Institution, 2011, p. V; Gao et al., 2014, p. 241; Lewandowski et al., 2021, p. 18)

2.2.2 Greenhouse Gas Protocol: Product Life Cycle Accounting and Reporting Standard

Simultaneously with the revision of the PAS 2050 standard, the GHG Protocol Product Standard was developed. This standard was also based on the potential for improvement derived from the first PAS 2050 version. As a result, the revised and new standards share the same basis and a consistent calculation methodology. (WRI & WBCSD, 2011a, p. 1)

The GHG Protocol was published by the World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). (Bhatia et al., 2011, p. 5)

The Product Standard is one of the seven GHG Protocol Standards, all of which are free to download. The GHG Protocol Initiative is led by the WRI and the WBCSD and is composed of a global multi-stakeholder working group of industry, government, and non-profit organizations. One of the standards they have developed is the Corporate Standard, which many companies worldwide use to calculate the CCF. (WRI & WBCSD, n.d.) Thus, applying the Product Standard can provide companies that calculate their CCF according to the GHG Protocol with the advantage of synergies and familiarity in structure and handling. (Hottenroth et al., 2013, p. 14; Lewandowski & Ullrich, 2022, p. 14) The Product Standard is principally derived from the PAS 2050, which was published in 2008, the same year in which the development process was initiated. According to the Product Standard, its "primary goal […] is to provide a general framework for companies to make informed choices to reduce greenhouse gas emissions from the products (goods or services) they design, manufacture, sell, purchase, or use". (Bhatia et al., 2011, p. 5) It also aims to provide detailed guidance and an international standard that increases comparability of products regarding their GHG impact. The standard is generic and applicable to companies in any industry and of any size worldwide. The PCF calculation is implemented using a step-by-step approach, which means that the initial calculation may include secondary data and assumptions in addition to primary data. Over time, the quality of the data should be improved by increasing the amount of primary data. (Bhatia et al., 2011, p. 5) The main difference with PAS 2050 is that the product standard provides not only guidelines for the calculation of greenhouse gas inventories, but also requirements for reporting. (Lewandowski et al., 2021, p. 4)

The standard is divided into several chapters, including "Boundary Setting," "Collecting Data and Assessing Data Quality," and "Allocation". These chapters consist of requirements for compliance with the standard, as well as guidance on how to implement these requirements. (Bhatia et al., 2011, p. 1)

2.2.3 ISO 14067

The ISO 14067 standard, first published in 2013, is the third frequently used standard for calculating the PCF. It was revised and published in 2018 after a test phase. This standard is based on existing ISO standards for life cycle analysis, as well as guidelines for ecological labels and product category rules. (Hottenroth et al., 2013, p. 14)The ISO standard breaks down the process into two steps. The guidelines provide instructions for quantifying the climate impact in the first step and rules for communicating the results in the next step. With the revision, the rules for communication have been split off into the separate ISO 14026 standard. (Lewandowski & Ullrich, 2022, p. 15) None of the ISO standards is available for free but can be purchased from the International Organization for Standardization. (ISO, 2018) Another difference from the first two standards is the concrete definition of guidelines for comparison with other CO_2 labels. (Lewandowski et al., 2021, p. 5)

2.2.4 Other Calculation Methods

In addition to the three standards presented, numerous others have yet to be finalized or have been developed specifically for individual sectors or countries. These include the TSQ0010 standard, which serves as a foundation for calculation in Japan and is exclusively applied to B2C PCF assessments, and the Product Environmental Footprint (PEF), which has been developed by the European Commission for an extended period but, similar to the LCA method, encompasses a broader array of environmental impacts beyond GHG emissions. (Finkbeiner et al., 2018, p. 37; Gao et al., 2014, p. 241) In the absence of specific German or retail sector standards that are appropriate for addressing the issue at hand, these alternative calculation methods will not be further considered in this paper.

2.3 Comparative analysis of PCF Calculation Standards

The following section presents a comparative analysis of the three pertinent standards: PAS 2050, the GHG Protocol's Product Life Cycle Accounting and Reporting Standard, and ISO 14047. It identifies the similarities and differences between these standards and offers insights into their respective approaches. The standards PAS 2050, the GHG Protocol's Product Life Cycle Accounting and Reporting Standard, and ISO 14047 serve as pivotal instruments for the calculation of a product's carbon footprint. While they are founded upon analogous tenets, their particular stipulations and methodologies diverge slightly.

The objectives of a carbon footprint calculation may vary depending on the specific company in question. The ISO standards are especially beneficial for the communication of information to customers. The GHG Protocol offers comprehensive guidance for the establishment of reduction targets and comprehensive reporting, while all three standards include requirements for the communication with stakeholders. (Lewandowski et al., 2021, p. 19; *Product Standard*, n.d.)

A crucial aspect of evaluating a product's carbon footprint is the identification of the specific greenhouse gases to be considered. All three standards are founded upon the six GHGs enumerated in the Kyoto Protocol. In accordance with the GHG Protocol, the reporting of these gases is obligatory; however, the inclusion of additional relevant substances is recommended, though not mandatory. (Gao et al., 2014, p. 241)

The ISO standard is the only one that allows for the examination of specific production processes or parts of the life cycle, whereas PAS 2050 and the GHG Protocol require consideration of the entire life cycle. (Lewandowski et al., 2021, p. 19)

A further crucial differentiating factor is the stipulations pertaining to emissions and the removal of biomass, which absorbs CO_2. In accordance with the GHG Protocol, reporting is obligatory in instances where carbon persists stored in products or components beyond the product life cycle. Conversely, ISO 14067 necessitates the reporting of carbon stored in biomass, though this is not to be incorporated into the calculation. (Lewandowski et al., 2021, p. 19; Weidema, 2022, p. 10; WRI & WBCSD, 2011b, p. 2)

Each standard allows for a degree of interpretation. The ISO 14047 standard provides the most comprehensive scope and greatest scope for interpretation, making it applicable to the majority of product categories. In contrast, the GHG Protocol offers highly precise guidance. (Bhatia et al., 2011; DIN-Normenausschuss Grundlagen des Umweltschutzes (NAGUS), 2018)

Furthermore, there are discrepancies in the evaluation of specific emissions and expenditures. To illustrate, PAS 2050 explicitly excludes capital goods, human energy use in processes, transportation of consumers to the point of sale, and employee commuting. Moreover, PAS 2050 permits the exclusion of up to 5 % of total emissions, provided that these emissions do not contribute more than 1 % to the overall impact. (Bhatia et al., 2011, p. 34; Lewandowski et al., 2021, p. 20; WRI & WBCSD, 2011b, p. 3)

The methodologies utilized for quantifying the carbon footprint also vary between the standards. All three standards recommend the use of activity data multiplied by emission or distance factors. The data may be derived from either primary or secondary sources. (Gao et al., 2014, p. 241)

Table 2 PCF Calculation Standards. Source: Own presentation

Standard	**PAS 2050**	**GHG Protocol**	**ISO 14067**
Organization	BSI	WBCSD & WRI	ISO
Release date	2008, 2011	2011	2013, 2018
Goal	Uniform standard for calculating greenhouse gases from products and services	Standard for calculating GHGs and setting reduction targets	Standard for calculating and communicating GHGs
	Requirements for calculating product-specific GHG emissions		
Scope	Calculation	Calculation, reduction and public reporting	Calculation and communication
Life cycle stages	Entire life cycle	Entire life cycle	Partial life cycle or entire life cycle
Application	B2B & B2C		
Incl. GHGs	Six GHGs in the Koyoto Protocol		
GWP	Fourth report of IPCC		
Biogenic Carbon	CO_2 stored within a100-year period must be deducted	Included with separate reporting for additional transparency	If stored CO_2 is calculated, it must be disclosed separately

Delayed emissions	Inclusion with weighting factor and separate reporting possible	Inclusion with weighting factor and separate reporting possible	Not included
Cut off criteria	1 % of GHG emissions; 95 % of life cycle must be calculated	No criteria: 100 % completeness required; however, insignificance threshold can be defined (~1 %)	Insignificant material and energy flows may be excluded (mandatory disclosure)
System Boundaries	Specific boundaries are set (e.g., exclusion of capital goods, transportation of consumers and employees)	Included all attributable processes above insignificance threshold (must be justified); non-attributable processes may be excluded	Non-attributable processes may be excluded (e.g., transportation of consumers and employees)

In conclusion, the three standards present disparate methodologies and stipulations for the assessment and reporting of greenhouse gas emissions associated with products. The selection of an appropriate standard is contingent upon the specific objectives and requirements of the company in question, with each standard exhibiting distinctive strengths and weaknesses. By meticulously selecting and implementing these standards, companies can develop and implement precise and efficacious strategies to calculate and report their CO_2 emissions.

3 TAKKT AG as a Model Company for Implementation

3.1 Company Profile and Business Divisions

TAKKT is a business-to-business (B2B) omni-channel retailer with operations in Europe and North America. In 2022, TAKKT generated approximately 1 billion Euro turnover through various channels, including online retail, print marketing, and key account managers. The revenue was almost evenly split between Europe (56 %) and North America (44 %). (TAKKT Group, 2023, p. 32) TAKKT's business is divided into three divisions: Industrial and Packaging, Office Furniture and Displays, and Food Service. Figure 2 gives a summary of the three business areas, the fully owned companies, the number of products and the respective target markets.

Table 3 Overview of TAKKT's Holding Structure. Source: Own presentation

Division	Companies	Product portfolio	Number of Products	Target Market	Source
Industrial and Packaging	Kaiserkraft Group, Ratioform, BiGDUG	Equipment for factory floor and warehouse in manufacturing and logistic industries	345,000	Europe	*TAKKT, 2023, p. 9*
Office Furniture and Displays	National Business Furniture, Displays2Go, Mydisplays	Office equipment for day-to-day use on company premises or when working from home, promotion products at the point of sale or at events	23,000	North America	*TAKKT, 2023, p. 11*
Foodservice	Hubert, XXLhoreca	Foodservice supplies, equipment for hotels, restaurants, and caterers	360,000	North America and Europe	*TAKKT, 2023, p. 13*

TAKKT integrated environmental protection into the management report for the first time in 2009. (TAKKT AG, 2009, p. 29) However, it did not establish a concrete strategic corporate goal for reducing CO_2e emissions and combating climate change until 2020. (TAKKT AG, 2021, p. 39) In the current annual report, “TAKKT has committed to reducing its greenhouse gas emissions at its sites [scope1 and 2] by 50 percent by 2030 compared to the base year 2021, with a target reduction of 20 percent by 2025”. (TAKKT Group, 2024, p. 199) The company's annual report for 2023 indicates a reduction of 11 % in comparison to the base year of 2021. (TAKKT Group, 2024, p. 196)

3.2 In-house Production and its Significance for the Company

The TAKKT companies primarily distribute purchased final products, except for Kaiserkraft within the “Industrial and Packaging” division. In addition to these purchased products, this subsidiary has its own production facility in Haan, Germany, where it manufactures approximately 1,000 products for the TAKKT-owned brand EUROKRAFT. The product portfolio includes products from series, individual, and customized production. (Kaiserkraft, n.d.-b) The paper is limited to series products, which make up the majority of production. Due to their constant product characteristics, they are more suitable for automated calculation. Customized products whose footprints must be calculated on an individual basis are not within the scope of this study.

Kaiserkraft's in-house production is crucial for the company's sustainability efforts. Enkelfähig is a TAKKT sustainability initiative that assesses every product in the entire portfolio of all companies based on various categories such as climate protection, circular economy, and biodiversity. A product's Enkelfähig score ranges from 1.0 to 5.9. A score of 3.0 or higher qualifies the product as Enkelfähig, indicating that it is more sustainable than other products from the product portfolio in the same category. (Kaiserkraft, n.d.-a) As TAKKT aims for a 40 % share of sustainable products by 2025, it is important to note that the products manufactured in-house have been predominantly assessed as sustainable (93 %). Therefore, they play a crucial role in achieving the corporate strategic goal. (TAKKT Group, 2023, p. 36) In-house manufacturing also enables easier changes to product design, leading to lower emissions and a more sustainable product.

In 2017, TÜV Süd conducted an LCA for part of Kaiserkraft’s product range. During this time, products that were considered more sustainable were labeled as “activeGREEN”. These products were subjected to an LCA and the resulting CO_2e emissions were offset. Given that the life cycle assessments of the selected products, conducted at the time, are no longer current and that the entire portfolio of in-house production is to be evaluated, not merely a single segment of the products, the objective of this study is to identify a time-efficient and cost-effective methodology for achieving this.

3.3 Requirements for a PCF Calculation Tool

3.3.1 Internal Requirements

The internal requirements described in this section have been collated through internal discourse with employees from the Sustainability department and with employees from the in-house production facility. These requirements are intended to ensure that the tool is not only technically effective but also strategically valuable. The principal requirements can be classified into the following categories.

A key prerequisite is the capacity of the tool to facilitate dynamic updates to the calculation model in order to accommodate the current state of the database. Consequently, the tool must be flexible and adaptable to be able to promptly take into account changes in the underlying data sources. This ensures that the accuracy and relevance of the PCF calculations are always guaranteed.

Another crucial point is the preservation of data sovereignty by TAKKT. The calculations are to be performed internally, thus avoiding the necessity of external services. This allows TAKKT to implement internal adjustments independently and to maintain the confidentiality of company information. This not only enhances the security of the data, but also reinforces control over the entire calculation process.

In addition, the calculation tool must incorporate functions for the identification of emission hotspots throughout the product life cycle. These functions are of the utmost importance to be able to derive targeted measures to reduce CO_2 emissions. By analyzing the distribution of emissions, areas with particularly high emissions can be identified, and corresponding optimization strategies can be developed.

In addition, ad hoc analyses are a crucial requirement. The tool must be capable of responding to spontaneous requests and delivering meaningful results in a timely manner. This flexibility is of value in order to enable a prompt response to new information or requirements.

In summary, it can be stated that the calculation tool utilized to determine the PCF of products manufactured in-house at TAKKT must fulfill a number of internal requirements in order to be utilized effectively and efficiently. These requirements ensure not only the technical functionality and data integrity of the calculations, but also their strategic relevance and credibility.

3.3.2 External Requirements

In addition to the internal requirements, it is important to consider the external requirements. These are identified primarily through an analysis of customer inquiries and an evaluation of standards and legal requirements pertaining to the collection of PCFs.

The calculation of PCFs serves not only internal monitoring and reduction purposes but also as an offer to external stakeholders. Consequently, the selected calculation method should prioritize transparency, traceability, and consistency in order to reinforce confidence in sustainability practices and align with the expectations of external stakeholders.

A crucial external requirement is the tool's capacity to respond to requests for the PCF of products from major customers. These customers attach great importance to carbon footprints of their purchased products in order to track their own sustainability targets and document compliance with them.

In addition, it is necessary to be able to process inquiries regarding reduction measures for both the corporate carbon footprint and the PCF. External stakeholders anticipate that TAKKT will provide tangible information and strategies for reducing CO_2 emissions throughout the entire value chain. This encompasses both direct and indirect emissions.

Furthermore, to enhance the credibility of the calculation tool with external partners, it is of the utmost importance that the tool is based on recognized standards. Compliance with such standards ensures that the PCF calculations are comprehensible and comparable. In the future, an external audit of the calculation tool is possible to confirm its reliability and accuracy through an independent assessment.

An additional essential stipulation emerges from the CSRD. For customers to be able to calculate their scope 3 emissions, they require precise PCF data from their suppliers. It is the responsibility of TAKKT to ensure that the calculation tool meets the requirements and is capable of providing the necessary data in a suitable format.

Transparency is an important element in enhancing customer confidence in TAKKT's sustainability initiatives. Consequently, the calculation tool must be designed in a manner that provides customers with comprehensible and transparent information. This necessitates the provision of clear documentation of the calculation methods and a transparent presentation of the results.

To conclude, it can be stated that TAKKT's calculation tool must satisfy a number of external requirements in order to meet the expectations of major customers, legal requirements and international standards. This encompasses the consideration of SBT and CSRD standards, the provision of transparent and traceable PCF data, and the capacity to respond to specific customer requests. It is only by fulfilling these requirements that TAKKT can gain the trust of external stakeholders and effectively implement its sustainability goals.

4 Realization of the Calculation Tool

4.1 Selection of the Calculation Method

In making a decision between the GHG Protocol and ISO 14067 for calculating the PCF, it is essential to consider a number of significant factors. PAS 2050 is not a relevant consideration in this context, as it serves only as a precursor to the GHG Protocol and ISO 14067. Consequently, it is used as a basis for these two standards. The following paragraphs present an overview of the various aspects of the decision regarding the calculation standard to be employed, based on the comparative analysis of the standards outlined in section 2.3.

Consistency and standardization

TAKKT has already adopted the GHG Protocol as the basis for calculating scope 1, 2, and 3 emissions for the CCF. In order to ensure consistency and uniformity in the calculation methodology, it would be prudent to also calculate the PCF using the GHG Protocol. This would avoid potential inconsistencies and facilitate the integration of the results into the existing reports and analyses.

Comprehensive instructions and detailed guidance

The GHG Protocol provides comprehensive instructions on how to execute its methodology, even for those without expertise in the subject matter. This enhances comparability and guarantees that calculations can be conducted in a consistent and reliable manner. The GHG Protocol's comprehensive guidance is particularly useful for ensuring that all relevant aspects of the product life cycle are considered.

CO_2 reduction strategy

The primary goal of the TAKKT organization is to implement an effective strategy for reducing CO_2 emissions. The GHG Protocol offers a framework for establishing and monitoring emission reduction targets in a transparent and accountable manner. This is of particular significance, as the objective is not merely to offset emissions; rather, it is to pursue a tangible plan to reduce CO_2 emissions.

In-depth life cycle analysis

While numerous software solutions for life cycle analysis (LCA) are based on the ISO standard, TAKKT's particular requirements necessitate a comprehensive examination of the entirety of a product's life cycle. As a fragmented view of individual life stages, as provided by ISO 14047, is not required for analysis, it is therefore not necessary to employ the ISO standard. The GHG Protocol allows for a comprehensive life cycle analysis while allowing for the integration of sector- or product-specific methods, should they be available.

Practicability and comparability

The GHG Protocol is used by many software provider and companies for CO_2 accounting. This not only makes it easier to implement, but also to compare our results with those of other companies. The GHG Protocol's detailed application steps and clear specifications help ensure that our calculations are understandable and transparent.

Costs and accessibility

ISO 14067 is a proprietary standard, whereas the GHG Protocol is available at no cost. Considering the company's cost-saving strategy, it is not economically viable to incur additional expenses for access to an ISO standard. The company's lack of full access to ISO 14067 precludes the possibility of implementing and applying the standard in its entirety and in accordance with the standard's specifications. In contrast, the GHG Protocol is fully accessible and allows for comprehensive implementation at no additional cost.

For these reasons, the GHG Protocol represents a superior choice for TAKKT. It is not only available at no cost and already integrated into existing processes within the company but also provides comprehensive instructions that facilitate implementation and comparability. Additionally, it effectively supports CO_2 reduction strategies and enables a thorough life cycle analysis. Accordingly, it is recommended that the GHG Protocol methodology be followed for the calculation of the PCF.

4.2 Applied PCF Calculation Methodology

4.2.1 Goal and Scope

Following the guidelines set forth by the GHG Protocol, the initial step is to define the business objectives and the scope of the calculation model.

The overarching objectives are to achieve greater transparency with regard to emissions, and to derive reduction measures from this. It is the intention to engage with suppliers in the future in order to achieve a reduction in GHG emissions. Furthermore, the objective is to provide customers with the necessary information to enable them to calculate their own emissions.

In regard to the scope of the calculation model, the result of the calculation is expressed in kilograms of carbon dioxide equivalent per kilogram and incorporates all six Kyoto gases.

It should be noted that the calculation model is not limited to a specific product; rather, it can be applied to all products manufactured in-house by the company, thus eliminating the need to select a specific product for analysis. The functional unit on which the calculation of PCFs is based is identical to that of the end products in the assortment. As the tool is employed in a generic manner, the result does not present a comprehensive report outlining the functions of the product in terms of scale, duration, and expected quality according to the GHG Protocol. Such information can be made available to the customer via the online web shop.

These considerations can be transferred to the reference flow, which is specific to each product and must be considered independently. It can be stated, however, that in order for a functional unit, i.e., a product, to fulfill its function, only one of these products need be manufactured. Furthermore, the operational lifespan of the majority of products has no direct impact on the emissions generated.

4.2.2 Boundary Setting

As required by the GHG Protocol, a cradle-to-grave system boundary was defined.

The system boundary encompasses the following life cycle stages: the procurement of raw materials for each component, transportation from the supplier to the in-house production facility in Haan, production processes in the in-house production facility, transportation to the distribution centers, electricity consumption during product use, which is only considered for electrified products, transportation to the disposal site, and disposal and recycling.

The processes included and excluded within the system boundaries are listed in Table 4.

Table 4 System boundaries defined for this study. Source: Own presentation

Included	**Excluded**
Materials used in production process	Transport from distribution center to customer
Energy consumption in production facility	Manual assembly
Manufacturing processes	Employee commuting (non-attributable)
Inbound transportation	Energy consumption in use-phase for electrified products
Outbound transportation	
Overhead operation (non-attributable)	
Disposal of process waste	

The transportation of goods from distribution centers to customers is excluded from the analysis, as the necessary data to calculate this aspect of the process using average values is not available. Furthermore, as proposed in the GHG Protocol, a rule of thumb of 1 % energy, mass, or emissions for insignificance is defined. (Bhatia et al., 2011, p. 42) The contribution of transportation to total PCF emissions is minimal, representing only 3-6 % of total emissions for all other transportation routes. Consequently, this process can be considered insignificant. Additionally, this process is classified as transportation between the customer and the retailer's location, and thus is not required to be included in the calculation according to the GHG Protocol. (Bhatia et al., 2011, p. 36)

Moreover, manual assembly with cordless screwdrivers, hot air devices, and binding machines is not included in the calculation, as the associated consumption is considered to be insignificant. (Bhatia et al., 2011, p. 42) The total electricity consumption of the production site is nevertheless incorporated into the calculation via the non-attributable processes in the overhead operations. Consequently, the emissions from manual assembly are also indirectly included in the PCF of the products. However, these emissions are allocated with a certain degree of inaccuracy based on average values, and thus are presented as excluded.

In addition, emissions related to employee commuting to and from the workplace are not included, as the GHG Protocol does not require such data to be included in GHG calculations. Moreover, no corresponding GHG data is available to allow for the inclusion of this aspect. (Bhatia et al., 2011, p. 36)

It is not feasible to include the use phase of the products in the analysis at this stage, as only a limited number of products are electrified, and the data pertaining to their energy consumption is not currently available. Nevertheless, this must be considered when further developing the calculation model to enable a valid assessment of the PCF for the limited number of electrified devices.

All other processes that can be attributed to the system are included in the system boundaries. Furthermore, the non-attributable process of overhead operations is incorporated into the system to ensure comprehensive coverage of all processes that contribute to electricity and gas consumption at the production site.

In order to facilitate the collection of data and to comply with the requirements set out in the GHG Protocol, a process map has been developed (see Figure 4). (Bhatia et al., 2011, p. 35)

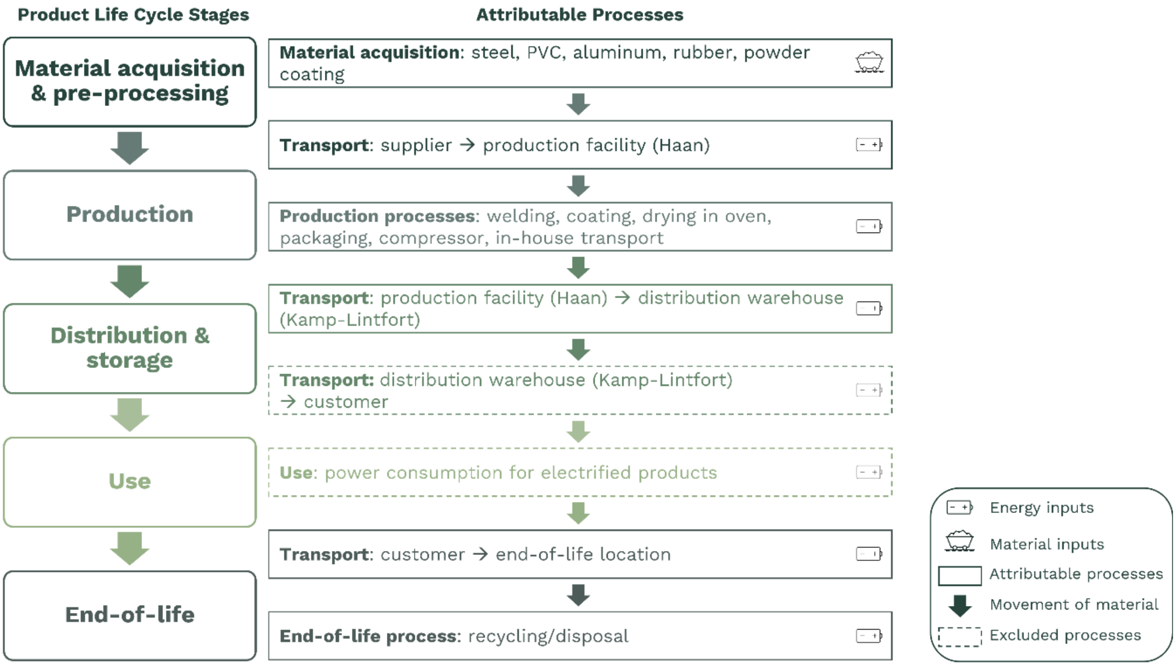

Figure 4 Process map. Source: Own presentation following Bhatia et. al, (2011), p.41

The process map shows the life cycle phases that are to be analyzed, as well as the processes that are to be carried out in each individual stage. It also shows the direction of flow of the product through the process map and indicates which processes are excluded from the analysis.

The data necessary for a calculation that encompasses all mapped processes is identified on the basis of the process map. As illustrated in Figure 4, the process map demonstrates that a material flow, either in the form of individual materials or components, passes through the entire process map initially in the first stage of life. From the production stage onwards, this material flow takes the form of a finished product. Furthermore, energy inputs are necessary for each individual process. These inputs may take the form of electricity, as required for machinery and forklift trucks in logistics, or natural gas, as required for transportation.

In the end-of-life phase, the conventional disposal and recovery methods of landfilling, incineration, and recycling are presumed to be applicable. In the future, the possibility of returning products to the supply chain for refurbishment may be considered as an additional option. Nevertheless, this approach has been deemed unsuitable at this time, as there are currently no established internal procedures in place to facilitate its implementation.

The subsequent step will entail the formulation of a data management plan, the objective of which will be to organize and document the data collection process in accordance with the process map that has been developed.

4.2.3 Data Collection and Processing

In alignment with the defined objective of this work, the primary focus is on the development of the tool, with the precise calculation of the individual PCFs based on actual measured data playing a secondary role. Accordingly, the available data for the products within the company has been collected and analyzed. No surveys have been conducted with suppliers or other stakeholders; instead, proxy and estimated data were utilized. This is an acceptable practice in line with the GHG Protocol, which allows for the saving of resources that can then be allocated to the development of the calculation model. (Bhatia et al., 2011, p. 58)

A data management plan has been developed with the objective of obtaining a comprehensive understanding of the data collected and its sources. As part of this plan, a comprehensive documentation of the data origin, timeliness, data types, data quality, and assumptions made has been conducted.

The following procedure has been used to collect the data: The process map and the defined system boundaries were used to determine which processes are to be subjected to an assessment as part of the PCF calculation model. As part of the process of creating the data management plan, the data requirements were identified and documented. These are the data on which the calculations are based, and which must be collected accordingly. For instance, data regarding the material type, country of production, quality (e.g., coated or galvanized), and weight are necessary for calculating the GHG emissions associated with material extraction and acquisition. This is conducted in accordance with the activity-based approach. Conversely, for the calculation according to the spend-based approach, data on costs are required.

Optional data screening, as described in the GHG Protocol, was not a necessary undertaking, as research indicates that raw material generally accounts for the largest proportion of emissions from products. (BASF, n.d.; Bhatia et al., 2011, p. 50; Joos-Bloch et al., 2023, p. 41) Moreover, the results of the internal measurements indicate that the manufacturing steps of the products do not have a significant energy consumption, and therefore, they contribute only a minor proportion of emissions. As part of the data management plan, an overview of the data required for each product was created, which is presented in Figure 5.

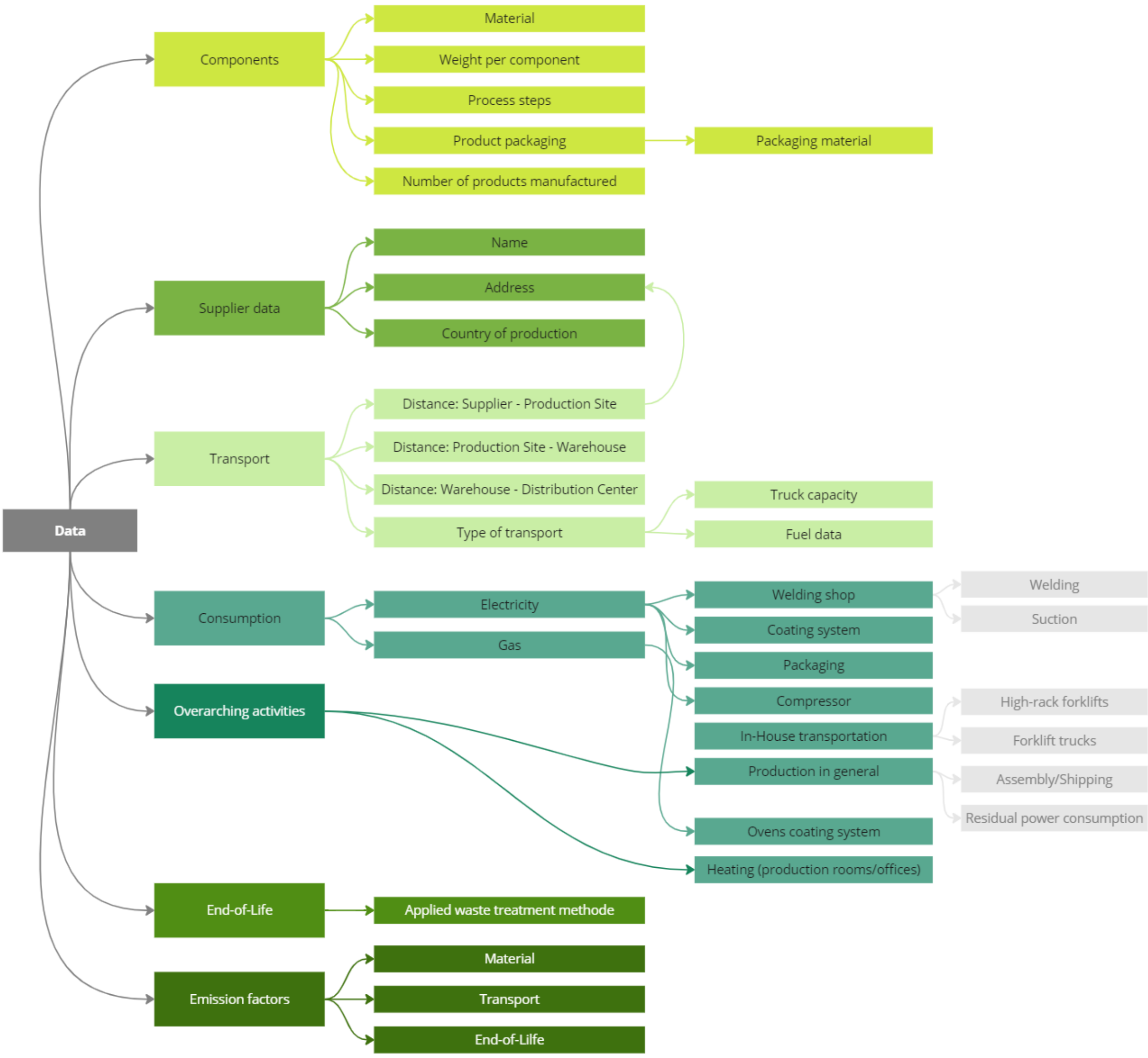

Figure 5 Required Data Overview, Source: Own presentation

The objective of the data collection was to obtain mainly primary data. However, this was not always feasible, as a considerable amount of the data was not accessible. Consequently, the primary data was supplemented with secondary data.

In the initial phase of the study, a comprehensive bill of materials (BOM) for all products was subjected to a detailed analysis and scanning process to identify the specific data points required for calculating the PCF. In particular, data were extracted including the primary material type of the components, their respective weights, and the suppliers associated with each. The multi-level BOM structure enables the assignment of components to products and the determination of production work steps required for each product.

The material emissions were calculated on the basis of the information on the primary material of the components and their respective weights, as outlined in the parts list. The country of production was researched online using the supplier allocation. In accordance with the requirements of the GHG Protocol, processes that are subject to the company's control must be calculated using primary data. (Bhatia et al., 2011, p. 52) Therefore, the electricity and gas consumption for individual production steps, as determined by measurements conducted in production, was used to calculate the production steps.

The calculation of transportation emissions is based on the determination of distances between individual locations. Included among the distances are those between the supplier's site and the production site, for example. The type of transportation, in this case limited to road transportation, is likewise of pivotal importance regarding the calculation, given that this represents the primary determinant of the level of transport emissions. Moreover, assumptions were made regarding the dimensions of the vehicles and their utilization rates.

To prevent double counting, the emissions associated with transportation in the upstream supply chain, which are typically incorporated into the material extraction and material production emission factors, were excluded from the calculation. (Climatiq, n.d.-b) This pertains to the transportation routes that have already been incorporated into the delivery to the respective supplier.

The end-of-life calculation is based on the materials that comprise the product. Additionally, secondary data regarding the type of disposal was researched and corresponding assumptions were made.

Following the requirements of the GHG Protocol, the calculation was primarily based on process activity data, specifically information regarding the consumption of energy in kilowatt hours, the use of materials in kilograms, and the distance traveled in kilometers. Financial activity data was employed only when implementation was not feasible. (Bhatia et al., 2011, p. 51)

Emission Factor Data Bases

The selection of emission factor databases was constrained by financial limitations, necessitating the consideration of only freely accessible options. To facilitate the choice of an appropriate database, the GHG Protocol offers a set of questions, which were employed as a framework. (Bhatia et al., 2011, p. 53) In accordance with the requirements of the GHG Protocol, it is essential to identify and understand the processes included in the emission factors. Such an approach ensures comprehensive and accurate data collection that incorporates all relevant processes within the product's life cycle, thereby facilitating a precise and exhaustive calculation of the PCF. (Bhatia et al., 2011, p. 52)

Table 5 provides a comparative overview of five distinct emission factor databases, with an emphasis on several key aspects.

Table 5 Comparison of key aspects of emissions database selection. Source: Own presentation

Name	**Climatiq**	**Oekobaudat**	**Exiobase**	**DEFRA**	**Ecoinvent**
Publisher	Climatiq	German Federal Ministry for Housing, Urban Development, and Building	Exiobase & Partners (Universities, independent research organizations, consultancy company)	UK Department of Environment Food and Rural Affairs	Ecoinvent
Source Type	-	Governmental	Academic	Governmental	Not-for-profit Organization
License	Free of charge	Free of charge	Free of charge	Free of charge	License required
Data Access	Web based	Web based	Web based	Web based	Web based
Applied Regions	Global	Europe	Global/ multi-regional	UK	Global/ multi-regional
Subject Area	Covers all subject areas	Building materials, construction, transportation, energy and disposal processes	Agriculture, buildings, consumer goods, energy, materials, organizational activities, transport, waste, water	Agriculture, consumer goods, energy, materials, organizational activities, transport, waste, water	Energy sources and systems, materials, chemicals, transportation, disposal, agricultural processes
Spend-based vs. activity-based	No restriction	Activity-based	Spend-based	Activity-based	Activity-based
Frequencies of update releases	At least monthly	Yearly	Irregular	Yearly	Yearly
Source	Climatiq, n.d.-b	BMWSB, n.d.	exiobase, n.d.	gov.uk, 2024	Ecoinvent, n.d.

The decision was made in favor of Climatiq, a database developed by a company based in Berlin and established in 2021. (Climatiq, n.d.-a) It offers a compilation of GHG emission factors, integrating data from multiple emission factor databases. It provides a compilation of GHG emission factors that integrates data from various emission factor databases. The databases from which the emission factors used originally originate are recorded for each emission factor in the calculation model in order to ensure transparency and traceability. The decision to select Climatiq as the emission factor database was based on a number of factors. The free accessibility of the database is a significant factor in the decision to utilize Climatiq. This eliminates the need for additional resources typically associated with a paid database, which is particularly advantageous for projects with limited budgets. The linking of multiple databases allows for the exploitation of their respective advantages, ensuring comprehensive coverage of diverse subject areas. These include energy sources, materials, disposal, and transportation. The integration and diversity of the information contained in Climatiq make this a valuable research tool.

Another advantage of Climatiq is its intuitive and accessible design, facilitating comprehension among users with varying levels of prior experience and technical expertise. The database is relatively straightforward to comprehend, even for individuals lacking technical expertise, as it offers a comprehensive overview of information in a concise manner. The disclosure of information is also an essential element for ensuring the quality and transparency of the data. Each emission factor in Climatiq includes six key pieces of information:

1. “A link to the source from which the emission factor was retrieved
2. The life cycle analysis (LCA) activity that the emission factor refers to
3. The publication year of the emission factor by the source
4. The region to which the emission factor applies
5. Any uncertainty (expressed as a percent) associated as reported by the source
6. A well-defined unit (e.g. weight or money)”

(Climatiq, n.d.-c)

Moreover, Climatiq provides access to emission factors that are not constrained to Germany but can be selected for a multitude of countries across the globe. This enables the selection of emission factors that are optimally suited to the given conditions, irrespective of the region in which the data is required.

The implementation of Climatiq as a web-based database has the advantage of obviating the necessity for an IT security process to be run through within the company. This results in savings in terms of human resources and time, as no additional IT infrastructure is required. The Climatiq database provides users with the option of selecting both activity-based and spend-based emission factors. (Anastasia Lobanova & Cathleen Berger, 2021) This flexibility allows the approach to be freely chosen or a combined approach to be used, ensuring a high degree of adaptability to different calculation requirements.
Another reason for the selection of Climatiq is the timeliness of the data. The database provides year-specific data, enabling the use of both current and historical emission factors. Furthermore, the data is updated at least monthly, ensuring the incorporation of new data and the updating of existing data in accordance with the latest findings. (Climatiq, n.d.-c)
An additional factor that supports the selection of this database is Climatiq's quality assurance process. A team of scientists assesses the data in accordance with pre-established criteria, including completeness, scientific credibility, certification, and user feedback. (Climatiq, n.d.-c) This process ensures that the data meets the requisite standards prior to its inclusion in the database. Moreover, Climatiq asserts that it is in compliance with the stipulations set forth by the GHG Protocol, which serves to reinforce the credibility and relevance of the database. (Climatiq, n.d.-c)

The transport emissions data utilized for calculation was derived exclusively from the Global Logistics Emissions Council Framework (GLEC). This framework is aligned with the GHG Protocol and is dedicated to the estimation of logistics-related GHG emissions. (Global Logistics Emissions Council Framework, 2023, p. 9)

Data Quality Assessment

The quality of the data is of primary importance for the informative value of the PCF and the identification of potential for improvement. Accordingly, the GHG Protocol places significant emphasis on the assessment and documentation of data quality. In alignment with the GHG Protocol's stipulations, indicators were established to measure data quality. These indicators provide insights into both the representativeness and the quality of the data measurement. The five indicators outlined by the GHG Protocol and adopted in this study are presented in the first column of Table 6. (Bhatia et al., 2011, p. 48)

The indicators are rated on a scale of 0 to 3, where 0 points represents "poor”, and 3 points signifies "very good." A higher score is indicative of superior data quality. The maximum total score that can be achieved for a given data point is 15.

Table 6 Data quality assessment: Average score per indicator. Source: Own presentation

Indicator	**Average score per indicator**
Technological representativeness	2.20
Temporal representativeness	3.00
Geographical representativeness	2.84
Completeness	1.88
Reliability	2.16

Table 7 Data quality assessment: Average score per life cycle stage. Source: Own presentation

Life cycle stage	**Average score per life cycle stage**
Material data	10.00
Processing data	11.40
Transport data	13.50
End-of-Life data	11.00

The assessment of data quality indicates that the data pertaining to material emissions is of the poorest quality, with an average overall score of 10.0 points (see Table 7). In contrast, the quality of the transportation data is the highest, with an average overall score of 13.5 points. Moreover, it can be stated that the category "temporal representativeness" has the highest average value of three points, while the category "completeness" has the lowest average value, with a score of 1.9.

Life cycle stage	**Average score per life cycle stage**
Material data	10.00
Processing data	11.40
Transport data	13.50
End-of-Life data	11.00

It is important to note that the evaluation should be conducted in an objective manner, employing the pre-defined indicators and scales. However, the generally accepted formulation of the scales presents certain challenges. The temporal representativeness of the data is therefore classified as "fair," with one point assigned on the rating scale. It is anticipated that a current measurement would not reveal any significant changes, provided that the same machines are utilized. It is recommended that these circumstances be given special consideration in the event of a potential collection of new or updated data. Conversely, the emission factor for purchased electricity is of a particularly time-sensitive nature and thus requires regular updating.

The utilization of data characterized by a considerable degree of uncertainty poses a considerable risk of compromising the quality and integrity of the data. These limitations are discussed in greater detail in chapter 5, which outlines the potential limitations of the PCF calculation tool.

As part of the data management plan, data gaps were identified. In accordance with the requirements of the GHG Protocol, these data gaps were closed either with proxy data, for example for similar materials or processes, or with estimated data. The estimation of data is based on assumptions in the absence of available proxy data. One example of this is the missing weight of certain components in the BOM. While the collection of primary data from the supplier is the ideal scenario, this was deliberately omitted in this case due to the aforementioned reasons. Instead, an industry average for the material weight was used as a proxy.

In instances where it was not feasible to close data gaps through reasonable effort or in cases of exceedingly low elementary flows, cutoff criteria were employed.

In conclusion, it can be stated that the process of data collection and processing is the most time-consuming and, at the same time, the most critical element of the entire process, as the quality and credibility of the results are contingent upon it. It is, therefore, essential to engage in continuous monitoring and improvement of data quality to ensure the reliability of PCF calculations.

4.2.4 Allocation

The allocation of emissions plays a pivotal role in the PCF calculation, as outlined in the GHG Protocol. However, when analyzing the production and transport steps, it was not always feasible to completely avoid the allocation of emissions, as recommended by the GHG Protocol. (Bhatia et al., 2011, p. 62)

An illustrative example is the application of powder coating, which is a standard process for the vast majority of products manufactured in-house. The total annual consumption of electricity and gas was quantified as part of the study. However, the products differ in terms of size and complexity, which results in varying coating times and, consequently, electricity and gas consumption. As the precise dwell time of the products within the coating plant was not determined, it was not feasible to further subdivide the process in order to avoid allocation. In the present study, a physical allocation method was employed. The overall electricity consumption of the coating system in 2023 was divided by the total quantity of goods produced during this same period to calculate the average electricity consumption per unit. The aforementioned method was also applied to the gas consumption of the oven utilized for curing the coating. The allocation factor (AF) was calculated according to the following formula:

$$AF = \frac{total\ consumption\ of\ electricity\ or\ gas\ per\ year}{number\ of\ products\ manufactured\ per\ year}$$

In determining the appropriate physical allocation factor, the proposal put forth by the GHG Protocol for the denominator was utilized as a reference. (Bhatia et al., 2011, p. 69)
In the context of emissions allocation in the transportation phase, where multiple products are transported collectively, mass represents the primary limiting factor. This is particularly the case with road transportation, as only a certain maximum payload weight is permitted. (Bundesamt für Justiz, n.d.) According to the GHG Protocol, the limiting factor in the case of rail transportation would be volume. (Bhatia et al., 2011, p. 68) In the present case, the transportation is exclusively by road, with several different products transported in a single vehicle. The allocation is therefore based on the mass of the products. To this end, the emissions for one kilogram of payload were first calculated and multiplied by the weight of the product.
Regarding the recycling process, the GHG Protocol distinguishes between two methods: the "closed loop approximation method," which involves substituting raw material with identical properties within system boundaries, and the "recycled content method," which pertains to open loops where the recycled material substitutes raw material in another product cycle outside the system boundaries. In this study, the "recycled content method" was employed, given that the product's potential lifespan is expected to be considerable and the extent of recycling during the end-of-life phase is inherently uncertain. In accordance with the principles of the recycled content method, the emissions generated by the recycling process and those avoided by the substitution of virgin materials are incorporated into the life cycle encompassing the utilization of the recycled material. This consequently indicates that the recycling of materials effectively reduces the necessity for waste treatment, which subsequently results in a diminution of emissions. Furthermore, the utilization of recycled materials can result in the avoidance of emissions, provided that the recycling process yields

a net reduction in emissions when compared to the raw material extraction process. This can ultimately contribute to a net reduction in overall emissions.

4.2.5 Calculating Inventory Results

The GWP over a period of 100 years was employed to calculate the GHG inventory in accordance with the sixth assessment report of the IPCC. (IPCC, 2022, p. 1831) This enables the determination of emissions in a comparable unit, expressed as CO_2e. The fundamental mathematical model for calculating the PCF is based on the emissions generated by the various stages of the product's life cycle, including material extraction and pre-processing (E_M), production (E_P), transportation (E_T), and end-of-life (E_{EOL}). The underlying mathematical model for calculating the PCF may be represented as follows:

$$PCF = E_M + E_P + E_T + E_{EOL}$$

The general calculation formula was employed to calculate the emissions generated at the various stages of the individual life cycle:

$$GHG\ emissions = activity\ data \times emission\ factor$$

The following section details the emissions calculations for each life cycle stage.

Material

A specific emission factor was assigned to each material used, depending on the country of origin. This emission factor was multiplied by the weight of each component made from that material to calculate the total emissions per component. Since a product consists of several components, the emissions of each component were added. The calculation is based on the following formula:

$$E_M = emissions\ component\ 1 + emissions\ component\ 2 + \cdots + emissions\ component\ n$$

Production

Electricity and natural gas are the main energy consumed in in-house production. The emissions for each operation were calculated by dividing the total electricity or gas consumption by the number of goods produced and then multiplying by the emission factor. For energy, a regional emission factor was used to avoid double counting, as required by the GHG Protocol. (Bhatia et al., 2011, p. 52) The emissions per product were allocated to the products that go through that process step. Since each product goes through more than one process step, the sum of the emissions from all the process steps that are assigned to the product was calculated. Therefore, the general formula for the calculation of the emissions from the production phase is the following:

$$E_P = \frac{total\ energy\ consumption}{number\ of\ products\ manufactured} \times regional\ emission\ factor$$

Transportation

Transportation is not an independent life cycle stage, but rather the transition between all stages to move the elementary flow from one site to another, as the individual stages typically take place at different locations. Nevertheless, the individual transport stages are considered as a whole in this study because the calculations are based on the same assumptions, calculation logic and emission factors. The emissions caused by the transportation of components and products have also been calculated in several steps. The basic calculation is to calculate the sum of all emissions for each transport route as follows:

$$E_T = E_{inbound} + E_{internal\ transport} + E_{outbound} + E_{EOL\ Tansport}$$

The parameters fuel type, transport type, transport mass in kilograms and distance in kilometers were considered for all transport routes. In this case, the fuel type is diesel, and the transportation mode is road. In addition, it was assumed that 12-ton trucks with an unladen weight of 5 tons and a payload of 7 tons would be used. It was also assumed that the trucks are used at an average of 80 % of their capacity.

All assumptions and calculations were made using the most conservative cases to ensure that no emissions were left unaccounted for. This can be seen here in the fact that for each trip an empty return trip was considered, although it is probable that round trips were planned by the logistics company. (Global Logistics Emissions Council Framework, 2023, p. 107) Emissions were calculated using the GLEC Framework, which allows for the calculation of a product-specific CO2e factor with the unit emissions per transported ton. To obtain the inbound transport emissions per product, the result of the emissions caused by the specified parameters per kilogram of payload is multiplied by the weight of the individual components that go into a product.

$$E_{inbound}\ per\ transported\ ton = \frac{\left(\frac{(distance \times emission\ factor)}{0.8}\right)}{7{,}000}$$

$$E_{inbound} = E_{inbound}\ per\ transported\ ton \times product\ weight$$

In order to calculate the emissions from internal transportation from the production site in Haan to the warehouse in Kamp-Lintfort, the distance between the two sites was first determined. The same calculation logic and assumptions that were used for the inbound transportation were also employed in this instance. Based on the defined parameters, the emissions per kilogram of load were calculated and then multiplied by the weight of the products.

Given the lack of available data regarding the allocation of products to specific distribution centers and the quantities delivered to each center, it is necessary to employ assumptions and average values to calculate outbound transport emissions. To this end, the mean distance between the warehouse in Kamp-Lintfort and all distribution centers was established. Based on this distance, emissions per unit of capacity utilization were determined. These figures were then multiplied by the product weights to determine the attributable emissions for each product.

It is standard practice to include transportation to the waste treatment facility in the emission factors, so a separate calculation would result in double counting. (Climatiq, 2024) Nevertheless, an approximation of the potential transportation emissions was determined in order to validate and pursue a conservative approach through a series of assumptions regarding distance estimation. The result was that these emissions account for only 0.3 % of the total life cycle emissions and are therefore negligible.

End-of-Life

Initiating the process of calculating emissions at this life cycle stage entails identifying the specific products or product components that are subject to recycling or disposal, as well as the manner in which this occurs. A review of the literature was conducted to identify the recycling rates of the materials from which the products are manufactured. The findings of the research indicate a high probability of recycling aluminum, cardboard, polyethylene film, and steel. (BMUV, 2024, p. 23; Daten Und Fakten Zur Stahlindustrie in Deutschland, 2023, p. 34; Gesamtverband der Aluminiumindustrie e.V., 2020, p. 4) In contrast, it can be postulated that all other materials will be incinerated, as this is the most prevalent waste treatment method employed in Europe. (BMUV, 2020, p. 1) The calculation of emissions resulting from the disposal of materials in the form of incineration is based on the use of emission factors and the weight of the materials. Given the unavailability of primary data from waste treatment facilities, the relevant data on waste type, weight, and associated emission factors had to be utilized. (WBCSD, 2021, p. 27) A specific emission factor was identified for each of the materials in question, which was then multiplied by the weight of the respective component. Subsequently, the total emissions of the end-of-life stage were calculated by adding together the emissions of the individual components attributable to the product. With regard to all components for which a recycling process is assumed, this study has not identified any further emissions during the life cycle. In consideration of the "recycled content method," it can be concluded that no emissions are generated by the recycling process for the products in question in the case of open loop recycling. In accordance with the requirements of the GHG Protocol, these emissions, as well as the avoidance of emissions through the replacement of virgin material, are attributed to the products that utilize the recycled material. (Bhatia et al., 2011, p. 73)

In alignment with the guidelines set forth by the GHG Protocol, the preparation of the GHG inventory did not incorporate any weighting factors pertaining to delayed emissions, offsetting, or avoided emissions. In accordance with the requirements of the GHG Protocol, the overview of results demonstrates the percentage share of the individual life cycle stages in the total PCF. The cradle-to-gate result and the gate-to-gate result are presented separately, in alignment with the GHG Protocol's stipulations. (Bhatia et al., 2011, p. 86)

4.3 System Architecture and Result Presentation

The PCF calculation tool was developed in accordance with the internal and external requirements set forth in section 3.3. The following section describes the implementation of this approach.

The calculation model is based on database logic, with data for each stage of the product life cycle recorded in a separate tab. Furthermore, a list of the applicable emission factors was compiled in a separate tab for each life cycle stage. This structure enhances transparency regarding the data used and facilitates the expansion of the database with the incorporation of additional products and their corresponding data points.

The initial setup of the model was limited to six different products to streamline the process and prevent the introduction of erroneous data resulting from an excessively granular dataset. A unique product number serves as an identifier that can be assigned to the components, suppliers, and calculated emissions. The internal product number is identical to the external article number, which is the identifier used in the web store for this product. This number enables the user to select and display all results for the given product in a results overview.

The interconnectivity between the databases and the calculation overview guarantees that alterations and enhancements are exclusively implemented in the data sheets. Subsequently, the data are automatically transferred to the calculation overview and the results page. In particular the calculation model enables the expeditious addition of products sharing comparable attributes and sourced from identical suppliers, facilitating the automated generation of associated emissions data.

Figure 6 and Figure 7 illustrate the results page within the calculation tool.

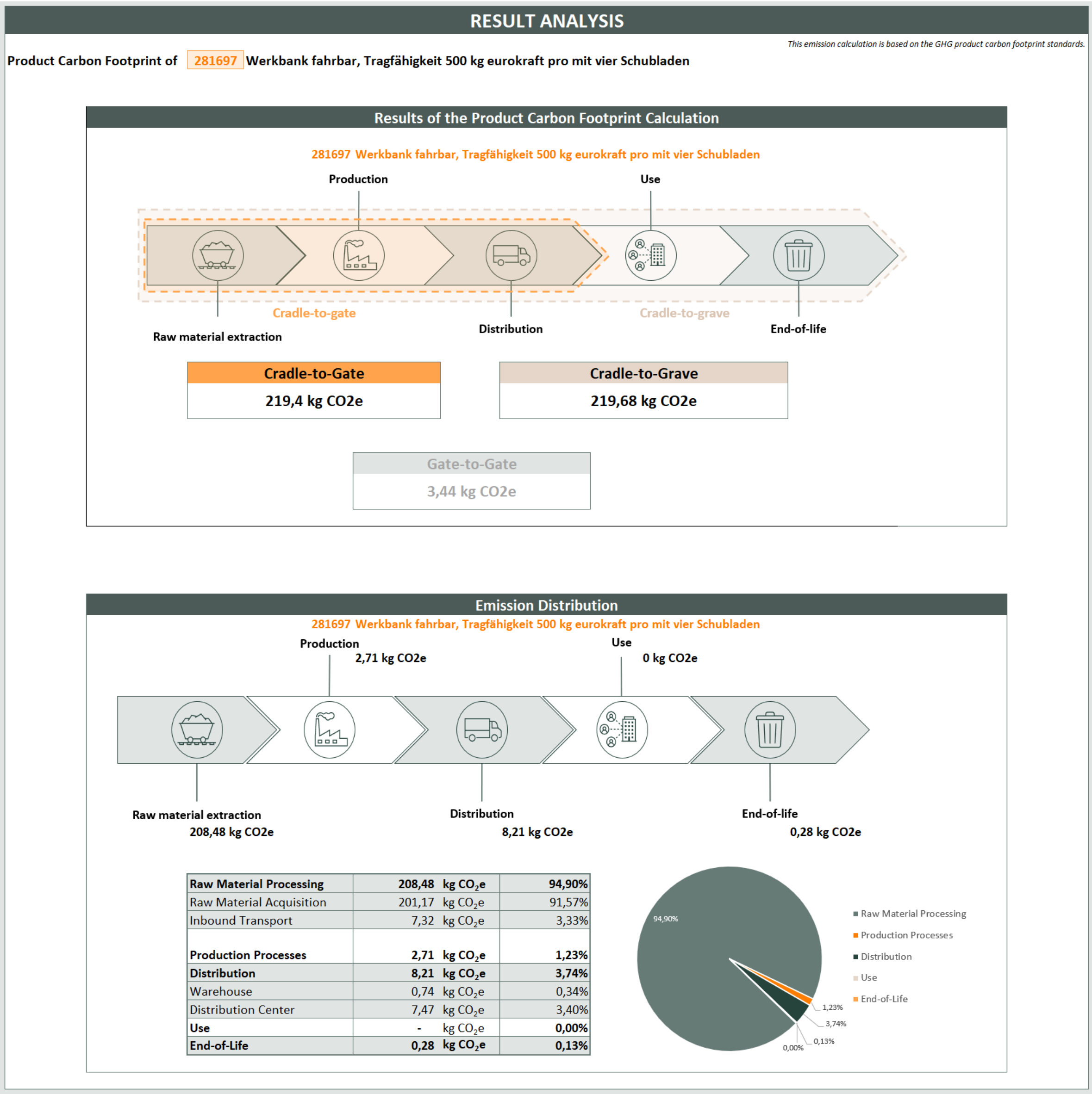

Figure 6 Screenshot of the PCF result overview

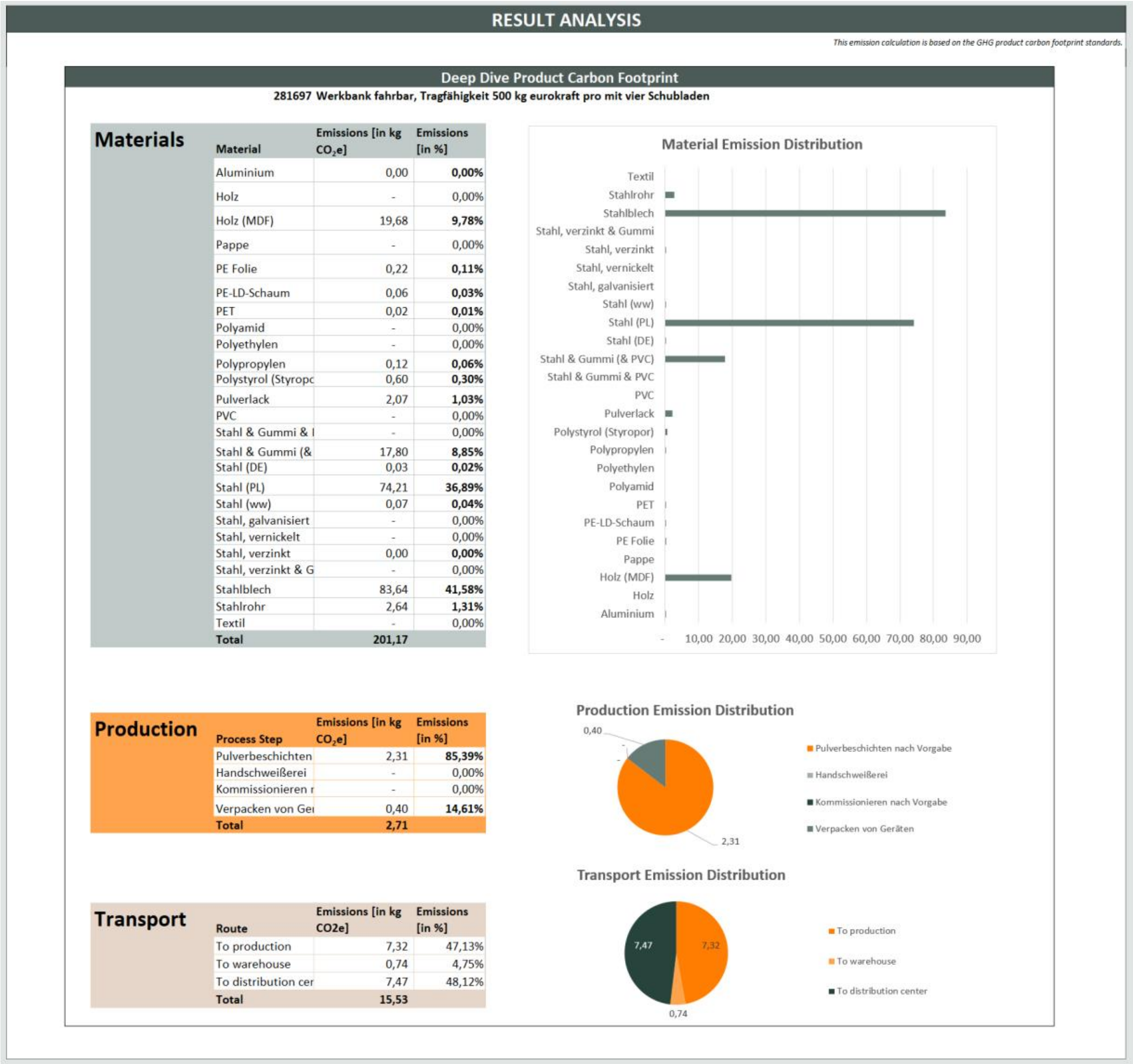

Figure 7 Screenshot of the PCF result deep dive

To select the desired product, the relevant product number, displayed in orange in Figure 6, can be entered into a dropdown menu. Once the product number has been entered, the PCF results for that product will be displayed. Both the cradle-to-gate PCF and the cradle-to-grave PCF are displayed at the upper part of the page. The distribution of emissions throughout the life cycle of the product is illustrated in a pie chart in the lower section. Figure 7 presents a detailed analysis of the material, production, and transportation processes, with each component broken down into its constituent materials, process steps, and transport routes.

Moreover, a separate page allows the user to perform a comparative analysis between two products in terms of their respective GHG emissions (see Figure 8).

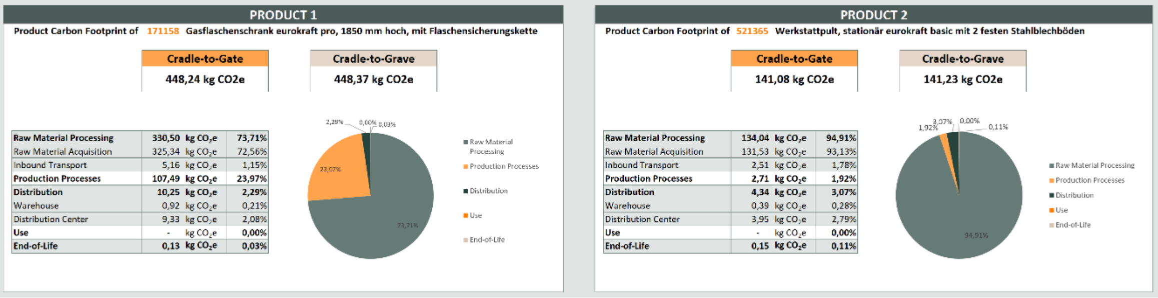

Figure 8 Screenshot of the PCF product comparison

While this is not a stipulation of the GHG Protocol, the transportation emissions for each product are presented in an aggregated format across the entirety of the product's life cycle. This allows for the presentation of the proportion and emissions in absolute figures for this recurring process on a standalone basis.

A disclaimer in the calculation tool provides an explanation of the defined scope of the study, the conceptual framework underlying the calculation of the PCFs, and the limits of the calculations. This is done to ensure transparency, credibility, and comprehension of the methodology. A significant benefit of the tool is that it ensures data sovereignty. As the calculations are conducted internally, the data is not transferred to external service providers. Even when sharing the results page, no internal data or calculation logic is disclosed externally. The presentation is designed to ensure traceability and transparency without disclosing additional information. The presentation of the emission shares on the results page allows for the identification of emission hotspots, which can then be utilized as a foundation for the implementation of reduction measures. A further crucial element of the requirements is compliance with established standards in the calculations. This is guaranteed by aligning the calculation tool with the standards set forth by the GHG Protocol, thereby enhancing the tool's reliability.

External requirements primarily arise from the need to provide the PCF, which is demanded by customers or the public for various reasons outlined in section 3.3.2. It is essential to ensure the provision of an up-to-date PCF upon request, which can be guaranteed by the tool if product modifications are regularly maintained within the tool. The external provision of PCFs necessitates particular attention regarding the transparency, traceability, and consistency of the calculation logic employed. This can be achieved by considering the requirements of the GHG Protocol and by providing comprehensive documentation of the data basis, sources, timeliness, calculation logic, and assumptions made.

5 Limitations and Challenges in Implementation

5.1 General Limitations of PCF Calculations

One of the principal limitations of the PCF is that it exclusively considers climate-related impacts. This results in the potential for trade-offs between different environmental impacts, which are not taken into account in the PCF. For example, a low carbon footprint does not provide any information on factors such as resource use, biodiversity loss, or human health risks associated with particulate matter. It is thus possible that recommendations for action based solely on the result of the PCF calculation may result in increased environmental impacts. Consequently, it is crucial that any communication regarding the PCF always be limited to climate-related impacts. It is not feasible to make universally applicable assertions regarding the environmental compatibility or sustainability of a product based on the PCF alone. The PCF provides a single metric for a product's environmental performance, and it should not be used as the sole criterion for sustainability decisions.

A further challenge that must be addressed is that of ensuring comparability of PCFs. Even when identical calculation standards are employed, discrepancies such as the selected system boundaries can significantly impact the comparability of results. While the designation of system boundaries may be considered transparent, this does not inherently facilitate a comparison of products. Furthermore, uncertainties result from the assumptions that must be made, reported, and justified in the calculation, which further complicates the process of comparison.

Another critical aspect is that of emission factors. Although these must be verifiably stated and their quality documented, there can be considerable deviations due to differences in collection methods, geographical differences, and the timeliness of the data. This can lead to a distortion of the PCF result, which in turn makes it even more difficult to compare different products.

In conclusion, while the PCF is a valuable tool for evaluating the climate impact of products, it is not without limitations. It is important to recognize that the PCF only reflects a narrow aspect of the overall environmental impact, and therefore should not be viewed in isolation.

5.2 Adaptation to Changing Standards and Legislation

A significant limitation of the PCF calculation tool is the difficulty of maintaining its currency considering evolving external conditions. The standards and requirements in the field of climate protection are subject to continuous change, necessitating the adaptation of the calculation tool to align with current methodologies and requirements. The field of climate protection is characterized by a dynamic evolution, with scientific advancements continuously informing new insights. These insights are incorporated into legislative frameworks, such as the CSRD, and into standards, such as the SBT, influencing the requirements for calculating carbon footprints.

It is essential to ensure that emission factors, which are subject to regular updating in emission factor databases, are also updated on a regular basis in the PCF calculation model. Otherwise, there is a risk of a reduction in the quality of the temporal representativeness of the data. To guarantee the currency of the calculation tool, it is essential to define the internal responsibilities of those with the requisite expertise to oversee the requirements and ensure the regular updating of the data. These managers are tasked with monitoring the latest changes in the standards and laws and integrating them into the calculation tool.

Another significant consideration is the documentation of modifications to the calculation tool. It is crucial to document all adjustments to guarantee the traceability of alterations in the outcomes. This is also essential to facilitate external audits, when necessary, and to substantiate that the calculations align with the prevailing requirements. A dedicated table has been incorporated into the PCF calculation tool in Excel for this specific purpose, which provides a listing for possible modifications. However, ensuring the accuracy and reliability of this table is a significant challenge, as it necessitates a high level of discipline and precision, and clearly defined accountability.

Despite best efforts, there will always be a certain time lag inherent in the process, making complete timeliness difficult to guarantee. While clear responsibilities, continuous monitoring, and updates can help to minimize this discrepancy, it cannot be completely eliminated.

In sum, it can be stated that the process of adaptation to evolving standards and legislation is an ongoing challenge. To guarantee satisfactory quality and time-sensitivity in PCF calculations, it is imperative to implement a system of continuous monitoring, regular updates, and comprehensive documentation. Nevertheless, the necessity for absolute up-to-date accuracy is an inherent limitation.

5.3 Technological Limitations and Restrictions

The calculation of the PCF using an Excel-based tool is associated with a number of technological challenges and limitations, which must be taken into account when interpreting the results.

The high degree of complexity within the master data structure presents a significant challenge to the automation of the calculation tool. The introduction of new products necessitates the manual input of data into the relevant databases. While the automated display of calculations and results is a guaranteed feature, the manual input of data remains a considerable effort, particularly in the case of emission factors, distance calculations, and the allocation of energy consumption for various steps of the production process.

The databases on which the calculation tool is based are still in the developmental phase. The requisite data is not yet available for a significant proportion of the products in question. Nevertheless, once additional products with the required data have been incorporated into the model, the calculation of new PCFs will become considerably more straightforward, as the necessity for the addition of further data will be greatly reduced.

Another limitation is that electrified appliances are not included in the calculation model, given that no calculation of the use phase is provided for. Should such a calculation become necessary in the future, it would entail a significant increase in the required effort, as the use phase would need to be modeled in great detail and integrated into the overall process.

The public accessibility of PCF data, for instance in the web store, necessitates a connection between the Excel calculation tool and the ERP system. Such a link would facilitate automation, which would display alterations to products on an ad hoc basis and thus guarantee that the data is current. However, such a link has not yet been implemented, which negatively affects the efficiency and timeliness of data publication.

The Microsoft Excel application has not been designed with the capacity to efficiently process large amounts of data. When confronted with extensive data sets, the system's performance is constrained, which can potentially impact the reliability of the calculation tool. To attain a scalable and robust solution, it is essential to utilize specialized software tools that are optimized for processing an extensive quantity of data.

The evaluation of the PCF calculation tool in Excel demonstrates its utility as a basis for calculating PCF. However, in order to ensure the most accurate and efficient calculation of PCFs, it is essential to consider the limitations of the tool and incorporate them into its further development and use.

5.4 Data Availability, Quality and Uncertainty

The calculation of the PCF is dependent on the availability and quality of data collected throughout the entire value chain. However, the low level of data exchange along this chain presents a significant challenge. Obtaining data from direct suppliers is difficult, and data

from Tier N suppliers is almost inaccessible. Even when data is collected by querying suppliers, verifying the quality of this data is challenging. Nevertheless, the quality of the PCF is directly dependent on the quality of the underlying data.
Furthermore, internal data is not always fully available, as it necessitates extensive measurements. Consequently, secondary data and estimates based on assumptions are frequently employed in practice. The overall quality of the results may be significantly compromised, particularly if the underlying assumptions are based on unrepresentative facts that do not apply to the specific product or system. This may occur, for instance, in the event of regional differences or insufficient temporal representativeness.

The reliability of the PCF results may be compromised by the inevitable inaccuracies in the preparation of a GHG inventory. In order for the results to be deemed fit for purpose in internal product management decisions, it is essential to document and assess these inaccuracies. In accordance with the GHG Protocol, there are three categories of inaccuracies that must be considered: parameter uncertainty, scenario uncertainty, and model uncertainty.
Parameter uncertainty describes the uncertainty associated with the model parameters, including emission factors and activity data. These parameters are typically intended to represent quantitative data, but this is not always possible due to limitations in measurement accuracy or the presence of data that is not representative of the underlying phenomenon. In order to assess the uncertainty associated with these parameters, a sensitivity analysis is often employed to calculate the probability distribution of potential values.
Scenario uncertainty is a consequence of methodological flexibility. While calculation standards such as the GHG Protocol or ISO 14067 mitigate this type of uncertainty by establishing standardized requirements, there is still scope for decision-making when selecting methodologies within a standard. This includes, for example, the allocation of process emissions or end-of-life assumptions. Scenario uncertainty is quantified through scenario analyses, which evaluate and compare the results of different methods.
Model uncertainty refers to the inherent limitations associated with the utilization of models as a representation of reality. It is not feasible to construct a model that fully and accurately represents reality. This results in inaccuracies and uncertainties. In contrast to parameter and scenario uncertainties, which also arise from the model-based representation of reality, model uncertainty refers to the lack of completeness and accuracy in the overall representation of reality.

In conclusion, it can be stated that the quality and availability of the data, in addition to the various uncertainties, present considerable challenges for the PCF calculation. To guarantee the reliability and applicability of the findings, it is essential to diligently document and assess these variables.

6 Discussion and Critical Review

6.1 Assessment of the Practical Application of the Tool

The research question and the subordinate objectives outlined in chapter 1.2 were employed to assess the outcomes of this study.

A PCF calculation tool has been developed in Excel to facilitate the calculation of the PCF for products manufactured by TAKKT. Nevertheless, it remains unfeasible to automatically calculate the PCF for each product derived from in-house production, despite the incorporation of all pertinent product-specific data into the tool's databases. At present, this is only feasible for products comprising exclusively materials for which emission factors have been previously stored in the databases, sourced from suppliers recorded in the databases, and requiring no additional production steps beyond those documented in the databases. In the case of products that necessitate supplementary materials, additional suppliers, or further production phases, it becomes essential to extend the calculations within the tool. This can be achieved with greater ease through the utilization of the tool in comparison to a "greenfield" approach. This is due to the fact that the tool provides a framework, comprising analogous calculations, which facilitate the attainment of the methodological standards of the GHG Protocol. Furthermore, the computations are predefined by linking within the file, thereby enabling the automatic generation and presentation of the results.

Following a comprehensive comparative analysis, the GHG Protocol has been selected as the most appropriate calculation standard for the methodology. The GHG Protocol is aligned with TAKKT's corporate objectives and provides detailed guidance that facilitates the initial calculation of a PCF. However, the selection has been significantly influenced by the financial constraint of a free standard. In this regard, it should be noted that financial limitations also influenced the choice of the emission factor database.

The internal and external requirements were compiled and, with few exceptions, incorporated into the tool. Such requirements include, for instance, the retention of internal data sovereignty and the ability to identify emission hotspots. It is important to note that not all PCFs are currently available on request, as required, due to the fact that the databases have not yet been expanded to include all products. Prior to the publication of the results and their utilization for customer inquiries, it is necessary to conduct an evaluation of the necessity for an external audit. In the absence of an external audit, there is a risk that the results will be perceived as lacking credibility. In addition, it is important to note that an external audit serves to verify and secure the basis for internal decisions regarding reduction measures that affect the company's objectives.

The utilization of standardized parameters, including system boundaries, assumptions, and methodological approaches, within the calculation tool ensures the comparability of product results. The specific parameters are clearly defined and thoroughly documented within the Excel calculations.

The tool is designed to accommodate evolving requirements and standards through manual and internal modifications, as outlined in section 5.2. The responsibilities associated with this process have yet to be defined. In order to enhance the quality of the data, it is essential to achieve an internal consensus regarding the allocation of resources, given that this process is considered to be time-consuming and resource intensive. Moreover, close collaboration with suppliers is necessary, during which procedures for data collection and regular data updates must initially be established. Additionally, measurements should be conducted within the company processes to replace secondary data with primary data. This is a stipulation of the GHG Protocol for processes under the company's control, with the objective of enhancing data accuracy. The implementation of measurements necessitates the allocation of an appropriate level of resources.

To summarize, the PCF calculation tool that has been developed can be considered a significant reduction in the complexity of the process. However, it is important to note that not all products can yet be recorded in an automatic manner. Further internal resources and close cooperation with suppliers are necessary to fully automate and improve data quality. Despite the inability to guarantee complete up-to-date functionality, the tool provides a valuable basis for calculating and comparing PCFs.

6.2 Opportunities and Further Possible Development

6.2.1 Internal Use and Optimization Opportunities

The following section is intended to demonstrate the possible applications of the PCF calculation tool in Excel, particularly in relation to internal processes, and to illustrate the potential for optimization.

In the context of internal use, it is necessary to determine which individual or entity is clearly assigned responsibility for ensuring the timely updating, maintenance, and improvement of the data. Three departments are of particular significance in terms of the utilization of the calculation tool. The sustainability team is comprised of individuals with the requisite expertise, and thus the tool would be a valuable asset for monitoring and attaining sustainability objectives. The utilization of the calculation tool facilitates the identification of reduction potential, thereby contributing to the achievement of reduction targets. The tool may be employed initially to calculate the base value of the PCF. In consequence, reduction opportunities are identified, and corresponding targets defined. The tool can be used to identify and record the progress and achievement of reduction targets in percentage change compared to the baseline value. (Bhatia et al., 2011, p. 109) The in-house production development department is an optimal choice for conducting simulations of new products. The product data is available in this area, facilitating efficient and streamlined modifications without the need for numerous intermediate steps. Moreover, the development phase offers the greatest depth of knowledge about the products. The category management department provides the input data for the product characteristics displayed on the e-commerce platform. Once the external verification process is complete, the results of the PCF calculations can also be displayed. These will then also fall under the responsibility of this department. Moreover, the department possesses not only comprehensive product expertise but also a close working relationship with the company's other suppliers. Inquiries are already made to these suppliers regarding the availability of PCF results for their respective products. The calculation tool developed provides users with a more comprehensive understanding of the data requirements and the calculation methodology for determining a PCF, thereby facilitating more effective supplier discussions.

The GHG Protocol suggests the implementation of a particular process to enhance the quality of the data. (Bhatia et al., 2011, p. 58) The initial step is to identify data of poor quality, after which new data must be collected to replace it. If newly collected data is determined to be of comparable quality to the original data, it is recommended to continue utilizing the original data until superior quality data is available and to concurrently collect new data. Given the significant impact that data quality has on the overall quality of the PCF, it is imperative that this process be accorded a high degree of priority. In the event of resource scarcity, the GHG Protocol suggests focusing on the emission sources with the greatest proportional impact. (Bhatia et al., 2011, p. 55)

The availability of data can be enhanced through the utilization of questionnaires administered for suppliers. This enables the substitution of assumptions with tangible supplier data, thereby facilitating an additional enhancement in data quality. The GHG Protocol presents the option of documenting and reporting information regarding the proportion of suppliers who participated in the surveys, the data collection methods employed, and the sources utilized. (Bhatia et al., 2011, p. 107)

Another optimization option of the PCF tool is scenario modeling. It permits a comparative analysis and evaluation of prospective modifications to products. Both minor alterations, such as the substitution of an energy-intensive material with a recycled one, and more substantial modifications, such as the transition to renewable energies or the acquisition of more energy-efficient machinery, can be assessed in terms of their potential impact for climate-related optimization. This approach can also be valuable for the evaluation of new products as part of the product development process.

The implementation of the PCF calculation tool presents opportunities for internal utilization and enhancement of sustainability performance, while also offering potential for further optimization. It is important to clearly define responsibilities, enhance data quality, and facilitate greater data accessibility. Furthermore, scenario analyses and the definition of reduction targets contribute to the achievement of pre-established sustainability goals.

6.2.2 Transferability to Other Companies and Industries

One of TAKKT's objectives is to enhance the number of PCFs submitted by suppliers. This is due to the fact that these are also subject to customer requests, and therefore, it is beneficial to provide support in the creation of PCFs for their products. The logic of the PCF calculation tool in Excel has been demonstrated to be an adoptable model, especially for small and medium-sized companies whose value chain is generally not as complex and comparable to that of TAKKT. However, the utilization of this instrument necessitates a specific degree of expertise, as it must be adapted to the distinctive characteristics of the individual product, including the materials employed, the transportation routes utilized, and the work processes involved. A significant challenge is to develop the calculations in a manner that ensures their universal validity, thereby enabling their application to a range of products. The model can be applied to similar products with comparable complexity, no emissions during the use phase, and similar life cycles with minor adjustments. However, product-specific data must be entered manually. It should be noted that individual calculations, such as emissions from production processes, are highly company-specific and must be adjusted after data input. The same is applicable to transportation emissions. In contrast, the calculations of material emissions are relatively universal and require fewer adjustments when new products are added.

The initial model has been designed with the objective of calculating PCFs as part of TAKKT AG's in-house production process. However, future deployment in collaboration with suppliers necessitates additional development steps. The model should for example be extended to allow for the adaptation of life cycle phases and the incorporation of production processes with minimal effort.

In conclusion, it can be stated that the PCF calculation tool in Excel has the potential to be transferred to other companies and sectors, particularly those with comparable product structures. The flexibility of the tool allows for broad applicability through specific adaptations. However, there is still a necessity to provide expertise to customize and maintain the data and calculations to ensure accurate and reliable results.

7 Conclusion

7.1 Key Findings

This thesis aims to examine the potential and limitations of automating the calculation of PCFs for an entire in-house production product portfolio, based on Excel calculations.

The results demonstrate that the implementation of a calculation model that automates the PCF calculations to the greatest extent possible is a viable and successful approach. However, the quality and accessibility of the data necessary for calculating the PCF is fundamental for practical implementation within organizations. Thus, it is essential that TAKKT invests in this to improve the accuracy and reliability of the resulting PCF data.

The study illustrates that the GHG Protocol represents the optimal choice for companies with comparable requirements to those of TAKKT. While the calculation standards PAS 2050, ISO 14067, and the GHG Protocol entail similar requirements for the calculation of a PCF, this decision is ultimately contingent upon the specific internal and external requirements of the company, as well as other considerations such as technical expertise and business objectives.

The developed calculation tool is already capable of calculating the PCFs of six products, and it allows for the calculation of additional PCFs with minimal additional effort. Nevertheless, the quantity and intricacy of the data, which ultimately results in an exceedingly complex data structure for the Excel calculation tool, must not be underestimated.

The findings of this study indicate that the tool is particularly applicable for calculating the PCF of products that are characterized by low complexity. However, the assessment of suitability for complex products reveals that the automation created is only marginally useful, as a significant number of supplementary calculations would be necessary for the use phase, for instance. This is particularly evident in the case of the limited number of individualized and electrified products from TAKKT.

In contrast with the initial intention of this study, it proves unfeasible to devise a calculation model for every product produced by TAKKT in-house as part of this work. Nevertheless, a framework with automated calculations and presentation of results has been developed that significantly simplifies the calculation of further products and fulfills the identified requirements. This is achieved by using a database logic, developing a transparent and documented calculation methodology, and aligning the framework to the GHG Protocol guidelines.

The development of the tool is based on a solid, scientifically validated calculation methodology of the PCF. As such, it can be expected that an external audit would confirm its validity. The Excel tool provides a robust preliminary assessment of the emissions generated by a product.

A detailed examination of potential future actions is provided in the following section, and it is advised that these be considered.

7.2 Outlook

The ongoing enhancement of the PCF calculation tool in Excel presents a multitude of opportunities for a more thorough evaluation and optimization of the environmental impact of products. A significant advancement would be the incorporation of PCF calculations into a comprehensive LCA. This approach would facilitate the incorporation of a broader range of environmental considerations, including carbon emissions, as well as other impacts such as water consumption, acidification potential, and ozone depletion. This would facilitate a more informed evaluation of the environmental impact of products.

To ensure the optimal utilization of the tool in external contexts, such as marketing initiatives, it is recommended that an external audit be conducted. The presentation of the data in a readily comprehensible manner to customers would enhance the clarity and accessibility of the resulting information. Such a comparison could be made, for example, between the performance of two products. By contextualizing the figures in this manner, the insights derived from the analysis can be perceived as more meaningful and actionable.

Cooperation with suppliers also presents a significant opportunity for improvement. By jointly calculating the PCFs of purchased products, both the customer's requirements and the company's own scope 3 emissions from purchased goods can be met with greater precision. This represents a mutually beneficial scenario, as both TAKKT and the suppliers stand to gain from an enhanced database.

It appears feasible to extend the sustainability targets to encompass explicit reduction targets for PCFs. One potential methodology would be to define a percentage reduction target that is relative to the value of a specified base year. In alignment with TAKKT's preceding sustainability objectives, the targets should also correlate with the Sustainable Development Goals (SDGs) established by the United Nations, thereby illustrating the extent to which the TAKKT Group is contributing to the realization of these global objectives.

This outlook presents an overview of evident and, in some instances, essential recommendations for action, some of which can be implemented with minimal effort. These include, for example, the definition of reduction targets based on the results of the PCF. In contrast, other recommendations are resource- and time-intensive. These include the creation of an LCA or the external review of the calculation tool. It is therefore necessary to prioritize and adapt the subsequent measures to the corporate strategy and the current company situation.

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