NORDDESIGN CONFERENCE
REYKJAVIK, ICELAND, 12-14 AUGUST 2024

Revealing Methodological Approaches to Account for Circular Economy in Support of the Science-Based Targets for Carbon Emissions

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Abstract: This article analyses and proposes a few methodological approaches to account for carbon emissions of circular economy strategies within manufacturing companies designing circular products and services and to report their emissions reduction targets under the Science-based Target initiative (SBTi). We specifically reviewed the current accounting formulas for two strategies that cannot be currently accounted for Scope 3 emissions: 'Lowest suitable grade' and 'Technical product longevity'. Our results provide potential solutions to account for these strategies before reporting back to the SBTi.

Keywords: Circular Economy, Carbon Emissions, Product Lifetime, Sustainability

1 Introduction

Over recent years, there has been growing theoretical and empirical supporting evidence on how shifting from linear to circular economy (CE) models can contribute to reducing global environmental challenges such as waste, pollution and climate change (Çimen, 2021; Hailemariam and Erdiaw-Kwasie, 2023; Yang et al., 2023). Within the global corporate sector, more and more companies have started their journey towards circular economy by experimenting with new circular business models and using circular strategies for the design and support of multiple products and services (Pieroni et al., 2019; Pigosso and McAloone, 2021; Ünal and Shao, 2019). Such a transitioning process towards CE could also represent a valid strategy for companies to achieve their corporate climate actions and to support the United Nations Framework Convention on Climate Change (UNFCCC) response in stabilising the global increase in temperatures between 1.5° to 2° Celsius by 2050 (Fink, 2018; Zomer et al., 2022).

Corporate climate actions have become more ambitious after the 2015 Paris Agreements due to the introduction of the Science-Based Targets initiative (SBTi). Led by the UN, WWF and CDP, SBTi is recognised as a consolidated global organisation that engages thousands of companies around the world to implement ambitious carbon reduction targets (SBTi, 2023a). Companies can voluntarily adopt carbon reduction targets that work as complementary corporate targets to the Paris Agreements (Bjørn et al., 2022; Rekker et al., 2022). The SBTi has shown that the targets have been quite effective until today in reducing CO2e emissions of the corporate sector (up to 30% of Scope 1 and 2 emissions between 2015 and 2020) (SBTi, 2023b). Nevertheless, overall performances still require evaluation and several studies indicate the potential of diverging results (Giesekam et al., 2021; Ruiz Manuel and Blok, 2023).

For many companies, transitioning the business model from linear to circular could help reduce carbon emissions, and implementing circular economy strategies (e.g., product design for circular economy) might bring effective solutions to achieve the SBTi targets. Today, there are many examples of companies that can already gain economic benefits and improve their environmental performance from implementing circular economy strategies (Blomsma et al., 2019). One example is the company Fairphone (www.fairphone.com) which designs and manufactures modular smartphones that allow the users to replace and upgrade individual parts of the phone such as components and parts, enabling in most cases to successfully extend the smartphone lifetime.

Companies that decide to implement CE strategies to achieve the SBTi can use the Greenhouse Gas (GHG) reporting guidelines, such as the GHG Protocol (GHGP) Standards (GHGP, 2015, 2013, 2004), to calculate the circularity impacts on their product and services in terms of CO2e emission reduction and report back their performance to SBTi. Manufacturing companies can account for a wide range of CE strategies' emissions in all GHG Scopes 1,2 and 3 by using the GHGP [1]. Nevertheless, the GHGP lacks calculation formulae to account for a few important CE strategies in Scope 3

[1] GHG emissions' Scopes are the types of categories of emissions accountable by organizations at a universal or standard level. Scope 1 emissions refer to the direct emissions of an industry sector or company (e.g., combustion of fuel). Scope 2 emissions relate to the indirect emissions caused by the purchase of energy/electricity that allow for a company's industrial activity. Scope 3 emissions are indirect emissions that occur because of the company's operations along the entire value chain, from the upstream to the downstream level.

emissions (which comprises about 75% of total manufacturing sector's emissions), thus effectively discouraging their adoption (Hertwich and Wood, 2018). Scope 3 emissions are indirect emissions resulting from an organization's activities but from sources not owned or directly controlled by that organization. For instance, when a company buys products and services or its employees travel to work, they generate emissions. Accounting for these emissions means considering the environmental impact of the organization's entire supply chain and business activities (Scalbi et al., 2021).

The calculation formulae that might be limiting for accounting CE emission reduction potentials are within Category 1 ('Purchase of Goods and Services') and Category 11 ('Use of Sold Products') of the Scope 3 emission GHGP inventory (Marini et al., 2024). In Category 1, a formula is missing to account for the CE strategy 'Lowest suitable grade' material selection within the 'Restore, Reduce & Avoid' Category of the CE Scanner proposed by Blomsma et al., (2019). According to this strategy, it is possible to pursue a prioritisation of materials used as inputs for the manufacturing processes of products for example by deciding to use a more precious material as input for a certain industry process or task and choosing a lower quality material as a substitute. In the construction sector, for example, sustainable materials such as fly ash, ground granulated blast furnace slag, silica fume and other secondary materials might be used in substitution to cement utilization and reduce CO2 emission (Shah et al., 2022).

The second formula relates to Category 11 ('Use of Sold Products') and in particular the CE strategies ('Technical product longevity', 'Subjective product longevity' and 'Low consumables') within the 'Restore, Reduce & Avoid' Category, all the strategies within the 'Recirculate' Category and the strategies within the 'Rethink and Reconfigure' Category of the CE Scanner. A company or organisation implementing this formula may be discouraged from increasing the lifetime of their products, since more emissions will have to be reported over the reporting periods in agreement to the GHGP formula for Category 11 (Section 2.2), potentially hindering the ongoing achievement of the SBTi targets. This might lead to major circular trade-off issues (e.g., when pursuing a CE strategy might lead to an increase in the total emissions) for manufacturing companies. CE trade-offs represent a big challenge for companies' practitioners due to their limiting effects in reducing emissions (Berlin, 2023; Kravchenko et al., 2021; Ünal and Sinha, 2023; Zomer et al., 2022)

The main goal of this paper is to discuss the methodological limits of existing calculation formulae that are either missing or in need of refinement within Scope 3 Category 1 and 11, and correctly define and propose alternative calculation formulae to be considered by the 2023-2024 GHGP Scope 3 reform process (GHGP, 2023). Important limits (i.e., clear existing trade-offs) within the formulae were considered to correctly define solutions for manufacturing companies to support their SBTi potential achievement. This is in line with the calls from the latest survey carried out by the GHGP between November 2023 and March 2024 that request a revision of the latest (2013) available GHG guidelines that are more inclusive of the SBTi methods (GHGP, 2023).

Our main research questions were: How can we make sure companies can implement these CE strategies to achieve carbon reduction? How can we make sure they implement these strategies without getting penalised toward achieving carbon reduction (E.g. implementing this strategy will not necessarily increase their overall emissions that need to be reported to the SBTi)?

2 Methodology applied

2.1 Documentation review

This study consisted of selecting all the missing/ineffective formulae to account for CE strategies emissions at the level of Scope 3 Categories for a generic manufacturing company. The latter were previously identified by accounting for all the possible lists of CE strategies that a manufacturer might use to report their emissions to the GHGP (Blomsma et al., 2019; Marini et al., 2024). The major focus was at the level of Scope 3 emissions where the manufacturing industry contributes primarily in terms of GHG emission (up to 70-80% of the total footprint) (CDP, 2023; Hertwich and Wood, 2018; Lloyd et al., 2022; Stenzel and Waichman, 2023). However, as certain CE strategies applied at the Scope 3 level might be able to influence Scope 1 and 2 emission levels, the latter were also considered in the overall analysis to avoid disregarding their potential effects.

Thereafter, information was collected regarding how to improve incomplete or missing formulae within the GHGP by screening the current literature and documentation in the field. In particular, the latest available GHGP accounting documentation (GHG Protocol, 2013) was analysed, as were the SBTi requirements regarding emission reporting and monitoring (SBTi, 2023a).

Furthermore, recent reports referring to the concept of avoided emissions were consulted in order to disregard potential avoided emissions from our analysis, which are not allowed to be accrued from the emission categories of the GHGP (Stephens and Thieme, 2020; Valeri et al., 2023). Finally, calculation results were refined, based on a few expert consultations (i.e. emission accounting experts) and internal iterations within the authors´ research team.

2.2 State-of-practice: The current GHGP formula for extended lifetime (Scope 3 – Category 11)

Based on the GHGP Scope 3 documentation for Category 11 (GHG Protocol, 2013), the following accounting formula is the main formula used by companies to account for direct emissions during the use of products over their lifetime.

*Σ (Total lifetime expected uses of product * number sold in reporting period * fuel consumed per use (kWh) * emission factor for fuel (kgCo2e/kWh)* [2]

When a manufacturing company implements CE strategies to extend the use phase (Cat. 11 – Scope 3) of a product/service, the present GHGP calculation formulae can be limiting: As the formulae multiply the expected emissions of a product service (over its lifetime) by the quantity of CO2e emissions per use, an extension of the 'technical product longevity' of product/services (or increasing the total lifetime expected uses of products), will necessarily lead to an increase in the overall reported Scope 3 emissions.

It is important to notice that the GHGP formulae (Cat. 11 – Scope 3) might be able to account for a reduction in emissions (that can be reported only in the long term) when the quantity of sold products with a longer lifetime is reduced over time (i.e., if the product lasts twice the amount of time of a reference, only half the amount of products will be needed to fulfil the same needs). However, despite the occurrence (or not) of this effect (which still needs to be investigated), a company might start selling an increased quantity of products by extending the lifetime, thus counterbalancing expected emission reduction effects (Jensen et al., 2021). This is particularly true in some geographical areas where consumers (depending on their lifestyles) are inclined to purchase new products or replace them more often than in other countries.

2.3 Simplified case study approach for Category 11 of GHGP

To better explain the numerical functioning of the new formulae, a simplified case study was created, consisting of two scenarios in which two different products were purchased from a manufacturing company. In a car scenario, we considered the purchase of 10 products that consume energy during their lifetime (i.e., 10 cars); in a bike scenario, we considered the purchase of 10 products that do not consume energy during their lifetime (i.e., 10 bikes) (Table 1).

Table 1. Main numerical variables for the case setup

Products considered	Product uses per year (n)	Fuel consumed (kWh)	Fuel emission factor (kg CO2/kWh)	Emissions for production (kg CO2e)	Emissions from new parts/materials (kg CO2e)
Car	100	2	1,5	5000	50
Bike		0	0	100	10

In both car and bike scenarios, we then explored the effects of implementing a CE strategy to increase the lifetime of a product during its use phase by two years, for example by enhancing the product robustness with additional materials or the provision of repair services from the manufacturing company (substituting faulty parts and components) for a product.

2.3.1 Application example

Below, we provide a numerical example of the current GHGP formula for Cat. 11 introduced in Section 2.2 based on the car scenario from the previous case study example (Table 1 – Section 2.3). A car manufacturer decides to report their Scope 3 Cat. 11 emissions in a reporting period of one year (i.e., the usual period of reporting used) for 10 cars sold that would last three years - or 100 times in terms of use. The company can then account for its Scope 3 (use) emissions by using the current GHGP formula:

*Σ (Total lifetime expected uses of product * number sold in reporting period * fuel consumed per use (kWh) * emission factor for fuel (kgCO2e/kWh)) = 100 * 10 * 2 * 1.5 = 3000 kg/CO2e*

However, in the same reporting period, the company might also have implemented a CE strategy to increase the expected use of the cars sold by two years - or 66.6 times in terms of use (see below).

*Σ (Total lifetime expected uses of product * number sold in reporting period * fuel consumed per use (kWh) * emission factor for fuel (kgCO2e/kWh)) = (100 + 2/3 * 100) * 10 * 2 * 1.5 = (100 + 66.6) * 10 * 2 * 1.5 = 5000 kg/CO2e*

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[2] We adopted this GHGP formula as representative to account for emissions due to fuel consumption. However, the GHGP also provides formulae to account for electricity-driven energy consumption and indirect energy consumption of products (GHG Protocol, 2013). These other formulae might also be used as alternatives in this study.

Using the same GHGP formula, the amount of emissions that would be reported due to an increase in the use of products relative to two years would be equal to 5000 kg/CO2e. Therefore, the incentive to extend the lifetime of products is limited.

We aimed therefore to modify the GHGP formula to remove these discouraging results (i.e. more emissions to be reported) associated with extending the product's lifetime for a manufacturing company. The goal was to develop a formula that is better inclusive of *all* the consequences regarding the increased lifetime of products. An expected successful target for this formula is that the increased lifetime CE strategy might not necessarily increase a company´s overall emissions to report and, hence, might not discourage the company´s decision to implement this strategy for achieving the SBTi targets.

3 Results

3.1 Scope 3 – Cat. 11 (Use of sold products): Defining an accounting method inclusive of the 'Technical product longevity' and related CE strategies

The following equations were developed to account for the possibility of increasing the product lifetime (or, how many times this product will be used over time) starting from the formula developed by the GHGP in relation to one type of product from a company's portfolio (Section 2.3).

$$Ei = \Sigma \text{ (Total lifetime expected uses of product * number sold in reporting period * fuel consumed per use (kWh) * emission factor for fuel (kgCO2e/kWh))} \quad (1)$$

$$ES_3 = Py * [(y/x * Ei/Px) + (Enm)] \qquad \text{where } Px > 0 \quad (2)$$

$$ET_3 = Ei + ES_3 \quad (3)$$

$$ES_{1+2} = Py * (y/x + Emp) \quad (4)$$

$$ET = ET_3 - ES_{1+2} \quad (5)$$

Where *Ei* is the total direct emissions during products use in their "standard" lifetime – from the original GHGP formula; ES_3 is the total Scope 3 direct emissions during the use of products with extended lifetime (where the implemented CE strategy increases the 'Technical product longevity'); ET_3 is the total emissions during products (direct) use with and without extended lifetime; ES_{1+2} is the total Scope 1 and 2 emissions from the production of products with extended lifetime; and *ET* is the hypothetical total emissions a company should report by extending the lifetime of products.

Within Eq. *(2)* and *(4)*, *x* is the number of current (expected) uses of products during the lifetime of the product, *y* is equal to the number of additional (expected) uses given to a product (after extending their lifetime), *Py* is the number of products sold with extended lifetime in the reporting period, *Px* is the number of products sold without extended lifetime in the reporting period, *Enm* are the emissions in kg/CO2e due to the new materials used to extend the lifetime of the product, *Emp* are the emissions in kg/CO2e related to the production processes (considering Scope 1 and 2) for the products *Py*.

If a company decides to increase the lifetime of its product by increasing its uses relative to e.g. two years, equation *(4)* allows it to add (or eventually subtract – in case of negative emissions) the amount of emissions that are expected to occur during the two additional years based on the direct use, assuming the same emission factors for both *Px* and *Py*. Equation *(5)* represents the (avoided) production costs (in terms of emissions) associated with the extended lifetime products that are detracted from the direct emissions caused due to both the "standard" and "extended" lifetime use of products.

3.1.2 Car scenario

We assessed the car scenario by applying equations *(1)*, *(2)*, and *(4)*. The company might account for the 10 cars with a standard expected number of uses per year (100) to account for the extended lifetime of two years (66.6 car use time).

$$Ei = 100 * 10 * 2 * 1.5 = 3000 \text{ kg/CO2e}$$

$$ES_3 = 10 * (0.66 * 3000/10) + 10 * 50 = 1980 + 500 = 2480 \text{ kg/CO2e}$$

$$ET_3 = 3000 + 2480 = 5480 \text{ kg/CO2e}$$

$$ES_{1+2} = 10 * (0.66 * 5000) = 33000 \text{ kg/CO2e}$$

$$ET = 5840 – 33000 = - 27160 \text{ kg/CO2e}$$

Using Eq. *(3)* a company would report more emissions than the original GHGP formula (Eq. *(1)*) due to the extended product emissions.

However, by implementing Eq. *(4)* we can quantify the avoided emissions costs of not producing new cars due to the increased lifetime of the cars sold. Overall, Scope 1 and 2 emissions would have a high reduction impact on the total emissions of the same company (33000 kg/CO2e avoided). Implementing Eq. *(5)* we obtained a saving emission potential of 27160 kg/CO2e.

Eventually, all equations can also be used together in an overall accounting process where only one part of the products sold have an extended lifetime. For example, during the same year of reporting, a company can account for part of their cars sold (e.g., 8) with a normal lifetime of three years using *(1)* and part of their cars sold (e.g., 2) with an extended lifetime of two years using. Substituting in numbers we obtained:

$Ei = 100 * 8 * 2 * 1.5 = 2400\ kg/CO2e$

$ES_3 = 2 * (0.66 * 2400/8) + 2 * 50 = 396 + 100 = 496\ kg/CO2e$

$ET_3 = 2400 + 496 = 2896\ kg/CO2e$

$ES_{1+2} = 2 * (0.66 * 5000) = 6600\ kg/CO2e$

$ET = 2896 – 6600 = - 3704\ kg/CO2e$

As a result, applying Eq. *(4)* resulted in an increased total amount of emissions (2896 kg/CO2e compared to 2400 kg/CO2e in the reporting year for Scope 3, Cat. 11). However, if we subtract the resulting emissions from Eq. *(3)* from Scope 1 and 2 emissions (Eq. *(4)*), the estimated total amount of emissions saved would be 3704 kg/CO2e.

This result would occur when the company decides to implement a lifetime-increasing strategy for a car. This might encourage the implementation of other similar related CE strategies to increase the use phase of their products (i.e. cars) to achieve a reduction in Scope 1, 2 and 3 emissions.

However, companies should be aware of the risks of double accounting. For example, for the *Enm* parameter it is necessary to consider Scope 3 emissions related to the purchase of new/additional materials or eventually/additional capital goods that allow the product to become more robust or to be efficiently repaired to support a longer utilisation period. It is therefore necessary to ensure a proper understanding of the formulae by at the same time prescribing a simple application logic to be followed systematically.

3.1.3 Bike scenario

In the bike scenario, we implemented the new equations for a bike:

$Ei = 100 * 10 *1000 * 0 = 0\ kg/CO2e$

$ES_3 = 10 * (0.66*0) + 10 * 10 = 100\ kg/CO2e$

$ET_3 = 100 + 0 = 100\ kg/CO2e$

$ES_{1+2} = 10 * (0.6 * 100) = 600\ kg/CO2e$

$ET = 100 – 600 = -500\ kg/CO2e$

Overall, the total Scope 3 emissions were 100 kg/CO2e, indicating for the bike scenario, a potential reduction in the overall emissions by 500 *kg/CO2e.*

3.2 Scope 3 – Cat. 1 (Raw Materials and Sourcing): Defining an accounting method inclusive of the 'Lowest suitable grade' CE strategy

Figure 1 shows a visual representation of how to potentially account for the differences in Scope 3 emissions due to the change in the quantity or type of material allocation (within their industrial systems, sub-systems, and production processes) when the company implements the 'Lowest suitable grade' CE strategy. To exemplify these results, two timeline scenarios were visualised: one business-as-usual scenario (a) at a time t = t0 visualising an initial product system of a manufacturing company A and a second scenario (b) at a time t = t1 where the same company A implements the 'Lowest suitable grade' CE strategy (Figure 1.a and 1.b).

In the business-as-usual scenario (Figure 1.a), a company is using all different materials (M1-M4) as inputs in the product system which results in three types of final outputs (O1-03). Following the normal GHGP accounting procedure, all the CO2e emissions from the manufacturing processes (P1-P4) will be accounted for as Scope 1, while all indirect emissions related to the upstream inputs (M) and the downstream outputs (O) will be accounted for as Scope 3 emissions. At a time, t = t0 (Figure 1.b) the same company might decide to implement the 'Lowest suitable grade' strategy and eliminate or reduce a certain quantity of materials as inputs (M4 from P4) and dedicate these materials to a "prioritised" process (P1) and/or replace them as inputs (from process P1 to P4). Assuming the same quantity of outputs in both periods, Figure 1 shows that only after the decision to implement a prioritisation of input materials (i.e., at a time t = t1) and after defining the new product system, a company or practitioner will be finally able to account for the CE strategy's emissions. This is because, due to the main modifications expected from this CE (types and quantities of material inputs in the production processes), for a manufacturing company is reasonable to expect a major difference in Scope 1 emissions from t0 to t1, which might also modify the quantity or types of materials supplied as upstream inputs at Scope 3 level. Thus, Scope 1 emissions formula will capture the performance of this CE strategy. Moreover, if a manufacturing company decides to implement this CE strategy and report on Scope 3 emissions to SBTi, it will be necessary to account for Scope 1 and 2 before accounting for Scope 3 emissions since this strategy might be particularly relevant in terms of Scope 1 and 2.

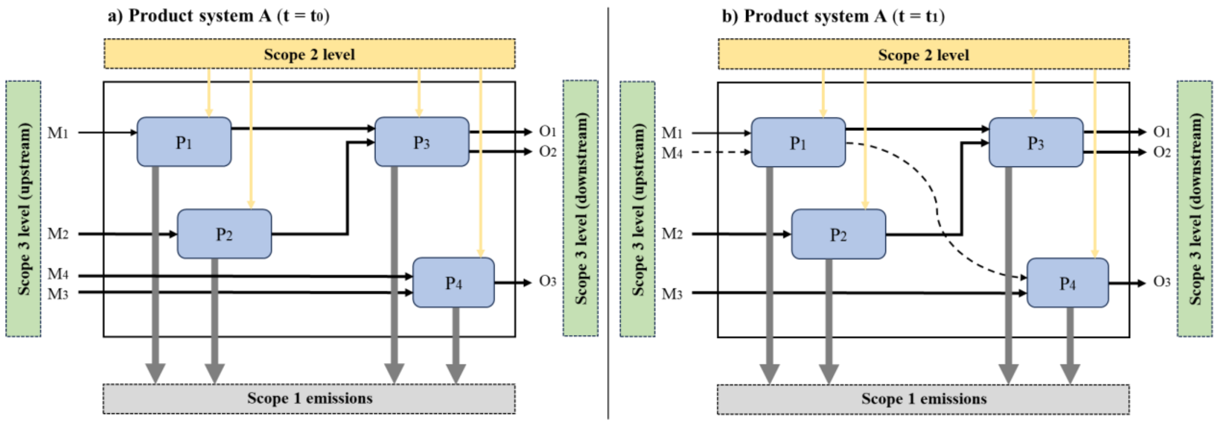

Figure 1. Schematic example and representation of the material flows and Scope 1,2 and 3 emissions from the same product system or industry (A) before (a) and after (b) implementing the 'Lowest suitable grade' strategy. P = Process, M = Material flows.

4. Discussion

This research focused on analysing and developing alternative accounting criteria for manufacturing companies and GHG accounting practitioners when implementing two CE strategies that are currently unaccountable in the GHGP and being able to report on their emissions toward the achievement of the SBTi targets. The focus was on the 'Lowest suitable grade' (Cat.1 of the GHGP) and the 'Technical product longevity' and all related CE strategies (Cat.11 of the GHGP). The scope of this analysis was to establish a bridge between the GHGP accounting procedures and the need of manufacturing companies to report emissions inclusive of all potential CE strategies. Indeed, for many manufacturing companies, designing more circular products can lead them to achieve important potential results for achieving their SBTi targets.

While the 'Lowest suitable grade' strategy did not require the development of an additional formula but rather remarking the importance for companies or practitioners of calculating their emissions after implementing the CE strategy, the 'Technical product longevity' strategy required the definition of an additional formula for Cat. 11 as there is currently no direct incentive for companies to implement a CE strategy for longer lifetime of products to achieve the SBTi. Indeed, the current GHGP calculation formula can correctly consider Scope 3 emissions in the use phase, but companies might exhibit a reduction in emissions only in the long term when the quantity of sold products with a longer lifetime should be, in principle, reduced over time. While more research is necessary to illustrate how the current GHGP formula accrues the emission performance due to lifetime increase of products/services and (in relation to that) fewer products sold over time, developing a more precise formula that includes emissions that will be avoided (already in the first year of reporting to SBTi) because of more durable products/services in operation might create a strong incentive for companies as this paper showed (Farsan et al., 2018).

4.1 Criticalities of the new proposed formula for 'Technical product longevity'

The new/additional formulae presented in Section 3.1 aim to create a stronger incentive for companies to report their emissions, especially for products with increased lifetime. Nevertheless, the new formulae could add a few layers of operational complexity for companies in two main areas. First, the reporting year variable of the formulae might add challenges when companies implement the new formulae to account for a part of extended lifetime products from their product portfolio. For example, if a company decides to report on a five-year reporting period, it might be necessary to discount from the original formulae only the years when the CE strategy of increased product lifetime is expected to enter into force. A second area of complexity might be the deduction/inclusion of Eq. *(4)* (Scope 1 and 2 emissions) from Eq.

(5) (Scope 3 emissions). While in this context avoiding double accounting is fundamental, a proper way for accounting the emission that would not occur because of the extended product lifetime is needed considering Eq. *(2)* and *(3)*.

To calculate *Emp* in Eq. *(4)*, the adoption of Life Cycle Assessment (LCA) methodologies might be utilised by companies to account for the carbon footprint of their single products and services, thus being able to allocate them into the different emissions categories (Scope 1 and 2). In this context, the possibility of bringing the best practices from lifecycle assessment into the way the emissions are calculated in the GHGP would provide incentives to companies to extend the lifetime and deliver the products' functional unit with an overall lower emission impact (Jerome et al., 2022; Kaddoura et al., 2019). Defining a functional unit in the way that Scopes 1, 2 and 3 Categories of emissions are calculated would enable us to assess the benefits of increasing the lifetime of a product: If a product lasts double the amount of time, then it will be required half of the same product to fulfil the same functional unit, and this would minimise the reference flows (how many of the same products are needed) to fulfil that functional unit and meet the market demand.

It is important to notice that the *Emp* emissions are fundamentally different from the avoided emissions concept as they are based on the same quantity of products that would be sold in the same reporting period *anyway*. Therefore, as a general principle, the factor *Emp* is aligned to the original GHGP formula (Section 2.2) that tries to allocate direct-use phase emissions over the lifetime of a product based on the embedded future emissions that need to be accounted for at the present moment - in respect of the Scope 3 accounting philosophy (King, 2022). According to King (2022), Several Scope 3 Categories of the GHGP have to account for future embedded emissions (GHG Protocol, 2011), and the requirements on future assumptions or expectations could also be an increasing source of potential emission trade-offs, similar to the Cat. 11 of the GHGP. More research might be conducted at this level, to evaluate whether the GHGP Scope 3 calculation formulae create emissions trade-offs when implementing circularity and how to possibly address them. Using systemic analytical approaches such as LCA methodologies might help when considering circularity implementation and supporting the avoidance of trade-offs effects for companies (Glogic et al., 2021).

Finally, indirect emissions from product use are listed as optional in the SBTi accounting process (SBTi, 2023a). Nevertheless, Eq. *(2*, *3* and *4)* might be adapted and utilised with the original GHGP to account for indirect emissions during the use phase of a product (if a product indirectly consumes energy during the use phase). In this case, it would be necessary to select and utilise use-phase scenarios that include the total (%) lifetime use of a product and create a weighted average of the indirect emissions of the different scenarios based on the actual activity.

4.2 Alternative solutions for 'Technical product longevity'

This study provided one possible solution for better aligning the GHGP Scope 3 guidelines with the SBTi framework.

In this context, many proposals to link the GHGP schemes to the SBTi requirements are currently under evaluation in the latest 2023/2024 GHGP revision process, including the provision of new guidelines and tools to enhance the methodological accounting process (GHGP, 2023). Within the calculation revision process, a few proposals were put forward by several interested parties (companies, organisations) regarding Scope 3, Cat. 11 (GHGP, 2023). The first group of proposals/ideas would encourage the elaboration of public-accessible transparent tools for companies for the provision of more detailed emissions profiles at a product, energy and material level. These could, for example, be driven by assessing the average consumer behaviours during the lifetime for each product/service of different geographical areas or based on more qualitative or quantitative methodologies such as the EU Digital Product Passport (Damen et al., 2023). In theory, by more precisely knowing the average durability of products, materials and their energy consumption level, the implementation of the GHGP formula for Cat.11 (Section 2.2) would be more accurate and reliable when companies report on their emissions.

A second group of proposals would aim to find solutions to the trade-off issues of the formula, as discussed in this paper. Accordingly, there is a need to positively emphasise the longevity of products. One solution would be to fix the emissions use in one year for companies; another would be to set depreciation methods on products that could be linked to the warranty of products given by the same products' owners. The idea would be to link the concepts of products and corporate accounting in the broader sense of circular economy and align companies with the new regulatory frameworks (e.g., the new EU Corporate Sustainability Report Directive (CSRD)).

4.3 Research considerations for designers

A few important considerations for the product designers and developers emerged from this research. First, implementing circularity is possible and measurable in terms of emission reduction impact via the GHGP methodology. Therefore, we encourage them to implement circularity strategies and options in the design phase of their products as this is recognized as the most impactful in terms of sustainability potentials (McAloone and Pigosso, 2021) and report back their emissions achievements to SBTi. Second, we acknowledged that certain strategies, such as extending the lifetime of the products, require the adoption of new calculation parameters and, possibly, new standards, that can increase the accounting process complexities. While the scientific community should keep focus on finding solutions to the accounting process (eventually adopting AI as a tool to refine calculation methods), product designers and developers might greatly support the research community in testing the implementation of research solutions and proposals (e.g., measuring the product lifetime in different markets and testing appropriate ways to extend warranty periods for their products and services) and increasing industry collaboration to test and share alternative solutions and proposals. In the EU, this process would be of utmost importance considering that, following the enforcement of the new EU CSRD in January 2023, it is now becoming mandatory, especially for large companies, to report their sustainability performance (EC, 2023; Flood, 2023). Within the new reporting requirements, an entire section is dedicated to CE, focusing on resource inputs, types of materials used, types of waste produced and waste handling formats (Milošević et al., 2023; Morea et al., 2021)

5. Conclusions

This research revealed possible methods to account for the emissions of specific CE strategies within the Scope 3 Greenhouse Gas (GHG) accounting process for manufacturing companies - i.e., 'Lowest suitable grade' within Category 1 of the GHG Protocol and one additional formula for reducing the trade-off issue related to the 'technical product longevity' and similar CE strategies within Category 11 of the GHG Protocol. It was found that while the 'Lowest suitable grade' strategy might be easily accounted as Scope 3 emissions after implementing the strategy and calculating Scope 1 and 2 emissions, the 'technical product longevity' requires additional formulae compared to the current formula provided by the GHG Protocol. Implementing the new formulae proposed can support companies and practitioners to increase the durability of products and services and be able to account (promptly) for their expected benefits to achieve the SBTi targets. A future line of research might be focused on how to test the equations performance in a more realistic case with industrial data. Furthermore, there is a need to demonstrate how the current GHGP Cat 11. formula will lead to reduce a company´s total emission (in the long run) by increasing the lifetime of a product. Another line of research might investigate how to enhance the latter GHGP formula focusing on the consumer/user behaviours for a certain product in a certain geographical area to collect and define more precise parameters to be used by companies when reporting the lifetime expectancy of the product sold.

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