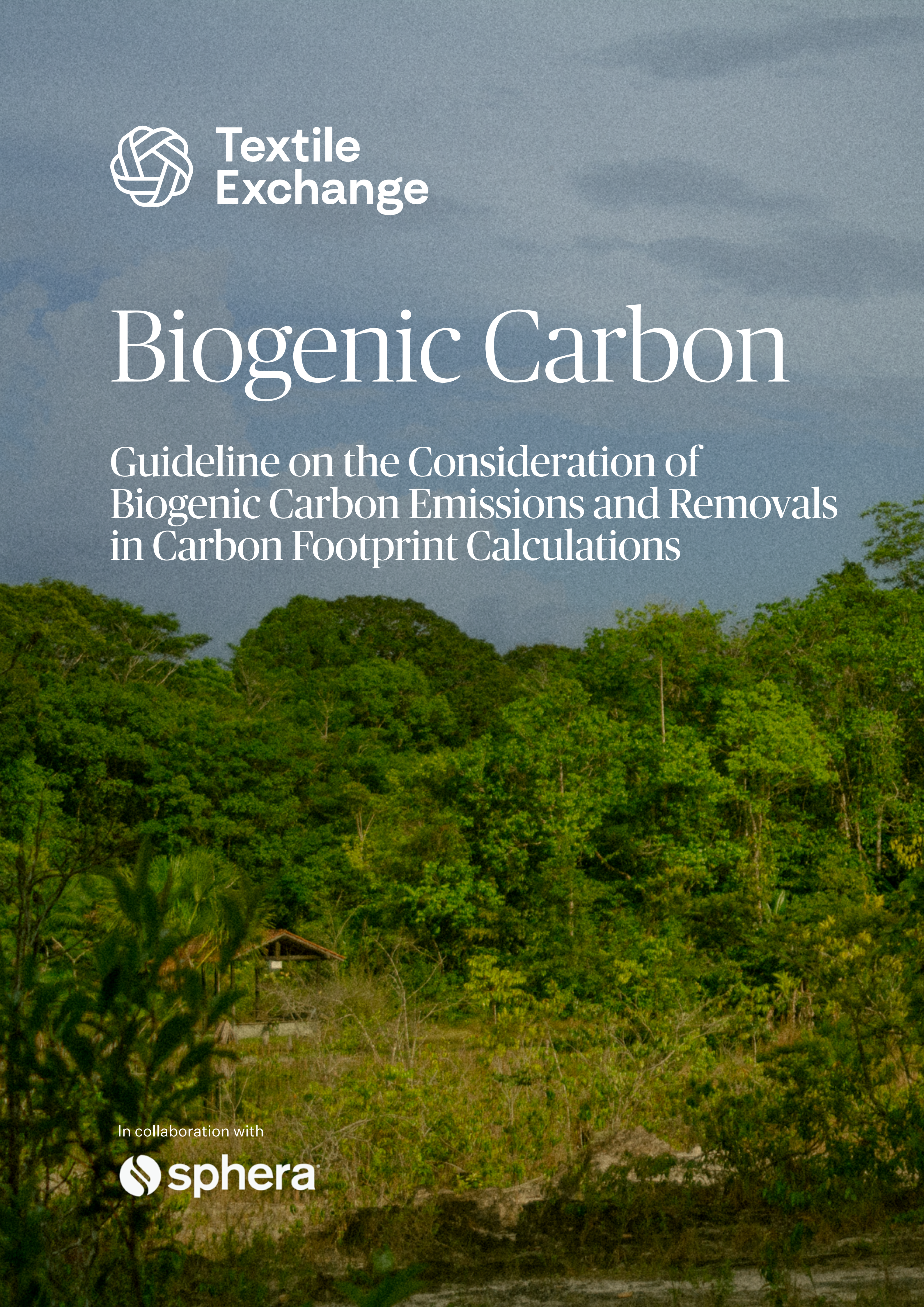

Textile Exchange

Biogenic Carbon

Guideline on the Consideration of Biogenic Carbon Emissions and Removals in Carbon Footprint Calculations

In collaboration with

sphera

Title: Guideline on the Consideration of Biogenic Carbon Emissions and Removals in Carbon Footprint Calculations

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List of Acronyms

AFOLU	Agriculture, Forestry and Other Land Use
CDR	Carbon dioxide removal
CFP	Carbon Footprint
dLUC	Direct land use change
EoL	End-of-life
FAO	Food and Agriculture Organization of the United Nations
FLAG	Forestry, Land and Agriculture
GHG	Greenhouse Gas
iLUC	Indirect land use change
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
LU	Land use
LUC	Land use changes
PEF	Product Environmental Footprint (initiative of the European commission)
RED	Renewable Energy Directive
SBTi	Science-based target initiative
SEP	Soil Enrichment Protocol
SOC	Soil organic carbon

1. Executive Summary

The emission pathways assessed by the Intergovernmental Panel on Climate Change (IPCC) to limit global warming to 1.5°C or 2°C by the year 2100 require not only the reduction of emissions but also the utilization of carbon dioxide removals (CDR).

Many companies have set their emission targets in line with 1.5°C, aiming to achieve net-zero eventually. This has led to an increased awareness of GHG emissions in the supply chain (scope 3 emissions), where agricultural products can represent important hotspots, especially where deforestation occurs. At the same time, there is hope that agriculture can be part of the solution, e.g., through soil carbon sequestration supported by improved agricultural practices.

One key point in this matter is **biogenic carbon**. This type of carbon is absorbed from the atmosphere by plants as they grow and can be released back into the atmosphere later when the plants burn or break down.

There is no doubt that biogenic carbon stocks are important for emissions and mitigating carbon levels. However, the extent of changes in these biogenic carbon stocks and the methods to quantify these changes have been highly controversial and a subject of debate for many years.

This paper aims to provide guidance on navigating the difficult terrain of old and new standards and guidelines that cover accounting methods for biogenic carbon. The following guidelines and standards were analyzed for the purposes of this paper:

- GHG Protocol (2023): Land Sector and Removals Guidance Draft
- Product Environmental Footprint method of then European Commission
- ISO (2018): ISO 14067:2018 - Carbon footprint of products
- WWF/SBTi (2023): Forest, Land and Agriculture Science-Based Target-Setting Guidance V1.1

Key takeaways

- Although there may be variations in terminology, approaches, and technical details between the different standards and guidelines, they all have one concept in common: **removals should only be considered in carbon footprint calculations if their permanence can be ensured.**
- The guidance on the inclusion of removals for reporting requirements in the GHG Protocol Land Sector and Removals Guidance are particularly relevant in this regard:
  - Primary data use
  - Validation of results by quantitative and statistically significant uncertainty estimates
  - Continuous monitoring of stored carbon
  - Full transparency and traceability of the process
  - Accounting and reporting of reversals from previous removals
- The storage of carbon in biobased products (carbon contained in the product) will be temporary in most cases. The **carbon stored in the product should not be claimed as being removed if it cannot be considered to be removed permanently** (under strict criteria as laid out in the GHG protocol). In partial carbon footprints, results should include a

simplified end-of-life (EOL) assessment or show impacts based on both the -1/1 and 0/0 approach, but it should be clearly communicated that the temporary storage shown in the -1/+1 approach is not a removal.

- Delayed emissions should not be included in carbon footprint assessments. If assessed, they should be reported as additional information.
- Carbon emissions from land-use change (LUC) contribute significantly to global warming. Therefore, the **avoidance of emissions from LUC should be a top priority** for all companies. This requires organizations to gain a better understanding of the origin of their supply chains and improve the traceability of the material they purchase. Ideally, product- or value chain-specific historic land-use data (reaching back 20 years) should be collected; however, the use of statistical data is acceptable if site-specific data is not available.
- Removals should only be claimed if occurring directly in the value chain and if strict criteria to claim removals from GHG Protocol are met. Offsetting cannot be included in a carbon footprint.
- **The uncertainty around removals with soil carbon sequestration remains high**. In some circumstances, significant soil organic carbon (SOC) sequestration is possible; however, due to the associated uncertainty within quantification methods, SOC sequestration should only be one part of a broader emission reduction strategy. Even without carbon sequestration claims, promoting healthy soil environments is worthwhile. If removals are being claimed, the principles of permeance shall be established. More importantly, it remains to be seen how the sequestration of carbon in soils and its quantification can be put into practice in a scalable way.

2. Introduction

While global CO_2 emissions are still on the rise and reached the highest atmospheric CO_2 concentration of 424 ppm in 2023 [1], the global target of keeping global warming below 1.5°C to limit the irreversible and detrimental impacts of global climate change is becoming increasingly urgent [2]. One **key approach** that will be imperative **to slow down climate change** is the removal of CO_2 from the atmosphere and storing it in carbon sinks. The emission pathways assessed by the IPCC to limit global warming to 1.5°C or 2°C by the year 2100 require not only the reduction of emissions but also the **utilization of carbon dioxide removals (CDR).** This term describes "*anthropogenic activities that deliberately remove CO_2 from the atmosphere and durably store it in geological, terrestrial or ocean reservoirs, or in products*" [3]. An example to mention is the scenario SR1.5, in which "*all analysed pathways limiting warming to 1.5°C by 2100 with no or limited overshoot include the use of CDR to some extent to offset anthropogenic CO_2 emissions and the median of CO_2 removal across all scenarios was 730 Gt CO_2 in the 21st Century*" [3]. It is essential to highlight the range of the required removals, which can vary from 1-2 Gt CO_2 per year up to 20 Gt CO_2 per year from 2050 onwards [3].

In this context, an increasing amount of companies have set their emission targets in line with 1.5°C, aiming to achieve net-zero eventually, as seen with the Science-Based Target initiative (SBTi) [4]. This has led to an increased awareness of GHG emissions in the supply chain (scope 3 emissions), where agricultural products can represent important hotspots, especially where deforestation occurs. At the same time, initiatives such as the "4 per 1000", introduced by the French government during COP21 in Paris, aim to promote agriculture as part of the solution (i.e. soil carbon sequestration through improved agricultural practices[i]) [5].

The **increased interest of CDR** in politics, sustainability reporting initiatives, and by the industry has led to the need for a **definition of a scientifically robust and detailed carbon accounting guidance**. The current discussion is not new, and existing standards include guidance on the conditions under which carbon removals can be included in carbon footprint results (e.g., ISO 14067). However, with the ongoing debate, new guidance has been published, new initiatives are under way, and updates of existing standards are under discussion. The following are examples of initiatives considering this topic:

- In 2022, the World Resource Institute published the "Land Sector and Removals Guidance Draft" [6]. This was an update of the GHG Protocol to align with the SBTi, which provides guidance to the agriculture, forestry, and other land use (AFOLU) sectors on setting emission reduction targets related to preventing deforestation and other land emission impacts [6]. The final version is expected to be released in Q1 of 2025.
- The UN Life Cycle Initiative recently started a project aimed at identifying and recommending best practices in approaches to account for the (temporary) storage of biogenic carbon in Life Cycle Assessments (LCAs) [7]

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[i] The "4 per 1000" Initiative, also known as "Soils for Food Security and Climate", was introduced in 2015 at the UNFCCC CoP 21 as part of the Lima-Paris Plan of Action. The initiative aims to improve levels of organic matter and foster carbon sequestration in soils through the implementation of land management methods appropriate to local environmental, social, and economic conditions. The name "4 per 1000" comes from the initiative's proposal that if the level of carbon stored by soils in the top 30 to 40 centimetres of soil increased by 0.4% (or 4‰) per year, the annual increase of carbon dioxide in the atmosphere would be significantly reduced [5].

- Methods of biogenic carbon removals in Product Environmental Footprint (PEF) are currently being debated within the Technical Advisory Board (TAB) of the EU's Environmental Footprint initiative.ii

In general, the discussion on how to account for potential CDR focuses on the following areas:

- Carbon storage in products
- Land management-based emissions and removals
- Other technological removals

Biogenic carbon is a topic of particular interest, especially in the first two mentioned areas. It refers to carbon absorbed by the atmosphere as plants grow that may be released back into the atmosphere at a later point due to plants burning or breaking down [8]. Biogenic carbon emissions and removals together form the natural carbon cycle and are therefore part of a complex system. There is no doubt that biogenic carbon stocks are important for emissions and mitigating carbon levels. However, quantifying how much these biogenic carbon stocks change has been highly controversial and a subject of debate, as mentioned above.

This paper aims to provide guidance on navigating the difficult terrain of old and new standards and guidelines. Principally, there will be a focus on **carbon footprint calculations for biobased products,** and this paper will describe the approaches that can be used to consider biogenic carbon emissions and removals in the supply chain of these products. The goal is to promote informed decision-making and add value to current discussions by consolidating key definitions, approaches, and requirements from relevant sector standards. This is done by considering their application within the sector as well as on future developments. This paper does not include detailed assessments of calculation methods, formulas, or models. Specifically, **technological removals,** such as direct air capture technologies (DACCS) as well as bioenergy with carbon capture and storage (BECCS)[iii], **are excluded from the scope**. Among the CDR strategies – including carbon storage in products, land-based emissions and removals, and other technological removals for biogenic carbon – some of the most interesting and important **topics are storing biogenic carbon in products, changes in land use, and land management removals** (especially SOC sequestration). These topics are analyzed further in this paper.

The following guidelines and standards were analyzed for the purposes of this paper:

- GHG Protocol (2023): Land Sector and Removals Guidance Draft [6]
- Product Environmental Footprint method of then European Commission [9]
- ISO (2018): ISO 14067:2018 - Carbon footprint of products [10]
- WWF/SBTi (2023): Forest, Land and Agriculture Science-Based Target-Setting Guidance V1.1 [11]

As outlined above, the focus of this paper is on **product** carbon footprints for biobased products. While the GHG Protocol Land Sector and Removals guide and the SBTi's FLAG Guidance focus on company-wide accounting methods, **there is a clear overlap between product carbon footprint calculations, life cycle assessments (LCA), and the scopes in the company accounting**

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ii Sphera is represented within the PEF working group that is also involved in the TAB group, currently discussing the topic of biogenic carbon – discussion items and outcomes are not yet published; however main discussion points are reflected throughout this paper based on publicly available sources and Sphera's expertise in working in this sector.

iii Biochar is included and discussed in section 2 on biogenic carbon stored in products

schemes. Therefore, this paper tries to layout the principles and reporting requirements of the above standards in a way that they could be applied to both company and product carbon footprint calculations. However, any further guidance on company-wide reporting requirements and methods are outside the scope of this guidance.

The following is a brief overview of the contents in this paper:

- **Section 1 – Executive Summary**
- **Section 2 – Introduction**
- **Section 3 – Biogenic Carbon Stored in Products**:
  Modeling and reporting the storage of biogenic carbon in the long or short term within human-made systems.
- **Section 4 – Land Use Change:**
  Emissions (and potential removals) caused by changes in land use, such as deforestation and reforestation.
- **Section 5 – Land Management Removals:**
  Potential removals of carbon through land management, focusing on the increased stocks of soil organic carbon.
- **Section 6 – Summary and Conclusions**

Each section includes four subsections, which can be described as follows:

- **Definitions:** Lays out the basis for each section by defining the key terms and concepts.
- **Applicability:** Puts the defined concepts and their relevance for biobased products into context.
- **Standards:** Provides an overview of the requirements of relevant sector standards.
- **Summary and Recommendations:** Recommendations consolidated by Sphera and Textile Exchange.

3. Biogenic Carbon Stored in Products

In the context of biobased products, two common pathways for carbon sequestration are often considered: storing biogenic carbon in products and transforming biomass into biochar. Both are covered below in the respective subsections.

3.1. Terms and definitions

Biogenic carbon stored in products.

The GHG Protocol defines the carbon pool for biogenic products as “carbon in products or materials derived from living organisms or biological processes but are not fossilized or from fossil sources” [6]. Examples of biogenic products are crops like cotton, wood-based products, animal fibers, but also synthetics based on bioplastics such as polylactide acid.

The carbon contained in biobased materials has been extracted from the atmosphere via photosynthesis (referred to as biogenic carbon, see also section 2). This means that the carbon content in all such materials corresponds to an amount of CO_2 temporarily removed from the atmosphere for the duration of the product and its materials’ lifetime [6]. The emphasis on temporary is important in this context since the materials will eventually emit some or all the carbon back into the atmosphere at the end of their life cycle.

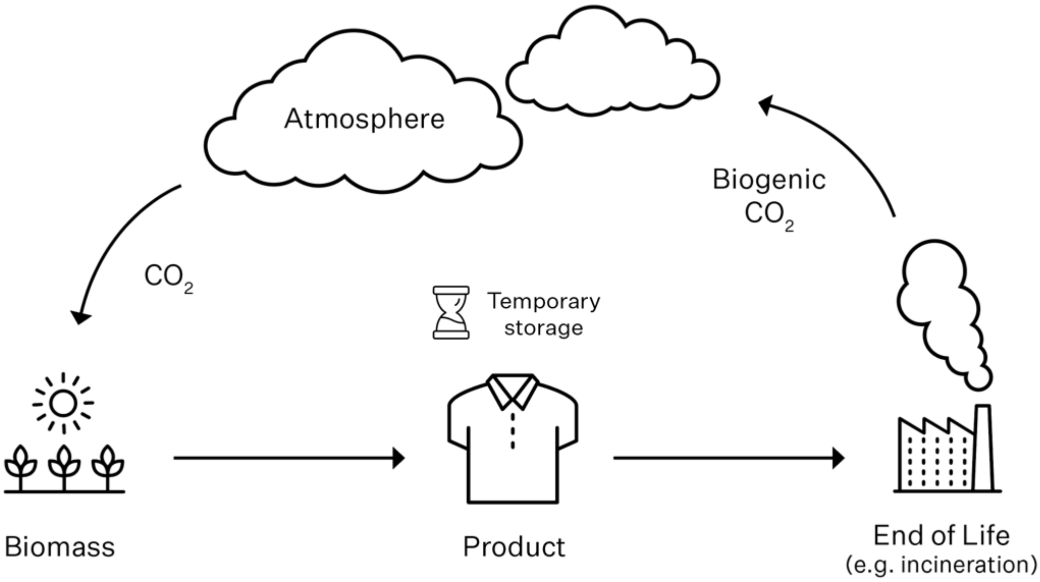

Figure 1: Schematic display of biogenic carbon cycle

In Europe, for example, most EU member states have laws banning or severely restricting the disposal of household waste via landfills [12]. This means that most consumer products are eventually incinerated [13], and the carbon stored in the product is released[iv]. Most products reach their end-of-life (EoL) in only a few years and this temporary storage period does not contribute

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[iv] Developing countries often have a limited waste management infrastructure. In the context of this paper, this will still mean that short lived consumer goods will eventually be incinerated (potentially in backyard burning) or decompose, and the carbon stored in them cannot be considered to be removed permanently.

significantly to climate change mitigation. However, if products are sent to landfill (e.g., the predominant EoL scenario in the US [14]), a fraction of the carbon they contain could **potentially** be considered permanently removed. Biobased materials that are readily biodegradable will eventually degrade, but non-liable carbon-based products could represent long-term storage potentials (see next section). The main challenge and key discussion point is on the biodegradability of the carbon-based material and its EoL scenario. If the products have a long and useful product lifespan, they may be considered temporary carbon sinks and, effectively, delay the re-emission of CO_2 back into the atmosphere. If the carbon is not emitted at the EoL, it may be considered permanently removed.[v]

Various guidelines provide different approaches for accounting carbon uptakes by plants and biobased materials, as well as for tracking the release of carbon back into the atmosphere or its storage in various sinks throughout the life cycle of biogenic products. The most common methodological approaches are described below[vi], together with graphs that provide an exemplary representation of the different approaches.

- **The 0/0 approach:** In this approach, the absorption of CO_2 by plants and the release of biogenic CO_2 are not accounted for. It is possible to model both flows, however, they are assigned with a characterization factor of 0 for climate change – hence why this approach is also referred to as "biogenic carbon neutrality". Biogenic CO_2 is considered part of the natural carbon cycle, where its return to the atmosphere is balanced by the regrowth of plants. Therefore, any temporary delay in emissions is irrelevant compared to the permanent impacts of fossil-based CO_2 emissions. The 0/0 approach represents a simplified approach that can easily be applied; however, it does not account for carbon removals or delayed emissions. This approach causes some challenges when studies focus on intermediate carbon footprints or LCA, particularly those that only assess impacts from cradle to gate, excluding EoL impacts, discussed in the next section.
- **The -1/+1 approach:** Compared to the previous approach, the -1/+1 approach accounts for biogenic carbon emissions and removals by assigning a characterization value of -1 to the plant CO_2 uptake flow and +1 to the release of biogenic CO_2. While this approach enables the tracking of carbon uptakes and emissions, ensuring carbon mass balances, it also carries the risk of potential misinterpretation or miscommunication of impacts, especially in partial (cradle-to-gate)[vii] carbon footprint or LCA studies.
- **The 0/+1 approach:** As an alternative to the -1/+1 approach, the plant CO_2 uptake flow may be characterized with a value of 0 if there is no proof that the biomass is replanted and the carbon re-absorbed. This method is mainly suitable for forest products[viii].

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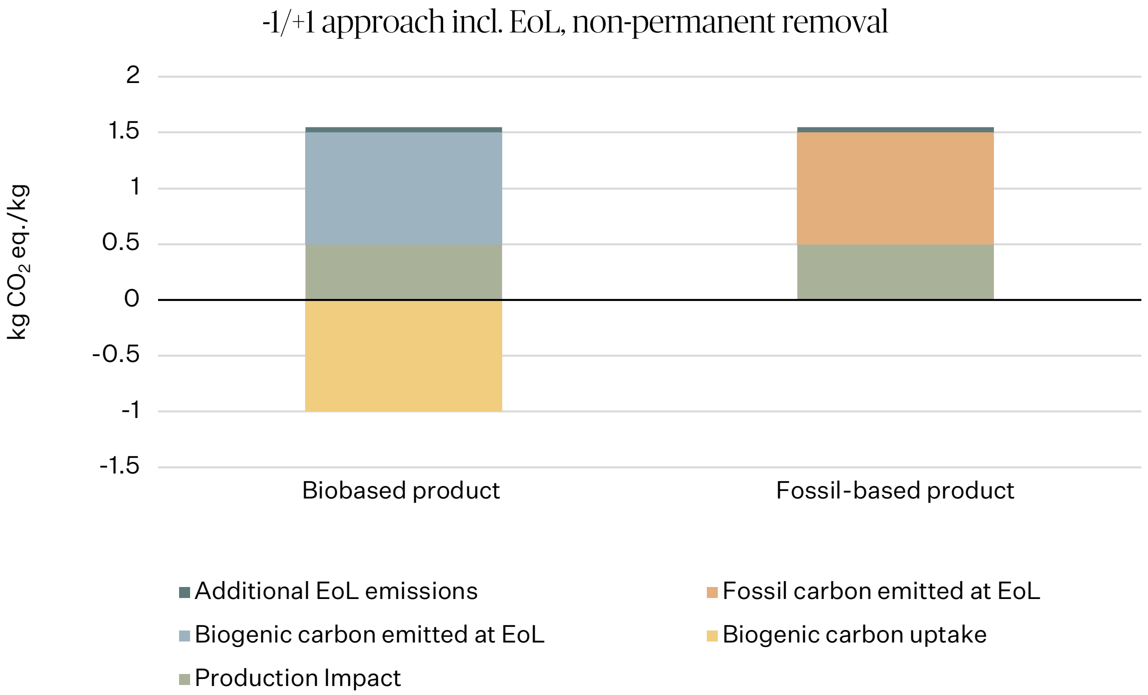
[v] Fossil carbon stored in a fossil based product could – potentially – also be permanently stored in landfills if the product does not decompose. In this case, there would be no (or lower) emissions at the EoL phase of such products.

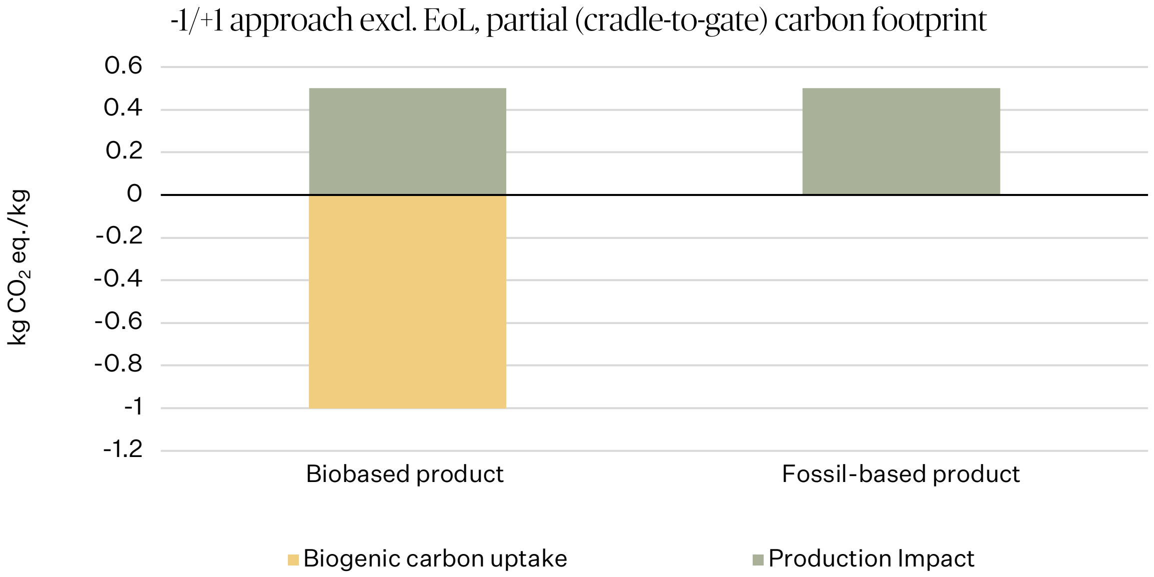
[vi] All approaches request to take into account if biogenic carbon is converted into biogenic methane emissions, i.e. biogenic methane emissions are not characterized with a factor of zero

[vii] A partial carbon footprint refers to the total GHG emissions generated by a product over certain stages of its life cycle. For example, a cradle-to-gate, or partial, carbon footprint considers all the processes from extraction of resources through manufacturing of precursors and the manufacturing of the final product itself up to the point where it leaves the company gate (Source: ISO 14067).

[viii] There has been sharp criticism around assuming that biomass used for the generation of bioenergy (e.g., wood pellets) considered carbon neutral, even if it is not known whether biomass is subsequently regrown and the emitted carbon is reabsorbed [50]. This criticism is behind the suggestion of the 0/1 approach. The approach would not be applicable for



Biogenic carbon uptake is considered (negative number) and emitted at EoL. The carbon contained in a fossil-based product is emitted as well, but not balanced out with an uptake.



Biogenic carbon uptake is considered (negative number), but the emission back into the atmosphere is omitted because EoL is not considered (partial carbon footprint). Results for biobased products can appear negative.

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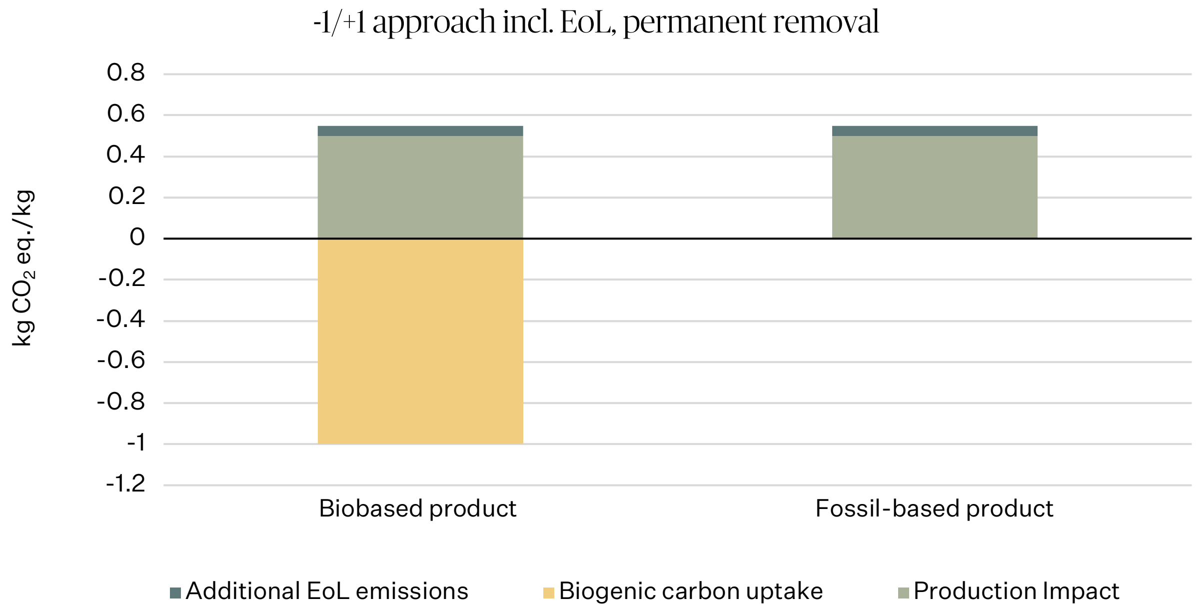
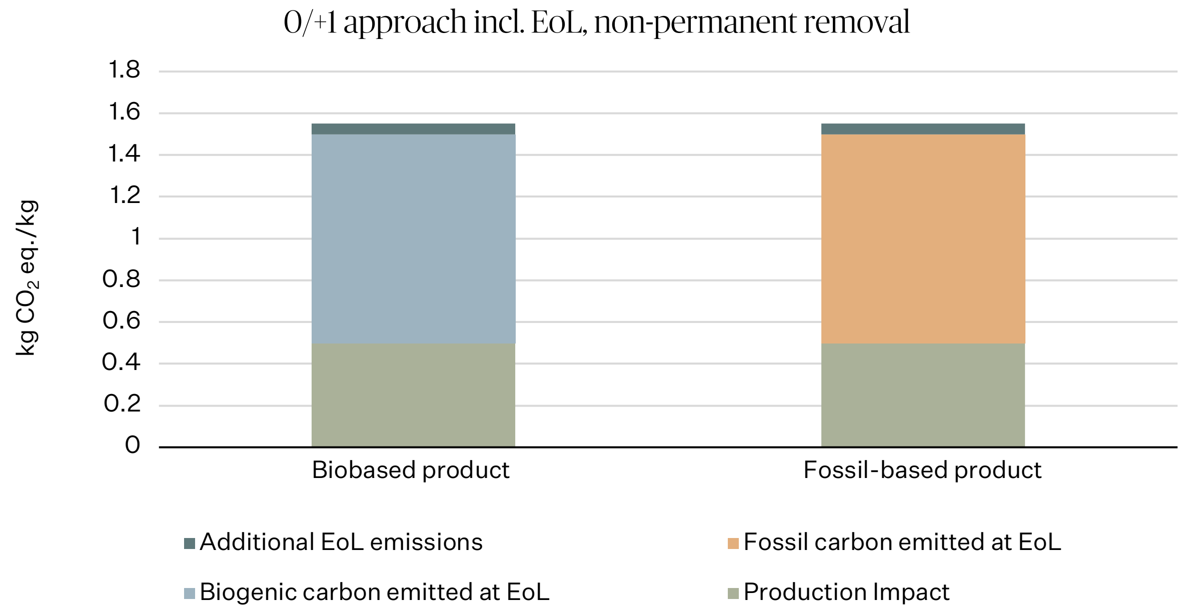
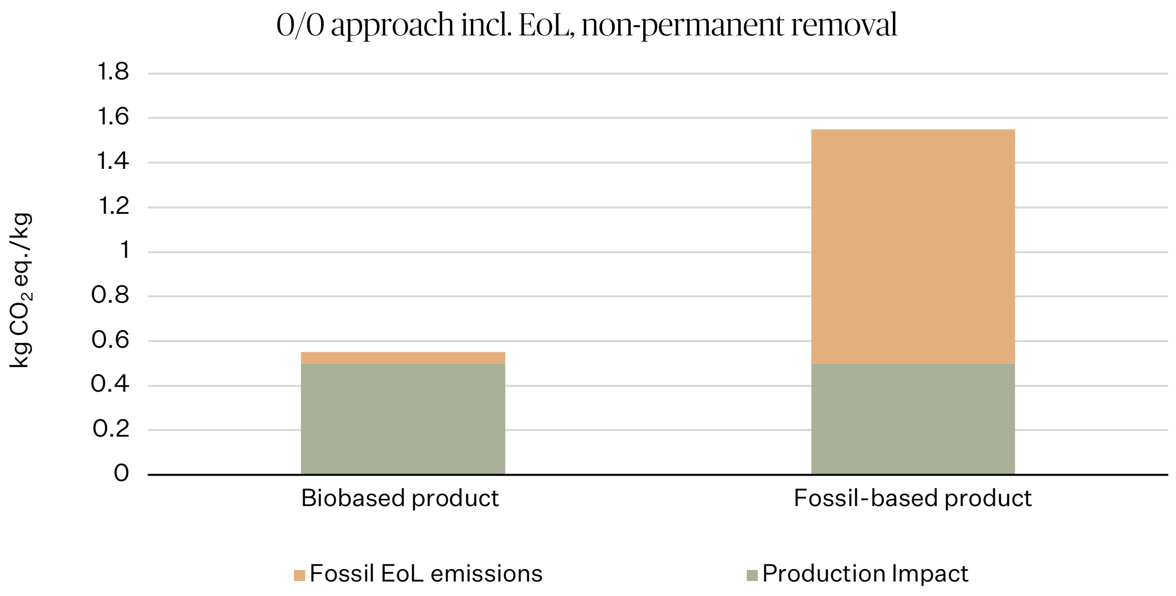
annual crops as the assumption is that the carbon is released within a short-term timeframe, but the crop is part of a crop rotation with yearly renewals of biomass. The 0/1 approach is currently not applied often in LCA practice; however, it is expected that there will be more discussions around this approach in the near future at least for forest products.



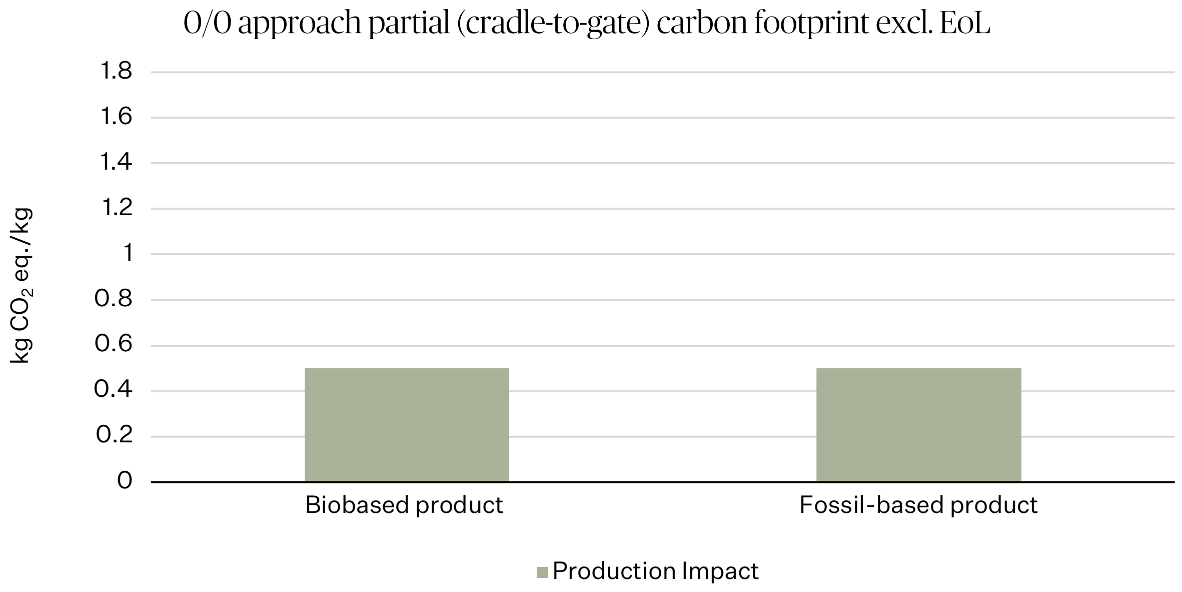
Biogenic carbon uptake is considered (negative number). Emission of carbon contained in the product (biogenic or fossil) back to the atmosphere does not occur if permanent removal can be assumed.



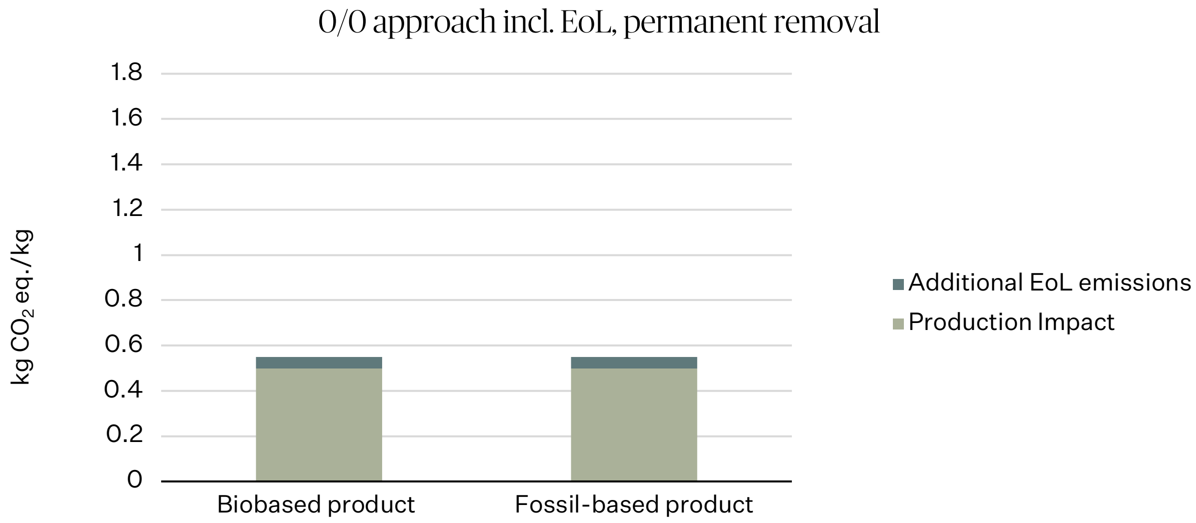
Biogenic carbon uptake is not considered (characterized with zero) if evidence is missing that the biomass is replanted and the carbon re-absorbed. Emissions at EoL are considered.



Biogenic carbon up-take is not considered (characterized with zero). Emissions at EoL of biogenic carbon are also not considered (characterized with zero). Fossil emissions are characterized.



In partial carbon footprints that use a 0/0 approach, uptake and emissions are not considered (characterized with zero). Therefore, in this schematic example, the fossil and the biobased product show the same impacts.



Biogenic carbon uptake is not considered (characterized with zero). Emission of carbon contained in the product (biogenic or fossil) back to the atmosphere does not occur if permanent removal can be assumed.

Figure 2: exemplary representation of the different approaches to account for biogenic carbon contained in the product

Timeframes and Permanence

When considering carbon stored in products and non-liable carbon deposited and stored in landfills, but also for soil carbon sequestration for example (see section 4), the difference between “temporary” and “permanent” removal is essential. Some guidelines consider removals that last more than 100 years to be “permanent” for the purposes of LCA accounting [54], [10], [48] .The arbitrary timeframe refers to the global warming potential (GWP) of greenhouse gases (GHG) over a 100-year time horizon. The GWP is used to convert GHGs, other than CO_2, into CO_2 equivalents. The IPCC also provides GWPs for timeframes of 20 and 500 years. The 100-year timeframe was chosen as a compromise covering short-term and long-term impacts in connection with realistic political timeframes.

Using this timeframe to consider permanence can therefore only be of indicative value. No timeframe to specify permanence are given in the above-mentioned standards. The GHG protocol has indicated that the removals should only be considered permanent if there is scientific evidence to support the claim (lignin on landfills that cannot decompose anaerobically is taken as an example). Therefore, the best approach is to claim permanence only when there is a realistic possibility and intention of permanent removal, with assurance for at least the first 100 years.

Considering the 100-year timeframe, one approach to address uncertainty regarding permanence is to account for carbon removals at a rate of 1/100 (or 1%) per year. This method is outlined in the GHG Protocol Land Sector and Removals Guidance (referred to as a discounting approach) or in the Soil Enrichment Protocol [45].

Biochar

Biochar is generated by heating carbon-rich materials including biomass, synthetic carbon, geological sources (e.g., coal), or solid waste to temperatures above 350°C, with controlled and limited oxidant concentrations to prevent combustion [2]. This process, known as thermochemical conversion, includes pyrolysis, gasification (producing syngas as a potential by-product), torrefaction, and hydrothermal carbonization. Biomass, such as animal manure, wood, agricultural residues (rice husks and rice straws), nut shells, and biosolids (paper sludge, sewage sludge), is commonly used as renewable feedstock for biochar preparation [15]. The resulting product is stable and resistant to chemical or biological decomposition. Biochar has been extensively studied for various applications, including replacing sand in concrete or below urban trees; treating waste gases and wastewater; and most commonly, as a soil amendment in agriculture. Beyond carbon storage, biochar has shown additional benefits such as improving soil nutrient retention and improving water-holding capacity[16][ix]. While biogenic materials transfer carbon from land-based carbon pools to product pools, biochar, when used as a soil amendment, transfers carbon back to land-based carbon pools, with delayed emissions.

3.2. Applicability for biobased products

Biogenic Carbon Stored in Products

As highlighted above, the product's durability and EoL scenario is the most important aspect to consider for storing biogenic carbon in a product. The IPCC guidelines provide a Tier 1 first-order decay model to estimate methane (CH_4) emissions from landfills resulting from decomposition [15]. For example, the degradable organic carbon (DOC_f) fraction of waste types can be as low as 10 wt% (e.g., wood, engineered wood products, or tree branches) to as high as 70 wt% (e.g., food, yard, and garden waste) [15]. However, landfill CH_4 emissions also depend on other variables including landfill management [ibid].

The impact of biogenic carbon contained in bioplastics on landfills is of particular interest. In the IPCC guidelines, plastics are considered inert, and no decomposition rates are given [ibid]. This is in line with a study from Chamas et al. [17] that reviewed degradation rates of plastics in different environments. In the study, landfilled materials showed no detectable decomposition or a very long half-life (more than 2500 years). This does not include low-density polyethylene (LDPE) plastic bags and biodegradable plastic bags (bioplastics were not assessed separately). However, they also conclude that reliable data is hard to find. In a review examining the degradation rates of biodegradable plastics, Foline et al. [18] concluded that additional research is necessary to determine how quickly these plastics biodegrade under anaerobic conditions. Biodegradable plastics are expected to break down in landfills, potentially releasing all or some of their biogenic carbon back into the atmosphere.

[ix] Relevant regulation classifying biochar as a fertilizer and authorizing its application in the EU are first, regulation (EU) 2019/1009. This regulation lays down rules on the making available on the market of EU fertilising products. It includes a provision for the assessment of biochar and its inclusion in Annex II to the regulation if it is concluded that EU fertilising products containing biochar do not present a risk to human, animal or plant health, safety, or the environment, and ensure agronomic efficiency [52]. And second: COMMISSION DELEGATED REGULATION (EU) 2021/2088: This regulation amends Annexes II, III, and IV to Regulation (EU) 2019/1009 for the purpose of adding pyrolysis and gasification materials as a component material category in EU fertilising products. The regulation allows for the inclusion of biochar in Annex II to Regulation (EU) 2019/1009 if recovery rules in that Annex ensure that the material is to be used for specific purposes, that a market or demand exists for it, and that its use will not lead to overall adverse environmental or human health impacts [21]. Biochar is also already in the list of fertilizers allowed for organic agriculture (Regulation EU 2019/2164).

This paper does not assess the advantages and disadvantages of landfill as a potential method for carbon storage. Some experts have debated whether treating carbon stored in landfills as negative emissions should be ruled out in carbon footprint standards to discourage the use of landfill as a waste treatment option.

Partial (Cradle-to-Gate) Carbon Footprint and LCA Studies

In LCA guidance documents, the most common approaches recommended for accounting biogenic carbon uptake and emissions from biobased materials are the 0/0 or -1/+1 approach (see section 3.1). However, both approaches can influence study outcomes and potentially lead to misleading conclusions. For example, the -1/+1 approach may result in negative carbon footprint results in partial carbon footprint studies because biogenic carbon uptake is considered as negative emissions. Yet, emissions at EoL, which would balance out the uptake, are not included in cradle-to-gate studies. This oversight might incorrectly suggest that products lead to carbon removal and act as carbon sinks, despite the carbon being only temporarily stored (see above). On the other hand, the 0/0 approach may unfairly treat biobased products since it does not account for the fact that the carbon they contain has been removed from the atmosphere. If EoL were included, there would be a distinction in LCA results, as fossil-based products would have additional emissions (e.g., from incineration) compared to biobased products where the emissions are treated as carbon neutral. Figure 2 illustrates this example, section 2.3 below provides more information on which approach different guidelines recommend, and section 2.4 provides recommendations in this regard.

Biochar

A crucial consideration in biochar production is ensuring that biomass production is climate-neutral, meaning it does not diminish existing carbon removals through changes in land use (see section 3). This can be achieved, for example, by using agricultural residues, by-products from other processes (e.g., biofuel production), rapidly growing biomass (e.g., algal blooms), or other waste recovery and resource recycling opportunities. Wood sourced from sustainably managed forests can also meet these criteria [16]. In Europe, the Ithaka Institute for Carbon Strategies certifies sustainable biochar production through the European Biochar Certificate (EBC), which is a voluntary industry standard. The EBC also promotes a list of sustainable biomass sources for biochar production [19]. Recently, the EU has implemented a specific law governing biochar. The status of biochar in the EU has been a subject of debate, particularly whether it is considered waste or not. This depends on several factors, including whether its feedstock is classified as waste, or if it is exempt from the waste regime because it is non-hazardous waste, a by-product, or has reached the end-of-waste status. With the introduction of the Fertilising Product Regulation and the corresponding Delegated Regulation, the EU has set up criteria applicable across the EU to facilitate the classification of biochar as a by-product or an end-of-waste material [20] (see also footnote (10)). Annex II to Regulation (EU) 2019/1009 outlines the types of usable feedstock that qualify biochar as a fertilizer product [21].

3.3. Standards

Biogenic Carbon Stored in Products

The Land Sector and Removals Guidance of the **GHG Protocol** is currently only available in its draft version and the final publication is expected to be published in 2024. Currently, the guidance draft requests one of the following two options for the accounting and reporting of net emissions and net removals from product carbon pools:

- Simplified approach assuming no carbon stock changes (corresponding to a 0/0 approach)

- Stock-change approach (corresponding to a -1/+1 approach)[x]

The basis of the GHG Protocol's stock-change accounting approach is an annual storage monitoring framework to implement the permanence principles for all carbon pools[xi] [6]. The permanence principles include ongoing storage monitoring, traceability, primary data, uncertainty, and reversal accounting.

Alternatively, companies may use storage discounting frameworks which estimate the impacts of delayed emissions from temporary carbon storage, based on ex-ante (i.e. before the event) assumptions[xii]. Storage discounting frameworks are to be reported outside of the scopes in a separate category called "temporary carbon storage" [6][xiii].

In the **SBTi FLAG Guidance,** product carbon storage cannot be included in FLAG targets, and data used for FLAG target development do not include product carbon storage. In general, they refer to the GHG Protocol Land Sector and Removals Guidance and request that companies only include CO_2 removals with ongoing storage and monitoring (see also section 5).

According to **ISO 14067:2018**, biogenic carbon removals and emissions must be included in the final carbon footprint results and reported separately, following the **-1/+1 approach**. The assumptions used to assess how much carbon is stored need to be clearly documented. Biogenic carbon uptake is accounted for, and if a portion remains permanently stored beyond the EoL phase of the life cycle (i.e., permanently stored), it can lead to a reduced (or even negative) carbon footprint. However, the underlying timeframes are not specified. The standard refers to the GHG Protocol, which states: *"the amount of carbon stored will depend on the waste treatment process, the scientific understanding of the product's degradation in certain environments, and the time period chosen"* (see also textbox on timeframes and permanence in section 2.1) [22].

Regarding delayed emissions, ISO 14067 requires that *"all GHG emissions and removals shall be calculated as if released or removed at the beginning of the assessment period without taking into account an effect of delayed GHG emissions and removals"* [10]. However, if there is a delay between sequestration (production of the product) and emission (in the use phase or at EoL) of more than 10 years, the timing of the emission needs to be reported in the inventory, but the impact on the carbon footprint is still not considered. This impact can be calculated and reported separately: *"The effect of timing of the GHG emissions and removals from the product system (as CO_2e), if calculated, shall be documented separately in the CFP study report"* [10].

In its current version, the Product Environmental Footprint method (**PEF method)** has taken a more restrictive approach. While biogenic carbon removals and emissions need to be inventoried, they are characterized with a factor zero in the impact assessment **(i.e., 0/0 approach)**, which means

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[x] Two of the open questions in the GHG protocol draft and a significant fraction of the methodological aspects in the guideline cover the differentiation of gross and net changes in the pools, and where they should be reported. Current outline is that the gross changes (flow-based accounting at the source and sink) should be reported outside the scopes and the resulting net changes inside the scopes. Since the present paper focuses on product carbon footprints, these aspects are less relevant and will not be discussed further.

[xi] i.e. land carbon pools, geological carbon pools, and biogenic and Technological Carbon Dioxide Removal (TCDR) -based product carbon pools

[xii] E.g., using discounting factors calculated based on years carbon in a given product type is stored. E.g., if the assumption is that the storage period is 100 years or more, the discounting factor is 1/100, i.e. 1/100 of the carbon stored in the product is accounted for per year. See also section 2.1 on timeframes and permanence

[xiii] The GHG Protocol also highlights that net emissions and net removals from product storages are only applicable to scope 3, either category 11 (Use of sold products) or category 12 (EoL treatment of sold products).

that biogenic removals and emissions are not part of the climate change results of a product under PEF. This might be seen as a useful simplification to avoid misleading negative results when only looking at partial carbon footprints of biobased materials. At the same time, this is a contradiction to ISO 14067 and can lead to confusion when comparing cradle-to-gate results for fossil-based materials with biobased alternatives (see section 3.2). Like ISO 14067, the PEF method does not consider delayed emissions.

Biochar

A method for assessing biochar has been proposed in the **2019 refinement of the IPCC guidelines** [23], including values for the fractions of carbon transferred from the original material to the stabilized biochar, and for the permanence of this carbon when applied to soils. With these additions, biochar can now be included in LCAs just as any other input (or output) material. This means that the environmental impacts associated with producing biochar (biomass production and transport, energy use in the pyrolysis, etc.) must be accounted for. Regarding biogenic carbon contained in biochar, the approach mirrors that described above (biogenic carbon stored in products). During thermochemical conversion, some carbon from the biomass used to produce biochar is stored in the resulting biochar (using IPCC values if source-specific data is unavailable), while the remainder is emitted. When biochar is applied to soil amendments, a fraction of the carbon stored in the biochar is considered sequestered for more than 100 years (65 to 89% according to the IPCC guidelines [23]). This fraction will not appear as an emission in the product's carbon footprint calculation; instead, the difference between uptake and emissions contribute to reducing the product's carbon footprint.

In the Land Sector and Removals Guidance Draft by the **GHG Protocol,** biochar is included in the carbon storage methodology, subject to the permanence principles for carbon removals (e.g., ongoing storage monitoring, traceability, primary data, uncertainty, and reversals). The guidance explicitly mentions biochar application to soils as a process that transfers carbon from product-based pools to land-based pools. The **SBTi Guidance** includes biochar in carbon removals and storage as well and refers to the GHG Protocol Land Sector and Removals Guidance for the calculation methodology. Biochar application is not specifically mentioned by **ISO 14067:2018**.

3.4. Summary and Recommendations

- The debate on how to account for carbon stored in products has been ongoing for a long time. Part of the controversy stems from the different carbon accounting rules as stipulated by ISO 14067:2018 and the PEF method. The publication of the long-awaited GHG Protocol Land Sector and Removals Guidance has not yet clarified the preferred method for accounting and reporting biogenic emissions and removals. Moreover, new initiatives are being introduced that are bringing this subject back onto the agenda (see section 1).
- Non-permanent removals cannot be considered reductions in the carbon footprint of a product or product system. The GHG Protocol Land Sector and Removals Guidance specifies the requirements regarding permanence of removals, which include ongoing storage monitoring, traceability, primary data, uncertainty, and reversal accounting.
- The difference between the 0/0 and -1/+1 approach is less relevant in studies that cover the full life cycle of a product, including EoL emissions. Therefore, the best option might be to include EoL emissions even in partial carbon footprint studies, even based only on a simplified assessment.

- If the EoL phase cannot be included in a partial carbon footprint assessment, the results should be shown using both a 0/0 and a -1/+1 approach[xiv]. If the carbon stored in the product can only be assumed temporarily stored, this should be clearly communicated, and this storage should not be claimed as a removal.
- This paper does not asses the advantages and disadvantages of landfilling as a potential method for carbon storage, as this is beyond its scope. The differing approaches taken by countries like Germany (where landfilling of untreated waste is prohibited) and the US (where landfill is the main EoL treatment) highlight the controversy surrounding this issue. Regardless of the approach, EoL treatment scenarios must be carefully evaluated before proposing a specific procedure and claiming potential benefits. Most importantly, adherence to the waste hierarchy (reduce, reuse, recycle) is essential.
- The evaluation of EoL scenarios mentioned above also applies to the degradation rates of plastic in landfills. For non-biodegradable plastics, permanent carbon storage in landfills could be assumed if supported by scientific literature (some cited above). However, this assumption does not apply to biodegradable plastics, where a careful review of degradation rates needs to be conducted to compile realistic EoL scenarios.
- In LCA, the use of biobased products has other advantages even at EoL. For example, when incinerated at EoL, the emissions may be considered carbon neutral in contrast to incineration of fossil-based products. The comparison of biobased materials with fossil alternatives is a typical application field of LCA and is beyond the scope of this paper.
- Although some scientific debate and uncertainty remains, biochar appears to provide a stable form of concentrated carbon to soils that can also provide other agronomic benefits. An important aspect is to ensure that it is based on sustainable feedstocks. Updated EU regulation has addressed legal uncertainties, particularly within the EU (see also footnote 10). The key challenge is finding an economical and practical mechanism for increasing the production and use of biochar [24]. This issue is also mentioned in the GHG Protocol, which lists biochar as a land-based activity with low GHG mitigation potential [6].

[xiv] This approach is also in line with the guideline for calculating product carbon footprints (PCFs) from the "Together for Sustainability" (TfS) initiative, which includes 37 companies from the chemical industry. This guideline provides specific calculation instructions for emissions from "cradle-to-gate" for chemicals. This guideline also requests to report results including and excluding biogenic carbon stored in the product [56].

4. Land Use Change

Forests, wetlands (peat)[xv] and grasslands hold significant carbon stocks. When these areas are converted into agricultural land, for example, a large fraction of this carbon is released into the atmosphere, contributing to climate change. According to the IPCC, land-use change contributes approximately 6 Gt CO_2 eq. per year to global emissions [25][xvi] or about 12% of all anthropogenic emissions and nearly half of all agricultural emissions [ibid]. Therefore, considering land-use and land-use change (LULUC) is crucial when calculating the carbon footprint of biobased materials.

4.1. Terms and Definitions

The concept of land use (LU) and land use change (LUC) was developed by the IPCC Guidelines for National Greenhouse Gas Inventories (referred to as IPCC guidelines), in which land use is defined as “the total of arrangements, activities, and inputs that people undertake in a certain [area]” [23]. This also refers to land occupation, a continuous use of a land area within a specific land use type.

The following land use categories are defined by the IPCC [23][xvii]:

- Forest Land
- Cropland
- Grassland
- Wetlands
- Settlements
- Other Land

The categories are defined based on their robustness for estimating emissions and removals, their implementability, and their degree of completion (all land areas in a country may be classified into these categories without duplication). The exact classification of land use is determined by national inventories, but for biobased products, the classification should be straightforward. Some agroforestry systems might fall into a border area between forest and cropland. Sub-divisions can be used when assessing the extent and related carbon emissions of land use change [23]. For biobased products, distinguishing between perennial and annual cropland is most relevant. Forest land can be subdivided into managed and non-managed (primary) forest, and grassland includes (managed) pasture for grazing.

Land use change describes the change of land from one land use category to another, also referred to as land transformation or land conversion. The most prominent example being forest converted

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[xv] New research suggests that tropical peatlands are significant methane sources, and probably have a greater impact on global atmospheric methane concentrations than previously thought, and the associated radiative forcing effect of methane emissions has the potential to partly offset net CO2 uptake [57].

[xvi] These are net emissions, i.e. consider carbon sequestration from afforestation or reforestation

[xvii] The GHG protocol, the SBTi, and the accountability framework initiative have published a guideline to ensure that land use change scenarios are defined and treated consistently across target setting, measurement, and reporting on deforestation, conversion, and LUC emissions [58]. This guideline provides useful additional information on the integration of target setting, monitoring deforestation, and GHG emission modelling. The guidelines uses the same land use categories provided in the IPCC guidelines.

into cropland (e.g., rainforest to palm oil plantation). Land use change from one sub-category to another (e.g., from annual to perennial crop) is also considered. Changes within a land use category (e.g., change of management practices such as tillage or introduction of cover crops within the annual cropland category) are not considered land use change but are covered under the assessment of “land management removals”, see section 5.

Carbon emissions resulting from LUC are calculated by comparing the relevant carbon stocks of the previous land use with those of the current land use. The difference between these carbon stocks is considered an emission. The relevant land-based carbon pools are:

- Biomass (incl. above- and belowground biomass)
- Dead organic matter (incl. litter and dead wood)
- Soil matter (incl. soil organic carbon)

The calculated emissions are allocated to the current land use over a longer time period, usually 20 years ([23], [26], [6])[xviii]. This means that if a forest is converted into a cropland, the total difference in carbon stocks is divided by 20 and added to the yearly emissions of the crop. Therefore, the reference year to decide whether land use changes need to be considered is 20 years prior to the assessment.

The methodological approach to calculating LUC emissions can be divided into two concepts: **direct land use change (dLUC)** and **statistical land use change (sLUC)**. dLUC covers land transformation “directly on the area of land that a company owns/controls or on specific lands in the company’s value chain”. In contrast, sLUC refers to land transformation “within a landscape or jurisdiction [serving] as a proxy for dLUC where specific sourcing lands are unknown or when there is no information on the previous states of the sourcing lands” [6]. Since sLUC considers LUC occurring on larger spatial units than the one under assessment, it is considered to include elements of indirect LUC (see below).

The assessment of LUC requires information on the current land use, the previous land use, and regionally specific carbon stocks of each. If no site-specific data is available (i.e. sLUC), the IPCC guidelines provide default factors for different climate regions and dominant soil types. In combination with land use data from FAOStat [27], average LUC emissions per crop and country can then be calculated.

Indirect land use change (iLUC) refers to LUC “on lands not owned or controlled by the company, or in its value chain, induced by change in demand for (or supply of) products produced or sourced by the company” [6]. A typical example is an increased use of plant oil produced in Europe for production of biodiesel (assumed not to cause dLUC). If the oil is used as fuel instead of food, this can lead to increased demand for vegetable oils from other regions, where an increase of production can lead to LUC (e.g., palm oil in Indonesia).

The calculation of iLUC requires global market models.[xix] In contrast to dLUC, it cannot be assessed specifically for an area but requires assumptions on global shifts in supply and demand and related consequences in regions outside the actual assessment area. A study from 2014 by M. Finkbeiner [28] summarizes the situation as follows: *“Indirect land use change cannot be observed or measured (…) The economic LUC models cannot differentiate between direct (dLUC) and indirect*

[xviii] The timeframe of 20 years is a convention (introduced by the IPCC and taken up by PAS 2050) and not a necessity based on physical processes. However, this timeframe is now commonly used.

[xix] For example https://www.exiobase.eu/

land use change. There is no iLUC without dLUC. If every product on earth accounted for its dLUC, there is no iLUC – unless double-counted". Due to this complexity and the remaining large uncertainties, there is no universally agreed upon method to calculate emissions from iLUC. This also means that there is no consensus on the possible extent of the problem: *"The uncertainties are dominated by systematic rather than statistical errors. As a consequence, there is currently no way to determine which of the iLUC factors published is more right than any other"* [28]. Due to these uncertainties, these emissions are usually omitted from product or company carbon footprint assessments. However, this does not mean that the problem is not relevant. Risk assessments can be used to gain a better understanding of the possible relevance of iLUC for different biomaterials.

The **GHG Protocol Land Sector and Removals Guidance Draft** introduced alternative land tracking metrics, which can be utilized instead of iLUC calculations. The first metric are **carbon opportunity costs (COC)**, which are CO_2 emission equivalents that factor in the amount of carbon that could be stored if the land were to return to native vegetation [6], see also textbox on carbon opportunity costs below. The second available metric is **land occupation**, as described above, simply referring to the amount of land occupied for a certain time to produce a product, based on a hectare-basis.

Carbon Opportunity Costs

In a letter published in Nature 2019, Tim Searchinger (from the WRI) and colleagues introduced the concept of **carbon opportunity costs** [49]. In summary, the idea is to pay more attention to the area use of different production systems. They argue that if a production system requires less land, then this land is theoretically available for carbon storage (e.g., through reforestation) or puts less pressure on remaining forests. Therefore, they suggest allocating an additional burden to all land use, called carbon opportunity cost, representing the forgone carbon sequestration. This approach imposes a considerable burden on land-intensive activities, such as comparing organic to conventional agriculture, where organic product systems often have lower yields and therefore require more land to produce the same amount of product compared to a conventional production system. Their approach supports the shift to more vegan and vegetarian diets but also has significant implications for the assessment of biofuels and bioplastics.

While their line of reasoning is compelling, there are some concerns with this approach. Land is just one resource used in production systems, and if their approach is taken up, other inputs should also be considered for environmental opportunity costs, which would make environmental impact assessments of product systems really complex. In consequence, introducing hypothetical alternatives into a product system environmental impact assessment would exceed the basic principles of attributional LCA and clear system boundaries in general (see also [55]). In 2023, the GHG Protocol included this concept into their new guidance as an option to address the issue of iLUC. However, this guideline recommends comparing one product system against another (e.g., conventional vs. organic vs. forest), and including as many life cycle impact categories as applicable to achieve a broad understanding of the overall results before deciding on alternatives, rather than including benefits or burdens from one product system into another.

4.2. Applicability for Biobased Products

The dominant cause of LUC comes from agricultural activity. For instance, an expansion of cropland usually comes at the expense of forest or grassland. There is a strong regional variation in the extent of emissions caused by LUC. In most European countries and in the USA, the expansion of cropland no longer occurs and products from these areas show low to no emissions from dLUC [29]; however, iLUC may still occur. Regions with large **LUCs** are South America, parts of Africa and Southeast Asia [ibid]. Animal products can induce dLUC either through an expansion of pasture on forest land (e.g., cattle in Brazil) or through their feed intake (e.g., imported soybean feed provided to pigs in Europe). The largest emissions result from peatlands or forests being converted to croplands. Land use change to perennial crops can lead to carbon emissions or to carbon sequestration, depending on whether the previous land use was forest or annual crops. Therefore, LUC can add considerably to the total carbon footprint of a product[xx].

It is difficult to quantify the extent of regions or how products contribute to **indirect land use change**. Most studies on iLUC so far have focused on biofuels. A 2014 review by M. Finkbeiner [28] provided a wide range of emissions: from -116 g to 350 g CO_2 eq/MJ for bioethanol and from 1 g to 1434 g CO_2 eq./MJ for biodiesel, indicating significant variation and uncertainty. In a database for 500 food items sold in Denmark, iLUC increased the carbon footprint of the products by 11% on average [30]. However, if biomass is produced sustainably (e.g., waste materials; through increased efficiencies, or on marginal land), the risk of iLUC is considered to be very low.

4.3. Standards

Direct and Statistical Land Use Change

Given the significance of LUC to global GHG emissions, all relevant product carbon footprint (and LCA) standards require the consideration of LUC (either as direct or as statistical LUC, see below).

The **GHG protocol Land Sector and Removals Guidance Draft** requires the accounting and reporting of direct or statistical LUC across all carbon pools for a period of 20 years or more. Unlike older standards, the protocol offers the option to choose between a linear or equal discounting approach. The equal discounting approach allocates total emissions per year equally over a 20-year timeframe, while the linear approach allocates a larger fraction of emissions to the years following the LUC event and lower emissions towards the end of the period. The guidance provides detailed calculation approaches for both dLUC and sLUC [6].

ISO 14067 states: *"The GHG emissions and removals occurring as a result of direct land use change (dLUC) within the last decades[xxi] shall be assessed in accordance with internationally recognized methods, such as the IPCC Guidelines for National Greenhouse Gas Inventories and included in the CFP. The net dLUC GHG emissions and removals shall be documented separately in the CFP study report."* This means that emissions from dLUC are part of a product carbon footprint (i.e., included in the final results) and are documented separately. No specific reference to calculation methods is made in the standard except for a general reference to the IPCC guidelines.

[xx] Sphera assesses sLUC for biobased materials contained in their Managed LCA Content (GaBi Databases) based on the PAS 2050 guidelines and FAOStat with yearly updates. However, an in-depth assessment of dLUC/sLUC values of different crops and materials is outside the scope of this paper.

[xxi] The IPCC tier 1 period of 20 years is frequently used

Another noteworthy addition to the two standards (ISO 14067 and GHG Protocol) is **the Publicly Available Specification (PAS) 2050** [26]. It is a step-by-step calculation procedure provided to calculate dLUC based on the IPCC approach and statistical data from the Food and Agricultural Organization (FAO) with some default values for carbon stocks of different land use categories in different countries. In the absence of case specific primary data, the provided approach might serve as the best starting point for assessing crop and country specific LUC emission values with publicly available data. Sphera uses this approach to consider LUC for agricultural products in its Managed LCA Content Database. This standard is also referred to by the **PEF method** [9].

The Science Based Targets Initiative (**SBTi)** requires the inclusion of LUC in the company's baseline GHG inventory and target using either dLUC or sLUC in scopes 1 and 3 [11]. In addition to including all LUC emissions in a target-setting framework, the SBTi's Forest, Land and Agriculture (FLAG) guidance and tool requires companies to make a no-deforestation commitment with a target date of no later than 2025.

Land use change **can occur in both directions** and lead to carbon removals or emissions. For example, croplands can be converted back to forests and potentially lead to additional carbon removals and sequestration instead of carbon emissions. The classic example are **reforestation** projects. However, the GHG protocol and the SBTi **do not consider transitions that increase rather than decrease carbon storage as LUC events**, yet include them under land-based removals (see section 5 and textbox on land-based removals beyond soil organic carbon sequestration in this document). This is because the carbon stock gains are accounted for as annual net land carbon stock increases occurring in the reporting year, rather than over a historic assessment period of 20 years or more (as is used for LUC emissions, see above), annual carbon stock gains following conversion occur in the same land use category after the conversion (e.g., forest land), and management net carbon removals must meet the requirements for reporting removals (see section 4) [6].

Reforestation projects are usually covered by standards for carbon credit programs, ensuring project permanence, using representative baselines for comparison, and avoiding double-counting. The context of such assessments is usually focused on emission trading, carbon credits, and GHG offsetting rather than a product or company carbon footprint. According to **ISO 14067**, purchased **offsets** cannot be included in product carbon footprints. However, if the **value chain is directly considered** (e.g., the reintroduced forest itself is part of the product system, sometimes referred to as "insetting") the carbon removals and sequestration related to dLUC can be included in the product carbon footprint, similar to the logic of emissions from dLUC. ISO 14067 explicitly addresses emissions and removals related to dLUC. Similarly, the **SBTi** prohibits companies from using purchased carbon credits as offsets to meet near-term FLAG (or energy/industry) targets. Instead, only removals (not included under LUC but under land-based removals, see above) on land owned, operated, or within a company's supply chain can be included in FLAG pathways and count toward achieving a FLAG target.

Indirect Land Use Change

Since there is no universally agreed upon method to calculate emissions from iLUC these emissions are **usually omitted** from product or company carbon footprint assessments. **ISO 14067** states that: *"Indirect land use change (iLUC) should be included in Carbon Footprint of a Product (CFP) studies once an internationally agreed upon procedure exists".* PAS 2050 includes a similar statement but excludes iLUC from the assessments. The **PEF method** also excludes iLUC, which should only be reported as an additional environmental impact if assessed at all [9]. This point also reflects the debate about consequential and attributional LCA[xxii]. It can also be argued that iLUC follows a more consequential thinking since they are based on assumptions on shifts in demand and supply. The PEF method is attributional and intended to provide a statistical representation of average conditions and excludes market-mediated effects, which would omit iLUC per the definition.

Indirect land use change has been discussed intensively in the context of the European Commission's Renewable Energy Directive (RED). In a recently published review, Sumfleth at al. [31] suggest modelled crop-specific iLUC emissions are not suitable for regulatory measures and that the second version of RED introduced a risk-based approach instead, classifying feedstocks into high risk and low risk for iLUC along certain criteria. They provided an overview of studies, approaches, and criteria that could be used in the sustainability certification of low iLUC risk bio-based products: "*We have identified five potential practices for biomass production with low iLUC risk that are likely to be used by market actors. These are (i) increased agricultural crop yield, (ii) biomass cultivation on unused land, (iii) improved production chain integration of by-products, waste, and residues, (iv) reductions in biomass losses, and (v) improvements in livestock production efficiencies*" [ibid.]. In summary, these criteria could help to ensure that the biomass in question is sourced and produced sustainably. The Roundtable on Sustainable Biomaterials (RSB), for example, already offers and conducts such certifications [32].[xxiii]

As mentioned in section 4.1, the **GHG Protocol Land Sector and Removals Guidance Draft** requires the accounting and reporting of at least one land tracking metric (iLUC, Carbon opportunity costs – see textbox on land occupation) reported separately from emissions and removals. The newly introduced land tracking metrics provide a more pragmatic approach for the accounting of the potential pressure a cultivation system puts on other land areas. The **land occupation** metric is currently the most feasible option, with little to no required data collection. Generally, this indicator represents the amount of land required to produce raw materials (based on their yields) and, therefore, also shows the efficiency of the respective systems. However, due to its simplicity, it does not provide information on the extent and quality of the assessed land use nor the impacts on other land uses.

In the **SBTi's** FLAG guidance, iLUC is treated as a part of sLUC (see above). This is consistent with the GHG Protocol Land Sector and Removals Draft Guidance, which requires one of three land-tracking metrics (iLUC, land occupation or carbon opportunity cost) to be reported as additional metrics [11].

[xxii] An attributional life cycle assessment (ALCA) estimates what share of the global environmental burdens belongs to a product. A consequential LCA (CLCA) gives an estimate of how the global environmental burdens are affected by the production and use of the product [59].

[xxiii] A noteworthy exception to the approaches described above is California's Low Carbon Fuel Standard: here, fuels compete on their carbon intensity based on a complete lifecycle analysis that includes ILUC (assessment via GTAB model), rather than being supported or constrained by volumetric mandates or caps [36]. However, the debate around uncertainty of the results continues [ibid].

4.4. Summary and Recommendations

- When it comes to emissions from LUC, the challenge for companies lies not so much in the exact quantification methodology but in providing evidence that it does not occur within their supply chains.
- Companies need to hold their suppliers accountable for including potential LUC when they are providing product carbon footprint data, including whether LUC was assessed. If suppliers state that LUC is not applicable to their products, such claims need to be backed by robust data. Such data could include the following:
    - Official statistical data of land use in the area under consideration
    - Remote sensing data
    - Third-party certification of historic land use
- A prerequisite for such assessments is the traceability of the material's origin. Using statistical data and the approach of the IPCC guidelines, as specified in PAS 2050, companies can assess which crops or materials are at high risk of (direct) LUC occurrence. Robust data is needed to claim non-occurrence.
- As a 20-year reference timeframe is commonly used, data availability on LUC will improve as the reference year falls within periods of time where historic land use records may be available. This may result from better record keeping through increased awareness of issues surrounding LUC and use of technology (e.g., digitalization and/or through remote sensing).
- The new EU Regulation on Deforestation-free products (see Textbox EU Regulation on Deforestation-free products) represents a shift from voluntary reporting to mandatory regulation. While it is only applicable to a limited list of products, it demonstrates the relevance of the subject, and provides a recent example of how sustainability guidelines sometimes precede legislation, and implementing such guidelines assists organizations in their preparation for potentially forthcoming regulations.
- Removals and sequestration from dLUC can be considered if it occurs within the value chain and permanence is ensured. However, in that context, it should also be kept in mind that emissions from LUC are still occurring on a large scale, and that all impact reduction pathways focus on reduction first before any other measures, highlighting again the importance of avoiding emissions from LUC before trying to achieve net removals.
- The assessment of indirect land use change remains a large challenge. Moving from quantification to risk assessment seems to be the best method forward. However, this is not yet a common process, especially outside the bioenergy sector and product carbon footprints. More experience is required to make such classifications easily available to companies. Using area occupation as a proxy metric as introduced by the GHG Protocol Land Sector and Removals Guidance Draft may help in raising awareness but provides little information on actual risks and impacts of iLUC.

EU Regulation on Deforestation-free products

In May 2023, the new **EU Regulation on Deforestation-free products** came into effect with the aim to ensure products consumed by EU citizens do not contribute to deforestation or forest degradation worldwide.

The regulation covers seven commodities and their derived products: wood, soy, palm oil, coffee, cocoa, beef, and rubber. The regulation prohibits their placement on the EU market if they have led to deforestation or forest degradation after 31 December 2020 and if they are not produced according to the local law in the producing country.

Operators and traders who place these products on the EU market or export them from the EU must ensure plot level traceability and provide proof of compliance with the regulation. The regulation is enforced by designated competent authorities in the member states and the European Commission.

The regulation aims to reduce the EU's impact on global deforestation and forest degradation, which are major drivers of climate change and biodiversity loss. The implementation of this regulation is expected to reduce carbon emissions caused by the EU consumption and production of the relevant commodities by at least 32 million metric tonnes a year.

5. Land Management Removals (with focus on soil organic carbon)

As mentioned in section 1, there is a renewed focus on carbon dioxide removal (CDR) opportunities — especially in soils. As soils are the largest terrestrial carbon pool, they have tremendous carbon sequestration potential. Current estimates of their cumulative sequestration potential are up to 130 Gt CO_2 by the end of the century [33]. As a result, there has been growing interest in approaches that could increase the carbon uptake in soils and have been referred to as "*carbon farming*" or "*regenerative agriculture*" [34]. These methods are mainly defined by agricultural land management practices, which also influence the rate of carbon sequestration in soils [35].

In 2022, Textile Exchange published the Regenerative Agriculture Landscape Analysis [36], intended to provide the apparel, textile, and footwear industry with a clearer understanding of tools, programs, initiatives, guidance, and best practices within the regenerative agriculture landscape. The report offered a detailed analysis of regenerative agriculture, the science behind soil carbon sequestration, and best practices when engaging in regenerative programs. This analysis will not be repeated here. This section focuses on the main terms and definitions regarding soil carbon sequestration and highlights the reporting requirements of the guidelines, as mentioned previously.

Sphera has published a white paper aiming to provide an overview of the current challenges and possibilities of integrating the quantification of soil organic carbon into the carbon footprint calculations of agricultural products. The following sections include material from this white paper – please refer to the full paper for more details [37].

Soil organic carbon sequestration is the most widely discussed land-based removal option, and therefore is at the center of this section. However, the principles to account for removals also apply for other land-based removals such as agro-forestry or afforestation, which are discussed briefly in the textbox at the end of this section.

5.1. Terms and Definitions

Soil carbon is carbon stored in soils and includes both soil organic[xxiv] matter and inorganic carbon (e.g., carbonate minerals). Although both organic and inorganic forms of carbon are found in soils, land use and land management can both impact organic carbon stocks [23]. Consequently, the methods discussed in this section focuses on **soil organic carbon** (SOC). The influence of land use and land management on SOC is very different in a mineral soil compared to an organic one. Organic soils are defined as having a minimum of 12% (by weight) organic carbon and develop under poorly drained conditions, such as in wetlands with the most common product being peat [ibid]. All other soils are classified as mineral soil types and typically have relatively low amounts of organic matter, occur under moderate to well drained conditions, and are predominant in most ecosystems [ibid]. Converting an organic soil to a mineral soil (cropland) falls under land use change (e.g., wetland to cropland). See section 3 for further detail.

In the context of product and company carbon footprints, the impact assessment of land management practices on biogenic carbon emissions and removals within a land use category (land

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[xxiv] In the following section, the term "organic" is used in its chemical sense (i.e. in differentiation to inorganic or mineral) and does not refer to organic farming practices (that are also sometimes included in "regenerative agriculture" practices).

use in contrast to land use change, see section 3.1) usually focus on the **organic carbon stock changes in mineral soils**.

Changes in SOC stocks are influenced by many factors and are therefore highly dynamic and comparatively difficult to assess. First, SOC stocks are influenced by climatic conditions and soil characteristics. Soil characteristics can vary widely within small spatial units (i.e., within meters). As a result, large scale assessments (e.g., of a whole production region) are complicated. In addition, land management practices can have a large impact on SOC stocks. The main **management practices** that affect soil carbon stocks in croplands include the following [23]:

- Tillage intensity
- Water management
- Fertilizer application (both mineral fertilizers and organic amendments),
- Residue management
- Choice of cropping system (e.g., continuous cropping versus cropping rotations with periods of bare fallow, mixed systems with cropping and pasture or hay in rotating sequences)
- Increased below-ground inputs

Textile Exchange's Regenerative Agriculture Landscape Analysis [36] provides a more detailed review of practices that are expected to benefit soil health and support soil carbon sequestration. Please refer to this publication for details and an in-depth discussion of these measures.

Quantification Methodologies

In summary, the following approaches are most relevant for the quantification of SOC:

Soil measurements: Measurement-based approaches "are typically used to estimate carbon stocks based on sampling within a given stratum that represents a relatively homogeneous land area with respect to both natural and management factors impacting carbon stocks" [6]. Soil measurements are time-intensive and costly to execute, but they are the most accurate method for determining carbon stocks.

SOC models: Model-based approaches "use mathematical modelling based on various input variables [and] fixed parameters to estimate stocks" [24]. Calibration is the fundamental influence on accuracy. The right calibration models can enable more flexible and independent assessments.

Remote sensing: Remote sensing-based approaches "can be considered a subset of model-based approaches where remote sensing data are used to inform model predictions" [24]. This technology is generally associated with advantages such as a broader spatial coverage and faster data processing. On the other hand, this approach presents various technological challenges (i.e. interference from vegetation cover, variations in soil moisture and roughness, instrument configurations, and the need for various corrections [38]).

Hybrid approaches: Combining two or more methodologies, hybrid approaches are a robust alternative. Often, hybrid approaches are required, for example, in the calibration of SOC models with SOC measurements. This combination can potentially reduce associated costs by lowering measurement requirements while also utilizing the advantages of SOC models.

Until now, SOC **models** have typically been the most appropriate solution for assessments at higher spatial resolution. As is often the case with environmental assessment methodologies, such as the

IPCC guidelines, SOC models are sorted into three ranking levels based on specific characteristics: Tier 1, 2 and 3 models:

- Tier 1 models are also referred to as empirical models, as they have the lowest degree of complexity and data requirements. They use a limited set of data points, such as the climatic region, soil type or land use, as well as estimated initial SOC stocks, some of which are partly available as default values.
- Tier 2 models represent soil-centered models, which combine process and dynamic-oriented approaches by applying climatic conditions (such as monthly precipitation, air temperature, and evaporation), soil parameter (such as clay content and bulk density), and initial SOC stock and management variables (such as carbon inputs, manure inputs, and type of tillage).
- Tier 3 models serve as ecosystem models which can simulate complex dynamics (such as nutrient cycling or below-ground plant biomass growth). This means that these models rely on additional parameters and may require more high-quality data.

An in-depth discussion on the various SOC models developed to date is beyond this paper. Further information on Tier 1 and Tier 2 models are provided in the IPCC guidelines [23] [xxv]. A widely used Tier 3 model are Century/DayCent [39] and the DNDC Model [40].

5.2. Applicability to Biobased Products

There are high hopes that soil carbon sequestration in agricultural soils can provide a significant contribution to climate change mitigation. The “4 per 1000” initiative introduced by the French government during COP21 serves as one example [5]. In theory, **all agricultural systems** could contribute, as the management practices in question (see section above) are not limited to certain crops or materials. The measures most commonly discussed are changing tillage practices (from ploughing to no-till and direct seeding) and increasing the carbon input into the agricultural system by introducing cover crops between cultivation periods (see also section above and Textile Exchange’s Regenerative Agriculture Landscape Analysis [36]).

The contribution of **livestock systems** is also widely discussed. While livestock production systems are responsible for a large portion of the global carbon footprint [25], they are mostly based on grazed rangelands, grasslands, and pastures, which offer significant potential for carbon sequestration if managed accordingly [41].

Many companies are involved in **soil carbon “trading programs”** where they partner with farmers to develop soil carbon sequestration projects and either use generated credits to offset part of their own emissions or sell it to other companies to offset their emissions. The list includes major corporations such as Bayer, Cargill, and Indigo [42]. This has led to a “gold rush” where companies have quickly set up individual programs, as they fear being left behind, which has created a confusing variety of programs, certifications, and payment schemes [43]. The development of the recently published “Soil enrichment protocol” for the US can be seen as an attempt to provide more guidance on the subject (see also section 4.3 below).

There is less euphoria in the scientific community concerning soil carbon sequestration claims. Scientists have worked for decades on the assessments of changes in soil carbon stocks, including the development and improvements of computer models. However, there are **large uncertainties** related to the measures and claims associated with the increase in soil carbon sequestration. An in-

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[xxv] The IPCC Tier 2 model is described in more detail in Sphera’s white paper on soil organic carbon [37]

depth summary of the challenges can be found in the World Resources Report “Creating a Sustainable Food Future” [24]. These challenges include the following:

- the differential yield effects of the proposed management changes
- the need to count only additional carbon and biomass (or to count only net gains if diverting this biomass from another use)
- the need for more nitrogen
- the multiple practical challenges faced by farmers who try to change tillage, crop rotations, and manure- and residue-management practices
- the accuracy of soil carbon measurements
- the potential increase in nitrous oxide emissions that can cancel out the benefits even of large carbon gains
- short-term gains can quickly be lost through changes in management due to changing markets and farm conditions

Nevertheless, the World Resource Institute’s report also highlights opportunities: *“Despite the challenges and uncertainties, it is obvious that some types of farming tend to result in more soil carbon than others (even if only because they lead to smaller losses) and that increased soil organic carbon has important agronomic benefits in addition to mitigating climate change. In many systems, it will be worthwhile to continue to push no-till farming forward to help reduce soil erosion and improve water retention*” [24]. It then draws the following conclusion: “*The challenges and uncertainties involved in boosting soil carbon do not imply a complete lack of opportunities to improve soil management, but the uncertainties are too high to project how much. We also believe the best evidence indicates that agricultural soils are losing carbon today (…). We believe that the reasonable goal in the short and medium term should be to maintain global soil carbon.”* [24].

5.3. Standards

Due to the large uncertainty of the extent and permanence of soil carbon sequestration, as described above, they have been omitted from product carbon footprint standards in the past. With the renewed interest in the subject, this practice has been reconsidered in recent product carbon footprint standards, although the uncertainty still exists.

The **GHG Protocol Land Sector and Removals Guidance** requests a differentiation between emissions and removals, which must be reported separately. In addition, the requirements of the GHG Protocol to include removals in reporting are quite comprehensive (as outlined in the previous sections):

- Requirement for primary data used in calculation
- Validation of results by quantitative and statistically significant uncertainty estimates
- Continuous monitoring of stored carbon
- Full transparency and traceability of the process (still subject to an open question addressed in the draft)
- Accounting and reporting of reversals from previous removals

The new GHG Protocol guideline also addresses the uncertainties that are associated with measuring and modeling SOC. The guideline does not include a list of recommendations for methods or tools. Instead, it provides a list of questions that can be used to assess the choice of methods or tools. This means that the validation of specific methods or tools seems to depend on the interpretation of users — or ultimately, on the approval of the GHG Protocol directly.

ISO 14067 states: *"If there is a net increase of soil or biomass carbon due to modified land use practices, the net increase shall be included in the CFP and the partial CFP only if measures are in place to address its permanence"* [10]. This permits the use of government-approved and published quantification methods. There is ongoing research to develop methodology and models to provide data for the inclusion of soil carbon change in GHG reporting. However, no specific methods or models are recommended. ISO 14067 also recognizes the possibility of regular soil sampling and refers to ISO 10381 for principles and rules for designing soil sampling strategies and techniques.

The Product Environmental Footprint (**PEF)** method is stricter: *"Soil carbon uptake (accumulation) shall be excluded from the results (…). Soil carbon storage may only be included in the PEF study as additional environmental information and if proof is provided"* [9][xxvi]. For category rules outlined in the Product Environmental Footprint Category Rules (PEFCR) Guidance, the technical secretariat can allow the inclusion of soil carbon storage as additional information. If so, the category rules need to be specific on the modelling and calculation rules and the type of evidence needed for approval. In case there is sector-specific legislation, this shall be used as a basis for modelling and calculating SOC results [ibid.]

In summary, if there is robust evidence for a long-term accumulation of carbon in soil, it may be included in the carbon footprint of a product under ISO 14067 but only reported as additional information under the PEF method. However, both standards are not very precise in regard to the type of evidence required to justify their inclusion, leaving the decision to individual reviewers.

On the other hand, the **SBTi** currently only includes emission reductions and no removals in the pathways but recognizes that removals should be included for the forestry, land and agricultural (FLAG) sectors as they are a critical component of land-based mitigation [11]. However, as they align closely with the GHG Protocol, the same strict conditions can be expected when it comes to accounting for soil carbon sequestration.

Two standards should be highlighted here that were published very recently (early and late 2020) and are not related to product or company carbon footprints but are applicable for projects that want to sell generated credits in emission trading schemes:

- **The Global Standard for the Global Goals** (also referred to as "Gold Standard") - Soil Organic Carbon Framework Methodology [44]
- **The Soil Enrichment Protocol** (SEP) [45] by the Climate Action Reserve (CAR) that develops standards for offset projects in the North American voluntary carbon market.

Both standards cover important aspects of carbon credit programs such as baseline and project definition, requirements for permanence, additionality, and verification. The soil enrichment protocol contains sections on the accounting of GHG emissions and removals in addition to changes in soil carbon stocks. Summarizing these standards goes beyond the scope of this paper. An important aspect that should be mentioned here though is that **both standards allow the use of models** to quantify the changes in soil carbon - **but only in combination with soil sampling**. Furthermore, both standards require setting aside a portion of the generated credits to serve as a buffer for reversibility. The SEP suggests a conservative approach for projects where long-term

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[xxvi] The PEF agricultural modelling method is currently also under review. Sphera is supporting this process; however, modelling of soil carbon sequestration is currently not in focus of these updates.

carbon storage (i.e. at least 100 years) isn't assured and only account for 1/100 (1%) of the sequestered carbon per year for the duration that sequestration is guaranteed.

There are more standards related to soil carbon sequestration and the issuing of carbon credits than the two mentioned above. The Environmental Defence Fund (EDF) published an extensive review of these standards recently, which is a good source for more details [46].

5.4. Summary and Recommendations

- Current standards provide specific requirements for the quantification and reporting methods of SOC, but they often lack clarity on practical application. The lack of harmonization in standards impacts ongoing debates, pilot projects, and case studies, and further discussion on this aspect is expected in the future. It is crucial to monitor developments, actively participate, and increase involvement in these processes. The FAO argues that "once consensus is reached on a method of estimating and reporting SOC changes, they could rapidly be accepted within the boundaries of life cycle carbon footprinting" [41].
- The variability and uncertainty associated with soil carbon sequestration are significant, highlighting the need for further development of methods to support the evidence of long-term sequestration. Therefore, it's likely that claims or carbon trade programs will face high scrutiny before any evidence is deemed sufficient.
- Assessing carbon sequestration in soils accurately can only be done on small scales, usually at the farm level. While this isn't necessarily a problem for farmers, it poses a serious challenge for companies or brands with diverse and complex supply chains. Large-scale assessments (e.g., production regions or at the federal state level) can be done for national inventories or scenario analyses, but their reliability for precise company reporting is questionable[xxvii].
- To validate modeled results, standards suggest soil sampling measurements — a measure that can only be conducted in small spatial resolution. This poses a challenge in itself as mentioned in the previous paragraph. In addition to that it's important to remember that these are long-term commitments. A baseline is established before changes occur and measurements are made regularly over the course of the project, with the minimum meaningful assessment period being five years. Ideally, projects should aim for an impact of over 20 but preferably 100 years (see [44]).
- Tier 1 and Tier 2 models may not be precise enough for reliable sequestration claims[xxviii]. Tier 3 models, while more accurate, require a large set of regionally specific input data and calibration, requiring regular, laborious, and intensive soil sampling from small spatial units. Additionally, the effort and level of expertise required to run these models is often beyond the reach of most sustainability practitioners in companies or consultancies. Future technological developments, such as remote sensing or Geographic Information System (GIS) data combined with farm activity assessments (as available for US farmers with the COMET farming tool [47]), might facilitate large-scale assessments but will not eliminate the need for onsite validation.

[xxvii] The question of whether removals can be assessed at the land-scape level is an open question in the GHG land sector and removals guideline draft.

[xxviii] The Gold Standard allows the use of the IPCC Tier 2 model, but only in combination with soil sampling. See also Sphera's upcoming whitepaper [37].

- Certification of soil carbon sequestration will mainly occur within the context of emissions trading and offsetting schemes, where most of the activity is currently observed. In product carbon footprints, it is often considered as an additional environmental impact or within scenarios, if at all. This is also reflected in the small coverage within footprint-related standards, compared to the SEP's extensive guidelines.
- To avoid double counting, companies must ensure that their farmers are not selling carbon credits, while they report reduced emissions at the same time in their carbon footprints (which then in return are used by the companies in their scope 3 reporting). It is important to set clear system boundaries to avoid this issue.
- Despite the uncertainty, the potential to sequester carbon in soils is just one expected positive impact. Even without carbon sequestration claims, promoting soil health improvement is valuable as it supports improvements in other environmental impact areas such as biodiversity and water.
- In conclusion, companies should not solely rely on soil carbon sequestration in their emission reduction efforts. While significant SOC sequestration is possible in some instances, the associated uncertainty within quantification methods means SOC sequestration should only be one part of a broader emission reduction strategy.
- An overarching goal is to find a balance between providing practical, robust, and tested methods for the LCA community without compromising the assessment quality, given the inherent uncertainties with SOC quantification. Fundamentally, SOC quantifications for the sustainability assessment of agricultural crops need to be accessible to a wider group of users. Assessments should be simple to adapt but still deliver high-quality results.
- Textile Exchange's Regenerative Agriculture Landscape Analysis [36] provides a more detailed review of tools, programs, initiatives, guidance, and best practices within the regenerative agriculture landscape. It includes a step-by-step engagement pathway and a review of farm-level accounting tools, with references to carbon credit protocols for those seeking credits. It also emphasizes that regenerative agriculture is, and must be, a fundamentally holistic systems approach that centers on humans and ecosystems, acknowledging its roots in Indigenous practices.

Land-based removals beyond soil organic carbon sequestration – biomass and dead organic matter

Above- and belowground **biomass,** along with dead organic matter (DOM), are the two land-based carbon pools other than soil carbon mentioned in the GHG protocol. Agroforestry is a typical application for biobased products, where trees grown in combination with agricultural activity represent a growing biomass and carbon pool.

The methods for estimating changes in biomass and DOM carbon stocks are the same as for soil organic carbon, i.e., measurement, modelling, remote sensing, or hybrid approaches. The options are described extensively in the GHG protocol. Most importantly, the same criteria for claiming carbon removals apply to biomass or DOM removals: ongoing storage monitoring, traceability, primary data, uncertainty assessment, and reversals accounting. Where applicable, agroforestry can have a carbon sequestration potential in biomass comparable to or even larger than soil carbon sequestration, while still enhancing soil carbon sequestration [25].

6. Summary and Conclusions

Table 1 summarizes how biogenic carbon emissions and removals are considered in carbon footprint calculations across different guidelines. Although there may be variations in terminology, approaches, and technical details between the different standards and guidelines, they all have one concept in common: **removals should only be considered in carbon footprint calculations if their permanence can be ensured.**

The guidance on the inclusion of removals for reporting requirements in the GHG Protocol Land Sector and Removals Guidance are particularly useful and are summarized here:

- Primary data use
- Validation of results by quantitative and statistically significant uncertainty estimates
- Continuous monitoring of stored carbon
- Full transparency and traceability of the process
- Accounting and reporting of reversals from previous removals

As organizations begin to adapt to the new guidelines, strict requirements on claiming removals in impact reporting can help prevent greenwashing in sustainability claims[xxix].

Carbon stored in biobased products is temporary in most cases. **Such storage should not be claimed as a permanent removal unless it meets strict criteria as laid out in the GHG protocol**. For partial carbon footprints, results should include a simplified EoL assessment or show impacts based on both the -1/1 and 0/0 approaches, making it clear that the temporary storage shown in the -1/+1 approach is not a permanent removal.

For products like biochar, long-term (i.e., more than 100 years) carbon storage is less controversial. The environmental impacts and benefits can be captured in carbon footprints following the principles of life cycle assessment, where emissions and removals are followed from cradle-to-grave. The challenge here is economic and technical feasibility and scalability of such approaches.

LUC emissions contribute significantly to global warming, so avoiding these emissions should be a top priority for all companies. This requires organizations to gain a better understanding of their supply chain origins and improve the traceability of the purchased material. Statistical methods can be used to screen the supply chain for the largest risks and to collect data on potential LUC impacts. Further, the new EU Regulation on Deforestation-free products (see Textbox: EU Regulation on Deforestation-free products) is a recent example of how following sustainability guidelines can help to prepare for subsequent legislation.

Carbon removals from LUC, such as through reforestation, can occur[xxx]. For most companies, there will be a limited range of products (and production regions) where they can incentivize changes in

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[xxix] Such requirements could even be introduced by legislation, e.g., the “proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a Union certification framework for carbon removals”. The proposal sets out four quality criteria for carbon removals: quantification, additionality, long-term storage and sustainability. Carbon removals should be accurately measured, go beyond legal and market requirements, ensure durable storage of carbon, and have a neutral or positive impact on other environmental objectives [51].

[xxx] As described in section 4.3 the GHG protocol and the SBTi do not consider transitions that increase rather than decrease carbon storage as LUC events, but include them under land-based removals.

their own value chain. If the LUC occurs to their benefit in their own supply chains, they will be able to account for the removals in their carbon footprint calculations. However, the same criteria for claiming removals described above will apply, and ensuring the permanence of such land-based removals might be especially challenging. If removals are discounted due to uncertainty, their impact on GHG reduction from a product or company perspective will be lowered. Organizations can in some cases encourage land-based removals and then consider the removals when calculating a product or company carbon footprint. However, following the SBTi's logic, avoiding LUC emissions and reducing emissions should be a priority.

The same can be said about soil carbon sequestration, as organizations should not solely rely on this method as part of their emission reduction efforts. SOC sequestration can be significant in some cases, but it should be part of a broader emission reduction strategy. Nevertheless, despite the uncertainty, the potential to sequester carbon in soils is just one expected positive impact. Even without carbon sequestration claims, promoting healthy soil environments is beneficial. If removals are claimed, permanence principles must be established. More importantly, it remains to be seen how the sequestration of carbon in soils and its quantification can be put into practice in a scalable way (see also Sphera white paper [37]).

This paper aligns with WRI's Creating a Sustainable Food Future report [24] and the SBTi approach, emphasizing that emission reduction must come first [11]. This can happen through increased productivity, linking agricultural activity with natural ecosystems protection (e.g., through effective legislation to avoid LUC) and better management practices (e.g., fertilizer application, manure management, energy use, irrigation practices, optimizing enteric fermentation, etc.). The choice of materials used in marketed products (or diets in the case of food production) also plays an important role.

For external communication of results, Sphera recommends working with established standards as discussed in the previous section and including external critical review or verification to ensure conformance with these standards. Standards often only provide a framework and specify general reporting requirements but intentionally leave open the rules surrounding specific quantification methods, type of supporting evidence, and measurement requirements (e.g., frequency, calibration, treatment of missing data, etc.). Regulatory and voluntary bodies and agencies can then adapt such frameworks and prepare specific guidelines and rules. Therefore, this paper cannot provide a conclusion. The decision on such subjects is often an iterative process during the review where transparency becomes the main tool to overcome uncertainty and confusion surrounding different standards.

Table 1: Summary of ISO 14067, PEF Method, and the GHG Protocol on the quantification of biogenic carbon emissions and removals in carbon footprints

	ISO 14067	PEF method	GHG Protocol Land sector & removals guide	Recommendations
Biogenic carbon stored in the product	-1/+1 approach, carbon stored in the product is considered and included in the carbon footprint but is reported separately.	0/0 approach, biogenic carbon is included in the inventory, carbon content of product should be reported, but biogenic carbon stored in product is not considered in the impact assessment.	Simplified approach assuming no carbon stock changes (corresponding to a 0/0 approach) or stock-change approach (corresponding to a -1/+1 approach) can be used. However, strict requirements apply when considering carbon stored in product to be removed permanently under the stock-change approach.	Carbon stored in the product should not be claimed as removed if it cannot be considered removed permanently (under strict criteria as laid out in the GHG protocol). In partial carbon footprints, results should include simplified EoL assessment or show impacts based on both the -1/+1 and 0/0 approach, but it should be clearly communicated that the temporary storage shown in the -1/+1 approach is not a removal.
Biogenic carbon stored in the product – delayed emissions	Delayed emissions cannot be considered, only permanent removal (more than 100 years; typically landfill at EoL) can be reported as additional information if emissions are delayed by more than 10 years.	Not considered.	Storage discounting frameworks are reported outside of the scope in a separate category called "temporary carbon storage".	Delayed emissions should not be included in carbon footprint assessments. If assessed, they should be reported as additional information.
LUC – carbon emissions (e.g., deforestation)	Needs to be accounted for under all standards. Avoidance is key.	Must be included in a dedicated sub-category called "Land use change". All carbon emissions and removals shall be modelled following the guidelines of PAS 2050:2011 (sLUC can be assessed if more accurate data is not available).	Needs to be included. Detailed assessment guideline available. dLUC or sLUC can be assessed.	Important metric. Focus on traceability, product/value chain specific historic land use data (reaching back 20 years) is required, statistical data accepted if site-specific data is not available. For some products, legislation in the EU is already implemented.
LUC - carbon removals (e.g., reforestation)	LUC removals can be included if the product itself is concerned. Inclusion of purchased offsets are not allowed.	See above (LUC - carbon emissions), explicitly mentions "all emissions and removals"	Not considered under LUC, but as land-based removals, criteria apply to account for removals: ongoing storage monitoring, traceability, primary data, uncertainty, and reversals.	Removals should only be claimed if occurring directly in the value chain, and if strict criteria to claim removals from GHG Protocol are met. Offsetting cannot be included in a carbon footprint.
Indirect LUC	Omitted due to lack of standardized assessment methods but does not prevent their inclusion at a later date in the future when a reputable method can be agreed upon.	Excluded, should be reported as additional environmental impact if assessed.	Should at least include one tracking metric: land occupation (area use), carbon opportunity costs, or modelled iLUC.	No consensus on how to assess iLUC; therefore, they can be omitted from carbon footprint studies. Land occupation is a metric that is easy to assess without additional data collection and modelling, for reporting purposes.
Soil carbon	Can be included if backed up by robust evidence (for PEF: only as additional environmental impact).	Can be included if backed up by robust evidence but only as additional environmental impact.	Strong criteria apply to account for removals: ongoing storage monitoring, traceability, primary data, uncertainty assessment, and reversals accounting.	Currently, use of accepted models backed up by soil samples seems the best way to provide robust evidence. Permanence of interventions must be ensured, or removals should be discounted if permanence is uncertain.
Biochar	No explicit guidelines but can be included following LCA principles.	No explicit guidelines but can be included following LCA principles.	Included in the carbon storage methodology and, hence, the permanence principles for carbon removals apply (ongoing storage monitoring, traceability, primary data, uncertainty, and reversals).	Ensure permanence (IPCC provides permanence factors for application to soil).

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