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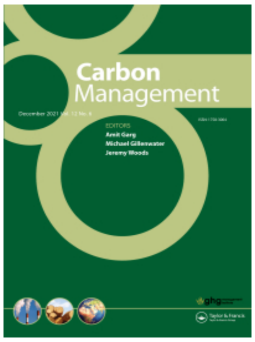

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COMMENT

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Methods that equate temporary carbon storage with permanent CO_2 emission reductions lead to false claims on temperature alignment

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ABSTRACT

There has been renewed interest in equating temporary carbon storage with permanent CO_2 emission reductions, both within corporate GHG inventories and for carbon offset accounting. Proposed methods discount future emissions, such that carbon stored temporarily can be accounted for as (some fraction of) a permanent reduction in emissions. These approaches are problematic as long-term temperature change is primarily caused by cumulative CO_2 emissions and delayed emissions accumulate in the atmosphere the same as any other emission of CO_2. This perspective article uses illustrative examples to show how discounting future emissions results in false temperature alignment and net zero claims. We recommend that emissions and removals should be reported without discounting to ensure that GHG accounts accurately reflect contribution to cumulative emissions. There is value in temporarily storing carbon, e.g. it can reduce peak warming and buy time to implement permanent mitigation measures, but it cannot be treated as equivalent to permanent mitigation, and alternative approaches should be used to convey the value of temporary storage.

HIGHLIGHTS

- Discounting emissions from temporarily stored carbon creates false alignment claims.
- Emissions should be reported without discounting.
- Temporary storage has value but must not be equated with permanent mitigation.

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Temporary carbon storage; tonne-year accounting; discounting greenhouse gas emissions; permanence of stored carbon

1. Introduction

There has been renewed interest in accounting for carbon that is stored temporarily, as the result of CO_2 removal or avoided emissions, as equivalent to some fraction of a permanent reduction in fossil CO_2 emissions. For example, the GHG Protocol's draft *Land Sector and Removals Guidance* proposes that companies may report the benefits of temporarily storing carbon in products as if such benefits were permanent [1]. Similarly, within the field of carbon offset accounting, various bodies, including the Supervisory Body for Article 6.4 of the Paris Agreement, have recently either consulted on, or formally adopted, approaches that would treat temporary storage as equivalent to a fraction of permanent CO_2 mitigation [2–6]. Moreover, in the academic literature, two recent articles propose the use of economic discounting to calculate an equivalence ratio between CO_2 stored for one year and CO_2 stored permanently [7, 8].

All of these proposals seek to establish equivalence by applying discounts to reversal[1] emissions, such that the physical quantity of a future emission is marked down based on when it occurs.[2] Such accounting approaches are problematic, however, as temporarily storing carbon out of the atmosphere does not mitigate long-term temperature change, which is predominantly driven by cumulative CO_2 emissions and is insensitive to the timing of those emissions [9–11].[3] Although many of the arguments and evidence against discounting reversal emissions are not new, and, indeed, the scientific basis for rejecting discounting has only strengthened over time [12], the renewed interest in discounting within policy, accounting, and academic contexts requires a renewed articulation of the reasons that it is problematic. This perspective paper therefore seeks to highlight and explain the problem with discounting, and in addition, propose a new accounting approach for corporate GHG inventories, in order to reflect the value of temporarily stored carbon.

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The remainder of the paper is structured as follows: section 2 briefly describes the background and nature of discounting methods; section 3 illustrates and explains the problem with discounting; section 4 critiques one of the common arguments for discounting; section 5 discusses the value of temporary storage and suggests alternative ways of conveying this value; and section 6 offers concluding remarks.

2. Background and nature of discounting methods

There appear to be the following two broad categories of discounting method applied to reversal emissions.

Method 1: Discounting based on avoided radiative forcing during a specified time period

This form of discounting approach was first proposed within the field of climate change policy and carbon offsetting in the early 2000s [13, 14], but has also been explored within the field of product life cycle assessment [15–17]. Although a number of proposed variations of this type of discounting method exist (see Brandão et al. [18] for a detailed discussion) they share the common feature of discounting emissions based on the amount (or some approximation of the amount) of radiative forcing, i.e. change in energy flux in the atmosphere, avoided during a specified time period (often 100 years). Emissions beyond the specified time horizon are discounted to zero. For example, the European Commission ILCD Handbook [15], which is broadly representative of this type of approach, applies a discount factor of 0.01 for each year of temporary storage as a simplified approximation of avoided radiative forcing, and emissions after a 100 year horizon are treated as zero (or reported as separate information).

To give a simple worked example, if there is a removal of -1tCO_2, and the carbon is stored for 50 years and then released, the reversal emission would be discounted to 0.5tCO_2 (1tCO_2 $\times$ 50 years $\times$ 0.01 = 0.5tCO_2), and the overall "net" removal would be reported as -0.5tCO_2 (with removals represented as a negative number).

Method 2: Reduction in present value damage costs (economic discounting)

This form of discounting approach has been discussed within the academic literature since at least the late 1990s [19], but has received renewed attention more recently with the publication of Parisa et al. [7] and Balmford et al. [8], and its proposed use under Article 6.4 of the Paris Agreement [4]. This type of discounting method applies an economic discount rate to calculate the reduction in the present value of damage costs achieved by delaying climate impacts, and then applies that reduction to mark-down the physical quantity of CO_2 reversal emissions that are reported.

To give a simple worked example, if the economic discount rate (the rate at which future welfare is worth less than present welfare) is 3%; and a removal of -1tCO_2 is stored for 50 years and then released, the reversal emission would be discounted to 0.228tCO_2, as expressed by Equation 1. The overall "net" removal would be reported as -0.77 tCO_2.

$$Discounted\ tCO_2 = \frac{tCO_2}{(1 + discount\ rate)^{years}} = \frac{1tCO_2}{(1+0.03)^{50}} = 0.228\ tCO_2$$

Equation 1

As noted above, both methods of discounting are used to compute equivalence ratios between temporary storage and permanent storage or reduced fossil CO_2 emissions [7, 13].[4] For example, the ILCD discount factor of 0.01/year entails that 100 "tonne-years" (e.g. storing 100 tCO_2 for 1 year) are equivalent to 1 tCO_2 of permanent storage or reduced fossil emissions (1 $\div$ 0.01 = 100). The following section explores the problems with discounting and the implied equivalence between temporary and permanent storage.

3. The problem with discounting

The problem with discounting is that long-term temperature change is driven by cumulative CO_2 emissions and is insensitive to the timing of those emissions [9–11]. This fact underpins the concept of a "carbon budget", i.e. a fixed quantity of net additions to the atmospheric stock of CO_2 before a given temperature threshold is reached, e.g. 1.5 degrees [10, 11, 20, 21]. If carbon accounting methods do not accurately reflect the contribution to cumulative emissions, then reporting entities can report that they are operating within a specified carbon budget, or that their life cycle emissions are "net zero", while the physical reality is that they are not. This section provides two examples to illustrate the problem created by discounting, focusing on corporate-level inventories and

Table 1. Illustration of discounting within corporate GHG inventories.

Description	Data	Notes
Fossil emissions associated with production in 2020 (tCO_2)	100	
Removals associated with production in 2020 (tCO_2)	−100	
Reversal emissions associated with production in 2020 (but occurring in 2070) (tCO_2)	100	
Discounted reversal emissions (tCO_2)	50	($100tCO_2 \times 50$ years $\times$ 0.01)
Reported net life cycle emissions associated with production in 2020 - with discounting (tCO_2)	50	($100tCO_2$ emissions + −100 tCO_2 removals + $50tCO_2$ reversal emissions (discounted))
Actual net life cycle emissions associated with production in 2020 (tCO_2)	100	($100tCO_2$ emissions + −100 tCO_2 removals + $100tCO_2$ reversal emissions)
Under-reporting of contribution to cumulative emissions (tCO_2)	50	($100tCO_2$ actual net emissions – discounted net emissions)

offset accounting, though the problem applies equally to any form of GHG accounting, including LCA and national GHG inventories.

Table 1 provides illustrative data for a corporate GHG inventory, e.g. a wooden furniture manufacturer. The company has emissions in 2020 totalling $100tCO_2$, but also books $100tCO_2$ of removals, which are assumed to be fully re-emitted after 50 years. These removals and reversal emissions, as is current practice for all other upstream or downstream value chain emissions, are reported in the inventory year in which the input is purchased or the output is sold, rather than the year in which the emission/removal physically occurs [22]. If the ILCD discounting method is used, the $100tCO_2$ reversal emissions would be discounted to $50tCO_2$, and the total reported net emissions for 2020 would be $50tCO_2$ ($100tCO_2$ + $-100tCO_2$ + $50tCO_2$ = $50tCO_2$). This is problematic as the actual net contribution to cumulative emissions over time will be $100tCO_2$, and net emissions are under-reported by $50tCO_2$. This means that the GHG accounts cannot be used for carbon budgeting, temperature alignment goals, or science-based targets, all of which require information on contribution to cumulative emissions. For illustration, if the company in the example has a carbon budget for 2020 of $75tCO_2$ it can report that it is operating within that budget, while its actual net contribution to cumulative emissions over time will exceed the budget. The accounts will mislead companies and their stakeholders into believing they are on track for aligning with the Paris temperature goals whilst the opposite is the case.

To illustrate the effect of discounting on the validity of offsetting claims, Table 2 provides data for a project that temporarily enhances storage, such as a delayed forest harvesting or avoided deforestation project (though the principle of the illustration applies equally to removal-type projects with temporary storage). The project avoids the release of $100tCO_2$ in 2020 (relative to the project's baseline), but after 20 years a reversal occurs such that carbon stocks are reduced back to baseline levels. Using the ILCD method for illustration, the project would qualify for one carbon credit (representing $1tCO_2$) for each year the $100tCO_2$ of carbon remains stored, amounting to 20 credits over the 20-year period. The rationale is that for each year of maintaining storage the project avoids approximately $1/100^{th}$ of the radiative forcing that would have occurred during the 100-year period following the start of the project ($100tCO_2 \times 0.01 = 1$ tCO_2). The net result is equivalent to discounting the reversal emissions that occur after 20 years by 80% ($100tCO_2 \times 0.01 \times 80$ years remaining = $80tCO_2$).

The carbon credits from the project could be used by a buyer to claim that they have offset $20tCO_2$ of fossil emissions, and are "carbon neutral" or "net zero". However, the total change in cumulative emissions achieved by the offset project is zero and not -$20tCO_2$, and any claim to have neutralised or offset the buyer's contribution to cumulative emissions would be false. A more limited claim to have "offset the radiative forcing during a specified time period" could be made, or if using economic discounting "to have avoided climate change damage of equivalent net present value". But such offsets could not be used for claims on alignment with carbon budgets, science-based targets, or temperature/Paris alignment goals, all of which relate to cumulative emissions.

It is worth noting that although the different methods for discounting, whether economic or based on radiative forcing, result in different discount rates and equivalence ratios the overall conclusion that discounting results in false temperature alignment or net zero claims applies to all methods. It is also worth noting that many existing carbon offsetting programmes adopt a form of discounting by selecting a time horizon beyond which reversal emissions are treated as zero, with effective time horizons varying between 5 years [23] and 100 years [24]. This is effectively a "stepped" form of discounting, with no discount

Table 2. Illustration of discounting within offset accounting.

	2020	2040	Total
Baseline emissions (tCO_2)	100	0	100
Project scenario emissions (tCO_2)	0	100	100
Discounted project scenario emissions (tCO_2) ($100 \times 0.01 \times 80$)		80	80
Net change in reported emissions with discounting (tCO_2)			−20
Net change in physical cumulative emissions (tCO_2)			0

applied during the chosen time period, but a discount rate of 100% applied to reversal emissions occurring after the time horizon. The same conclusion applies to this approach, i.e. offsets based on discounting or omitting reversal emissions create false claims to temperature alignment.

4. Critique of GWP-100 as an argument for discounting

One argument frequently advanced to justify a focus on radiative forcing over 100 years, rather than cumulative emissions, is that this aligns with an apparent policy consensus to compare the effects of different non-CO_2 greenhouse gases using 100-year global warming potentials (GWP-100) [13–15]. The use of 100-year GWPs in contexts like national greenhouse gas accounting and reporting under the United Nations Framework Convention on Climate Change might suggest that policy-makers are primarily concerned with: a. cumulative radiative forcing; and b. climate impacts over the next 100 years. The history of the selection of GWP-100 as a common metric, however, suggests a more complicated reality [25]. Furthermore, the Paris Agreement's stated long-term temperature goals are flatly at odds with the idea that society's primary concern is radiative forcing over arbitrary time horizons.

In short, the Paris Agreement's temperature goal of "holding the increase … to well below 2 °C … and pursuing efforts to limit the temperature increase to 1.5 °C" [26] clearly indicates the world community's concern with temperature change (which is driven by cumulative emissions), and not solely with cumulative radiative forcing. The Paris Agreement does not say "… hold the increase to well below 2 °C, but *only for the next 100 years*". Indeed, the choice of a 100 year time horizon for calculating GWPs should not be taken as reflective of society's time period of concern, but should rather be viewed as an "inadvertent consensus", solely for the purpose of calculating GWPs [25].

The primary purpose of GWPs is to allow the comparison of different GHGs by converting them to units of CO_2e, which necessitates the selection of an arbitrary time period over which integrated radiative forcing is compared. However, the misalignment between GWPs and the Paris Agreement's temperature goal has been cited as a reason for using alternative methods to compare different GHGs, notably GTP (global temperature potential) and GWP*, which reflect the relative contribution of different GHGs to temperature change [27–29]. In the case of comparing CO_2 emissions with CO_2 removals, or delayed CO_2 emissions, no conversion to a common unit is needed as all are in units of CO_2, and there is no need to select an arbitrary time period.

5. Value of temporary storage and solutions

Although temporarily storing carbon out of the atmosphere does not reduce cumulative emissions and therefore does not limit long-term temperature change, it is important to recognise that temporary storage does have benefits. First, it can slow the rate of temperature increase, which gives ecosystems more time to adapt to climate change [30]. Second, under the right circumstances it can help to reduce peak warming [31, 32]. Third, it "buys time" for society to develop and deploy alternative mitigation actions [33]. Therefore, there is a need for GHG accounting methods that provide information on *both* contribution to cumulative emissions and the amount and duration of temporary storage. The following focuses predominantly on some possible solutions for corporate GHG inventories, with some remarks to highlight that solutions for offset accounting already exist.

One possible solution for corporate-level GHG inventories is to use a "time-series" approach in which future downstream value chain emissions (and removals) are reported at the time that they occur, which coheres with the idea of the "reality principle" for GHG inventories, i.e. that inventories should report emissions/removals when and where they occur [34]. This approach would ensure that no emissions or removals are omitted *via* discounting, and it would also reflect the amount and duration of temporary storage. To clarify, the emission would be reported in the inventory for the year in which it occurs, rather than each annual report being comprised of a time-series of projected future emissions. Using the example of the wooden furniture company, the reversal emission would be reported in the company's GHG inventory for 2070, at which point the company would have to balance the emission with further removals to keep within its carbon budget. Determining the year in which the reversal emission occurs could either be done *via* on-going monitoring of stored carbon stocks, although this would entail additional costs and potentially additional emissions associated with monitoring activities, or *via* the use of default half-lives or decay rates, as per the approach for harvested wood products under national inventory accounting [35].

The GHG Protocol's consultation on its draft *Land Sector and Removals Guidance* asks whether reporting companies should be able to separately report their net removals using discounting methods in order to convey information on temporary storage in products [1]. A weakness with this approach is that discounting based on radiative forcing during a specified time period treats all durations of storage beyond the time horizon identically, and therefore does not recognise or incentivise maximising the duration of storage. For example, using the ILCD method, the value of storage for 100 years would be reported as being identical to the value for 500 years, while, in contrast, the time-series approach would accurately reflect that these different durations are not equivalent. A further benefit of the time-series approach is that it can also be used to show the duration of "carbon debt" [36], i.e. when a company creates upfront emissions which are later "paid back", e.g. if natural forests are harvested and the carbon is released to the atmosphere, followed by subsequent replanting and recapture of the emissions.

One weakness with the time-series approach is that when a company reports an initial removal it may not be immediately apparent within the inventory for that year that a future emissions liability has been created, i.e. the information reported would not clearly differentiate between a removal with permanent storage and a removal with temporary storage. Furthermore, questions may arise about what happens if companies go out of business before future reversals occur, in which case those reversal emissions may never be reported. This could be remedied to some extent by separately reporting that the storage is expected to be temporary, together with an estimate for the anticipated duration of storage (based on default half-lives or decay rates), and/or a commitment to long-term monitoring. In essence, companies could separately report on their outstanding "carbon liabilities" in each reporting period. Although current practice for corporate accounting avoids this problem by reporting all upstream and downstream life cycle emissions in the year that the product is produced, rather than the year in which the emissions/removals occur [22], this approach does not convey any information on the duration of temporary storage. If this approach is maintained, the lack of information on temporary storage could be remedied by separately reporting the amount and anticipated duration of storage associated with the products produced in that year, or by separately reporting the rate of increase in cumulative tonne-years for stored carbon following the approach proposed in Matthews et al. [32].

It is worth noting that a time-series approach is also highly applicable to both attributional and consequential LCA, which are typically very poor at conveying the temporal dimension of the life cycle inventory and impact assessment [37]. In addition to reporting a single aggregate number for net emissions and removals over the life cycle of a product, a time-series should be reported to convey information on when the emissions and removals occur.

Finally, solutions to temporary storage within the field of carbon offsetting already exist. Temporary crediting, for example, involves the issuance of credits that expire after a period of time and have to be replaced with either further temporary credits, in perpetuity, or with credits from project-types that have permanent storage/mitigation [38]. This approach accurately reflects the temporary nature of carbon storage and adjusts net emissions accounting accordingly, over an indefinite timeframe. Although demand for temporary credits was limited under the Kyoto Protocol's Clean Development Mechanism, the method offers a theoretically sound approach to using temporary storage as an "offset" to permanent CO_2 emissions. An alternative solution, given the mismatch between permanent fossil emissions and mitigation involving temporary storage, would be to move away from using temporary storage for offsetting [39]. Instead, credits from such projects could be used to make "contribution" claims or "buying time" claims, without claiming to have "offset" fossil emissions, and such credits could be denominated in units of tonne-years [39].

6. Conclusions

Mitigating temperature change is one of the primary goals of the Paris Agreement, which entails maintaining cumulative emissions below the threshold at which temperature goals are exceeded. When future emissions associated with temporary carbon storage are discounted, reporting entities may effectively claim that they are operating within a given carbon budget, or have achieved net zero emissions, when this is not the case. We therefore recommend that emissions and removals must be reported without discounting to ensure that GHG accounts accurately reflect contribution to cumulative emissions. There is value in temporarily storing carbon, e.g. it buys time to implement permanent mitigation measures, but this is not the same as permanent mitigation, and must not be treated as such. Alternative approaches should be used to convey the value of temporary storage, such as adopting a time-series approach for corporate GHG inventories, temporary crediting for offsets, or creating alternative credits for "buying time" and lowering peak warming.

Notes

1. A "reversal" occurs when carbon that was previously stored or preserved as a result of a mitigation activity is later released to the atmosphere, "reversing" the mitigation achieved. "Temporary storage" refers to the storage of carbon in non-atmospheric pools as a result of a mitigation activity and the duration of storage is less than the time period over which a CO_2 emission perturbs global mean surface temperature.
2. Using discounting as the basis for computing an equivalence between temporary storage and permanent mitigation is often referred to as "tonne-year accounting" as a "tonne-year", which denotes 1 tonne of CO_2 stored for 1 year, can be used to denominate the "value" of delaying emissions [14, 40].
3. This issue applies to any form of enhanced carbon storage in reservoirs, e.g., enhanced storage due to avoiding emissions of carbon from a reservoir. It is particularly relevant for removals, however, that store carbon in biospheric reservoirs, such as trees and soils, and which may be relied on to counteract the effect of fossil CO_2 emissions.
4. Some proposals also combine these two methods. The approach adopted by NCX, for example, uses both physical discounting based on radiative forcing as well as economic discounting (see Chay et al. [40]). A similar approach was also proposed in discussion documents for the Article 6.4 Supervisory Body [4].

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Data availability statement

There are no datasets associated with this article.

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