

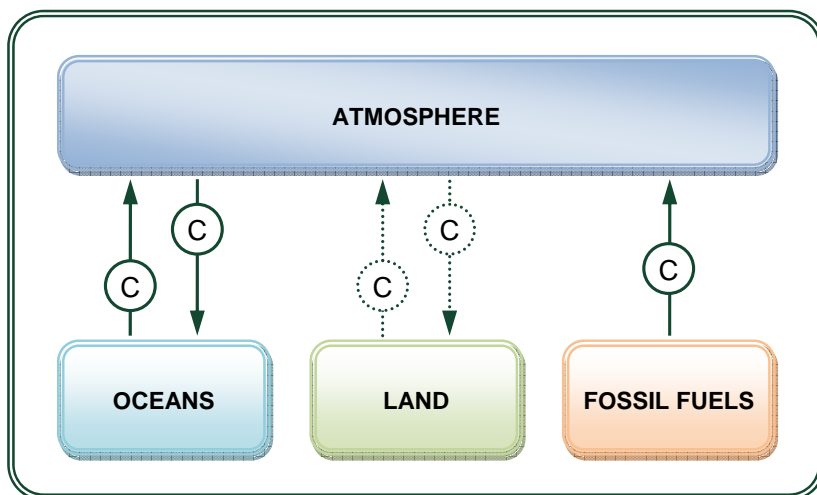


# Assessing Temporary Carbon Storage in Life Cycle Assessment and Carbon Footprinting

Outcomes of an expert workshop

7<sup>th</sup>-8<sup>th</sup> October 2010, Ispra (Italy)

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This report summarises the presentations and discussions that took place at the Expert Workshop on Temporary Carbon Storage for use in Life Cycle Assessment (LCA) and Carbon Footprinting (CF), held at the Joint Research Centre (Ispra, Italy) on 7-8 October 2010. It is presented in minutes format with the discussion grouped into themes rather than reflecting the exact chronological order of the discussion.

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## Executive Summary

Land and wood products, among others, represent temporary carbon sinks. Since the embodied carbon is retained outside the atmosphere for a period of time, some radiative forcing is postponed. Carbon removal from the atmosphere and storage in the biosphere or anthroposphere, therefore, may have the potential to help mitigate climate change.

Life cycle assessment and carbon footprinting are increasingly popular tools for the environmental assessment of products that take into account their entire life cycle. A robust method is required to account for the benefits, if any, of temporary carbon storage for use in the environmental assessment of products. Despite significant efforts to develop robust methods to account for temporary carbon storage, there is still no consensus on how to consider it.

This workshop brought together experts on climate change, carbon footprinting and life cycle assessment to review available options and to discuss the most appropriate method for accounting for the potential benefits of temporary carbon storage. The workshop continued the work developed under the International Reference Life Cycle Data System (ILCD), which provides methodological recommendations for use in business and policy for assessing the environmental impacts of goods and services, taking into account their full life cycle. This report is a summary of the presentations and discussions held during this workshop.

## Table of Contents

1	Introduction .....	1
1.1	Background .....	1
1.2	Radiative forcing and Global Warming Potentials.....	2
1.3	Tonne-year approaches.....	3
1.4	Temporal preferences and value choices.....	5
1.5	The metrics of climate change.....	6
2	The role of temporary carbon sinks.....	8
2.1	Problems related to temporary carbon storage.....	8
2.2	The use of different indicators.....	8
2.3	Benefits of temporary carbon storage .....	9
2.4	Do temporary carbon storage and delayed emissions matter? .....	9
3	Existing approaches and rationale for adoption .....	11
3.1	LULUCF sector under the Kyoto Protocol .....	11
3.2	Existing approaches for LCA and CF .....	11
3.3	Developing approaches for LCA and CF .....	12
3.4	Accounting level.....	13
3.5	The choice of a time horizon .....	13
3.6	Discounting future emissions .....	15
3.7	Treatment of biogenic carbon.....	15
3.8	Which approach to choose for carbon footprinting? .....	16
4	Application of alternative methods .....	19
5	Conclusions .....	21
6	References .....	22
7	Appendix .....	23
7.1	Need for Relevant Timescales in Temporary Carbon Storage Crediting.....	23
7.2	Treatment of carbon storage and delayed emissions.....	24
7.3	Strengths and limitations of the Global Warming Potential and alternative metrics .....	33
7.4	Temporary Carbon Sequestration Cannot Prevent Climate Change.....	38
7.5	Accounting for sequestered carbon: the value of temporary storage .....	51
7.6	ILCD Handbook recommendations.....	54
7.7	Treatment of temporary carbon storage in PAS 2050 .....	57
7.8	ISO 14067 Carbon footprint of products.....	58
7.9	Greenhouse Gas Protocol Supply Chain Initiative.....	59
7.10	Biogenic CO <sub>2</sub> emissions and their contribution to climate change .....	60
7.11	The upfront carbon debt of bioenergy: a comparative assessment .....	61
7.12	Quantifying climate change impacts of bioenergy systems - An overview of the work of IEA Bioenergy Task 38 on Greenhouse Gas Balances of Biomass and Bioenergy Systems .....	65
7.13	Assessing temporary carbon sequestration and storage projects through LULUCF with dynamic LCA .....	69

# 1 Introduction

Land and wood-based products, among others, represent temporary carbon sinks. Since the embodied carbon is retained outside the atmosphere for a period of time, some radiative forcing is postponed. Carbon removal from the atmosphere and storage in the biosphere or anthroposphere, therefore, may have the potential to help mitigate climate change.

Life cycle assessment (LCA) and carbon footprinting (CF) are increasingly popular tools for the environmental assessment of products that take into account their entire life cycle; from the extraction of raw materials through to their end-of-life. A robust method is therefore required to account for the benefits, if any, of temporary carbon storage for use in these environmental assessment approaches. Despite significant efforts, there is still no consensus on how to best consider this.

This workshop brought together experts on climate change, carbon footprinting and life cycle assessment to review available options and to discuss the most appropriate method for accounting for the potential benefits of temporary carbon storage. The workshop continued the work developed under the International Reference Life Cycle Data System (ILCD) [1], which provides methodological recommendations for use in business and policy for assessing the environmental impacts of goods and services, taking into account their full life cycle.

This report is a summary of the presentations and discussions held during this workshop. Sections 1 to 4 sum up the principal topics of the four sessions of presentations given by experts, including discussions. Section 5 gives the final conclusions and recommendations coming from these discussions. Finally, the abstracts provided by the different speakers are found in the Appendix (see Section 7).

## 1.1 Background

There is increasing interest in accounting for temporary carbon storage in the LCA and CF of products. Current LCA methodology does not consider giving any benefits to temporarily keeping carbon out of the atmosphere. Indeed, since the timing of emissions is not considered, the amount of carbon sequestered in biomass (negative emission) is simply added to the amount of carbon released at the product end-of-life (positive emission), which results in carbon neutrality. No additional credits are given for the time of storage.

Some recently published standards and methods, such as the British PAS 2050 [2] and the European Commission's ILCD Handbook [1], propose a way to account for the timing of GHG emissions in

LCA and CF. Other standards and methods, still in development, such as the WRI/WBCSD GHG Protocol and the ISO 14067, are also looking into this issue. Nevertheless, there is still no consensus on which method to use, nor on the different value-laden decisions that have to be made, such as the choice of a time horizon. Section 2 addresses some of these general issues.

## 1.2 Radiative forcing and Global Warming Potentials

As demonstrated later in this report, the time-horizon selected for comparing the impacts of different greenhouse gases in terms of e.g. radiative forcing potential has implications on the relative importance of temporary carbon storage.

There is generally a consensus in LCA and CF on the use of Global Warming Potentials (GWPs), developed by the International Panel on Climate Change (IPCC), to assess the global warming impact of greenhouse gas (GHG) emissions [3]. GWP is a climate-change metric to determine the relative contribution of GHG emissions, but it can also be used as a basis to analyse the benefits of carbon sequestration and storage. Time horizons are important in deriving GWPs.

The GWP index for a given GHG is calculated by dividing the value of the radiative forcing caused by a unit mass pulse-emission of the gas, integrated over a given time horizon, by the same value obtained for carbon dioxide (CO<sub>2</sub>) for the same time horizon (see Equation 1).

$$GWP_x = \frac{\int_0^{TH} a_x \cdot C_x(t) dt}{\int_0^{TH} a_{CO_2} \cdot C_{CO_2}(t) dt} \quad (1)$$

where  $a$  is the instantaneous radiative forcing per unit mass increase in the atmosphere [ $W \cdot m^{-2} \cdot kg^{-1}$ ],  $C(t)$  is the time-dependent atmospheric load following a pulse-emission,  $TH$  is the time horizon and  $x$  stands for the given GHG. For CO<sub>2</sub>, the atmospheric load curve is given by the revised Bern carbon cycle-climate model [4], and for other GHGs, it is given by a first-order decay equation.

The most common time horizon used for GWP is 100 years, since it was adopted by the UNFCCC for the Kyoto Protocol. However, there are other time horizons considered by the IPCC (20 and 500 years). The implications of the time horizon are that, essentially, the radiative forcing occurring after the adopted time-horizon is not considered, so that more importance is given to the radiative forcing occurring within the defined time-horizon. This has implications on the importance relative to CO<sub>2</sub> given to the different GHGs. It equally has implications in relation to the issue of intergenerational equity, as radiative-forcing impacts after the chosen time-horizon are neglected.

One argument for this methodological choice of a 100-year cut-off is the assumption that in the future humanity will be better positioned to cope with climate change through e.g. technological improvements (see Sections 3.5 and 3.6 and [5] ).

### 1.3 Tonne-year approaches

The first presentation, given by the organisers of the workshop, introduced the problematic of temporary carbon storage, and presented the aim of the workshop, which was to review available options and to discuss the most appropriate method for accounting for the potential benefits of temporary carbon storage in LCA and CF. The Moura-Costa [6] and the Lashof [7] methods, both tonne-year approaches developed for that purpose and presented in the IPCC special report on land use, land-use change and forestry (LULUCF) [8], were presented.

The Moura-Costa and the Lashof approaches were proposed ten years ago to account for temporary carbon storage. Some participants explained that these authors were involved in the development of the IPCC special report on LULUCF published in 2000 [8], and that the subject was closed in 2003, when the IPCC published the good practice guidelines adopting the mass balance stock change approach. Some years after that, timing issues were again receiving attention with the development of the British standard PAS 2050 for carbon footprinting, where benefits are given to temporary carbon storage and delayed emissions. Other standards still in development, such as the GHG Protocol and ISO14067, are also investigating temporal issues.

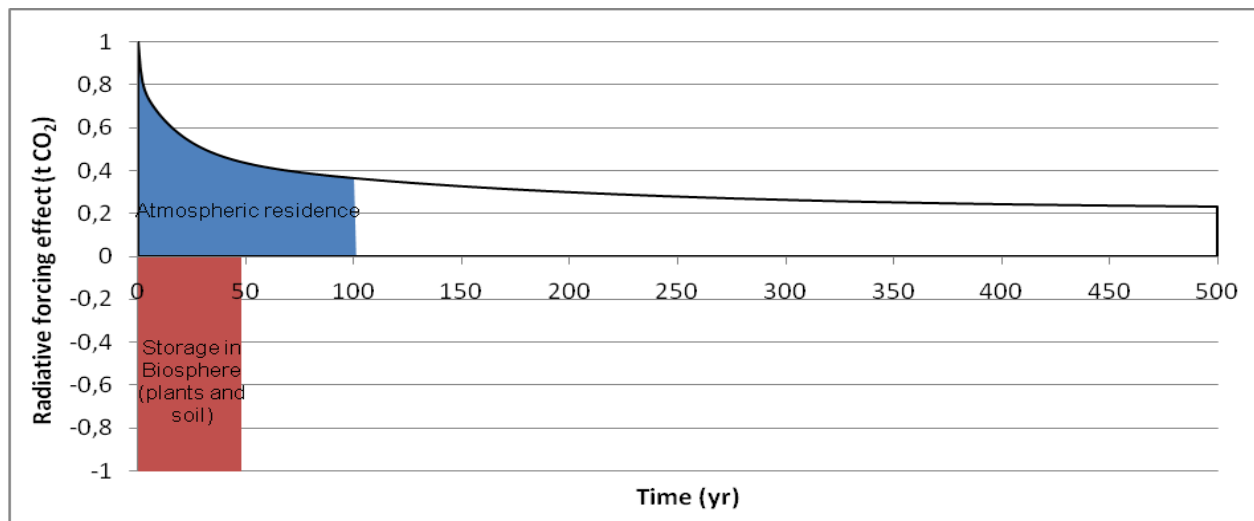
These tonne-year methods aim at calculating a credit in kg-eq CO<sub>2</sub> for keeping carbon out of the atmosphere for a given number of years. This credit can then be subtracted from a GHG inventory, as it is assumed to compensate for the impact of an equivalent GHG emission.

The baseline for these methods is the cumulative radiative forcing, integrated over a given time horizon (usually 100 years), caused by a one-tonne pulse-emission of CO<sub>2</sub>. For a time horizon of 100 years, the integral of the CO<sub>2</sub> decay curve is approximately 48 tonne-years.

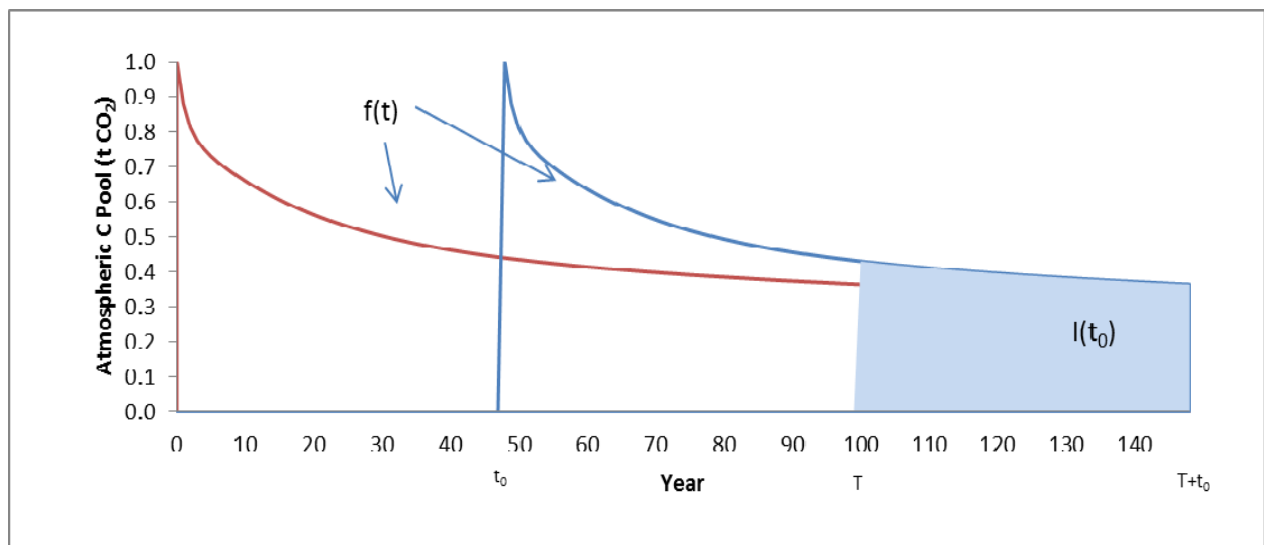
The Moura-Costa approach (see Figure 1) is based on a fixed duration over which impacts occur after an emission. This reflects typical practice in LCA and CF, as the time when an emission occurs is not considered. According to this approach, 48 tonne-years of CO<sub>2</sub> is equivalent to 1 tonne of CO<sub>2</sub>-eq. Consequently, storing one tonne of CO<sub>2</sub> for 48 years is equivalent to avoiding the impact of a one-tonne CO<sub>2</sub> emission, which also means that storing one tonne of CO<sub>2</sub> for one year can fully compensate for the impact of an emission of 0.02 tonne (1/48) of CO<sub>2</sub>.

Alternatively, the Lashof approach (see Figure 2) considers that storing carbon for a given number of years is equivalent to delaying a CO<sub>2</sub> emission until the end of the storage period. The decay curve is

then pushed back from a certain number of years, equal to the storage time, and the portion of the initial 48 tonne-years area which is now beyond the 100-year time horizon corresponds to the benefits of the perceived storage. For example, when storing one tonne of CO<sub>2</sub> for a period of 48 years, the portion of the area under the decay curve beyond 100 years is 19 tonne-years. This means that storage for 48 years would be equivalent to avoiding an emission of 0.4 tonne (19/48) of CO<sub>2</sub>; i.e. 40% of the value of 1 tonne proposed using the Moura-Costa method for the same sequestration and storage period.



**Figure 1.** The Moura-Costa approach calculated for a 100-year time horizon. Sequestering and storing one tonne of CO<sub>2</sub> during 48 years (red area) is equivalent to the impact of a 1-tonne CO<sub>2</sub> pulse-emission integrated over 100 years (blue area).



**Figure 2.** The Lashof approach calculated for a 100-year time horizon. Sequestering and storing one tonne of CO<sub>2</sub> for a period of 48 years is equivalent to delaying a CO<sub>2</sub> emission to  $t_0$ , and the benefit is the portion of the decay curve which is now beyond the 100-year time horizon (blue surface).

## 1.4 Temporal preferences and value choices

From Sections 1.2 and 1.3, one of the key points in determining the benefits of temporary carbon storage is the choice of a time horizon.

From an infinite time perspective, there is no benefit in an individual event considered in isolation that takes carbon out of the atmosphere and releases it back later, as the burden is merely shifted further in time; unless temporary carbon removals are repeated permanently to ensure an equivalent permanent carbon removal.

In contrast, adopting a finite time perspective implies using a time horizon beyond which impacts are not considered. This choice violates the principle of inter-generational equity, embedded in the concept of sustainable development, since it assumes that e.g. Society will be better able to cope with climate change in the future.

In her presentation (see Section 6.1), Jørgensen raised two conflicting aspects regarding the choice of a time horizon for the assessment of temporary carbon storage: i) the long-term persistence of CO<sub>2</sub> in the atmosphere, which warrants the consideration of longer time horizons, and ii) the urgent risk of crossing irreversible tipping points, which lead to the use of shorter time horizons to encourage earlier actions that quickly decrease the atmospheric CO<sub>2</sub> concentration before a tipping point is reached.

Temporary storage may allow buying time, but it is important that the chosen time horizon leads to real climate benefits. To address this contradiction, the authors propose to use two different ways of crediting climate mitigation, one for the long-term solutions, and one for the short-term solutions.

A discussion followed this presentation regarding the relevance of using two different crediting systems for both short-term and long-term climate mitigation. It is important in many assessment applications, such as for policy options, to clarify the difference between short- and long-term actions, and the usefulness/significance of such a distinction.

As temperature increases, some tipping points may be reached, this is a continuous process. Jørgensen explained that the idea behind a short-term crediting system would be to act as a bridging solution. If it is assumed that the next 100 or 150 years are critical and that tipping points should not be crossed, it may be beneficial to postpone emissions to a period where the atmospheric concentration will be lower. Another possibility is to give a higher impact score to short-term emissions than to long-term emissions on a continuous scale. A more complete discussion about the time horizon issue can be found in Section 4.5.

In her presentation (see Section 6.2), Kerckhof discussed the general issues regarding the treatment of temporary carbon storage and delayed emissions in LCA and CF methods:

The first issue was the setting of temporal boundaries in LCA. Two different options were presented: i) to include all the processes and emissions occurring over the life cycle without any temporal cut-off, which prevents from giving any benefit to temporary climate mitigation, or ii) to establish a temporal boundary in the scope of the study.

The second issue was the inherent value judgement in giving more importance to present impacts compared to future ones. Two different worldviews were presented and related to the choice of a time horizon for climate impact assessment: i) valuing sooner emission reduction compared to later ones, in opposition to ii) the need to manage carbon now as well as in the future without any distinction.

The third issue looked at how the consideration of temporary carbon storage and delayed GHG emissions can incentivise different behaviours, such as choosing durable products or products made from biogenic materials. A procedure was presented in the form of a decision tree to help making these value-laden choices.

## **1.5 The metrics of climate change**

In his presentation (see Section 6.3), Peters explained the physical basis of the widely used Global Warming Potential (GWP) concept as a metric for climate change, and the different value judgements involved.

Climate change metrics can be based on different indicators, such as radiative forcing, temperature increase, sea level rise, and economic costs; this reflects different levels of modelling along the cause-effect chain or environmental mechanism. Arguments are hence analogous to those of midpoint vs endpoint modeling discussions that took place in the LCA community. They also involve several choices, such as the use of an instantaneous or an integrated value, the use of a time horizon, discounting of future emissions, a constant background or a scenario-based one, accounting for regional variations, etc.

The Global Temperature Potential (GTP) concept was then presented as an alternative metric to GWP, and the differences between both of them were explained using the results of a few case studies. Finally, the implications of the different value-laden choices in the selection of a climate change metric were discussed.

A question was raised regarding how to apply the use of different metrics to CF, in which we want to have a single number to encourage people making the right choices. There is probably no answer to that question, as this presentation showed that we can take different decisions depending on the metric

we are using, and also that these decisions are based on value judgements, such as the choice of a time horizon, which can vary from one person/group to another.

A discussion followed on how decisions can be made when different metrics are used that give different answers, and different value judgements which can significantly alter the results. It is very important to know what the target is and to identify all the value-laden choices we make explicitly. Looking at different metrics can help us identifying what we want to promote, and then use the metric that better expresses it. It is also important to make sure that all the choices are consistently made.

## **2 The role of temporary carbon sinks**

This session of the workshop presented two opposing views regarding the role of temporary carbon storage for climate mitigation.

### **2.1 Problems related to temporary carbon storage**

In his presentation (see Section 6.4), Kirschbaum discussed the effectiveness of using temporary carbon storage to mitigate climate change. The widely used GWPs account for the impacts caused by cumulative temperature increases. Other types of impact on climate change are related to the instantaneous temperature increase and to the rate of temperature increase. He argued that any measure that includes only one of these impacts cannot fully capture the full scale of the issue. This presentation showed, using climate models and different IPCC scenarios for future CO<sub>2</sub> atmospheric concentrations, that temporary carbon storage only reduces impacts related to the cumulative effect of increased temperature, and can worsen the other types of impact. The message was that the assessment of the mitigation potential of temporary carbon storage should include each of these different kinds of impacts, as well as the feedbacks of the global carbon cycle.

### **2.2 The use of different indicators**

Following this presentation, the relation between the three indicators presented (i.e. cumulative radiative forcing, instantaneous temperature and rate of increase in temperature) was discussed. The instantaneous temperature approximately follows the integrated radiative forcing (plus an impulse response for temperature), and the rate of increase in temperature (which is the derivative of the temperature) is proportional to instantaneous radiative forcing. This means that radiative forcing could be a good approximate of these three metrics, as long as the instantaneous and the cumulative values are considered to account for the different types of impacts.

The adoption of three different indicators for climate change in LCA was proposed to account for the three different types of impact presented by Kirschbaum, although some participants argued for one single indicator for climate change. This single indicator could be developed by going further in the impact chain (damage modeling), while considering three different pathways (mid-points) before aggregating, as is done with other impact categories in life cycle impact assessment (LCIA). If mid-point modeling is preferred to damage modeling, three different indicators would suffice, even though the general tendency in LCA is to have only one indicator. The existence of multiple indicators may add complexity in terms of decision-making and, hence, may not be well accepted in the business and policy communities. Nonetheless, only multiple indicators can express both cumulative and

instantaneous impacts. In LCA, some impact categories are covered by multiple indicators at the midpoint level (e.g. human toxicity uses both cancer and non-cancer effects). For including temperature increase and rate of change, extensive work is still needed, although it would be promising and should be investigated further.

### **2.3 Benefits of temporary carbon storage**

In his presentation (see Section 6.5), Marland gave environmental and economic arguments in favour of temporary carbon storage: it buys time for technological progress and learning, it postpones climate change, some temporary sequestration may become permanent, sequestering carbon keeps us on a lower carbon path and mediates the approach of tipping points, etc. There is also an economic argument which states that temporary carbon storage has value as long as carbon emissions have a monetary value, whether this value is related to a cap-and-trade system, a carbon tax, or emission permits. An analogy was developed with the life insurance industry to show that the expected life time of temporary storage can be described in probabilistic terms, in order to give it a financial value, which could be used to determine the cost of the temporary credits. Credits for permanent storage could be bought and sold, and credits for temporary storage could be rented.

### **2.4 Do temporary carbon storage and delayed emissions matter?**

When assessing temporary carbon storage, a time frame needs to be defined, since there is no benefit for it on an infinite time basis. If the time frame is 100 years, storing carbon for a few years is important, but if the time frame is much longer, it becomes insignificant. Kirschbaum presented three types of impact related to global warming: i) the instantaneous temperature increase, which leads to extreme weather conditions and diseases, ii) the rate of temperature increase, which has an impact on ecological adaptation, and iii) cumulative heating or radiative forcing, which impacts on long-term effects such as sea level rise. Storing carbon for a few years and releasing it back to the atmosphere has two consequences: it decreases the cumulative heating of the atmosphere over a defined time frame, and it increases the temperature at a given time in the short term. With a longer time horizon, both effects would become less significant. It is important to determine whether impacts occurring in the short-term are more important than those occurring in the long-term.

The carbon cycle is dynamic. Taking carbon out of the atmosphere has consequences on the carbon flows elsewhere in the cycle, e.g. ocean uptake. Releasing one tonne of carbon to the atmosphere or storing it for a period of time and releasing it later would lead to different CO<sub>2</sub> concentrations at a given time in the future. It would lead to the same concentration for an infinite time frame, but the trajectories to that point there would be different, so the timing of the emissions matters with finite

time frames. The impact of delaying an emission can be positive for a given metric (cumulative radiative forcing over a given time frame), and negative for another metric (instantaneous temperature increase at a given time in the future).

### **3 Existing approaches and rationale for adoption**

The presentations held during this session gave an overview of the existing approaches and those under development.

#### **3.1 LULUCF sector under the Kyoto Protocol**

Blujdea presented the way carbon accounting is done at the country level for the purposes of meeting and monitoring targets for the Kyoto Protocol, and more particularly for the LULUCF (land use, land-use change and forestry) sector. Every type of land use must be covered and there are different review processes to check how the numbers are estimated. The accounting follows a stock change approach based on mass balances. Different sources of uncertainty are related to the accounting process. This is because: assessments are done every 10 years and computations are used to get yearly estimates; emission factors rely on proxies; there is an imbalance between forest, which receives the highest attention, and the other types of land use; there is a lack of transparency for some types of emission; and some carbon flows are not taken into account. Temporary carbon storage under clean development mechanism (CDM) only applies to reforestation and afforestation projects. There are two different ways to account for it: 1) to account for the reduction only when the project is finished, or 2) to use temporary certified emission reductions.

Following this presentation, it was pointed out that some carbon flows are taken into account at the country level, but not necessarily in the LULUCF sector, which can explain why some carbon flows seem to be lacking. Flows coming from crops for biofuels, for instance, can be included in the energy sector, and not in the LULUCF one. A distinction was also made between reporting and accounting. Changes in carbon stocks can be reported, such as the burning of wood for energy, but are not necessarily accounted under the Kyoto Protocol target, depending on the situation.

#### **3.2 Existing approaches for LCA and CF**

In his presentation (see Section 6.6), Wolf explained how temporary carbon storage and delayed GHG emissions should be taken into account according to the ILCD Handbook [1]. The general rule is that temporary carbon storage and delayed emissions shall not be considered in LCA, unless the goal of the study clearly warrants it. If so, temporarily sequestering and storing carbon in a product is argued to be analogous to delaying a fossil CO<sub>2</sub> emission. The rationale behind the use of GWP 100 for accounting for the radiative forcing occurring over the 100 years following the assessed emission is its wide adoption, even though this introduces a time perspective that is not adopted by any other impact categories.

In the inventory, a delayed emission is accounted for with dedicated elementary flows and the emission (in kg) is multiplied by the number of years the emission is delayed, up to 100 years. These flows carry a characterization factor for GWP100 (-0.01, -0.25 and -2.98 per kg and year for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O, respectively). An emission occurring beyond 100 years shall be inventoried as a long-term emission.

This approach differentiates biogenic and geogenic CO<sub>2</sub> and CH<sub>4</sub> elementary flows, and allows using the same inventory for modeling, or not, temporary carbon storage or delayed emissions. Details are explained in Appendix 6.6.

The other existing approach presented (see Section 6.7) by Clift is the British carbon footprinting standard PAS 2050 [2]. The developed method is based on the Lashof approach, which accounts for carbon storage in biomass by looking at the effect of delaying an emission on radiative forcing, integrated over a 100-year period. The formulae used in PAS 2050 are a linear approximation of this concept. There is no discounting applied, but a temporal cut-off is used, since any emission occurring after 100 years following the sale of the product are not considered. The same concept could be applied to other GHGs, even though this is not done in the standard, as all the GHG emissions are transformed in kg CO<sub>2</sub>-eq before applying the delay credit.

### **3.3 Developing approaches for LCA and CF**

Two developing approaches aiming at giving guidelines for carbon footprinting of products were also presented by Wuehrl and Draucker. The International Standard Organisation is developing a new standard for carbon footprinting of products, ISO 14067 (see Section 6.8). This standard will give guidelines for the quantification (part 1) and communication (part 2) of carbon footprint of products and services over their life cycle. The final version is intended to be published at the beginning of 2012. Several discussions were held in the working group regarding the need to consider temporary carbon storage, and no consensus on the subject is yet to be reached.

The World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) are developing the Product Life Cycle Greenhouse Gas Accounting Standard (see Section 6.9). The goal of this standard is to provide guidelines on how to calculate life cycle based GHG inventories of products or services. Several discussions have been held at different levels of the organization on the topic of temporary carbon storage and delayed emissions, but the final position is not yet known, as the standard is still in development like ISO 14067. The position (at the time of the presentation) is to include every carbon flow (uptakes and emissions), but not to consider their timing

(no credits for storage or delayed emissions), as there is no scientific consensus on the value-laden choices that need to be made.

### **3.4 Accounting level**

Two accounting levels were identified: i) the national level, where the focus is on the amount of carbon stored in the forests of a given country or landscape, and ii) the project level, where the focus is on the carbon stored in a product throughout its life cycle. The national level type of accounting is used under the Kyoto Protocol; time issues are not considered, as accounting relies on mass balances. A participant mentioned that the product level is inadequate, as cutting trees does not necessarily mean that carbon is released to the atmosphere if the forest is managed appropriately, because of tree re-growth and carbon accumulation in the soil. Others argued that, virtually, the sum of all the project or product level accountings would give the same result as the national-level accounting. The objective of this workshop is to discuss how we should account for the benefits, if any, of temporarily storing carbon in a product for LCA and carbon footprinting purposes, so that the product level will be used for the following discussions.

### **3.5 The choice of a time horizon**

A discussion followed regarding the choice of a time horizon. A participant criticized the use of a 100-year cut-off, saying that it would encourage people to emit GHGs at year 99, so that their impact would be considered only over one year. The use of a 100-year time horizon would also encourage fossil emissions to become acceptable, as long as some temporary carbon storage compensates for it. Another participant mentioned that the idea behind the use of GWP100 is to provide a relative weighting of the different GHGs, and that the choice of a time horizon is merely to fix this ratio, but that does not mean that impacts occurring after that time horizon are neglected (which is the rationale behind those approaches). It was pointed out that the aim of PAS 2050, for instance, is to look at the impacts on global warming of a given purchase, so it is logical to bring all the life cycle emissions on a common time scale. A too short time horizon would give more weight to delayed releases, and we may not want to promote that. On the other hand, a too long time horizon would not take into account that something must be done about climate forcing emissions within the next few years, and not within the next centuries.

The choice of a time horizon is an important aspect in assessing temporary carbon storage. A time horizon of 100 years is generally chosen because it is used for policies, such as those related to the Kyoto Protocol. The question was raised whether a 100-year time frame should be used for every

impact category in LCA, for consistency reasons. Some participants argued that the time horizon matters only for a few impact categories, and that it should not be applied to all of them.

An extract from a paper written by Keith Shine, one of the lead authors who proposed the GWP concept in the IPCC First Assessment Report, was read: “It seems to be widely believed that the Kyoto Protocol chose a 100-year time horizon because it was the middle one of the three: 20, 100 and 500 years that happened to be presented in the IPCC report. There is certainly no conclusive scientific argument that can defend 100 years compared to any other choices, and in the end the choice is a value-laden one. And no matter how uncomfortable the concept of discounting can be to physical scientists, the choice of any time horizon short of infinity is, de facto, a decision to impose some kind of discounting.” [5] Any limited time frame is arbitrary. In LCIA, most methods are using the GWP100 for defining characterization factors for climate change, but not all of them. IMPACT2002+ is using 500 years because it is closer to infinity. But using an infinite time frame for global warming would result in CO<sub>2</sub> having an impact, and other GHGs would be negligible, as the CO<sub>2</sub> concentration following a pulse-emission never returns to pre-emission levels.

A question was raised as to whether the three indicators presented by Kirschbaum would have different time perspectives. The relevant time horizon can be different for each of them, depending on the emergency of the problem. Sea level rise, represented by cumulative radiative forcing, may not be a problem in the short term, but will be in 300 or 400 years. For this reason, a 500-year time frame could be preferable instead of 100 years. The instantaneous temperature increase and the rate of change are more related to short-term impacts. A tipping point may be reached for temperature in a near future beyond which any mitigation action would be irrelevant. For these two metrics, using a shorter time horizon may be more relevant, as it is more urgent to reduce these impacts. The choice of a time horizon has a decisive influence on the value given to temporary carbon storage.

The time horizon already used in LCIA for GWP represents the time over which the impact is integrated after the emission occurs, and has nothing to do with the life cycle inventory time frame. For long life cycles, there is an inconsistency between this time horizon, used to assess climate change impacts, and the time frame chosen for the analysis. If a given time horizon is chosen because it is assumed that problems occurring during this time period are more important, relative to the point in time where we are now, the impacts should be assessed on a period going from when the emission occurs until the end of this time frame, calculated from the present time. With actual LCA, it is considered that all the emissions are occurring now, but as soon as it matters to account for the moment when these emissions occur, it is not consistent to use a fixed time horizon for GWP.

A fixed time horizon can be used (e.g. 100 years), which begins at the moment the first emission occurs, or a variable time horizon, which also begins at the moment when the first emission occurs, but finishes on a given year (e.g. 2100). With a fixed time horizon, the impact is assessed over the 100 years following the first emission. With a variable time horizon, the impact is assessed over a time horizon beginning when the first emission occurs and finishing in e.g. 2100. Policies are usually looking at a given point in time on which some targets are fixed. The same can be done in LCA and a variable time horizon can be used. However, the problem with a variable time horizon is that it will change through time. Each decade, for example, it will probably be pushed back another 10 years, so that it will be constantly updated. PAS 2050 and the ILCD Handbook<sup>1</sup> use a fixed time horizon as they are looking at the radiative forcing occurring 100 years following the formation of the product. To be consistent, an assessment done next year should use the same characterization factors as an assessment done today, which means that it is better to use a fixed time horizon.

### **3.6 Discounting future emissions**

A distinction was made between the choice of a time horizon and discounting, two different ways to express time preferences. Choosing a time horizon consists in looking at a particular environmental problem, which can be measured and documented, and then in making decisions on the emergency of the situation or the relevance of future actions. Discounting is based on the assumption that future impacts are less important because future generations will be better able to cope with the damage. There is science behind discounting (economics, social science), but it is different from the “physical discounting” on which time horizons are based. The general attitude in the LCIA community is to avoid discounting and time cut-offs. The choice of time horizons or discount rates is value-laden, but cannot be excluded from this subject because it is impossible to give a value to temporary carbon storage without using time preferences.

### **3.7 Treatment of biogenic carbon**

A general discussion followed on the treatment of biogenic carbon uptakes and emissions. The first comment was about the timing of the sequestration. If you have a forest, you cut a tree at time zero to make a wooden product, and then you plant another tree that will grow thereafter, the sequestration is not occurring at time zero, but is also delayed. This temporal issue should also be considered in the calculations.

The other issue treated was whether credits should be given to temporary carbon storage only and only if a new sink is created. Some argued that credits should not be given to transfer carbon from one non-

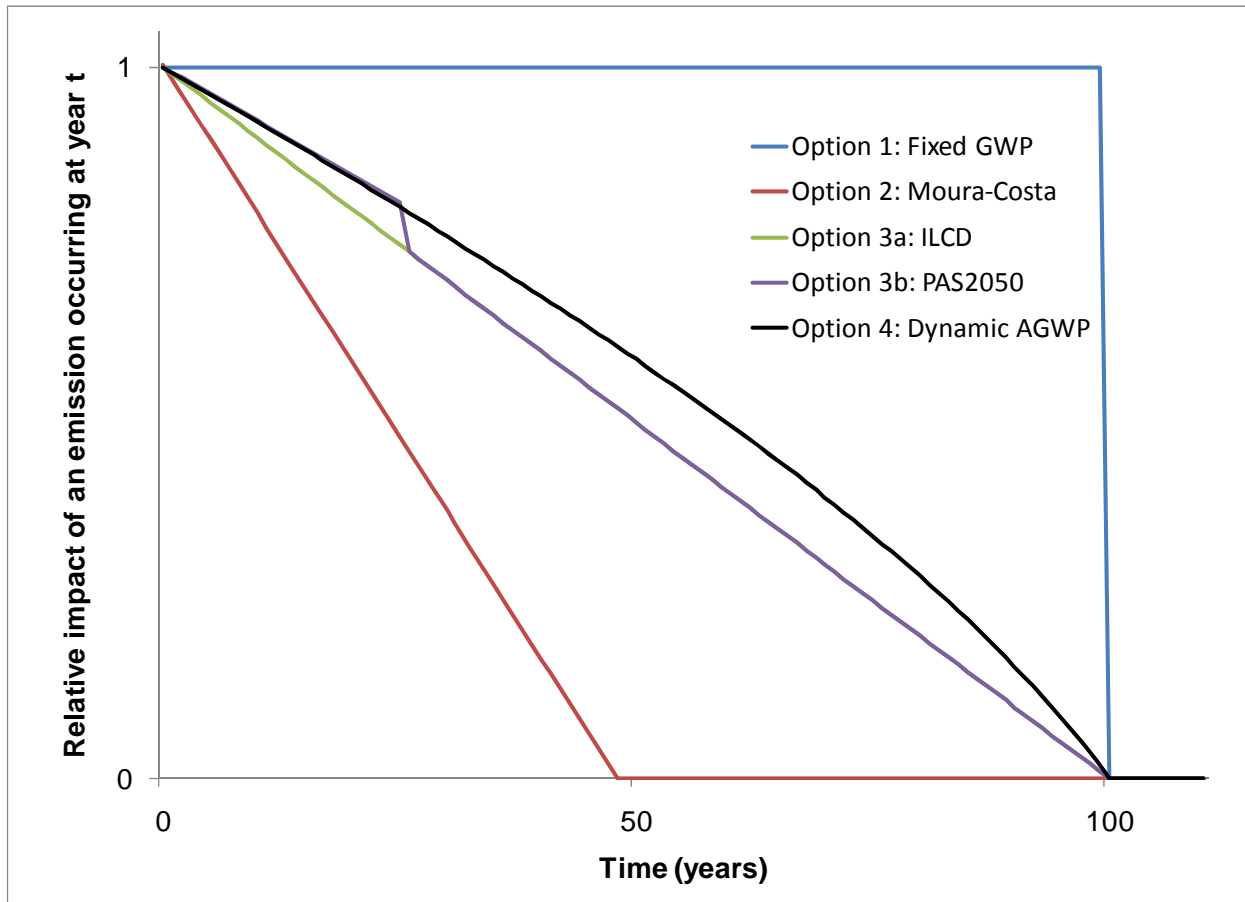
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<sup>1</sup> This is the case provided that temporary carbon storage or delayed emissions are part of the goal of the LCA.

atmospheric sink to another (from a tree to a wooden product, from crude oil to a plastic product, etc.), and that credits should only be given for taking carbon out of the atmosphere in an additional sink. Following this rationale, the only products that would get the credits are those coming from a new afforestation project, distinguishing forests established with the intention of sequestering carbon from standard managed forests. But here, a mechanism would be needed to make sure that the protected recent forest would not come at the expense of an unprotected old forest. Others argued that delaying a fossil emission is equivalent to storing carbon in biomass, the only difference between both being the sequestration for the case of biogenic carbon storage. Since the atmosphere does not make the difference between fossil and biogenic carbon, delayed fossil or biogenic emissions should be treated on the same basis. The difference is that, in the case of the biomass, there is a negative emission to consider for the carbon uptake from the atmosphere. To be consistent, we need to look at the flows of carbon between the product and the atmosphere. And if the decision to account for the timing of these flows is taken, it has to be done for every emission, regardless of their origin.

### **3.8 Which approach to choose for carbon footprinting?**

The principal conclusion from the previous discussions was that it may be needed to look at other indicators than GWP for climate change impact assessment. As these developments need time and resources for research, and as there is actually an important international consensus on the use of GWP100, the following discussion aimed at giving recommendations on how to assess temporary carbon storage and delayed emissions using the GWP concept and a given time horizon. Four options were discussed to determine how the timing of the emissions should be accounted for in CF using the cumulative radiative concept (see Figure 3). The x-axis represents the time when the emission is occurring, and the y-axis is the relative impact of this emission.



**Figure 3.** Illustration of the four options discussed for the assessment of temporary carbon storage and delayed emissions in LCA and CF

A time horizon (100 years in Figure 3) is chosen beyond which the impact is zero, because the problem is considered no longer relevant. Option 1 reflects a constant characterization factor. The problem with this option is that a high value is given for an emission occurring one year before the time horizon, and then no value for an emission occurring one year after. That means that a substantial benefit would be given for delaying an emission one year more, which does not reflect reality. For long time horizons, the consequences of this would not be significant, but for shorter time horizons, it is better to use a decreasing characterization factor. Option 2 is the Moura-Costa approach. The problem with this option, as stated in Section 2.1, is that it is inconsistent with the concept of time horizon, since the benefit of delaying a unit mass pulse-emission from a number of years equal to the time horizon is higher than the total impact of this emission integrated over this time horizon. That is why the impact of a delayed emission reaches zero at 48 years instead of 100 years. Option 3, as used in the ILCD Handbook and the PAS 2050 standard, is a linear approximation of option 4, which is dynamic AGWP, or the Lashof approach. A linear approximation has the advantage of being very simple to use in LCA, as the yearly benefit for delaying an emission is constant. As the difference

between the linear approximation (option 3) and the full approach (option 4) is not very significant, it could be used in LCA and CF.

## 4 Application of alternative methods

The way biogenic carbon uptakes and emissions are treated in different studies have been presented in this session of the workshop. In his presentation (see Section 6.10), Francesco Cherubini introduced a new indicator,  $GWP_{bio}$ , which was developed to assess the climate change impact of biogenic  $CO_2$  emissions while considering the dynamics of vegetation re-growth. Biogenic  $CO_2$  emissions are actually considered neutral, since the released carbon will be sequestered again by the biomass. However, these emissions cause an impact on radiative forcing before they are captured by vegetation re-growth. The  $GWP_{bio}$  index is expressed as a function of the rotation period of the biomass, and can be applied to any type of biomass species. It relies on the impulse response function originated from the perturbation caused by a  $CO_2$  emission to the atmosphere, as expressed by the Bern carbon cycle-climate model. The consequences of using this new indicator at a product level and at a national accounting level were presented.

Zanchi (see Section 6.11) introduced the concept of the carbon neutrality factor (CN) to quantify the GHG emission reduction caused by the use of biomass as an energy source. This factor is defined as the ratio between the net reduction/increase of carbon emissions in the bioenergy system and the carbon emissions from the substituted reference system, over a certain period of time. Currently, GHG emissions coming from the combustion of biomass are assumed neutral. When the time needed to sequester back this carbon in re-growing biomass is long, the capability of bioenergy to reduce the GHG emissions on a short- to medium-term is reduced. The discussion on bioenergy carbon neutrality is important, since the European Union adopted ambitious policy targets on the use of renewable energy sources. The CN for different bioenergy case studies were quantified and discussed.

Bioenergy was also the subject of the following presentation given by Annette Cowie (see Section 6.12), which raised different issues regarding the assessment of GHG mitigation benefits of bioenergy projects as identified by the IEA Bioenergy Task 38. Bioenergy systems are not carbon neutral, as several GHG emissions arise from other life cycle stages (biomass production, fuel production, transportation, etc.). The expansion of bioenergy can also lead to indirect land use change (LUC) emissions, since biomass production for energy may displace food production. To account for the timing of emissions and removals, the concept of Net Present Value (NPV) of radiative forcing over 100 years has been developed under Task 38. Bioenergy systems that involve land use change can also influence climate through impacts on albedo, which can be quantified and added to the calculation. The standard methodology for the assessment of bioenergy systems was presented, and some case studies discussed, with a particular focus on biochar.

Finally, the dynamic LCA approach (see Section 6.13), developed to account for the timing of the emissions in LCA, was presented by Levasseur, as well as its application to a case study assessing the ability of an afforestation project to mitigate an initial fossil-fuel based CO<sub>2</sub> pulse-emission. The dynamic LCA approach considers the temporal distribution of GHG emissions over the life cycle, and calculates their impact on radiative forcing at any time using dynamic characterization factors, which consist of the absolute global warming potential integrated continuously through time. The dynamic LCA approach enables to determine consistently the time-dependent impact on radiative forcing for every GHG and for any type of product or project life cycle. It also allows decision-makers to test the sensitivity of the results to the choice of different time horizons.

## 5 Conclusions

This report summarises the main methodological issues regarding the benefits of temporary carbon storage and associated metrics that were identified in the presentations and subsequently discussed throughout the workshop.

Climate benefits of an isolated temporary carbon storage event arise solely when time preferences are reflected in the method used. This means that accounting for any benefits relies on value-laden methodological decisions, such as the choice of a time horizon beyond which impacts are not considered. Indeed, the longer the time horizon adopted for integration of radiative forcing or impacts, the lower the benefits are from temporary carbon storage. This will only be different if the temporary storage is repeated, essentially becoming a permanent removal from the atmosphere.

If temporary storage is considered then it is common practice to adopt a 100-year time horizon using the Global Warming Potential index. Temporary storage benefits are then generally based on the Moura-Costa and Lashof approaches; assuming that (sequestration and) storage of 1 tonne for 48 and 100 years is essentially equivalent to not emitting 1 tonne.

However, no clear consensus has been reached from these discussions regarding whether or not to account for temporary carbon storage in general and, if so, which method to employ. The choice of a 100-year time horizon equally remains controversial

Since the benefits given to temporary carbon storage rely on value-laden choices, if considered then it is important to make them explicit and transparent when using any accounting method. Both short and long term time horizons should be considered.

It was suggested to do more research in order to improve climate-change modelling in LCA to include two other indicators (i.e. instantaneous temperature increase and rate of temperature increase), since they provide information on different types of climate-change impact, and can lead to different conclusions than the single use of cumulative radiative forcing. Furthermore, research is warranted on the dynamics of the carbon cycle (e.g. changes in sinks – biospheric, atmospheric and oceanic – are interdependent and cannot be assessed in the same linear way as fossil emissions with GWP). This is because any change in biospheric carbon stocks may be partially or totally compensated by the inverse process from other sinks (e.g. oceans), so this dynamism needs to be addressed.

## 6 References

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## 7 Appendix

### 7.1 Need for Relevant Timescales in Temporary Carbon Storage Crediting

Susanne Vedel Jørgensen and Michael Hauschild

When evaluating possible global warming mitigation potential of temporary carbon storage, it should be recognized that the challenge is two-fold: One aspect is the long-term persistence of anthropogenic CO<sub>2</sub> in the atmosphere, another is the urgent risk of crossing possibly irreversible tipping points. For the long-term issue, only storage of carbon on timescales long enough to simultaneously remove carbon from the near-surface parts of the global carbon cycle is relevant in terms of mitigation potential. This contradicts many current suggestions for crediting of temporary carbon storage, only considering removal from the atmosphere by natural uptake in terrestrial biosphere and upper ocean. From these superficial sinks, the carbon has a great risk of re-emission, due to e.g. global warming. Closer examination of the global carbon cycle reveals timescales of thousands of years for removal of carbon from the near-surface parts, whereas regeneration of fossil fuels takes millions of years. Many current suggestions for crediting temporary carbon storage, however, are based on a 100-year time horizon for global warming potential, which seems insufficient compared to the removal times of the global carbon cycle. It is illustrated how this time horizon disregards the long atmospheric lifetime of anthropogenic CO<sub>2</sub>, hiding long-term impacts of fossil fuel consumption and how the decision on time horizon is essential for the crediting results, making it crucial that the chosen time horizon ensures real climatic benefits. For the urgency issue however, storage on much shorter timescales may have a ‘bridging potential’ in terms of buying time. For this aspect, timescales need only be long enough to reach into a more carbon neutral future. It is recommended to separate crediting of global warming mitigation potential for the long-term issue and the short-term bridging potential, so possible short-term solutions can be acknowledged without appearing to solve long-term problems.

## 7.2 Treatment of carbon storage and delayed emissions

Annemarie Kerkhof and Mark Goedkoop

### 7.2.1. Introduction

At the CAIRO TC207 meeting, the draft carbon footprint standard was discussed. One of the issues discussed was whether the standard should have specific rules to account for carbon storage and delayed emission, such as is described in PAS 2050. The discussion focussed on the complexity of the topic; however, this is not just a technical discussion as the treatment of storage and delay emissions means making value choices.

The core discussion centres on the treatment of future (delayed) emissions and their impact, which can be grouped into two broad approaches:

1. by treating all emissions from a product, no matter when they occur, as having been produced when the product was produced, or
2. by treating future (delayed) emissions from a product differently to those emissions occurring today.

With this paper we address three aspects of the debate: the LCA perspective; the value choice perspective; and the “incentivising behaviour” perspective.

### 7.2.2. The LCA perspective

When conducting a LCA under ISO 14040/44, establishing a system boundary is an essential part of conducting the study. The system boundary establishes cut-offs, resulting in some processes (and their emissions) not being considered in the study. For carbon footprinting, the time boundary for the release of emissions (and their subsequent impact) needs to be considered: the impact of specifying a time boundary or not is discussed below.

#### 7.2.2.1. No time boundary

The LCA includes all emissions arising at any future time from the life cycle of the product (and their subsequent impact) as part of the study. This ensures that the footprint of the product fully reflects the total GHG impact of the product over time; however, this approach has some adverse consequences:

- It would not be possible to gain a benefit from semi-permanent storage, such as thorough forestry projects or carbon capture and storage, as the carbon contained in these processes will be released at some point in the future and would therefore included in the LCA of the product;
- It would ignore the real benefit arising from carbon storage in products. (E.g. timber building materials store carbon, and results in less atmospheric carbon.)
- It would result in differences in product life cycles being ignored (for two products with different emissions profiles, this approach would treat the products as being identical).
- It could encourage short-lived products, as there would be no incentive to manufacture longer-lived products that store carbon out of the atmosphere.

#### 7.2.2.2. Time boundary

Consistent with existing LCA and carbon footprinting standards, a time boundary is established as part of the scope of the study that follows one of the two approaches described below:

- a) Time boundary on the GWP impact of emissions from the supply chain (PAS 2050 approach), where the damage arising from emissions released as part of the supply chain of the product is established<sup>1</sup>; or
- b) Time boundary on emissions from the supply chain, including emissions occurring within the time boundary of the study together with the full GWP impact of those emissions.

Under these approaches:

- Products are assessed on a consistent time basis, ensuring that the impact of emissions occurring within the boundary of the study are treated on a consistent basis;
- The benefit of longer-lasting products that store carbon is reflected in this approach; and
- (For b above) The full GWP impact of emissions occurring within the time boundary are included (i.e. if emissions occur within the time boundary then the full GWP impact of the emissions is included, even though this extends beyond the 100 year time boundary)

#### 7.2.2.3. Guidance from the LCA standards perspective

The ISO 14040/44 standard establishes the need for boundaries; however, it is not very clear on whether and how time boundaries are to be used (note that the standard is clear that the system

boundary for data collection is not related to the boundaries for the impact assessment). Under ISO 14044, a mandatory aspect of life cycle impact assessment is “the temporal aspects, such as duration, residence time, persistence, timing, etc.” of the category indicator or characterization model.

The current draft of the European LCA handbook does have a rule for carbon storage (using a similar approach to PAS2050, although simpler – See Annex), and suggests reporting carbon storage as a separate parameter<sup>2</sup>: it does not address delayed emissions. Other publications addressing the temporal boundary issue include the Environmental Engineers’ Handbook and the Handbook on life cycle assessment (operational guide to the ISO standards).

### 7.2.3. The value judgement perspective

Both the storage and the delayed emission express the assumption that future impacts are less serious than present impacts. There are a number of perspectives on this choice.

#### 7.2.3.1. Worldview 1: we value emission reduction sooner rather than later

One worldview is to consider we have an urgent climate crisis to solve now, and thus we should value mechanisms that reduce emissions over the shorter term (or shift present emissions to the future). This view is already implicit in many national and global policy processes: the IPCC publishes GWP data on 20, 100 and 500 year bases, yet the 100 year timeframe is almost universally used as the basis for GHG assessment. This has important implications, as the use of 20 year and 500 year GWP data would encourage different actions (e.g. if 20 year GWP data was used, action against methane emissions would be much more important; if 500 year GWP data was used, it would encourage greater action on SF6 emissions).

The worldview 1 is basically an optimistic view, with regards to what future generations can manage. The view can be partially justified when we look what has happened in previous environmental issues, like the ozone layer depletion. This was very urgent in the nineties; now there is general agreement that ozone depleting emissions after 2040 will hardly have an impact. It is of course not clear if this is also true for carbon. However, it could also reflect concern that unless climate change is successfully addressed in the short term, the world will reach tipping points that no amount of future reduction will address.

### 7.2.3.2. Worldview 2: we need to manage carbon now and in the future

Under this worldview, climate change remains a very urgent issue during a much longer term, and that future generations face a similar, or even more serious problems, trying to manage carbon emissions. Future emissions may in this respect be even more serious, as a result of improving knowledge on climate science and as a result of historic emissions, and future generations have little ability to influence delayed emissions, as these emissions will be determined by decisions taken now.

This world view is not optimistic about the options for managing carbon at a later stage. This view can be supported, if we see the very big differences in economic development in combination with the still very large fossil reserves in tar sands and coal. It may be very difficult to resist the temptation to use these resources to generate wealth for people. In that respect the ozone layer problem solution was much easier, as cheap alternatives were available.

### 7.2.4. The “incentivising behaviour” perspective

All decisions taken in ISO 14067 will incentivise different types of behaviour: decisions around which gases to include will incentivise action around different gases, while decisions about the treatment of land use change emissions will incentivise different approaches to land management.

The approach to carbon storage will similarly incentivise different behaviour, and in this respect it is important to consider which behaviour we want the standard to incentivise. Products that store biogenic carbon, or delay emissions release to some time in the future, provide a real benefit in terms of reducing emissions now (compared to equivalent products that do not store or delay emissions). Should ISO 14067 create the incentive for organisation to take these actions? Or should the standard be neutral towards the time aspect, and both incentivising the reduction on the long and the short term. In essences this question is different depending on the worldview taken.

Establishing a time boundary will benefit products that store or delay emissions. It will be favourable to durable products, unfavourable for products with a short lifetime, and will benefit biogenic materials. It also implies we value short term over long-term emission reduction, as future generations have to live with the choices we make now. It is also consistent with established LCA practice of defining study boundaries.

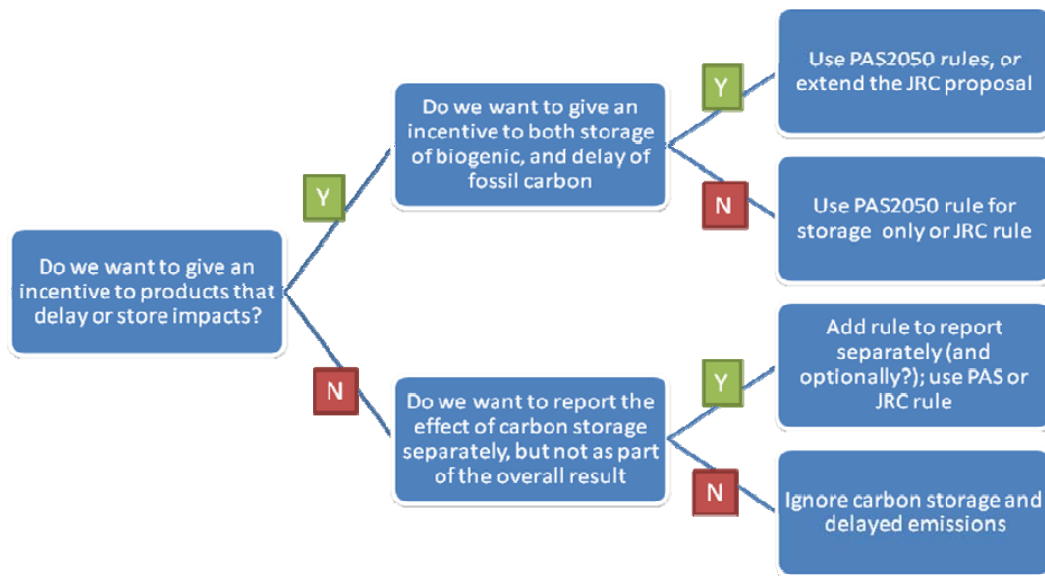
Including all emissions recognises that future emissions arise (to a large degree) from decisions made today; however, it is inconsistent with concepts of sequestration and storage, and does not represent the benefit of atmospheric carbon being retained in storage in products for the near future.

It is very difficult to make such a value judgement; however, a decision to set a time boundary or not will be a value judgement. One basis for such a value judgement is to refer to internationally accepted policy organisation views, and some examples are:

- Brundtland Report: Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. “Not compromising future generation” would, in a strict sense, mean a time boundary is not supported. The Brundtland definition is accepted by the United Nations as the concept for sustainability. IPCC is a part of UNEP, but IPCC seems to focus most of its assessments on the period covering about one hundred years. In the TAR2007 report the long-term problems are however often mentioned.
- Although not an international body, but widely recognised as principle, the Stern review, [http://en.wikipedia.org/wiki/Stern\\_Review](http://en.wikipedia.org/wiki/Stern_Review) clearly demonstrates that the cost effectiveness of carbon management on a short term is very high compared to carbon management on a long term.

#### 7.2.5. Proposed procedure for making the choice

In order to make the choice between a standard that accounts for carbon storage and delayed emissions, versus a standard that does not support this, the following decision tree could be used. The procedure starts with the value choice, as this is the most important reference. Next there are choices to be made on whether only storage or also delayed emissions are to be rewarded, and whether the reward of delayed or stored carbon are an optional and separate thing to report.



### 7.2.6. Annex 1: Approach in PAS 2050

PAS 2050 adopts a time boundary on the impact of emissions approach when assessing the carbon footprint of products. This annex provides further details of the approach used in PAS 2050, and also provides a discussion of the difference between discounting and boundary-setting.

#### 7.2.6.1. Carbon storage and delayed emissions in PAS 2050

In PAS 2050, two rules are used to take into account the carbon storage and the delayed emissions. These rules reflect the time boundary established by PAS 2050, as this standard assesses the impact of GHG emissions arising from the product over the 100 years following formation of the product.

##### 7.2.6.1.1. Carbon storage

Biogenic carbon (carbon stored in plants) that is released when the plant material is burned, is not included in the product carbon footprint.<sup>3</sup> In addition, where carbon of biogenic origin is stored in a product for more than one year (but released within 100 years) a weighting factor is used to reflect the proportion of emissions impact occurring within the 100 year assessment period. The formula used is:

$$\text{Weighting factor} = \frac{100 - (0.76 \times t_0)}{100}$$

$t_0$  = number of years between formation of the product and the single release of the emissions

The stored amount of carbon is multiplied with this weighting factor to calculate the benefit of storage. Relevant examples are carbon stored in wooden building materials, paper used for books, or long recycling chains, etc. (under PAS 2050, carbon benefit cannot be claimed for food or feed).

#### 7.2.6.1.2. Delayed emissions

The release of fossil carbon is counted as an emission; however, where emissions take place more than one year following formation of the product, the proportion of emissions occurring within the time boundary of the study is determined. The formula is:

$$\text{Weighting factor} = \frac{\sum_{i=1}^{100} x_i \cdot (100 - i)}{100}$$

i = each year in which emissions occur

x = the proportion of total emissions occurring in an year i

Relevant examples are: A car that emits carbon during 10 years, or a low energy light bulb over 20 years.

#### 7.2.6.2. Terminology: discounting and boundaries

The establishment of time boundaries in LCA studies for the treatment of GHG emissions is sometimes referred to as discounting: this is not correct. The following points summarise the difference between these two approaches to emissions assessment.

##### 7.2.6.2.1. Discounting

Economists often assume that future costs will be lower than present costs, and so apply a discount rate. There is often discussion regarding what the discount rate is, and discount rates are often partially based on interest rates, inflation and the perception of stakeholders: a discount rate of 3% means that costs that occur 100 years from now are hardly visible. While being accepted in economic theory, it is not necessarily accepted in environmental issues: for example, there is little evidence of people discounting their concerns regarding nuclear waste, even though the problem may occur in the distant future.

Under a discounting approach, future emissions are assumed to have less impact than emissions produced now: this view could be justified by assuming that climate change is less of a problem in the future, or that the cost of mitigation is lower in the future. Importantly, all emissions are included in a discounting approach (i.e. there is no time boundary); it is the significance of these emissions compared to current-day emissions that is “discounted”.

#### 7.2.6.2.2. Boundary setting

By establishing a time boundary for the LCA study (e.g. 100 years following formation of the product), emissions or the impact of emissions occurring within the time boundary can proceed. This approach does not discount future emissions, but rather it identifies which emissions are within the boundaries of the study, and which are not. This is consistent with the existing LCA standards (ISO 14040/44) which require the boundary to the study to be specified; in some cases emissions may fall outside the boundary of the study, but this is not considered within LCA methods to be “discounting”.

#### 7.2.6.3. Consistency with IPCC timeframes

In the PAS2050 a reference is made to the fact that the IPCC equivalency factors are used with a timeframe of 100 year, and that therefore the emissions inventory also need to have a time frame of 100 years. This is not so much an ethical perspective but more a consistency argument. IPCC never intended to express the fact that emissions taking place in the future are less important, but it introduced three different time perspectives for comparing the relative impact of different greenhouse gases. Most people use the 100 years perspective, but IPCC also publishes relative factors for a 20 and a 500 year perspective. The impact of CO<sub>2</sub> itself is not changed under these assumptions, only the impact of substances with an environmental lifetime that is either shorter or longer than the CO<sub>2</sub> lifetime (approx 150 years) does change. Scientifically there is no reason to prefer one over the other; the choice is based on the same considerations discussed in this paper.

#### 7.2.7. Annex 2: The ISO standards on time boundary

The 14040/44 standards do not explicitly require or even define the concept of time boundary. They usually refer to the concept of system boundary, which is defined as:

*system boundary: set of criteria specifying which unit processes are part of a product system*

*NOTE The term “system boundary” is not used in this International Standard in relation to LCIA.*

The only reference regarding the temporal aspects in LCIA is in ISO14044:

*4.4.2.2.3: Depending on the environmental mechanism and the goal and scope, spatial and temporal differentiation of the characterization model relating the LCI results to the category indicator should be considered. The fate and transport of the substances should be part of the characterization model.*

This means that the temporal aspects should be taken into account in the LCIA phase, but it does not refer to a link with LCIA. The note on the definition of the term system boundary seems to indicate that there is no link between the temporal boundary in LCI and the temporal characteristics in the impact assessment.

## 7.2.8. Annex 3: Methodology proposed in the Draft European handbook on LCA

Extract from the draft European Handbook on LCA

### 12.10.4 Temporary removal of carbon dioxide from the atmosphere in long-living products, landfills, storages

(Refers to aspects of ISO 14044 chapters 4.2.3.5, 4.2.3.6.2 and 4.3.2.1)

*Consultation note: The 100 years time perspective allows to separately address emissions that act beyond that time. The use of 100 year (compared to e.g. 20 or 500 years) is a choice that relates not only but also and very prominently to temporary carbon storage. Feedback on the general issue is specifically welcomed.*

The temporary removal of carbon dioxide from the atmosphere by incorporation into long-living bio-based products, into bio-based material remains in landfills, or in CO<sub>2</sub>-underground-storages is accounted for, as follows: the duration for which LCIA impacts of released emissions is calculated, is typically explicitly or implicitly indefinite. Exclusively in case of the Global Warming Potential (GWP) the much shorter perspective “GWP 100 years” is widely used (details and recommendations are provided in the separate LCIA guidance documents of the ILCD Handbook). The related characterisation factors used are typically those provided as part of the Intergovernmental Panel on Climate Change (IPCC) reports. Climate change is hence implicitly considered to be a problem of the next 100 years (3 to 4 generations). The long-term removal of CO<sub>2</sub> from the atmosphere and storage in long-living goods is hence politically promoted.

The difficulty is that the GWP 100 relates to the effect after the emission has taken place i.e. it counts the climate change impact of emissions that occur nowadays exert within the next 100 years. However, these emissions may also occur in the future (in e.g. 80 years when a now newly built house is broken down). Assigning a full GWP 100 factor to these emissions that happen in 80 years would contradict the logic of the GWP 100 detailed above, as in that case their climate change effect for 180 years from now would be accounted for. Also, no incentive would exist to temporarily store the CO<sub>2</sub> e.g. in the wooden beams of the house in the above example.

<sup>1</sup> Establishing a time boundary is not the same as discounting emissions; see the annex for further discussion.

<sup>2</sup> The GHG equivalent stored is multiplied by the number of years stored; the result is presented as kg CO<sub>2</sub>.yr.

<sup>3</sup> Biogenic materials are not necessary carbon neutral, as GHG emissions from processes such as growing, harvesting and transporting biogenic materials, and from land-use changes, are still included under the PAS 2050 approach.

### 7.3 Strengths and limitations of the Global Warming Potential and alternative metrics

Glen P. Peters and J.S. Fuglestedt

The United Nations Framework Convention on Climate Change (UNFCCC) requires climate policies to ‘be cost-effective so as to ensure global benefits at the lowest possible cost’ and that ‘policies and measures should ... be comprehensive ... [and] ... cover all relevant sources, sinks and reservoirs’. Many studies have shown the advantages of a comprehensive multi-gas agreement, but challenges remain in how to compare the climatic effect of different greenhouse gases (GHGs) [1]. The Kyoto Protocol (KP) sets limits on the emissions of six long-lived GHGs that are weighted together using the Global Warming Potential with a time-horizon of 100 years ( $GWP_{100}$ ).

Despite the policy acceptance of the  $GWP_{100}$  via the KP, the GWP concept has been critiqued from many angles [1]. It is arguably not widely understood that the  $GWP_{100}$  involves many value judgements, most of which have not been raised in policy discussions [2]. The GWP was chosen to be: the level of global mean radiative forcing (RF) integrated over a finite time horizon of 100 years, calculated from a global pulse emission of the gas in question, using  $CO_2$  as reference gas, with no discounting and a constant background concentration level. Surprisingly it is not known what the GWP physically represents in the climate system [3-5], and it was not intended that the GWP be applied directly in policy [2].

The GWP is certainly not a unique metric, and there are many ways that GHGs could be compared [6]. Initially, the basis for comparing GHGs could be based on different indicators, such as, radiative forcing, temperature change, sea level rise, or economic costs. Many time time-dimensions enter into a metric; should *instantaneous* or *integrated* quantities be used; should the time horizon be fixed or a function of a chosen target year; should past or future emissions be discounted; is the magnitude or rate of change more relevant; and so on. Other non-temporal issues arise such as what background climate should the metric be based on (constant or a given scenario) and should the metric be based on a pulse or sustained emission. Metrics also have a spatial dimension [7, 8]; the global response to the same mass emitted depends on location and time of emission; and likewise, there are regional variations in how the climate responds to equal emissions. The metric should also be consistent with the objectives of the policy it is designed to represent. The UNFCCC is framed in terms of cost-effectiveness, which may require certain metrics for consistency [9]. In addition, the current policy focus on a two degree temperature target may suite different metrics. Overall, there is no scientific basis to make these value-judgements and metric development requires a multidisciplinary approach [2].

To overcome some of the problems of the GWP the Global Temperature Potential (GTP) was developed [10, 11]. The GWP and GTP represent two fundamentally different ways of comparing emissions. While the GWP integrates the RF along the time path up to the chosen time horizon, and puts equal weight on all times between the time of emission and the time horizon, the GTP focuses on one particular chosen point in time and gives the temperature effect at that time (relative to that of CO<sub>2</sub>). For short-lived gases this difference in metric design has a large effect on the metric values since the climate system has a limited memory of the short-lived emissions. The GWP integrates RF and hence carries forward the short-lived forcing, while the climate system forgets the short-lived forcing as time progresses.

Several studies have shown the choice of metric between GWP and GTP can lead to significantly different weightings of GHGs. Black carbon is a short-lived and potent GHGs and has GWP values of 2900 and 830 for 20 and 100 years, with significantly lower GTP values of 290 and 60 for the same horizons [12]. Similar results are found at the sector level. In terms of integrate forcing over 100 years, aviation has one-quarter of the climatic effect as road transport and shipping has a cooling effect [13]. If analyzed in terms of the temperature effect, the shipping sector has a warming effect after 100 years, despite the short-term cooling effect, and aviation is one-sixth of the value for road transport [14]. These studies show that the choice between the two metrics, as well as the time horizon, will strongly affect which GHGs and sectors should be given priority in policy.

Several new areas of interest are placing increased pressure on the validity of the GWP as a metric. The GWP is a simple metric that does not account for the response of the climate system to emissions, while the more complex GTP accounts for the response in global mean surface temperature. With the renewed interest in comparing short- and long-lived components [15, 16], there is a particular need to develop metrics which are robust enough to compare components with vastly different time-scales. Similar to short-lived components, the renewed interest to compare albedo with other GHGs [17-19] requires a more thoughtful analysis as more than radiative effects become important [20, 21]. Fields such as Life Cycle Assessment and Carbon Footprint analysis have largely taken the GWP as a scientifically accepted metric [22, 23], but there is considerable scope to expand the impact assessments to different end-point indicators or include short-lived GHGs [24]. The current policy and scientific interest in short-lived components, albedo, and product based assessments are ideal points to initiate further research on metrics [6].

The choice of metric depends on which aspects of climate change one is concerned about and how it will be applied in a policy context. Metrics, and particularly the time dimensions, goes beyond the natural sciences as it requires value judgments [1, 6, 25]. These value judgements greatly impact the

relative importance of different GHGs and due to the various value-judgements there will not be a perfect metric, implying that every metric will require some sacrifices.

The value judgements that are inherent in metrics imply that the future development and analysis of metrics requires input from a variety of disciplines [2]; such as the natural sciences, economics, and political scientists. The natural sciences can use metrics to quantify the relative weights between the different GHGs, and how realistic those weights are to the physical realities of the climate system. Economists can quantify how different metrics impact on economic efficiency and distribution of costs between countries and sectors. Political scientists can assess the political feasibility of metrics. By working together, new metrics may be designed which come closer to striking a balance between competing issues. Importantly, an interdisciplinary approach to metrics may reinvigorate debate into metric design which will ultimately lead to a better policy outcome.

<b>2. Economic and policy framework</b>	
a)	<input type="checkbox"/> Cost-effectiveness approach (UNFCCC) <input checked="" type="checkbox"/> Cost-benefit approach
<b>3. Time considerations</b>	
a)	<input checked="" type="checkbox"/> Fixed time horizon <input type="checkbox"/> 20 years (IPCC) <input checked="" type="checkbox"/> 100 years (IPCC) <input type="checkbox"/> 500 years (IPCC) <input type="checkbox"/> Any other period <input type="checkbox"/> Time-dependent horizon
b)	<input type="checkbox"/> Discounting
c)	<input type="checkbox"/> Post-horizon effects
<b>4. Indicator of climate effects</b>	
a)	<input checked="" type="checkbox"/> Radiative forcing <input type="checkbox"/> Temperature change <input type="checkbox"/> Sea level rise <input type="checkbox"/> Damage
b)	<input type="checkbox"/> End-point <input checked="" type="checkbox"/> Integrated
c)	<input checked="" type="checkbox"/> Level of change <input type="checkbox"/> Rate of change
<b>5. Other Assumptions</b>	
a)	<input checked="" type="checkbox"/> Pulse emissions <input type="checkbox"/> Sustained emissions <input type="checkbox"/> Emissions scenarios
b)	<input type="checkbox"/> Emissions of 1kg <input type="checkbox"/> Emissions of a larger magnitude
c)	<input checked="" type="checkbox"/> Constant background <input type="checkbox"/> Transient background (emissions scenarios)
d)	<input checked="" type="checkbox"/> Global response <input type="checkbox"/> Regional response
e)	<input checked="" type="checkbox"/> Point estimate <input type="checkbox"/> Uncertainty
<b>6. Issues to consider</b>	
a)	<ul style="list-style-type: none"> <li>• Forcing relationship (linear/non-linear)</li> <li>• IRF specification (linear/non-linear)</li> <li>• Experimental setup</li> <li>• Model specification</li> </ul>

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## 7.4 Temporary Carbon Sequestration Cannot Prevent Climate Change

Miko U.F. Kirschbaum

Abstract. Biospheric C sinks can reduce atmospheric CO<sub>2</sub> in the short term. However, as this lowers the concentration gradient between the atmosphere and the oceans, it reduces the rate of CO<sub>2</sub> removal from the atmosphere. If C is released from temporary storage, subsequent atmospheric CO<sub>2</sub> will be higher than without temporary C storage. It is thus important to assess whether temporary C storage can mitigate climate-change impacts. That requires explicit quantification of climate-change impacts.

Impacts can be quantified:

- 1) as the instantaneous effect of increased temperature;
- 2) through the rate of temperature increase;
- 3) as the cumulative effect of increased temperatures.

Clearly, all three kinds of impacts are important, yet many analyses include only one of these impacts for constructing impact metrics. Global warming potentials implicitly count only the impact of cumulative temperature increases, whereas global temperature potentials are a measure of instantaneous temperature impacts. Any impact measure that includes only one of these impacts cannot fully capture the totality of relevant impacts. Instead, it would be warranted to explicitly quantify 'Climate Change Impact Potentials', with an explicit identification and quantification of the key climatic impacts.

Secondly, the critical time for impact mitigation needs to be defined. Options include:

- 1) to minimise the most severe impacts;
- 2) to minimise the sum of impacts;
- 3) to minimise the sum of severity weighted impacts;
- 4) to minimise time-preference and severity-weighted impacts.

The present analysis is based on the aim to minimise the most severe climate change impacts. It shows that temporary C storage only reduces impacts related to the cumulative effect of increased temperature. It could even worsen instantaneous temperature impacts, or impacts related to the rate of temperature change. Because temporary carbon storage improves some, but worsens other climate-change impacts, it achieves very little on average. Temporary carbon storage therefore cannot prevent climate change impacts.

Explicit consideration of impacts and relevant timing also changes the relative importance of different greenhouse gases. It would reduce the relative importance of methane and increase focus on the longer-lived greenhouse gases, instead.

#### 7.4.1 Introduction

Climate change is now recognised as a global problem, and the global community is seeking cost-effective means of reducing the net emission of greenhouse gases to the atmosphere. The use of trees, or more correctly the use of the biosphere for carbon storage, is often considered as a cost-effective means of reducing net emissions to the atmosphere. Trees are used as a means to ‘buy time’. The question is addressed here whether trees, or the biosphere more generally, can make a useful contribution to reducing net emissions to the atmosphere. This discussion is based on previous work (Kirschbaum 2003a, 2003b, 2006) and is developed further from those publications in the following.

It essentially combines considerations of feedbacks via natural carbon reservoirs, especially the world’s oceans, with an explicit definition of the key climate-change impacts we are concerned about. It leads to important consequences for the choice of timing of emissions and emission reduction activities.

Importantly, it allows a distinction to be made between net emissions and the atmospheric concentration of greenhouse gases. Net emissions are not important on their own, but it is the ultimate atmospheric concentration that leads to radiative forcing and thus climatic impacts. In the case of fossil fuel emissions, there tends to be a tight linkage between emissions and resultant atmospheric concentrations. There is little choice in the timing of emissions. Fossil fuels are emitted when they are needed to produce a service, such as generating electricity or driving a car. The timing of emissions is therefore determined by the demand for the ultimate service.

In the case of biospheric carbon stocks, however, there is more choice in affecting the timing of emissions, and more choice in affecting carbon-stock changes that are not associated with any end-use. Land can be converted between non-productive grassland and forests, with large carbon implications, or productive land can be managed in different ways to achieve lower or higher carbon stocks without necessarily affecting the service the products are put to. Since these carbon stock changes can be undertaken at different points in time, the importance of timing needs to be explicitly addressed.

#### 7.4.2 The Carbon Cycle

The World contains massive carbon pools that naturally interchange carbon between each other (Kirschbaum 2003b). The principal ones are the atmosphere, the oceans and the land area. The interchange between the atmosphere and these other carbon pools is diagrammatically represented in Figure 7.4.1.

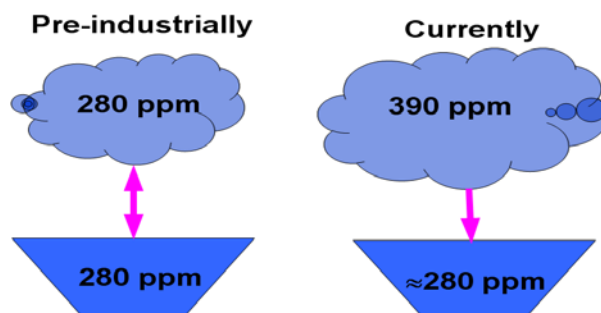


Figure 7.4.1: Diagrammatical representation of the interaction between the atmosphere and the natural carbon pools in the oceans and the terrestrial biosphere.

Pre-industrially, the carbon pools were in effective equilibrium, with no net exchange between pools. The atmospheric concentration was about 280 ppm in equilibrium with the same effective ocean concentration. Since the global carbon cycle was essentially in equilibrium, there could have been only minor net exchanges between the atmosphere and the oceans.

By 2010, however, the atmospheric concentration has increased to about 390 ppm, whereas the effective CO<sub>2</sub> concentration of the deep oceans has not changed much. The concentration in the surface oceans has changed as it can always remain close to conditions in the atmosphere, but the surface oceans comprise only a very small proportion of the total ocean water volume. The deep oceans, however, are not in direct contact with the atmosphere and transfer rates to the deep oceans are very slow so that it takes decades to centuries for these pools to come to equilibrium with each other.

Hence, there is currently a significant disequilibrium and an on-going carbon flux into the deep oceans, estimated at about 1.5-2 GtC yr<sup>-1</sup> and for a cumulative flux of about 140 GtC (updated from Kirschbaum 2003b). This flux is, of course, most welcome as it reduces the atmospheric CO<sub>2</sub> concentration, and the atmospheric concentration would be substantially higher without that on-going absorption by the oceans. This flux is driven by the concentration gradient between the atmosphere and the ocean, and any change in that gradient will have consequences in terms of the subsequent flux to the oceans.

This uptake can be described with a highly simplified model of the global carbon cycle, such as the Bern model, and Figure 7.4.2 (left panel) shows the effect of creating a 1 tonne carbon sink in 2000 and keeping the carbon stored in the sink in perpetuity. The middle panel shows the consequent effect on the atmospheric CO<sub>2</sub> content. Immediately following the CO<sub>2</sub> removal from the atmospheric content is reduced by the 1 tonne that is removed. However, the reduced atmospheric CO<sub>2</sub> content also lowers the gradient between the atmosphere and the ocean and through that, reduces the ocean uptake.

With reduced uptake the atmospheric CO<sub>2</sub> content trends upwards again, and 20 years after the initial removal, the atmospheric content is lowered by only about half as much as the initial amount removed.

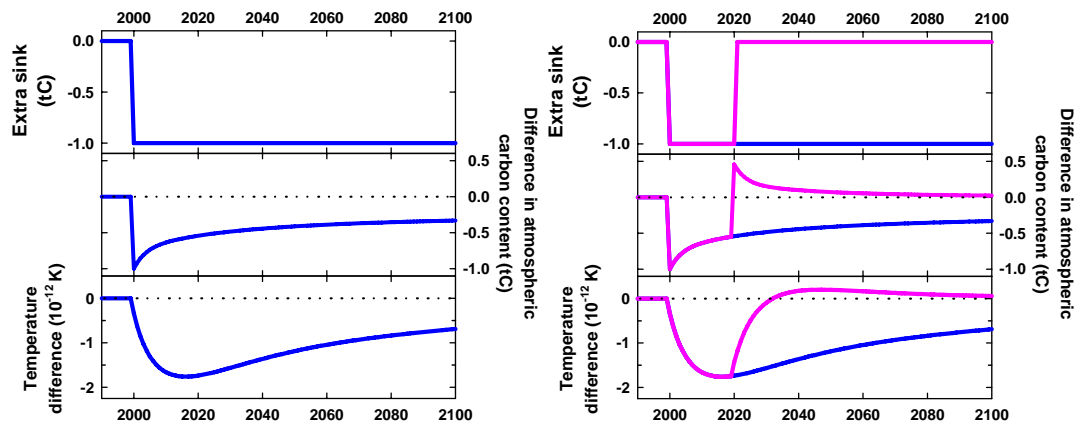


Figure 7.4.2: The effect of sink activity on atmospheric CO<sub>2</sub> concentration and resultant temperature. The Figure on the left shows the effect of a permanent sink, and the Figure on the right, the effect of a sink created in 2000 and reversed again in 2020. All curves show the change as a consequence of the sink activity. These changes are therefore additional to any CO<sub>2</sub> or temperature changes that may be occurring due to other factors (such as fossil-fuel emissions).

If carbon storage is only temporary and is reversed after 20 years (the pink line in Figure 7.4.2, right panel) then the atmospheric carbon content increases by 1 tonne again at the time of the carbon release. However, because the atmospheric content has increased over the time with reduced ocean uptake, the ultimate CO<sub>2</sub> content is greater than it would have been if there had been no temporary storage. That elevation in atmospheric carbon content is most pronounced immediately after the re-release of stored carbon and then trends back down towards the 0 line.

Changes in CO<sub>2</sub> concentration then have radiative forcing properties and affect global temperatures. Because of thermal inertia, temperature does not follow radiative forcing immediately, but only with some further delay. That has been modelled here with a simple 10-year time constant. The effect of different thermal delay constants has been explored to some extent by Kirschbaum (2003a). Importantly, following establishment of permanent carbon sinks, temperature is reduced the most about a decade after the sink activity and diminishes thereafter. Following the establishment of temporary sinks, temperature is reduced while carbon is stored, but temperature then increases again and ultimately is higher than it would have been without the use of temporary carbon sinks. The ultimate warming effect is greatest about 20 years after the re-release of carbon, and increases with the length of carbon storage.

### 7.4.3 Climate Change Impacts

So, is temporary carbon storage a useful strategy? Or for permanent carbon storage, what would be the best time for establishing carbon sinks? To address this question, it is necessary to explicitly quantify climate-change impacts, and various possibilities have been suggested in past work. In general, impacts can occur in at least three different ways:

- 1) by the direct and instantaneous effect of elevated temperature;
- 2) through the rate of temperature increase;
- 3) through the cumulative impact of increased temperatures.

The direct and immediate effect of temperature is the relevant measure for impacts such as heat waves and other extreme weather events. This metric is essentially the same as the Global Temperature Potential.

The rate of temperature increase is a concern because many aspects of a warmer world may not be inherently worse than current conditions, but the change from the current to a future, warmer world will be difficult for both natural and socio-economic systems. If change is slow enough then systems can be moved or adapted, but faster change may be too rapid for such adjustments.

The third type of impact relates to the cumulative impact of raised temperatures. This is the critical issue for impacts such as sea-level rise. The extent of sea-level rise is related to both the magnitude of warming and the length of time over which oceans and glaciers are exposed to increased surface temperatures. This metric is essentially the same as Greenhouse Warming Potentials.

These three impacts can then be calculated under any emissions scenario. This was done here for the SRES A2 scenario (Figure 7.4.3). It shows that under this (Business-as-usual) scenario, all three types of impacts are expected to increase through to the end of the 21<sup>st</sup> century and beyond. One can then ask the specific question by how much the experience of the same climatic changes can be delayed (or hastened) by specific land-use options. One can ask specifically how much ‘time trees can buy’. Hence, if the same threshold value in terms of climatic impacts would be reached on 1 February 2100, say, instead of 1 January 2100, it would constitute 31 days of time having been bought.

Figure 7.4.4 shows the difference in time for the experience of the same climatic changes by the use of either permanent (top panel) or temporary (bottom panel) carbon sinks. This is shown separately for the three types of climatic impacts, instantaneous temperature ( $T$ ), rate of temperature changed ( $\Delta$ ) and cumulative temperature ( $\Sigma$ ). The units are given in days (to experience a given climatic change) per GtC stored in a biosphere sink.

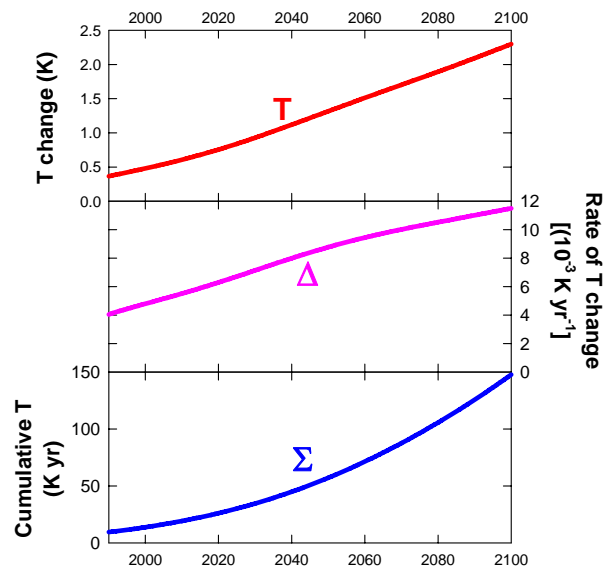


Figure 7.4.3: Future climate change impacts under the SRES A2 scenario. Updated from Kirschbaum (2003a).

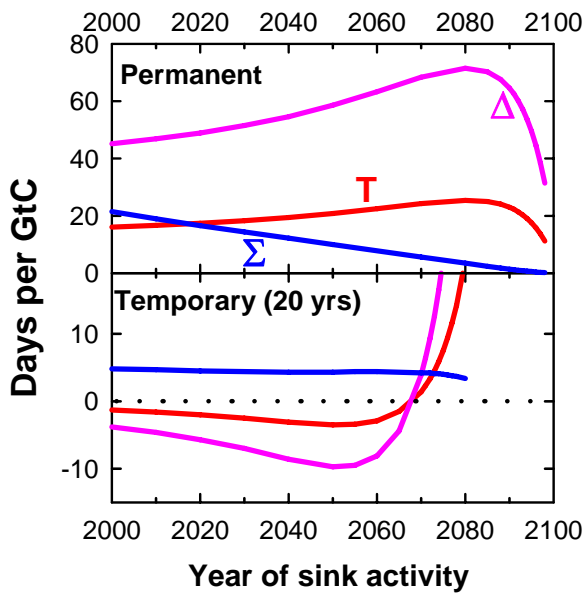


Figure 7.4.4: The time ‘bought’ by permanent (top panel) and temporary (bottom panel) carbon sinks. This is expressed in the number of days by which the experience of the same climate-change impacts can be delayed (or hastened) by the storage of 1 GtC. This is shown for the three separate climatic impacts (see text). Temporary carbon storage refers to carbon that is released again 20 years after the initial storage.

Each additional GtC sequestered in vegetation sinks and kept in perpetuity could delay the advent of the most severe impacts related to the rate of change, with time to maximum impacts delayed by about 70 days per GtC if the sinks are established close to the year 2100 (Fig. 7.4.4). Establishment of vegetation sinks earlier over the 21<sup>st</sup> century would have progressively less effect, with sinks established in 2000 leading to a saving of only about 45 days per GtC.

Time savings in terms of reducing impacts via instantaneous temperatures are smaller and reach a maximum of only 25 days  $\text{GtC}^{-1}$  even for sinks established close to the time of maximum impacts. Time savings in terms of reducing cumulative temperature impacts are even smaller, especially for sinks established late in the 21<sup>st</sup> century. Maximum effect can be achieved for sinks established in 2000 when a saving of about 20 days  $\text{GtC}^{-1}$  is possible, and it diminishes almost linearly with time that tree plantings is delayed.

In contrast to sinks that store carbon in perpetuity, temporary carbon sinks achieve numerically less, and can even affect a loss of time rather than any gain (Fig. 7.4.4, bottom panel). Beneficial effects on all impact measures only result for temporary sinks established late in the 21<sup>st</sup>. Cumulative temperature impacts can be reduced even by temporary carbon sinks, but the saving is numerically fairly small, with only about 5 days  $\text{GtC}^{-1}$  saved, with little difference between sinks established at different times.

Looked at from the perspective of instantaneous impacts and impacts via the rate of change, temporary sinks can make impacts worse. This can be understood by reference to Figure 7.4.2. When  $\text{CO}_2$  is temporarily removed from the atmosphere, it reduces the inherent  $\text{CO}_2$  uptake by the global carbon cycle, such as by the oceans. When the temporarily removed  $\text{CO}_2$  is released into the atmosphere again, subsequent  $\text{CO}_2$  concentrations will be higher than they would have been without the temporary sink. Temperature follows these changes in  $\text{CO}_2$  concentration although with further delays. Hence, maximum temperatures and maximum impacts to 2100 could be worsened by temporary sinks, and time would be lost rather than gained (Fig. 7.4.4, bottom).

Another way to ask the same question is given in Figure 7.4.5. This Figure assumes that a sink has been established in 2000, and the question is asked by how much each of the three kinds of impacts can be mitigated by maintaining the sink for different durations. This is expressed relative to the mitigation effect of maintaining the carbon in the biosphere sink beyond the year 2100, which would then also equate to the mitigation effect of saving fossil fuel emissions. In this analysis, instantaneous temperature impacts and impacts via the rate of temperature change are numerically identical. These analyses are shown based on the SRES A2 (Business as usual) scenario (Fig. 7.4.5) and the SRES B1 (sustainable) scenario (Fig. 7.4.6).

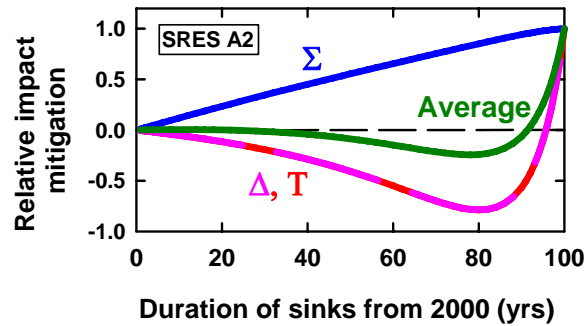


Figure 7.4.5: The relative mitigation effect of carbon sinks established in 2000 and maintained for different lengths of time under the SRES A2 scenario. This is shown separately for the three different types of impacts, normalised in each case to the mitigation potential of sinks maintained beyond 2100. The green line simply gives the average of the three individual types of climate-change impacts.

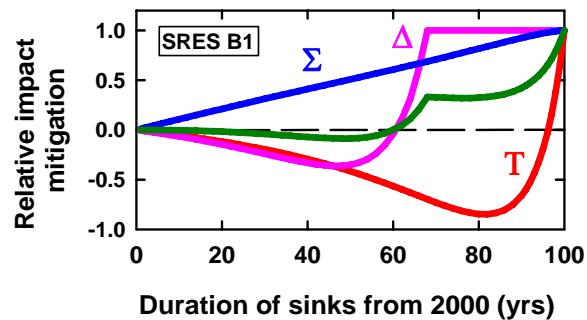


Figure 7.4.6: The relative mitigation effect of carbon sinks established in 2000 and maintained for different lengths of time under the SRES B1 scenario. Symbols as for Figure 7.4.5.

It shows that temporary carbon sinks worsen instantaneous temperature impacts and impacts via the rate of change, and the effect becomes more pronounced the longer the sinks are maintained up to about 2080. In contrast, temporary carbon storage can mitigate cumulative temperature impacts, and the mitigation effect increases almost linearly with length of time over which the sinks are maintained.

So, with some impacts being worsened by temporary sinks and others improved, what is the bottom line? One initial approach is to simply assign each impact equal importance and take the average of the three individual impacts, and that is shown by the green line in Figure 7.4.5. It shows that averaged across the mitigation impact of the three kinds of impacts, temporary sinks maintained for 50 years achieve no mitigation at all, and slightly longer maintained ones even worsen impacts. Only sinks maintained for close to the time of the analysis horizon (the end of the century), achieve useful mitigation outcomes.

The use of biosphere sinks to ‘buy time’ is often advocated as part of a strategy to move towards a more sustainable future with lower anthropogenic CO<sub>2</sub> emissions. Such a future is represented by the SRES B1 emissions scenario, under which maximum rate-of-change impacts would occur by the middle of the 21<sup>st</sup> century. Under this scenario, maximum impacts via the rate of change would be increased by temporary storage in sinks maintained to about 2060 (Fig. 7.4.6). For mitigation of the worst rate of change impacts, it would not matter how long sinks would be maintained beyond 2060 because the most serious impacts would have already been experienced before then.

However, for the sustainable SRES B1 scenario, the average mitigation impacts for sinks maintained for less than about 50 years also remain close to 0 and achieve essentially nothing. It shows that temporary biospheric carbon storage achieves very little climate-change mitigation under either high (SRES A2) or low (SRES B1) emission scenarios.

The preceding discussion has been based on the explicit aim of reducing the worst climate-change impacts. An alternative approach might have been to also introduce some element of cumulative impacts into this analysis. Four alternative impact mitigation aims could be:

1) The first option, and the one used above, is to minimise the greatest impacts to be experienced. Hence, the overall impact,  $I_o$ , and the one we would aim to minimise, would be the highest impact, which could be expressed as:

$$I_o = \max (I_t)$$

where  $I_t$  is each of the defined impacts at year  $t$ , and  $\max (I_t)$  is the highest impact expected. This also requires an assessment horizon to be given, and that could be set to the year 2100, or the next 100 years. It clearly becomes very difficult to predict the time course of any of those impacts one hundred years into the future so that we cannot know how a marginal addition of extra greenhouse gases will add to impacts at these future years. Hence, assessment horizons beyond 100 years are not very practical.

2) Option 2 would be to minimise the integral of impacts. That could be formally expressed as:

$$I_o = \sum I_t$$

where  $\sum$  means the sum or integral of impacts in individual years. A key problem with that formulation would be that it would scale impacts linearly so that a 2 degree temperature increase would be counted as making twice the contribution of a 1 degree temperature increase, or a 10° increase the same as a 1° increase over 10 years. Any threshold effects would thus be ignored. In this simple form, a cumulative model would not be very useful or realistically capture the relevant nature of climate-change impacts.

3) A third option, and one that more realistically captures the non-linear properties of climate-change impacts, would use the sum of impacts similar to option 2, but scale impacts first with some power function to indicate the non-linear scale of impacts. Hence, it could be expressed as:

$$I_o = \sum (I_t^s)$$

where  $s$  gives some severity index that describes the non-linearity in impacts. So,  $s$  should have some value greater than 1. With  $s = 2$ , and impact of 2 units (say, a temperature increase by 2°C) would count four times as much as an impact of 1.

4) Fourthly, there is the question whether to bring in any discount factor and thus count more distant impacts less than impacts in the less distant future. Hence, option 3) could be combined with a discount factor as:

$$I_o = \sum [I_t^s (1-d)^t]$$

where  $d$  is the discount rate. The discount rate is a most critical parameter, and with

$d = 0.01$ , impacts in 100 years count only 1/3 as impacts in the current year; with

$d = 0.02$ , they count 13%;

$d = 0.04$ , they count 1.7% (and become essentially irrelevant).

Mathematically, options 2 and 3 are, of course, sub-sets of option 4.

The effect of setting these different mitigations targets for assessing the usefulness of temporary carbon storage is explored in the following. It begins by setting a temperature scenario (the red line in Figure 7.4.7) and then adding carbon sinks that are reversed 20 years later. Two examples for sink establishment in 2020 or 2050 are shown in Figure 7.4.7 in green and blue.

A sink in 2020 but reversed in 2040 would have the effect of marginally worsening the most extreme temperatures but leading to more benign temperatures for several decades earlier before the reversal of the carbon sink. A sink established in 2050 would lower temperatures for several decades, including the year of expected highest temperatures. It would marginally increase temperatures towards the end of the 21<sup>st</sup> century, but that would be at a time when temperatures are on the way down again.

The relative impact mitigation under four options for quantifying the mitigation potential is shown in Figure 7.4.8. The first one ( $I_o = I_t$ ) is simply the one used previously and describes the situation of aiming to minimise the highest impact (option 1). Option 2 is not represented here. The second one ( $I_o = \sum I_t^4$ ) corresponds to option 3 with a fairly high exponent of 4. The third and fourth ones represent option 4 with different parameters, the third [ $I_o = \sum (1-0.04)^t I_t^4$ ], with a very high discount rate (0.04)

and a high exponent (4) of the impact measure. The fourth option [ $I_0 = \sum(1-0.01)^t I_t^2$ ], with a low discount rate and a low to moderate exponent (2).

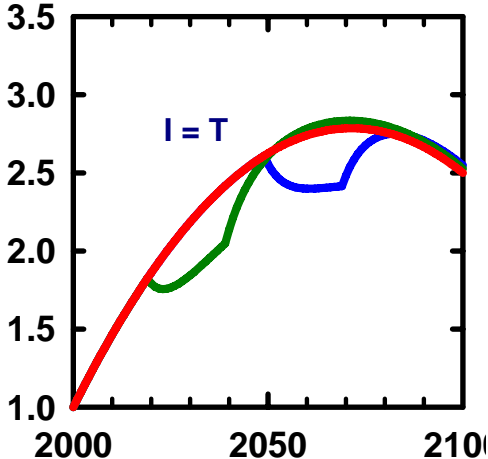


Figure 7.4.7: A notionally future temperature curve (in red) and the way it can be modified by temporary (for 20 years) carbon storage used in 2020 (in green) or 2050 (in blue).

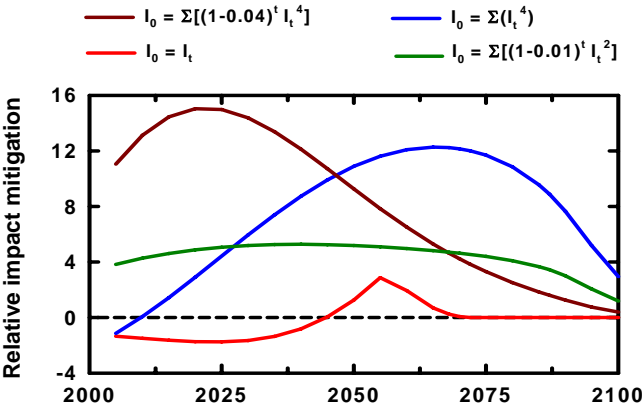


Figure 7.4.8: Climate change impact mitigation by temporary carbon sinks (as shown in Figure 7.4.7) quantified with the use of different impact metrics. These curves have not been normalised so that absolute values should not be compared, but only the relative time courses within each impact metric.

Case 1 (in red) shows the same picture as before, with a negative (worsening) effect of temporary sink activity for a sink established early this century, but achieving some useful mitigation if sinks are established at a time when carbon storage in the sink coincides with the time of highest temperature impact. Case 2 (in blue) presents a similar picture except that the line almost never dips below the 0 line. The positive effect increases substantially, however, if sink activity can be delayed.

The overall picture changes completely if discount rates are included, especially a high discount rate, such as for case 3 (in brown). With a high discount rate, near-term changes in temperature are so much more important to completely favour early tree planting. Even the very high exponent to greatly

increase the importance of higher impacts is not enough to negate the dampening effect by the discount rate.

If this impact assessment is used as the basis of decision making it would lead to a clear and definite support for early tree planting even for temporary carbon storage. Popular support for tree planting is probably largely based on an implicit model similar to this one. I would contend, however, that the explicit version of this model would not be supported and that a discount rate as high as 0.04 would inappropriately reflect our concern about the effect of climate change on future generations.

The more moderate version of the model with a moderate discount rate of 0.01 but also a weak to moderate exponent of 2 leads to the interesting outcome that tree planting is beneficial and almost equally beneficial irrespective of the timing of tree plantings.

Each of these parameter choices could be considered as defensible options, yet lead to vastly different outcomes for the desirability of tree plantings in temporary carbon storage. It is therefore urgently required to refine these fundamental quantifications of climate change impacts as the basis for rational mitigation policy in future.

This also has important implications for the relative importance given to different greenhouse gases. The Kyoto Protocol uses Greenhouse Warming Potentials for the relativities between different greenhouse gases, which essentially quantifies only the impact related to cumulative temperature increases. Methane has a fairly high Greenhouse Warming Potential because it has high radiative forcing, but it has a fairly short atmospheric life time (about 12 years) so that its high Greenhouse Warming Potential is comprised of its contribution over the first few decades after its initial emission. In contrast, methane emitted in 2010 would make only a negligibly small contribution to warming in 2100. Hence, the use of an impact metric based on future temperatures rather than the integral of future temperatures would greatly reduce the importance of methane relative to the longer-lived greenhouse gases CO<sub>2</sub> and N<sub>2</sub>O.

#### 7.4.4 Conclusions

Impact quantification is not handled well at present, yet a good and rational quantification is needed to underpin the development of rational mitigation efforts. An improved quantification of climate change impacts should begin by explicitly recognising at least three distinct types of climate change impacts:

- 1) by the direct and instantaneous effect of elevated temperature;
- 2) through the rate of temperature increase;
- 3) through the cumulative impact of increased temperatures.

The two currently most used and discussed climate change impacts, the Greenhouse Warming Potential and Global Temperature Potentials are more or less equivalent to cumulative temperature impacts and instantaneous temperature impacts, respectively. These metrics measure different aspects of climate-change impacts. It is important not to treat one as better than the other, but to acknowledge that they are all important, and should be included in a combined impact metric.

A rational assessment of the mitigation potential of different land-use options should explicitly include each of these different kinds of impacts. It also needs to explicitly include the feedbacks via the global carbon cycle.

Such an analysis re-affirms the usefulness of establishing permanent biospheric carbon sinks. However, it questions the usefulness of temporary carbon storage. Temporary carbon storage will increase future CO<sub>2</sub> concentrations and temperature after the re-release of temporarily stored carbon. It will thus improve some climatic impacts but worsens others. With a simple quantification of the three types of climatic impacts and concentrating only on the worst impacts to be experienced over this century, it has to be concluded that temporary carbon storage achieves virtually no useful climate change mitigation.

However, it is appropriate to take this framework further and equate the ultimately relevant impacts not just as the straight impact, but also apply some notion of cumulative impacts, and discount more distant impacts in some form. Use of different parameter values in such more comprehensive impact quantifications can result in different conclusions about the desirability of temporary carbon storage.

Hence, more discussion is needed on devising impact formulations to best capture the relevant impacts that society is concerned about. Optimal development of mitigation policy is not possible without the guidance by better developed quantification of climate change impacts.

#### 7.4.5 References

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## 7.5 Accounting for sequestered carbon: the value of temporary storage

Gregg Marland, Eric Marland, Kevin Shirley, Jenna Cantrell, and Kirk Stellar

Sequestration of carbon (whether in live trees, geologic reservoirs, wood products, deep oceans, or wherever) retains carbon that would otherwise enter the Earth's atmosphere as carbon dioxide, a greenhouse gas that would alter the radiative balance of the atmosphere. Permanent sequestration of carbon clearly helps to minimize the human impact on our climate system. The question posed here is whether temporary storage of carbon in these reservoirs also has value even though it is possible, or even likely, that this carbon will indeed be released to the atmosphere eventually. Despite arguments to the contrary (see, Kirschbaum, this volume), we believe that carbon sequestration has both economic and environmental value even if permanence cannot be assured.

The economic argument is clear and the benefit can be easily quantified whenever carbon emissions have monetary value, whether that value is related to a cap-and-trade system, a carbon tax, or emissions permits. In all cases a delayed payment has less net present value than a current payment so long as the cost does not increase faster than the discount rate. As stated succinctly by Richards (1997): "Wherever there is a positive time value to carbon there is a positive value to temporary capture and storage".

We have argued previously (Marland et al., 2001; Sedjo and Marland, 2003) that carbon emissions should be fully debited at the time of emission and that full credit should be available at the time of sequestration. Credits and debits would be symmetric and instantaneous. Given this, permanent carbon emissions credits can be bought and sold, temporary credits can be rented, and financial markets can determine the value of a temporary credit given the value of a permanent credit. The value of rented credits would vary with the credibility and responsibility of the host – the risk factors. More recently (Shirley et al., 2010), we have developed an analogy with the life insurance industry to show that if the expected life time of temporary storage can be described in probabilistic terms, then there is a large body of experience to provide insight on options for financial transactions and the value of trading permits at any time. The variety of the available options for determining the costs in these transactions is reflected in the variety of actuarial models proven to be useful in the insurance industry.

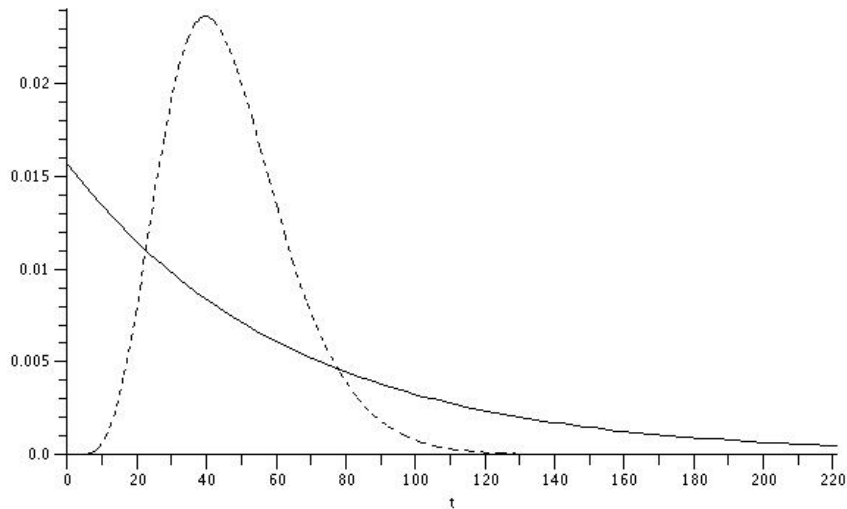
It seems clear that temporary carbon storage has financial value and that there are well-established alternatives for the functioning of appropriate markets.

In an earlier review of the literature we have identified (Marland et al., 2001; see also Marland and Marland, 2009) at least 9 reasons that it may be advantageous to acquire temporary carbon credits. Many of these are largely financial motivations but some are related to environmental or social

benefits. They are: 1.) it buys time for technological progress, 2.) it buys time for capital turnover, 3.) it allows time for learning to occur, 4.) it may not be possible to arrange insurance in perpetuity, 5.) it saves money for other reasons, 6.) hosts may be unwilling or unable to guarantee sequestration in perpetuity, 7.) it postpones climate change, 8.) some temporary sequestration may turn out to be permanent, and 9.) even if a specific carbon sequestration is temporary, sequestration in aggregate is likely to be increased if markets exist. In the absence of perfect vision of the future, sequestering carbon now keeps us on a lower carbon path than would otherwise be available and it mediates the approach of damages or tipping points. This is not unlike our purchase of insurance or the acquisition of a vaccination now rather than waiting until the day before an accident or infection. The prospects of permanent sequestration, a flow of temporary sequestrations, slowing climate change, finding a better low-carbon future, avoiding approaching tipping points, and/or moving forward with better understanding of what awaits are clear environmental benefits.

Accepting that there is value in temporary carbon sequestration implies that there is similarly value in delaying emissions and that it is important to describe as accurately as possible when emissions actually occur. If forests are harvested for the production of wood products, for example, it becomes important to acknowledge that all of the contained carbon is not necessarily released quickly as carbon dioxide. The net present cost of emissions will be less for longer-lived products. The commonly used assumption that forest products join a single pool that decays exponentially over time to carbon dioxide is an assumption that is both inappropriate and easily replaced. In the remainder of this presentation we develop a distributed decay model (see Marland et al., 2010) which acknowledges that the posts from this year's production of fence posts, for an example, are distinguishable from last year's fence posts, will remain in service until later, and that it can be economically important to describe the actual oxidation times as accurately as possible. The figure below shows the probability of oxidation over time for fence posts as described by an exponential decay and by a gamma function when both distributions have a mean life time of 40 years and 95% probability of decay within 80 years.

This paper does not address how time should be dealt with in life cycle analyses, but it does argue that there is value in temporary sequestration or in delaying emissions and that consequently we do need to deal with time.



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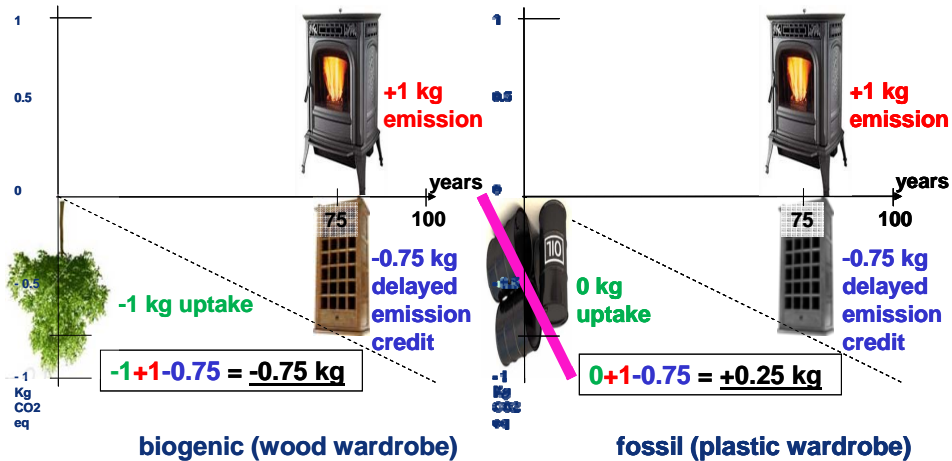
## 7.6 ILCD Handbook recommendations

Marc-Andree Wolf, Kirana Chomkhamsri, Miguel Brandão, Rana Pant, David Pennington

According to the “ILCD Handbook – General guide on LCA”, *temporary carbon storage, delayed greenhouse gas emissions and delayed credits in case of substitution shall not be considered in the LCIA results calculation, as LCA per se is not discounting emissions over time. This is unless the goal of the study would explicitly aim at including such storage and delayed emissions/credits, e.g. in related methodological studies.* In case carbon storage and delayed emission are considered, the ILCD foresees the following (details see “General guide on LCA” of the ILCD Handbook, chapter 7.4.3.7.3):

The logic behind accounting for biogenic carbon storage is that for the duration of storage e.g. in wood products, the CO<sub>2</sub> is not exerting a radiative forcing as it is temporarily not in the atmosphere. This makes sense only in case near-term radiative forcing is considered more relevant than future radiative forcing, as the later re-emitted biogenic CO<sub>2</sub> will still exert its full radiative forcing effect, only later. That is similar (while not the same) to the commonly used one hundred years perspective for GWP 100<sup>1</sup>, why both could be argued to be best used jointly.

It is to be noted that rewarding the temporary removal of CO<sub>2</sub> from the atmosphere in e.g. wood is fully equivalent to the effect of avoided radiative forcing due to delayed emission of fossil carbon dioxide, methane, nitrous oxide, and other greenhouse gases: While the uptake of CO<sub>2</sub> from the atmosphere is unique for biomass and considered in the impact assessment as negative impact, it does not matter whether one later burns a block of wood or of plastic and releases the CO<sub>2</sub> as emission: both biogenic and fossil CO<sub>2</sub> are identically contributing to radiative forcing when emitted. For Climate change it is the same whether one keeps a piece of wood or of plastic unburned for e.g. 60 years (provided the uptake of CO<sub>2</sub> from the atmosphere in the wood is accounted for). If the time when an emission takes place is considered for biomass it must also be considered for fossil materials. In other words: what is considered in carbon storage is in fact the timing (delay) of the emission only, hence THIS needs to be accounted for in both biogenic and fossil GHG emissions.



Example, in case carbon storage/delayed emissions are accounted for:

Note that also credits for delayed recycling would have to follow the same logic, i.e. result in a reduced credit.

The difficulty is that the GWP 100 relates to the effect after the emission has taken place i.e. it counts the climate change impact of emissions that occur nowadays exert within the next 100 years. However, these emissions may also occur in the future (in e.g. 80 years when a now newly built house is broken down). Assigning a full GWP 100 factor to these emissions that happen in 80 years would contradict the logic of the GWP 100 detailed above, as in that case their climate change effect for 180 years from now would be accounted for. Also, no incentive would exist to temporarily store the CO<sub>2</sub> e.g. in the wooden beams of the house. On the other hand does temporary storage of CO<sub>2</sub> and the delayed emissions not consider that the CO<sub>2</sub> will in any case exert its full radiative effect, only later. *As outcome of the development and consultation process, the ILCD Handbook sets the following requirement: For that reason carbon storage should only be considered quantitatively if this is explicitly required to meet the needs of the goal of the study. Otherwise, i.e. per default, temporary carbon storage and the equivalent delayed emissions and delayed reuse/recycling/recovery within the first 100 years from the time of the study shall not be considered quantitatively.*

To account for this and to at the same time ensure a transparent, plausible, and practice-applicable life cycle inventory, the following provisions are made. They allow to use the same inventory for studies that account for carbon storage / delayed emissions and those that do not:

As all emissions that occur within the next 100 years from the year of the analysis are inventoried as normal elementary flows, and all emissions that occur after 100 years are inventoried as long-term emissions, simply a correction elementary flow of storage/delayed emission can be introduced for each contributing substance.

For fossil carbon dioxide this flow is named "Correction flow for delayed emission of fossil carbon dioxide (within first 100 years)" as "Emissions to air". It is measured in the flow property "Mass\*years" and the reference unit "kg\*a". The flow is to carry a GWP 100 impact factor of "-0.01 kg CO<sub>2</sub>-equivalents" per 1 kg\*a. The information about the assumed time of emission and the actual amount of the emission shall be documented in the unit process and hence available for review. Flows for biogenic (i.e. temporarily stored) carbon dioxide and methane, but also for other, fossil greenhouse gases with delayed emissions can be developed analogously.

These new elementary flows should be used in addition to the normal elementary flows including the flow "Carbon dioxide" as "Resources from air" that model the physical uptake of CO<sub>2</sub> into biomass.

For the use stage of long-living goods the inventory would contain the integral of the emissions at different ages. This can be simplified in the common case that the use stage emissions are the same for all years: the total amount of use stage emissions would be multiplied with half of the assumed life time years.

The maximum amount of each correction flow that can be inventoried per kg delayed emission shall be 100 kg\*a. That is if the delayed emission takes place exactly 100 years into the future. It shall not be inventoried if the emission takes place beyond the 100 years.

<sup>1</sup> In case of the Global Warming Potential (GWP) "GWP 100 years" is widely used as a political/society choice. Climate change is hence implicitly considered to be a problem of the next 100 years. The related characterisation factors used are typically those provided as part of the Intergovernmental Panel on Climate Change (IPCC) reports.

## 7.7 Treatment of temporary carbon storage in PAS 2050

Roland Clift

To account for temporary carbon storage, PAS 2050 applies the approach which has been developed to develop values for global warming potential (GWP) for the principal greenhouse gases (GHGs): contributions to radiative forcing are integrated over a reference period, usually 100 years. No discounting is applied to future impacts; instead, the effects are simply cut off at the end of the accounting period. Although this is arguably not set out clearly in PAS 2050, the approach taken is that originally proposed by Lashof (see Fearnside et al., 2000). This contribution will explain how the Lashof method is applied, how it leads to the formula given in PAS 2050, and how it can be extended to general cases with carbon storage and release over time within the 100-year accounting period. Whereas Fearnside et al. were concerned with carbon storage in soil and biomass, the focus in PAS 2050 is on carbon-containing products such as furniture and building components. However, the Lashof approach could provide a rational and consistent approach to both cover land use and durable carbon-containing products.

The underlying thesis is that this approach provides a methodology which is consistent with the evaluation of GWPs used in international negotiations. If the approach raises methodological questions, they are questions over the common use of fixed reference periods.

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## **7.8 ISO 14067 Carbon footprint of products**

Katherina Wuehrl

Climate change arising from anthropogenic activity has been identified as one of the greatest challenges facing countries, governments, business and human beings with major implications for both human and natural systems. In response, international, regional, national and local initiatives are being developed and implemented to limit greenhouse gas (GHG) concentrations in the Earth's atmosphere. Such GHG initiatives rely on the assessment, monitoring, reporting and verification of GHG's emissions and/or removals.

Since 2008 the international working group ISO/TC 207/SC 7/WG 2 "Greenhouse gas management in the value or supply chain" works on a generic two-part standard ISO 14067 in order to create an International Standard which helps to assure quality, allow comparability and contribute to market development.

ISO 14067 will detail the principles and framework requirements for the quantification and communication of the carbon footprint of products (CFP) (including both goods and services). It includes requirements for determining the boundaries for the assessment of GHG emissions, removals and storage over the life cycle of a product. Requirements for partial carbon footprint (partial CF) assessment are also provided (ISO 14067-1). It also includes requirements and guidance for the development and use of information to communicate the CFP based on a report, to ensure comparability, reliability and transparency of the communication of the CFP (ISO 14067-2). ISO 14067 is based on relevant parts of ISO 14040, ISO 14044, ISO 14021, ISO 14024 and ISO 14025.

ISO 14067 is expected to benefit organizations, governments, project proponents and other affected parties worldwide by providing clarity and consistency for quantifying, reporting and verifying the CFP in a credible, consistent and transparent way.

The committee drafts (CD) of ISO 14067 (ISO/CD 14067-1, Carbon footprint of products – Part 1: Quantification and ISO/CD 14067-2, Carbon footprint of products – Part 2: Communication) were distributed in September 2010 to ISO members for a three month balloting and voting period. Comments are expected from more than 35 countries and Liaison organisations. The next meeting of the Working Group will take place in January 2011 where a Draft International Standard (ISO/DIS) will be prepared which then will be published in March/April 2011.

## **7.9 Greenhouse Gas Protocol Supply Chain Initiative**

Laura Draucker

The World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), following the success of the Corporate Standard and Project Protocol, are currently in the second public comment period of the draft Product Life Cycle Greenhouse Gas (GHG) Accounting Standard, set for final release at the end of the year. The goal of this standard is to provide a framework of requirements and guidance that enable companies to calculate reliable GHG inventories of the products or services they provide and disclose the inventory results in a public report. This presentation will first give a quick overview of the Product Standard and the standard development process, and then go into more detail on how we address temporary carbon storage, delayed emissions, biogenic carbon removals, and land use change in the current draft.

## 7.10 Biogenic CO<sub>2</sub> emissions and their contribution to climate change

Francesco Cherubini, Glen P. Peters, Terje Berntsen, Ottar Michelsen, Anders H. Strømman and Edgar Hertwich

Combustion of biomass is usually assumed carbon neutral because the CO<sub>2</sub> released from biofuel combustion approximately equals the amount of CO<sub>2</sub> sequestered by biomass re-growth. Based on this, CO<sub>2</sub> emissions from biomass combustion are essentially ignored in the existing GHG accounting regulations and in most of the primary research studies. This makes the bioenergy system climate neutral. However, before it can be captured by vegetation re-growth, the CO<sub>2</sub> emission causes an impact on the carbon cycle and radiative balance of the earth which contributes to climate change. The challenge is to measure this contribution with unit based indicators to be included in current GHG accounting frameworks.

In this work, a distinction between the concepts of carbon neutrality and climate neutrality is done and two calculation procedures aiming at estimating the effect of biogenic CO<sub>2</sub> on the climate are proposed. These procedures originate from different interpretations which can be adopted while modelling the biomass carbon cycle. In the first case, a conventional closed cycle approach for biogenic CO<sub>2</sub> emissions is followed. In the second case, the decay of biogenic CO<sub>2</sub> is modelled as an impulse response function originated from the perturbation caused by this emission to the climate system. In both cases, the absolute global warming potential is estimated and the resulting value is related to anthropogenic CO<sub>2</sub> emissions. This leads to an index (GWP<sub>bio</sub>) that is similar to the equivalency factors elaborated for the various GHGs. Since this index is expressed as a function of the rotation period of the biomass, the outcomes of these calculation procedures can be applied to all the different biomass species, from annual row crops to tropical, temperate and boreal forest. Furthermore, this paper provides an innovative insight into the current debate on carbon accounting, especially in the ongoing discussion between the stock change approach and the atmospheric flow approach. The adoption of this index in the existing GHG accounting frameworks brings important consequences both at a project and national level. At a single project level, the GHG emissions of the bioenergy systems are consistently raised; at a national level, the responsibility schemes between countries change, since the exporting country is still responsible for possible changes in terrestrial carbon pools and the importing country, where biofuels are burnt, becomes responsible for a contribution to climate change due to biogenic CO<sub>2</sub> emissions.

## 7.11 The upfront carbon debt of bioenergy: a comparative assessment

Giuliana Zanchi, Naomi Pena and Neil Bird

In the current climate change policy framework, the use of biomass for energy is considered a carbon neutral source. According to the principle of carbon neutrality, the GHG emissions produced by combustion of plant biomass are assumed to be recaptured instantaneously by new growing plants. This assumption is acceptable when the same amount of biomass that was burned will re-grow in a very short time as for annual crops. When the raw material is wood, the time needed to re-absorb the CO<sub>2</sub> emitted in the atmosphere can be long, depending very much on the source of wood. This delay can create an upfront “carbon debt” that would substantially reduce the capability of bioenergy to reduce the greenhouse gas emissions (GHG) in the atmosphere in the short to medium term.

The discussion on bioenergy carbon neutrality is fundamental, since the European Union (EU) adopted ambitious policy targets on the use of renewable energy sources and a substantial share of the total renewable energy will come from biomass. Biomass resources, which would not have been used without the new policies, and could have stored carbon in the biosphere, will be used to produce energy. According to estimates used by DG TREN, the projected renewable sources’ deployment in 2020 will require the use of 195 Mtoe from biomass. The energy generation from solid biomass and biowaste is projected to be 58% of the total renewable energy generation in 2020 (140 Mtoe of 240 Mtoe) and it will cover 12% of the gross energy demand in the EU.

The extent to which the use of bioenergy reduces GHG emission can be quantified with a Carbon Neutrality (CN) factor. The CN factor is defined as the ratio between the net reduction/increase of carbon emissions in the bioenergy system and the carbon emissions from the substituted reference energy system, over a certain period of time. The CN is time dependent and it includes emissions from carbon stock changes. This study shows that different sources of biomass for bioenergy can have very different climate change mitigation potentials according to the time horizon that is considered, by assessing the development of their CN over time. There is forest biomass that can produce a GHG benefit in the atmosphere from the beginning of its use but it is not carbon neutral. Other sources of woody biomass will require a long time before producing a GHG benefit in the atmosphere, while some other sources can be carbon neutral from their initiation:

- When harvest residues, previously left on the forest floor are extracted for bioenergy, there is a carbon stock loss in the dead wood, litter and soil pools. It was estimated that the mitigation potential of such bioenergy material in a 20 year time horizon is reduced by 10-40% by this loss (CN=0.6-0.9).

- Additional fellings for bioenergy can produce a decrease of the overall carbon stock in the forest that significantly affects the GHG balance of the bioenergy material. In the short-medium term (20-50 years), additional fellings could produce more emissions in the atmosphere than a fossil fuel system (CN<0). In such a case, the use of additional fellings would produce only very long term benefits, in the order of magnitude of 2-3 centuries.
- The GHG balance of biomass from new plantations is affected by the carbon stock change due to the conversion from the previous land use (direct and indirect). The biomass source can be carbon neutral when the carbon stock change is zero or positive (e.g. conversion from abandoned croplands). If there is an initial carbon loss (e.g. conversion from a forest area), the biomass will produce an atmospheric benefit only after that the carbon stock change is fully compensated by the same amount of avoided emissions in replaced fossil fuels (150-200 years).

In the current accounting of GHG emissions in the climate change policy framework, there are two major gaps concerning the use of bioenergy. The first is a gap in spatial coverage. This gap resulted from adoption of an inventory methodology designed for a system in which all nations report into systems in which only a small number of countries have emission obligations, i.e., the Kyoto Protocol (KP) and the Emission Trading Scheme (EU-ETS). The second is a failure to differentiate between a system in which very long time horizons are relevant – efforts to mitigate climate change over the long term – and systems concerned with shorter-term horizons such as the EU 2020 and 2050 targets. Since the KP adopted the UNFCCC Inventory Guidelines without considering these differences, current accounting systems’ difficulties in addressing the time-dependency of biomass’ carbon neutrality can also be traced to this decision.

Policy approaches currently under discussion that could address the spatial or temporal gaps, at least to a limited extent, include the following:

1. More inclusive accounting of emissions from the land-use sector
2. Value Chain Approaches, including use of sustainability criteria
3. Point-of-use accounting

All of them are primarily intended to address problems that have emerged due to the difference in spatial boundaries, and point-of-use accounting can also address the time delay between use of biomass for energy and regrowth.

A more inclusive accounting of emissions from the land-use sector has been under consideration in the UNFCCC fora by widening the number of activities whose emissions must be counted in Annex-I countries and by adopting a mechanism to support REDD+ that should encourage emission reduction

efforts in non-Annex-I countries. However, these approaches would only partially fill the existing spatial gap and they would be dependent on a continual series of policy agreements. A third option is a unified carbon stock accounting (UCSA) under which land-use sector emissions would be estimated across all managed lands without restriction to specific activities, but there is currently wide resistance to this approach. In addition, it would only partially resolve the accounting gap if only applied in Annex-I countries.

Under value-chain approaches GHG impacts along the entire series of steps – resource extraction or cultivation, transportation, and conversion to a final product – are taken into consideration. Under this approach bioenergy users are held responsible for the bioenergy embodied emissions and quantitative and/or qualitative criteria are set to limit the use of goods with high GHG-profiles. The EU Renewable Energy Directive's requirements for biofuel are an example of a value-chain approach. However, there is a disjunction between the Directive and the KP and EU-ETS. For the purpose of emission reduction targets, bioenergy will still enjoy zero emission status even if its GHG balance, assessed with the methodology in the Directive, is not zero. In addition carbon stock changes due to management changes are not accounted for.

Under point-of-use accounting, end-users are also held responsible for the emissions attendant on use of bioenergy and, in addition, emissions due to combustion would be assigned a non-zero multiplier (i.e., emission factor) to include the real GHG benefits due to bioenergy use. Under conditions where not all nations cap emissions in all sectors, point-of-use accounting is likely to provide better incentives and dis-incentives than other systems.

Two alternative ways to calculate emission factors at point-of-use are reviewed: calculating net value-chain emissions not covered by caps and use of Carbon Neutrality (CN) factors. DeCicco (2009) proposes a system in which assignment of emissions to biomass used for energy is combined with tracking the emissions occurring along its value chain that occur in non-capped sectors or nations. In such a system, the emission cap on fossil fuels serves as the incentive to lower the GHG emission profiles of biofuels.

CN factors can incorporate all emissions due to changes in carbon stocks. Moreover, they compare biomass emissions to the emissions of use of fossil-fuels in a time relevant manner. Thus, use of CN factors by bioenergy users could, in principal, address both the areal gaps and timing issues. These issues have emerged as a result of the combination of the use of a 'zero emissions' factor at the point of biomass combustion under the KP and EU-ETS with the lack of accounting for land use change in Annex-I and non-Annex-I countries. The use of CN-factor labelled biomass would provide a straightforward way to calculate emission benefits relative to use of fossil fuels.

It is very likely that accounting systems will remain partial through the foreseeable future. Not all nations will cap emissions from their land use sector and many of those that do are unlikely to adopt a UCSA approach. During this period, a CN factor based only on emissions not falling under caps may be a useful approach.

## **7.12 Quantifying climate change impacts of bioenergy systems - An overview of the work of IEA Bioenergy Task 38 on Greenhouse Gas Balances of Biomass and Bioenergy Systems**

Annette Cowie and David Neil Bird

IEA Bioenergy Task 38 is a research collaboration that aims to develop and demonstrate methodology for the calculation of net greenhouse gas (GHG) mitigation benefit of sequestration and bioenergy projects and support decision makers in selection of mitigation strategies, and in devising climate change policy.

The work of Task 38 focuses on methodology to assess the greenhouse benefits of bioenergy systems in contrast with fossil fuel systems, using a full life cycle approach. The Task undertakes case studies to assess the GHG balance of actual or proposed bioenergy projects in member countries, and contributes to development of greenhouse gas accounting methodologies for policy measures including renewable energy and emissions trading schemes.

Results of the Task 38 work, demonstrating the greenhouse mitigation potential of bioenergy systems around the world, are published on the Task web site (<http://www.ieabioenergy-task38.org/>), in journal papers and as a series of Task brochures. An outline of the standard methodology developed by the Task, and summary of results, are given below.

The bioenergy industry is expanding rapidly around the globe in response to climate change, rising oil prices and the need for rural development. Bioenergy is promoted as a renewable energy source, and claimed to be “carbon neutral” on the basis that it returns to the atmosphere the carbon that was fixed during growth of the plant. However, this does not mean that bioenergy systems have no net greenhouse gas emissions: there are greenhouse gas (GHG) emissions associated with producing and handling the biomass, such as from fossil fuel use in cultivation, harvest, processing and transport. There are additional emissions, such as the potent GHG nitrous oxide (N<sub>2</sub>O) emitted from fertilised soil and emissions resulting from production of fertiliser and herbicide.

Truly renewable bioenergy systems are those that are based on sustainably-sourced feedstock – that is, where the rate of GHG uptake through plant growth equals the rate of harvest for bioenergy. But bioenergy systems often extract a higher proportion of biomass than conventional crop and forest systems, leading to a reduction in carbon stock in biomass, and possibly also in the soil. Where supply of biomass depletes terrestrial carbon stocks this must be recognised as an emission from the bioenergy system, calculated as the change in long term average carbon stocks.

Furthermore, the expansion of bioenergy can lead to indirect land use change: where biomass production displaces food production, deforestation may occur elsewhere to meet demand for land resources. Particularly if high biomass forests and peatlands are cleared, this is a significant source of emissions. Methods for including indirect land use change in calculation of net mitigation benefit of bioenergy have been proposed, but none is yet widely accepted. Because indirect land use change is, by definition, outside the boundary of a bioenergy project, this is not readily included in project-scale LCA. It is more relevant to quantify (and manage) this issue at national/regional scale.

Generally Task 38 studies have summed the emissions and removals of GHGs over 100 years. However, this approach can obscure impacts of timing of emissions and removals, particularly where methane, which has a shorter atmospheric lifetime than CO<sub>2</sub> and N<sub>2</sub>O, is a significant contributor to emissions. To overcome this limitation, more recent Task 38 research has quantified impacts in terms of temporal pattern of radiative forcing, summarised as NPV of radiative forcing over 100 years.

Besides direct impact on GHG fluxes, bioenergy systems that involve land use change can influence climate through impacts on albedo. Quantifying climate change impacts through estimation of radiative forcing allows albedo impact to be readily included in the calculation.

Elements of the standard methodology:

- Compare the bioenergy project with the relevant fossil fuel reference system;
- Consider the whole system life cycle, including direct and indirect emissions, and non-CO<sub>2</sub> GHGs as well as CO<sub>2</sub>;
- Select the system boundary for both the project and reference case so that equivalent service is delivered in each case;
- Include the C stock change in biomass and soil pools;
- Express results as emissions reduction per unit limiting resource (ie per kg of biomass for bioenergy based on biomass residues, or per ha for purpose-grown biomass)
- Include the effects of albedo and timing of emissions and removals, as these can be important. These can be included when assessments are quantified as NPV of radiative forcing.
- Recognise that the GHG mitigation result is technology- and situation-specific

Bioenergy systems with the greatest GHG mitigation benefit are those based on use of residues as feedstock, and efficient energy conversion technologies such as combustion for heat or co-generation of heat and power. These can reduce emissions by over 90% compared with fossil energy systems.

Some “first generation” biofuel systems, such as ethanol from corn, and biodiesel from canola, deliver minor GHG mitigation benefits when the direct and indirect emissions associated with crop

production, processing and transport are considered. Other biofuel systems such as oil palm grown for biodiesel have apparently greater greenhouse benefits due to high yields, but indirect impacts of offsite deforestation and loss of soil carbon can negate this benefit.

Biofuels based on perennial ligno-cellulosic (woody) feedstocks (“second generation biofuels”) are expected to deliver greater benefit than first generation systems, both in terms of GHG mitigation and other environmental and socio-economic impacts, though few life cycle assessments of GHG emissions/removals for second generation biofuels systems have been published to date.

As an example, the Task 38 methodology has been applied to slow pyrolysis systems that produce bioenergy and biochar that is used as a soil amendment. The emissions reduction benefit of biochar systems is calculated as the difference in net emissions between the biochar and reference energy/land use cases.

The assessment includes:

- fossil energy use in plant construction, transport , processing, distribution, utilisation;
- fossil fuel emissions displaced through use of syngas as an energy source;
- direct and indirect carbon stock change in biomass and soil;
- net emissions of nitrous oxide and methane; and
- impact on crop yield, fertiliser and irrigation requirement, soil strength.

Other elements that may be significant are:

- radiative forcing of change in albedo
- timing of emissions and sequestration.

In this study, the net emissions reduction for different biochar scenarios ranged from 1.5-3 tCO<sub>2</sub>e/t feedstock, equivalent to 1 -2 times the CO<sub>2</sub>e of the feedstock. The greatest GHG mitigation is obtained for the cases that utilize waste material that would otherwise be landfilled, and where biochar is applied to a horticultural crop with high fertilizer requirements.

The main factors influencing GHG balance of biochar application, in order of significance, are

- avoided emissions of methane from landfill;
- biochar yield and carbon turnover rate in soil;
- net energy exported and the energy source it displaces, determining displaced fossil fuel emissions; and
- N<sub>2</sub>O emissions from soil.

The result is highly sensitive to the assumptions, and there is high uncertainty in many aspects, particularly:

- the assumptions associated with landfilling of biomass in the reference case (the extent of decomposition and the proportion of carbon released as methane);
- the impact on N<sub>2</sub>O emissions;
- the turnover rate of biochar under field conditions; and
- the longevity of the impact on crop yield and fertiliser requirement.

The net climate change benefit of bioenergy and biochar systems should be determined by comparison with the appropriate reference system, representing the conventional use of the biomass and conventional energy source. A whole system, life cycle perspective is required. The desk-top analyses undertaken to illustrate the methodology demonstrate that use of biomass to produce biochar for utilisation as a soil amendment can reduce net greenhouse gas emissions. The major contributions to mitigation vary depending on feedstock, target crop, and characteristics of the situation-specific reference system. The result is highly sensitive to the assumptions, and also to the reference system. Further research is needed to provide accurate data for these studies. Hence care should be taken in generalising outcomes of life cycle GHG balance studies.

## 7.13 Assessing temporary carbon sequestration and storage projects through LULUCF with dynamic LCA

Annie Levasseur, Pascal Lesage, Manuele Margni, Miguel Brandão and Réjean Samson

To properly assess temporary carbon sequestration and storage projects through land-use, land-use change and forestry, it is essential to consider their temporal aspects. Life cycle assessment (LCA) is increasingly used to assess climate change mitigation scenarios as it includes the contribution of every life cycle stage and it considers many types of environmental impact other than global warming. However, LCA does not currently consider the temporal aspects of the emissions and therefore, cannot be used to assess temporary carbon sequestration and storage projects.<sup>1</sup>

A dynamic LCA approach has been developed to account for the timing of the emissions in LCA.<sup>2</sup> In this approach, the temporal profile of the emissions is considered in the inventory, which is then assessed using dynamic characterization factors that are dependant of the moment when the emissions happen to get the instantaneous impact occurring at any given time. For global warming, the dynamic characterization factors are obtained by integrating continuously through time the Absolute Global Warming Potential (AGWP)<sup>3</sup> for any greenhouse gas (GHG).

A dynamic LCA has been realized for an afforestation project<sup>4</sup> which aims at mitigating a baseline pulse-emission of 1,000 kg CO<sub>2</sub>-eq over 70 years. The instantaneous impact on global warming was calculated for the baseline pulse-emission and for the combination of the baseline pulse-emission with the afforestation project for different end-of-project scenarios. The ratio of the baseline pulse-emission compensated by the project was also calculated to show whether the benefits of the afforestation project fully compensate for the impact of the baseline emission or not (see Table 1). The complete results of this case study has been submitted to Climatic Change.<sup>5</sup>

Table 1. Ratio of the baseline pulse-emission compensated by the project for different scenarios and different time horizons

	100 years	250 years	500 years
Neutral	62%	86%	93%
Fire	23%	8%	4%
Fire multi-gas	16%	5%	3%
Exploitation	43%	22%	10%
Exploitation-landfill	40%	46%	49%

For the neutral scenario, where we assume that no CO<sub>2</sub> uptake or emission is occurring after the 70-year sequestration period (permanent storage), the benefits of the project over an infinite time horizon fully compensate for the impact of the baseline emission. For the other scenarios, where a part of the carbon is released back to the atmosphere, it is not the case. The dynamic LCA approach enables to determine consistently the time-dependent impact on radiative forcing for every GHG and for any type of product or project life cycle. It also allows decision makers to test the sensitivity of the results to the value-laden choice of different time horizons, which can significantly influence the results.

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**Abstract**

Land and wood products, among others, represent temporary carbon sinks. Since the embodied carbon is retained outside the atmosphere for a period of time, some radiative forcing is postponed. Carbon removal from the atmosphere and storage in the biosphere or anthroposphere, therefore, may have the potential to help mitigate climate change.

Life cycle assessment and carbon footprinting are increasingly popular tools for the environmental assessment of products that take into account their entire life cycle. A robust method is required to account for the benefits, if any, of temporary carbon storage for use in the environmental assessment of products. Despite significant efforts to develop robust methods to account for temporary carbon storage, there is still no consensus on how to consider it.

This workshop brought together experts on climate change, carbon footprinting and life cycle assessment to review available options and to discuss the most appropriate method for accounting for the potential benefits of temporary carbon storage. The workshop continued the work developed under the International Reference Life Cycle Data System (ILCD), which provides methodological recommendations for use in business and policy for assessing the environmental impacts of goods and services, taking into account their full life cycle. This report is a summary of the presentations and discussions held during this workshop.

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